National Environment Protection Measure for Ambient Air Quality

Monitoring Plan for the Northern Territory

May 2001

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This Monitoring Plan has been prepared in accordance with the National Environment Protection Protocol in Part 4 of the National Environment Protection Measure for Ambient Air Quality (1998). This plan attempts to set out the processes to be followed in measuring the concentration of pollutants in the air of the Northern Territory. Compliance with the Standards and Goal of the National Environment Protection Measure will be determined.

Table of Contents

List of Figures

List of Tables

Appendices

1. SUMMARY

In June 1998, the National Environment Protection Measure (NEPM) for Ambient Air Quality set the desired environmental outcome for ambient air that allows for the adequate protection of human health and wellbeing. The Northern Territory has developed a Monitoring Plan for the purposes of assessing compliance with this Measure.

The Northern Territory has one region where monitoring will be undertaken – the Darwin Region.

Benchmark studies in the 2000 dry season indicate that PM_{10} is likely to be the only pollutant of concern in the Darwin region. Monitoring of PM_{10} was carried out at the CSIRO/Parks and Wildlife Commission complex adjoining the corner of McMillans Road and Vanderlin Drive, Berrimah.

It is proposed to locate a TEOM to monitor PM_{10} at the Bureau of Meteorology's new Darwin Airport complex, due for completion later this year. The Bureau is able to provide 24 hour technical support and a powered secure site.

The proposed site is approximately 3.6 km from the Berrimah site and is located such that it is able to sample regional air parcels moving over Darwin. Given its proximity to the more densely populated areas within the region, and that there are no localised sources of pollution adjacent, it will act as a GRUB station.

The Department of Lands, Planning and Environment intends to outsource data capture, handling and any associated interpretation, but will remain responsible for data archiving and formal reporting under the NEPM.

The proposed schedule is for commissioning of the TEOM by December 2002, routine monitoring to commence in February 2003, and formal NATA accreditation achieved by December 2004. Discussions with NATA indicate that there are no difficulties with accrediting the various components of the monitoring program even though there may be a number of discrete parties involved.

Screening analyses will be carried out for ozone and oxides of nitrogen when the CSIRO TAPM consultancy results are made available.

Monitoring of carbon monoxide, sulfur dioxide and lead is not required.

2. INTRODUCTION

On 26 June 1998, the National Environment Protection Council (NEPC), consisting of Commonwealth, State and Territory Ministers, made the Measure for Ambient Air Quality (hereafter referred to as the Measure). This measure established a set of Standards and Goal for six air pollutants, and outlined the methods by which these pollutants are to be measured, assessed and reported. The Standards are set out in Schedule 2 of the Measure, which is reproduced as Appendix A.

A formal requirement of the Measure is the establishment of monitoring procedures and commencement of assessment and reporting, in accordance with the protocols of the Measure, within three years after its commencement.

After making the Measure, the Ministers resolved to establish a Peer Review Committee (PRC) to advise on jurisdictional monitoring plans. Under its terms of reference, the PRC has two complementary roles. Firstly, the PRC is required to advise the NEPC on the adequacy of the monitoring plans submitted by jurisdictions. Secondly, it provides advice on technical issues related to the consistent implementation of the Measure's monitoring protocol. The PRC has developed a series of strategy papers that provide a basis for the preparation of individual monitoring plans (by jurisdictions) and for the assessment of monitoring plans (by the PRC).

It should be noted that the monitoring conducted as part of the requirements of the Measure may represent only a sub-set of the total ambient monitoring program of some jurisdictions.

This Report represents the Northern Territory's submission on how it plans to monitor, assess and report on air quality for the purposes of the Measure. The Report is structured according to the format specified by the PRC. This includes a consideration of:

- Regions to be monitored;
- Monitoring requirements of each region, including (as appropriate) physical and demographic characterisation, emission sources, air quality, identification of pollutants not required to be monitored, and monitoring network;
- Siting and instrumentation;
- Accreditation; and
- Reporting.

3. IDENTIFICATION OF REGIONS

The NEPM gives a very broad definition of the word "region", leaving the determination of regions and their boundaries to each jurisdiction. In order to provide guidance for jurisdictions, the PRC accepted the following definition of a region:

"A region for the purposes of monitoring performance is a geographical area where the air quality (for a particular pollutant) is determined either entirely or in large part by the influence of a common collection of anthropogenic emission sources."

Under Clause 14 of the NEPM, performance monitoring may be required in regions with a population exceeding 25 000 people.

The PRC also adopted the following definitions of different region types:

- Type 1 - a large urban or town complex with a population in excess of 25 000 requiring direct monitoring and contained within a single airshed;
- Type 2 - a region with no one population centre above 25 000, but with a total population above 25 000 and with significant point source or area-based emissions so as to require a level of direct monitoring; and
- Type 3 – a region with population in excess of 25 000 but with no significant point source or area-based emissions, so that ancillary data can be used to infer that direct monitoring is not required, under Clause 11 and 14.

The PRC has adopted the use of Australian Bureau of Statistics (ABS) population figures, specifically the "Urban Centres/Locality" data, as the most objective estimates for identification of potential Type 1 regions. Relegation of a Type 1 to Type 3 region must be supported by arguments based on local knowledge. Identification of Type 2 regions is also reliant on local knowledge of emission sources and airshed characteristics. The "Selection of regions" paper (PRC 2000a) provides a discussion of the use of ABS data and issues to consider when classifying regions.

Figure 3.1 is a map of the Northern Territory showing major centres. The Darwin region is classified as Type 1.

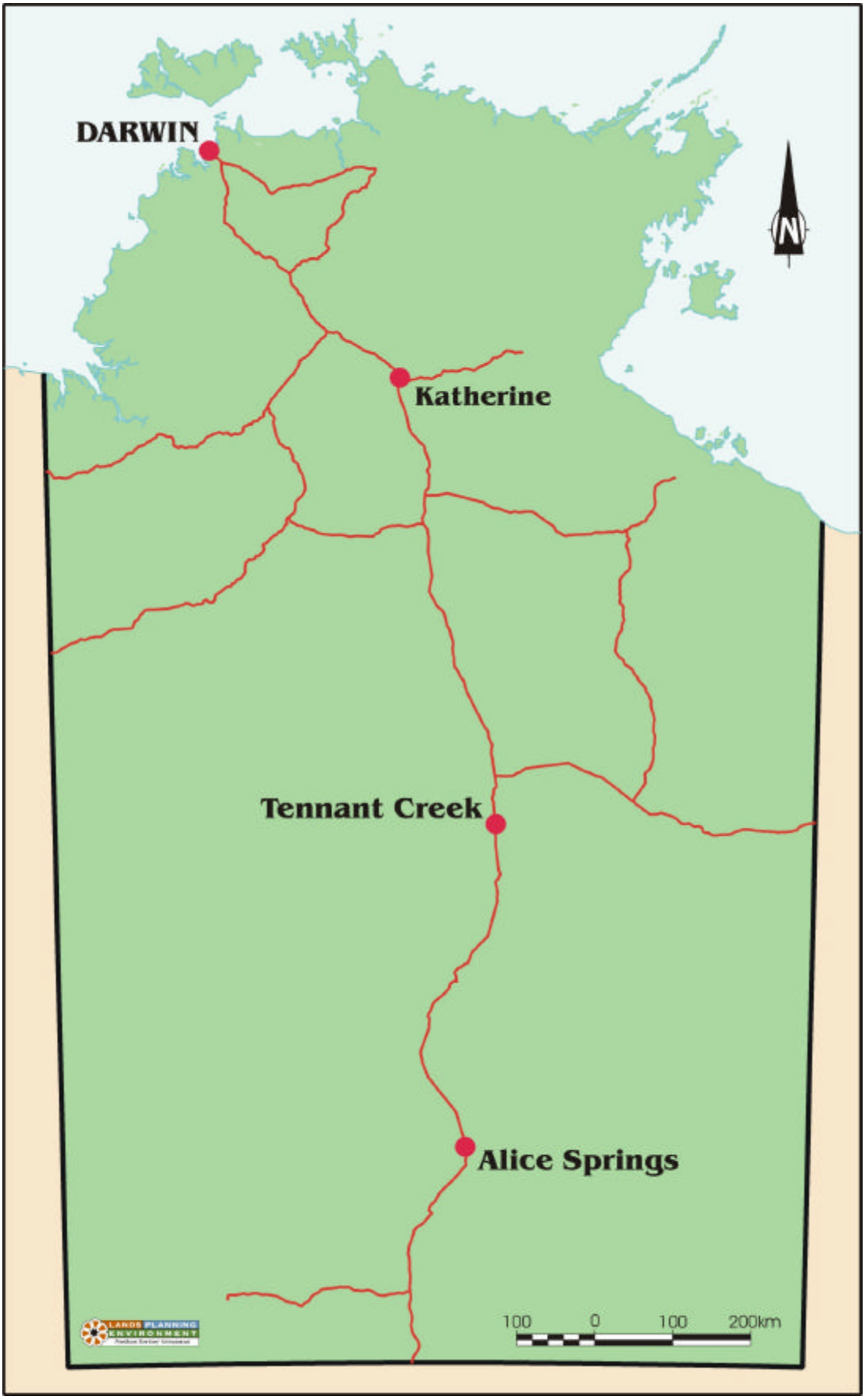

Figure 3.1 Map of the Northern Territory showing major centres

Table 3.1 gives the ABS Urban Centre/Locality data from the 1996 Census (most recent available) for Alice Springs and Darwin and surrounds. They are ranked according to size. All other "regions" in the NT have a smaller total population and need not be monitored for the purposes of the NEPM.

Table 3.1 ABS Urban Centre/Locality population data from the 1996 Census

Urban Centre/Locality	Number of Persons
Darwin (UC)	70 251
Alice Springs (UC)	22 488
Palmerston (UC)	12 233
Humpty Doo – McMinns Lagoon (UC)	4 798
Howard Springs (UC)	3 207
Virginia – Bees Creek (UC)	2 173
Coonawarra (L)	902
Belyuen (L)	234

The total population of the Darwin region is the sum of populations from Darwin, Palmerston, Humpty Doo – McMinns Lagoon, Howard Springs, Virginia – Bees Creek, Coonawarra and Belyuen. This amounts to a total of 93 798 people.

The ABS population for the Alice Springs region from the 1996 census is 22 488, which does not trigger the NEPM threshold.

4. PERFORMANCE MONITORING REQUIREMENTS OF THE REGIONS

Part 4 of the NEPM outlines the monitoring protocol to be followed by the jurisdictions for the purpose of determining whether the standards defined in the NEPM are being met. Clause 14 within Part 4 relates to the number of performance monitoring stations required. This clause is reproduced below:

Clause 14 Number of performance monitoring stations

(1) Subject to sub-clauses (2) and (3) below, the number of performance monitoring stations for a region with a population of 25 000 people or more must be the next whole number above the number calculated in accordance with the formula:

$$1.5P + 0.5$$

where P is the population of the region (in millions).

(2) Additional performance monitoring stations may be needed where pollutant levels are influenced by local characteristics such as topography, weather or emission sources.

(3) Fewer performance monitoring stations may be needed, where it can be demonstrated that pollutant levels are reasonably expected to be consistently lower than the standards mentioned in this Measure.

Subclauses (1) and (2) are self-explanatory. Subclause (3) allows jurisdictions the opportunity to demonstrate that, for a given region, fewer monitoring stations than indicated by the formula (possibly zero) are required. The PRC refers to this process as "screening" and has prepared guidelines to ensure a reasonable degree of consistency and rigour in the screening assessments is undertaken by jurisdictions. The guidelines identify a range of screening procedures that may be used for particular pollutants and assign an acceptance limit to each procedure reflecting the confidence attached to the procedure. The guideline document, entitled "Screening procedures", National Environment Protection Council (Ambient Air Quality) Measure Guideline Paper No.4 (PRC 2000c), appears as Appendix B to this report and should be read in conjunction with the assessment of monitoring requirements.

The following extract from a PRC paper entitled, "Monitoring strategy", National Environment Protection Council (Ambient Air Quality) Measure Guideline Paper No.3 (PRC 2000b), provides the rationale for siting of performance monitoring stations (underlines added).

> "In order to ensure equivalent protection for the overall population of a region, stations will generally be located so as to monitor the upper bound of the distribution of pollutant concentration likely to be experienced by portions of the population, while avoiding the direct impacts of localised pollutant sources. These generally representative upper bound for community exposure (GRUB) stations will be distributed to measure the upper bound concentrations in different portions of the populated area, reflecting different emission or dispersion regimes.
> An examination of the GRUB distribution stations relative to the distribution of population and pollutant will determine the need for, and location of, additional stations to achieve adequate representation of population-average concentrations.
>
> By using GRUB stations to monitor the ambient air across a region, we can be reasonably sure that, if the NEPM Standards are met at those sites, then most of the total population of the region will be exposed to air that meets the Standards. In this way, the NEPC aim of equivalent environmental protection is assured."

4.1 Darwin Region

4.1.1 Overview Description of the Region

Regional Boundaries

The Darwin region is comprised of Darwin, Palmerston, Humpty Doo – McMinns Lagoon, Howard Springs and Virginia – Bees Creek Urban Centres, and Coonawarra and Belyuen Localities.

For the purpose of the NEPM, the Darwin region boundaries are defined as shown in Figure 4.1. The northern and western boundaries of the region are defined by coastline.

Population Distribution

The ABS population for the Darwin region from the 1996 census is 93 798. The majority of this population is centred on the Darwin CBD, suburbs north of Darwin Airport, and Palmerston. Other urban centres and localities are shown on Figure 4.1.

Topography

Figure 4.1 also shows the topography of the region. The relief across the area is low, with generally flat plateaus with an average elevation of around 15m and spot heights up to 45m.

Sources and Emissions

The Northern Territory's manufacturing sector, traditionally linked to the mining and construction industries, also includes food and beverage processing and the defence industry.

The food and beverage sector produces dairy products, fruit/soft drinks, bread, poultry and beef, and is an increasingly significant contributor to the region's manufacturing output. The growing Northern Territory population, coupled with Darwin's proximity to South East Asian markets, is expected to lead to further consumer demand and consolidate future growth.

The increase in defence activity in the north of Australia is opening the door for Territory businesses to produce, service and maintain defence machinery.

Oil and gas industries will become more important as Timor Sea resources are being discovered and developed. However, apart from on-shore support industries, no oil or gas-based industries have yet been established.

The NT Government has undertaken an Air Emissions Inventory as part of the National Pollution Inventory, providing the following data as shown in Table 4.1.

Table 4.1 Air Emissions Inventory for Darwin

Pollutant	Amount (kg/year)
Oxides of Nitrogen	1.01×10^7
Particles as PM_{10}	6.08×10^6
Carbon Monoxide	6.09×10^7
Sulphur Dioxide	5.51×10^5
Lead	8.14×10^3

Sources of the pollutants may be broadly classified into four categories:

- Area-based sources refer to those urban features and activities that occur and produce emissions over wide areas of land. These include residences, dry cleaning shops, petrol stations and lawn-mowing activities. Controlled burning is also considered to be an area-based source;
- Linked-based emissions come from mobile sources, such as cars and freight trucks, and occur over defined network links such as streets and freeways;
- Point sources refer to individual sites, such as oil refineries and steelworks, where significant amounts of emissions are produced; and
- Biogenic sources refer to plant life and vegetation that produce emissions as by-products of natural processes.

Of these, fires in the dry season are the most significant source of pollution. Transport may be a contributing source in Darwin, as is the case in all other capital cities. Related to transport is the structure of the city which imposes transport and consumption patterns on its residents.

In summary, the Darwin region has minor point sources of pollution plus regional area-based emissions associated with dry season fires.

Figure 4.1 Darwin Region Topography and Population Density

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Air Pollution Meteorology

Darwin is within the monsoonal tropics of northern Australia and experiences two distinct seasons: the hot-wet season from November to March; and the hot-dry season from May to September. April and October are transition months between the wet and dry seasons.

The distinctive seasonality of the rainfall is the most distinguishing feature of the regional climate. There is a pre-wet season transitional period, commonly referred to as "the build-up", during October and November. This period is characterised by thunderstorms occurring at irregular intervals prior to the onset of the more general rain systems associated with the monsoon trough during the wet season. Darwin has an average annual rainfall of 1669mm (110 rain days), most of which falls within the wet season. Humidity over this period averages 70-80%. In the dry season humidity is often below 40% and there is virtually no rainfall.

While the maximum temperatures are hot all year round, November is the hottest month with a daily mean minimum – daily mean maximum range of 25-33°C. June and July normally experience the lowest temperatures with a daily mean minimum – daily mean maximum range of 19-30°C.

Darwin has a yearly average of 8.5 sunshine hours per day with August experiencing the highest monthly average of 10.2 hours per day.

Prevailing winds during the wet season are light west to north-westerly, freshening in the afternoon due to sea breezes. In the dry season, the prevailing winds are the south-easterly trade winds. Wind roses for Darwin Airport are presented in Figure 4.2.

The monsoonal tropics also experience cyclonic activity. The cyclone season in northern Australia extends from October to April. Tropical cyclones cause most damage within a distance of 50km from the coast. Once a cyclone is over land it weakens rapidly, but resultant storm surge can be of concern to coastal developments and flood damage can result from associated squally rains.

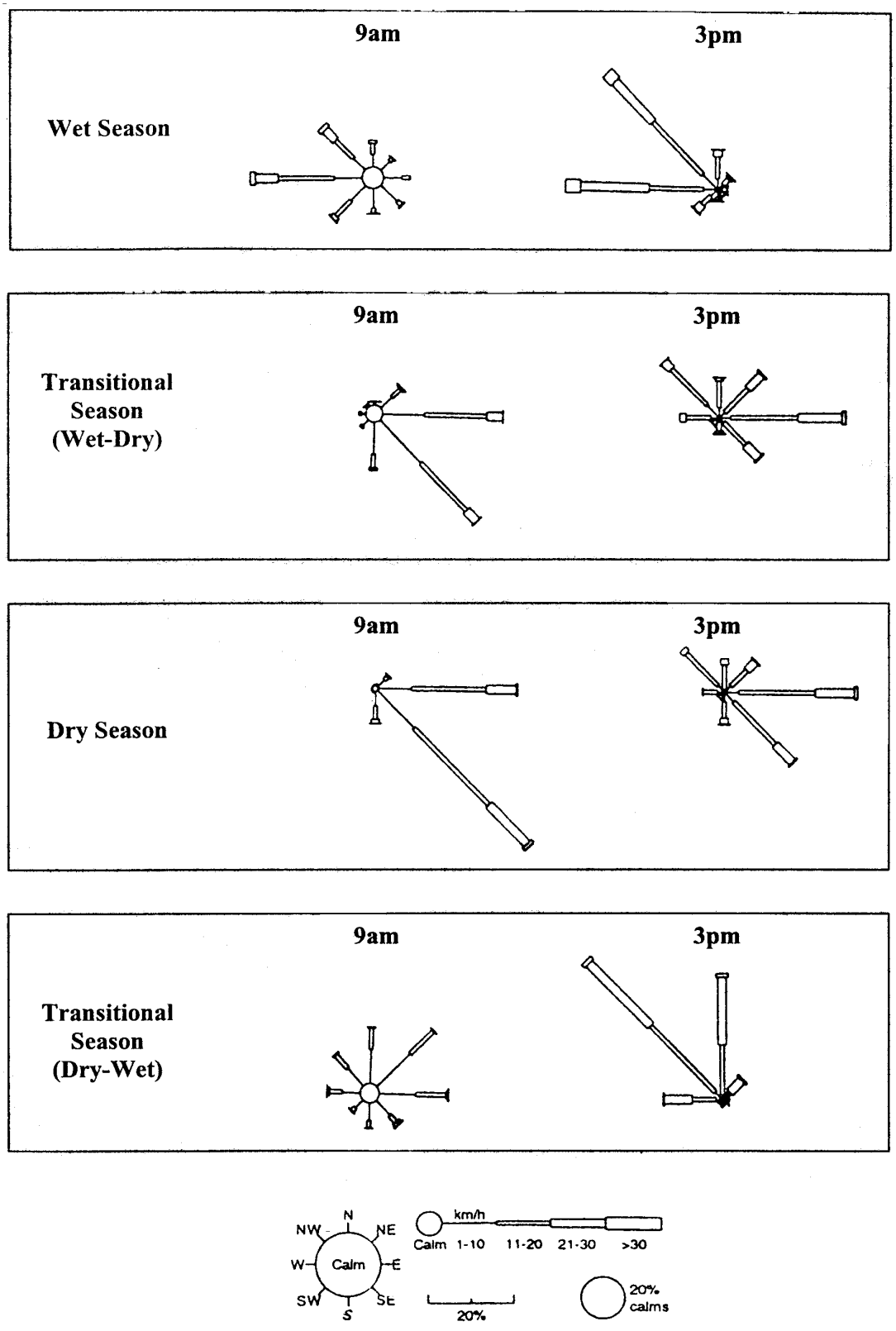


Figure 4.2 Seasonal Wind Roses - Darwin Airport
(Source: Bureau of Meteorology, 1998)

Air Quality Monitoring History

The Department of Lands, Planning and Environment contracted Northern Territory University and CSIRO Division of Atmospheric Research to undertake a study of Darwin's air quality, focussing on PM_{10}, but also measuring NO_2, SO_2, O_3 and lead. The purpose of this study was to provide benchmark data of selected NEPM Ambient Air Quality components in the Darwin area from February to December 2000, a period including both wet and dry season conditions. A final report is at Appendix D. Extracts from the report have been used where appropriate in the discussion of monitoring requirements for specific pollutants in the Darwin region.

4.1.2 NEPM Formula

With a population of 93 798 across the Darwin region, the NEPM formula indicates that one performance monitoring station is required.

A site at Darwin Airport has been selected by the Department of Lands, Planning and Environment for the main sampling location, to satisfy the requirements of a representative urban location with a secure site and controlled environment.

Prevailing dry season winds from the southeast (the main vector for pollutants) move regional air masses over the site and the more densely populated areas within the region.

The northern suburbs of Darwin border the north side of the airport. According to the 1996 Census, the population of the northern suburbs is 48 107, or 51% of the Darwin region population. Given that that there are no localised sources of pollution adjacent, the site is suitable for a GRUB station.

4.1.3 Photochemical Oxidants (as Ozone)

See Appendix A for the NEPM Standards for all 6 criteria air pollutants.

According to "*Urban Air Pollution in Australia*" (Australian Academy of Technological Sciences and Engineering, 1997) the major capital cities are likely to have substantial problems with ozone levels, particularly with the passage of time. However, the report also states that smaller urban centres, such as Darwin, are unlikely to have any problems in the immediate future.

Ozone (O_3) is related to UV radiation, emissions of NO_x and volatile organic compounds (VOCs), and air movements. Given the high UV climate, natural background levels of O_3 are expected. Previous monitoring by CSIRO near Darwin has indicated typical dry season levels of 0.020 - 0.025ppm and wet season levels around 0.012 ppm (see Appendix D, pp15-16).

A screening analysis will be provided when the information on ozone levels in smaller urban regions becomes available from the CSIRO TAPM consultancy.

4.1.4 Nitrogen Dioxide

Table 4.2, derived from *"Urban Air Pollution in Australia"* (Australian Academy of Technological Sciences and Engineering, 1997), estimates annual NO_x emissions in Australian capital cities and major industrial areas.

These data indicate that Darwin has an annual NO_x pollutant load of 3 000 tonnes, three-fifths that of Hobart and Canberra. However, the NPI data in Table 4.1 indicates emission at 10 000 tonnes, with the difference being due to the inclusion of bushfire sources from the Darwin hinterland. The main source of NO_x resulting directly from human activities is in motor vehicle use (80%). Other sources are petrol and metals refining, commercial manufacturing, food manufacturing and the combustion of fossil fuels. A potentially significant point source of this pollutant is the Channel Island Power Station.

Most NO_X in the Darwin region is generated by dry season fires, whether controlled burns or wildfires. A comparison of figures 2 and 13 in Appendix D (pp6, 16) demonstrates similar time trends for PM_{10} from bushfires and NO_x recorded by passive samplers.

Table 4.2 Annual NO_x emissions estimates

Location	NO_x (Kt)
Sydney	102
MAQS Region	239
Port Philip Region	83
Brisbane Region	74
Perth-Kwinana	46
Adelaide	34
Canberra	5
Hobart	5
Darwin	3
Latrobe Valley	52
Launceston	0.6
Port Pirie	0.4

Indications are that NO_x concentrations are expected to be generally low. Results from the 2000 dry season CSIRO air quality monitoring study show concentrations averaged 0.0043 ppm, with a maximum of 0.0080 ppm (Appendix D, p15). It is acknowledged that passive samplers lack the fine temporal resolution of more direct methods.

Consequently a screening analysis will be provided when the information on oxides of nitrogen levels in smaller urban regions becomes available from the CSIRO TAPM consultancy.

4.1.5 Particles as PM_{10}

Benchmark studies in the 2000 dry season indicate that PM_{10} is likely to be the only pollutant of concern in the Darwin region. Monitoring of PM_{10} was carried out at the CSIRO/Parks and Wildlife Commission complex adjoining the corner of McMillans Road and Vanderlin Drive, Berrimah (see Figure 4.1 for location).

The methods adopted for collection of benchmark PM_{10} data did not satisfy the NEPM requirements, principally in relation to NATA accreditation. However, particulates were monitored using a TEOM, which is considered to yield high quality data, and the monitoring site met the requirement of AS2922-1987 (Ambient Air – Guide for Siting of Sampling Units).

The TEOM at Berrimah recorded data including 30-minute, 1-hour, 8-hour and 24-hour mass loadings and integrated collected mass, using a number of built in corrections to convert to 1 atmosphere and 0 ^{0}C and an empirical correction required for US EPA PM_{10} equivalence.

Figure 4.3 shows 24-hour mean mass loadings from 23 February to 12 December 2000.

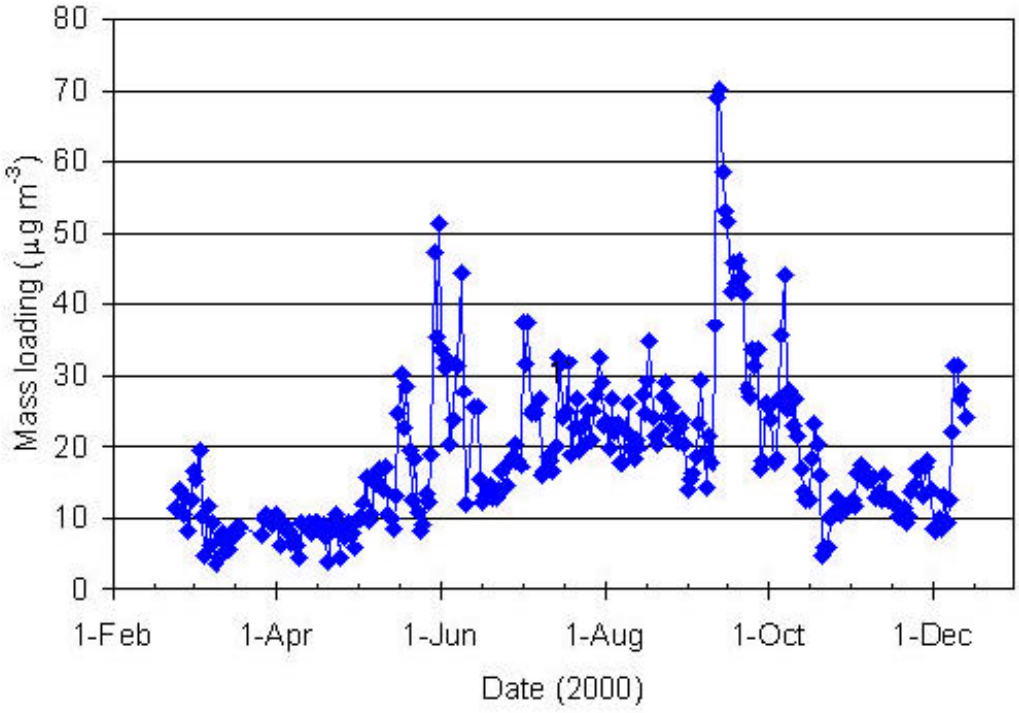


Figure 4.3 PM_{10} 24-hour mean mass loadings at Berrimah, February - December 2000 (1atm., 0°C, US EPA equivalent)

Mass loadings follow the expected general pattern of increase from the wet season into the dry season with occasionally stronger events. There were two main periods where the 24-hour mean PM10 mass loading exceeded the Air NEPM standard of 50 µg m^{-3}, both associated with local observations of smoke. The first occurred at the end of May, when a single day just exceeded the 50 µg m^{-3} level; the second was in early September when 5 consecutive days exceeded 50 µg m^{-3}. During this second period the loading reached 69 µg m^{-3} on 11th September and 70 µg m^{-3} on the

following day. Another smoky period was also observed near the end of the measurements in December, during a late dry period, although 24-hour loadings reached only about 30 $\mu g\ m^{-3}$.

Indications are that particulates from bushfire smoke constitute the most significant pollutant in the Darwin region. The Department of Lands, Planning and Environment has entered into a dialogue with the Bush Fires Council of the NT and the Bureau of Meteorology regarding strategies for managing bushfires which impact on Darwin's air quality.

4.1.6 Carbon Monoxide

This pollutant is not expected to be a problem on a regional scale but it may be a local issue. Motor vehicles are the dominant source of CO. Catalytic converters that oxidise CO to CO2 are fitted on cars manufactured since 1985. In time, as the use of cars built before 1985 diminishes, CO emissions are expected to decline. The NT has the youngest vehicle fleet in Australia with an average age of 9.2 years. Consequently CO from motor vehicles is not expected to be a problem.

The only major point source of CO emissions, 610 tonnes per annum, is at the relatively small (250 MW) Channel Island Power Station. Channel Island is some 10 km south of the Darwin CBD and 13 km southwest of Palmerston, and consequently well removed from the prevailing winds passing over those urban areas. There are no meteorological or topographical factors that would lead to recirculation of those emissions and subsequent impact on any residential areas.

Other sources may be fires (both wildfires and controlled burns) and some industrial processes, however all indications are that these will have only a minor influence on Darwin.

This can be illustrated by comparison with the Latrobe Valley in Victoria, which has a higher population, more of the industrial sources, fairly frequent incidence of smoke from burning vegetation and a more adverse climate and topography for worst-case pollution events. Carbon monoxide was monitored in the Latrobe Valley between 1983 and 1988. Morwell East exceeded 40% of the NEPM standard in 1983 and 1988, and Traralgon and Moe equalled 40% of the NEPM standard in 1984 and 1985 (Ambient Air NEPM Monitoring Plan - Victoria, 2001; Appendix D p68). Since the 1980s, the changeover to cars with catalytic converters would be expected to have reduced concentrations in the Latrobe Valley even further, and CO has generally trended downwards since 1985 (as indicated in various jurisdictional NEPM monitoring plans).

According to criterion F of Table 1 in NEPM Guideline Paper No. 4 (see Appendix B of this plan), such low concentrations in the Latrobe Valley indicate that carbon monoxide monitoring in Darwin is unnecessary, and hence will not be done.

4.1.7 Sulphur Dioxide

Sulphur dioxide is not a significant pollutant in the Darwin region. The only potentially significant point source in the Northern Territory is the Ranger mine site at Jabiru, 300 km east of Darwin, which emits 150 tonnes per year (NPI data).

The expected low levels can be illustrated by comparison with the Geelong sub-region in the Port Phillip Region. Geelong has a larger population (125,382), industrial emissions of sulphur dioxide, and more adverse climate and topography for worst-case pollution events. Concentrations there have not exceeded 40% of the NEPM standard (Ambient Air NEPM Monitoring Plan - Victoria, 2001; Appendix D p63).

This is supported by the results from the 2000 dry season CSIRO air quality monitoring study. Sulphur dioxide concentrations averaged 0.0005 ppm, with one maximum of 0.0013 ppm (Appendix D, p15). It is acknowledged that passive samplers lack the fine temporal resolution of more direct methods, but the extremely low levels support the case that monitoring is not required unless a major industrial emission source is established.

4.1.8 Lead

The data presented in Table 4.3 was sourced from the NEPM Impact Statement for Ambient Air Quality.

Table 4.3 Leaded petrol sales and emissions from lead-fuelled motor vehicles

State	Sales of leaded petrol (megalitres)			Estimated lead emissions from vehicles (tonnes)		
	1980	1990	1995	1980	1990	1995
NSW/ACT	4988	3668	2220	NE	NE	NE
Victoria	4131	3328	1989	1431	769	306
Queensland	2382	2212	1498	NE	1431	769
South Australia	1320	1071	652	854	536	151
Western Australia	1471	1193	772	NE	NE	178
Tasmania	425	357	256	147	124	59
Northern Territory	110	101	66	NE	NE	15
Australia	14772	11930	7542			

(NE: not estimated)

Lead emissions occur from pre-1986 cars using leaded petrol. The NT has the youngest vehicle fleet in Australia (9.2 years) and consequently there are few cars using leaded petrol on NT roads. This is supported by the NT data in Table 4.3. The phase out of leaded fuel will assist in ensuring compliance in major urban areas with the 0.5 $\mu g/m^3$ NEPM level.

In the 2000 dry season CSIRO air quality monitoring study, airborne lead in the PM_{10} fraction was determined at Berrimah using samples collected via the TEOM bypass flow and at the NTU Casuarina site using an Ecotech MicroVol sampler with a PM10 size selective inlet. Initially, samples were taken for 24-hour averages, however from 23rd July the sample period was extended to five days. This change in sampling duration was made because of the very low levels of lead encountered.

The laboratory analytical procedure has a detection limit of around 2 ng lead per filter. Where samples returned loadings per filter less than the minimum detection

level, a value corresponding to one half this minimum detection limit has been plotted.

Atmospheric PM10 lead loadings for the Berrimah and Casuarina sites are shown as a time series in Fig. 6 (p10) of Appendix D. The maximum lead loading observed was 11.1 ng m^{-3}, or 0.0111μg/m^3, at the Berrimah site. Adjusting this using the regression derived from Collingwood data in Appendix E of the Ambient Air NEPM Monitoring Plan - Victoria, 2001:

$$\begin{aligned} Pb\ (TSP) &= 0.011 + 1.14\ Pb(PM_{10}) \\ &= 0.011 + 1.14\ (0.011) \\ &= 0.024\ \mu g/m^3 \end{aligned}$$

This is well below the 55% acceptance limit of 0.275μg/m^3 for campaign monitoring contained in criterion A of Table 1 in NEPM Guideline Paper No. 4 (see Appendix B of this plan).

In summary:

- the dry season campaign monitoring captured the period most likely to have elevated lead levels, given the atmospheric scrubbing effect of intense tropical rainfall;
- very low levels necessitated an extension of the sampling period from 24 hours to 5 days;
- even with the extended duration sampling, some lead determinations were generally at or below detection limits of the analytical procedure;
- the maximum concentration of TSP lead at Berrimah is estimated to be 0.024 μg/m^3, compared to the 55% acceptance limit of 0.275μg/m^3.

Consequently monitoring for lead will not be undertaken in the Darwin region unless a major industrial emission source is established.

4.1.9 Summary of Monitoring Proposed for the Region

Monitoring of PM_{10} in ambient air by TEOM is proposed at a Bureau of Meteorology site at Darwin Airport to represent the Darwin region.

5. SITING AND INSTRUMENTATION

5.1 Details of Monitoring Stations

Benchmark studies in the 2000 dry season indicate that PM_{10} is likely to be the only pollutant of concern in the Darwin region. Monitoring of PM_{10} by TEOM was carried out at the CSIRO/Parks and Wildlife Commission complex adjoining the corner of McMillans Road and Vanderlin Drive, Berrimah, and gravimetrically at the NTU Casuarina Campus (see Figure 4.1 for locations).

The Department of Lands, Planning and Environment is negotiating with the Darwin Regional Office of the Bureau of Meteorology to enter into a Memorandum of Understanding to co-locate a TEOM at the Bureau's new Darwin Airport complex, due for completion later this year. In-principle agreement has been reached.

The Bureau will be able to provide 24 hour low level technical support and a powered secure site. The site will meet the requirements of the relevant Australian Standards.

The proposed site is approximately 3.6 km southwest of the Berrimah site and is located such that it is able to sample regional air parcels moving over Darwin.

In the dry season, the south-easterly prevailing winds pass over Berrimah, and later the NTU Casuarina Campus (see Figure 4.1 for locations). The CSIRO final report at Appendix D compares PM_{10} results (pp7-9) for the two sites and notes there is strong agreement (r^2= 0.79) given the 7 km separation.

This indicates that there is little variation in air quality with respect to PM_{10} at any one time between the sites and that both sites are sampling air parcels representative of regional air quality. Meteorological and topographic considerations support the presence of well-mixed regional air parcels.

Consequently, in the absence of localised sources of pollutants, it is considered that there are no significant differences between the sites at Berrimah, NTU Casuarina Campus and the proposed site at Darwin Airport in terms of sampling regional air parcels that pass over populated areas, and it is valid to designate the airport site as a GRUB station.

It is intended to commission a TEOM at the Darwin Airport site by December 2002, and commence routine monitoring operations in February 2003.

5.2 Monitoring Station Site Compliance

Monitoring station site compliance is based on an analysis of air quality monitoring sites and parameters required to be monitored. Australia Standard AS2922 – 1987 (Ambient Air – Guide for the Siting of Sampling Units) will be followed to the greatest extent practicable.

5.3 Description of Exceptions to Data Handling Procedures

The Department of Lands, Planning and Environment will ensure compliance with the requirements of the NEPM once monitoring commences, scheduled for February 2003.

The Department of Lands, Planning and Environment intends to outsource data capture, handling and any associated interpretation, but will remain responsible for data archiving and formal reporting under the NEPM.

5.4 Accreditation

The Department of Lands, Planning and Environment is committed to supplying high quality data for NEPM reporting purposes.

Formal NATA accreditation is scheduled to be in place by December 2004. Discussions with NATA indicate that there are no difficulties with accrediting the various components of the monitoring program even though there may be a number of discrete parties involved.

6. REPORTING

The NEPM clauses 17 and 18 describe the requirements for evaluation of performance and reporting. The Department of Lands, Planning and Environment will prepare Annual Reports to meet these requirements, including the components described below.

6.1 Background Information

The Report will reference the Monitoring Plan that should, at any given time, be up-to-date with respect to monitoring and associated activities. Any variations from the current monitoring plan will need to be noted and explained.

The Report will repeat only as much detail from the Monitoring Plan as is necessary to make the Report a stand-alone document. Information presented on the Darwin region in the Report will be clearly presented.

6.2 Determination of Exposed Population

In accordance with Clause 17, the exposed population will be stated in cases where standards have been exceeded. In cases where data is not obtained, the term “not demonstrated” will indicate its absence.

6.3 Evaluation of Performance Against Standards and Goal

If monitoring has taken place, the results will be clearly presented in the Annual Report. These will be compared with standards set in the NEPM.

6.4 Annual Air Quality Statistics

If the data set grows to meet the requirements of the NEPM, data will be presented in either graphical or tabular form. A plot may include all data obtained, to aid in identifying trend information.

7. REFERENCES

Australian Academy of Technological Sciences and Engineering (1997) *Urban Air Pollution In Australia*

PRC (2000a) "Selection of regions", National Environment Protection Council (Ambient Air Quality) Measure Guideline Paper No.2, November 2000

PRC (2000b) "Monitoring strategy", National Environment Protection Council (Ambient Air Quality) Measure Guideline Paper No.3, November 2000

PRC (2000c) "Screening procedures", National Environment Protection Council (Ambient Air Quality) Measure Guideline Paper No.4, November 2000

APPENDIX A

SCHEDULE 2, AMBIENT AIR QUALITY NEPM

Standards and Goal

Column 1 Item	Column 2 Pollutant	Column 3 Average	Column 4 Maximum Concentration	Column 5 Goal within 10 years Maximum allowable exceedences
1	Carbon monoxide	8 hours	9.0 ppm	1 day a year
2	Nitrogen dioxide	1hour 1 year	0.12 ppm 0.03 ppm	1 day a year none
3	Photochemical oxidants (as ozone)	1 hour 4 hours	0.10 ppm 0.08 ppm	1 day a year 1 day a year
4	Sulfur dioxide	1 hour 1 day 1 year	0.20 ppm 0.08 ppm 0.02 ppm	1 day a year 1 day a year none
5	Lead	1 year	0.50 ug/m^3	none
6	Particles as PM_{10}	1 day	50 ug/m^3	5 days a year

For the purposes of this Measure the following definitions shall apply:

(1) Lead sampling must be carried out for a period of 24 hours at least every sixth day.

(2) Measurement of lead must be carried out on Total Suspended Particles (TSP) or its equivalent.

(3) In Column 3, the averaging periods are defined as follows:

1 hour	clock hour average
4 hour	rolling 4 hour average based on 1 hour averages
8 hour	rolling 8 hour average based on 1 hour averages
1 day	calendar day average
1 year	calendar year average

(4) In Column 5, the time periods are defined as follows:

day	calendar day during which the associated standard is exceeded
year	calendar year

(5) All averaging periods of 8 hours or less must be referenced by the end time of the averaging period. This determines the calendar day to which the averaging periods are assigned.

(6) For the purposes of calculating and reporting 4 and 8 hour averages, the first rolling average in a calendar day ends at 1.00am, and includes hours from the previous calendar day.

(7) The concentrations in Column 4, are the arithmetic mean concentrations.

APPENDIX B

SCREENING PROCEDURES
National Environment Protection Council (Ambient Air Quality) Measure Guideline
Paper No.4
November 2000

1. Introduction

According to Clause 14 (3) of the Ambient Air Quality NEPM:

> "*Fewer performance monitoring stations may be needed where it can be demonstrated that pollutant levels are reasonably expected to be consistently lower than the standards mentioned in this Measure."*

In order to provide transparent and reasonable criteria by which jurisdictions may evaluate whether "*pollutant levels are reasonably expected to be consistently lower than the standards mentioned in this Measure*", the Peer Review Committee (PRC) has considered and documented a range of analyses that could be used. These analyses are called "screening procedures".

Screening procedures may be used to:

- Reduce the number of performance monitoring sites for a given pollutant below that proposed by the NEPM formula of Clause 14(1); or
- Justify not monitoring a pollutant in regions with a population over 25,000.

It is important to note that the use of screening procedures is limited to the purpose described in Clause 14(3) of the Ambient Air Quality NEPM. Clause 11(b) is very different in context to Clause 14(3). Clause 11(b) provides for the possible use of alternatives to performance monitoring stations in situations where performance monitoring would otherwise occur. In any situation where a jurisdiction employs Clause 11(b), it is obliged to report and employ the data generated by the Clause 11(b) assessment method in exactly the same way as if a performance monitoring station had been used (see Clause 17(2)). For instance, if the Clause 11(b) method is modelling, then results of the model (for example 1-hour time series predictions) must be used under Clauses 17 and 18 (evaluation and reporting) in the same way that monitoring data would.

As noted above, screening may result in monitoring not taking place in areas where it can be demonstrated that pollutant levels can be reasonably expected to be consistently lower than the NEPM Standards. Depending on the methodology employed to evaluate population exposures in unmonitored areas, there is potential for computational bias to be introduced in exposure assessments. To counter or minimise such potential bias, it will be necessary for jurisdictions to identify the area and populations to which the screening applies and the screening level concentration below which concentrations are expected to lie. This information should be documented in monitoring plans and when reporting,

2. Generic Types of Screening Procedures

When considering any particular region, it may not be possible to make a determination under Clause 14(3) based on a single screening procedure applied to all pollutants. For example, a region with a population of say 30,000 might clearly have low levels of O_3, NO_2, SO_2 and Pb, but might experience events which exceed the NEPM standard for PM_{10} due to domestic solid fuel heating or fuel reduction burns.

Nevertheless, it is possible to describe generic types of screening procedures and to rank these in terms of the confidence which can be attached to the respective screening determinations. It is then reasonable to formalise the use of screening procedures by setting acceptance limits, generally expressed as percentages of the NEPM standards. These acceptance limits would take account of the confidence attached to the associated screening procedures. Screening would be considered acceptable only if the procedure yielded a prediction of maximum pollutant concentration which was below the acceptance limit for that procedure. If a procedure with low confidence (large uncertainty) did not predict a maximum concentration below the acceptance limit, a different procedure with higher confidence and higher acceptance limit could be used. This is best explained by examining the generic procedures in Tables 1 to 3 for the various pollutants.

The screening procedure should allow for trends in projected emissions over five to ten years. This is consistent with the possible schedule for reviewing NEPM plans.

The hierarchy of procedures in Tables 1 to 3 can be applied to each pollutant in each region within a jurisdiction. Consider, for example, CO in a particular region which, according to Clause 14(1), requires 3 monitoring stations. Full performance monitoring at 3 stations is the default. However, the jurisdiction is permitted to apply any screening procedure in Table 1 as long as the concentration of CO predicted by that procedure is less than the concentration set by the acceptance limit.

In using the screening procedures presented in Tables 1 to 3, the following notes apply:

- The maximum acceptance limit for any screening procedure, no matter how reliable, has been set at 75%. In other words, the PRC considers that if concentrations in excess of 75% of the standard for a pollutant are probable within a region, performance monitoring (or an approved alternative under Clause 11(b)) should occur. This is in accord with the intent of Clause 14(3);
- To maintain a conservative approach, the maximum predicted or measured concentration should be used for comparison with acceptance limits, even though the NEPM goal may specify a number of exceedences; and
- For pollutants which have standards for more than one averaging period, the acceptance limit criteria to be used is that of the standard which is most difficult to meet in any given region. In the majority of cases, this is expected to involve the shortest averaging period.

3. Periodic Review of Screening Determinations

The NEPM does not specify the need for periodical review of determinations under Clause 14(3). The PRC recommends that a jurisdiction which has employed a screening procedure to demonstrate that performance monitoring is not required in part or the whole of a region, should formally review whether the determination is reasonable at five-yearly intervals thereafter, or sooner if there are indications of a significant upward trend in emissions or concentrations.

Table 1. Acceptance limits by screening procedure for carbon monoxide, nitrogen dioxide, sulfur dioxide and lead.

Screening Procedure	*Acceptance Limit* **(% of NEPM standard)**
A. Campaign monitoring at a Generally Representative Upper Bound (GRUB) monitoring location (with no significant deterioration expected over 5-10 years).	55% for 1 year of data 60% for 2 or more years of data
B. Use of historical data within a region which will contain one or more GRUB monitoring stations to demonstrate that the full number of stations (according to 14(1)) is not required, either to detect exceedences or gain a more representative depiction of pollutant distribution.	65% for 2 or more years of data 75% for 5 or more years of data
C. Use of modelling[(2)] within a region which will contain one or more GRUB monitoring stations to demonstrate that the full number of stations (according to 14(1)) is not required, either to detect exceedences or gain a more representative depiction of pollutant distribution.	55%
D. In a region with no performance monitoring, use of validated[(1)] modelling with detailed and reliable estimates of emissions and meteorological data. As above in combination with F.	45% 50%
E. In a region with no performance monitoring, and in the absence of emissions and detailed meteorological data, use of generic model results based on gross emissions estimates, "worst case" meteorology estimates and other conservative assumptions. As above in combination with F.	35% 45%
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential[(2)].	40%
G. Use of non-standard monitoring methods, including passive samplers, which have been "calibrated" against data from performance monitoring stations.	This procedure should only be used in support of C, D, E or F, adding say 5% to the respective acceptance limits

[(1)] Validation means demonstrated satisfactory correlations between observations and predictions in the same or similar airshed.
[(2)] Pollution potential must take into account meteorology and topography.

Table 2. Acceptance limits by screening procedure for photochemical oxidants (as ozone).

Screening Procedure	Acceptance Limit (% of NEPM standard)
A. Campaign monitoring at a Generally Representative Upper Bound (GRUB) monitoring location (with no significant deterioration expected over 5-10 years).	70% for 2 or more years 75% for 5 or more years
B. Use of historical data within a region which will contain one or more GRUB monitoring stations to demonstrate that the full number of stations (according to 14(1)) is not required, either to detect exceedences or gain a more representative depiction of pollutant distribution.	78% for 2 or more years 82% for 5 or more years
C. Use of modelling within a region which will contain one or more GRUB monitoring stations to demonstrate that the full number of stations (according to 14(1)) is not required, either to detect exceedences or gain a more representative depiction of pollutant distribution.	70%
D. In a region with no performance monitoring, use of validated[(1)] modelling with detailed and reliable estimates of emissions and meteorological data. As above in combination with F.	65% 68%
E. In a region with no performance monitoring, and in the absence of emissions and detailed meteorological data, use of generic model results based on gross emissions estimates, "worst case" meteorology estimates and other conservative assumptions. As above in combination with F.	58% 66%
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential[(2)].	60%
G. Use of non-standard monitoring methods, which have been "calibrated" against data from performance monitoring stations.	This procedure should only be used in support of C, D, E or F, adding say 5% to the respective acceptance limits

[(1)] Validation means demonstrated satisfactory correlations between observations and predictions in the same or similar airshed.
[(2)] Pollution potential must take into account meteorology and topography.

Table 3. Acceptance limits by screening procedure for PM_{10}

Screening Procedure	Acceptance Limit (% of NEPM standard)
A. Campaign monitoring at a Generally Representative Upper Bound (GRUB) monitoring location (with no significant deterioration expected over 5-10 years).	55% for 1 year of data 60% for 2 or more years of data
B. Use of historical data within a region which will contain one or more GRUB monitoring stations to demonstrate that the full number of stations (according to 14(1)) is not required, either to detect exceedences or gain a more representative depiction of pollutant distribution.	65% for 2 or more years of data 75% for 5 or more years of data
C. As in B above but using TSP and a conservative assumption about PM_{10}:TSP ratios.	70% for 5 or more years of data 60% for 2 or more years of data
D. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential[(1)].	40%
E. Use of non-standard monitoring methods, which have been "calibrated" against data from performance monitoring stations.	This procedure should only be used in support of C, D, E or F, adding say 5% to the respective acceptance limits

[(1)] Pollution potential must take into account meteorology and topography.

4. Screening Notes for Particular Pollutants

The PRC has determined screening criteria based on the best professional judgement with information available at the time. It is recognised that these criteria may need to be updated to reflect experience with their application.

4.1 Carbon Monoxide

- Jurisdictions may wish to continue to measure CO at a peak CBD site, representing a maximum for traffic-generated CO.
- High CO may be associated with wood fires. CO monitors may be required in centres which have wood smoke problems.
- Since jurisdictions are likely to have performance monitoring station data from a number of centres, most of which will show CO levels well below the standard, conclusions based on the lower emissions of smaller centres should be quite reliable, without the need to model. Modelling would be complicated by the difficulty in quantifying wood fire emissions. A check should nevertheless be made on the relative frequencies of stable meteorological conditions.

4.2 Nitrogen Dioxide

- Wherever ozone is monitored, it is recommended that NOx also be monitored irrespective of the likely NO_2 concentrations. Ozone distributions cannot be interpreted without NOx data.
- Emissions of NOx within a region can be fairly readily estimated. The time dependent conversion of NOx to NO_2 and loss of NO_2 via surface deposition and chemical reaction are factors which complicate modelling.
- A full 3D meteorology / dispersion / chemistry modelling exercise is possible but it is a major undertaking.
- A conservative screening modelling approach would be to assume all (or say 50% of) NOx is NO_2, ignoring reactions and losses, and simply modelling NO_2 dispersion (as a conserved tracer) for a few selected days with adverse meteorological conditions. The model would handle area and point sources (surface and elevated releases). It may be possible to avoid running a model in some cases where a worst case desktop calculation yields an NO_2 maxima well under than the NEPM standard.
- Passive samplers can be used to measure 24 hour averages of NO_2. For general urban emissions there may be a reasonably consistent relationship between 24 hour average and 1 hour maximum across populations centres of varying sizes. A combination of passive sampler measurement coincident with continuous monitor measurements in the capital city and a few smaller centres may provide a reliable method of screening via passive sampler alone in yet smaller centres. At the very least, passive sampling would be a useful component of ongoing assessment of a population centre which has been screened out (i.e. by providing long term trend information).

4.3 Photochemical Oxidants (as Ozone)

- Determining appropriate screening levels for photochemical oxidants (as ozone) has been made more difficult because the PRC recognises that, in Australia, there is often a substantial background level of ozone. This is formed from the interaction of naturally emitted substances: reactive organic compounds from trees, plants and grasses; and oxides of nitrogen from soil and the sea. The PRC agreed that the available Australian evidence points to the background being nowhere lower than

about 0.03 ppm. On this basis it was decided to generate screening percentages for photochemical oxidant by the following procedure. Use the percentages of table 1 for the gaseous pollutants which have negligible backgrounds and apply these to the *anthropogenic* component of the standard. Thus the percentages of table 1 were applied to the 0.07 ppm of the one-hour standard assumed to come from human activities and then this was added to the natural background. This result was then reconverting to a percentage of the standard. The same calculations were applied to the 4-hour standard resulting in values that were about 3 or 4 percent higher. The results were then rounded to the nearest 0, 2, 5 or 8 with preference given to 0 and 5 reflecting the inherent accuracy of the method (see below).

For example, in row F of table 1 the percentage is 40 %. For row F in table 2 the value has been determined as

Using the 1 hour standard
40/100 x 0.07 + 0.03 ppm expressed as a percentage of 0.10 ppm. The result is 58%.
Using the 4 hour standard
40/100 x 0.05 + 0.03 ppm expressed as a percentage of 0.08 ppm. The result is 62%.

Thus the value found in table 2 is 60% - the average in this case..

- It should be noted that even though the results are expressed to two significant figures, this does not imply that the screening process has this level of accuracy. The PRC recognises that screening is an imprecise tool which should be used as a guide not a prescription. Where measured or inferred levels are close to the screening levels presented in the tables, jurisdictions need to be careful in the application so as not to screen out situations which, with a less literal application of the guidelines, should either require monitoring or a stronger justification for its exclusion. This is particularly the case for one-hour ozone levels and table 2 where more lenient screening criteria have been established to recognise the impact of background levels on 4-hour average results.

4.4 Sulfur Dioxide

- SO_2 is relatively easy to assess, since it is almost entirely an industrial emission and reacts only slowly.
- Kwinana in the Perth region is a useful example of where procedure C from Table 1 might be applied. Kwinana and surrounds might be considered a sub-region containing all of the region's SO_2 emissions and the upper bound site(s). There will be a performance monitoring station downwind of Kwinana which will demonstrate NEPM compliance. The fact that concentrations reduce further downwind will be readily demonstrated by reference to the concentration gradients measured by the existing network of six "source management" stations and by previously validated Gaussian plume modelling. Lack of SO_2 emissions elsewhere in Perth will preclude the need for more than the single Kwinana station. SO_2 has been previously monitored at another site in the metropolitan area to confirm that concentrations are very low. This data could be used to support a Clause 14(3) assessment.
- Passive SO_2 samplers provide a useful means of confirming the reduction in SO_2 concentration with distance from sources. Data from these samplers is directly applicable to the 24-hour standard but can also be used to confirm the results of a model which produces estimates of both 1-hour and 24-hour concentrations.

4.5 Lead

- Jurisdictions are likely to want their CBD lead monitoring station to be a performance monitoring station and trend station for the purpose of the NEPM. This is possible under the wording of Clause 13(2), given that lead concentrations at the site are well below the NEPM and reducing. Lead levels in suburban areas are likely to be insignificant, a fact which could be confirmed by a brief campaign of monitoring.
- Modelling of near-roadside lead could be verified in a few instances by campaign monitoring and thereafter be used as a screening tool. Furthermore, it should be possible to develop simple conservative screening rules based on VKT per square kilometre and petrol lead content.

4.6 Particles (as PM_{10})

- Screening in centres subject to wood fire or prescribed burning smoke is not easy. High wood fire smoke concentrations occur locally under near calm conditions so total population is not a key determinant. Large prescribed burn plumes impact small and large centres alike over hundreds of kilometres.
- Hi-Vol samplers are relatively easy to install and operate on a six day cycle for a year to provide data to support a screening assessment.
- If TSP data exists for an area, it can be used to assess the likelihood of PM_{10} exceedences by applying a conservative TSP/PM_{10} ratio.
- There are doubts about the use of particle counters for general NEPM measurements, however they may have a place in providing measurements of relative smoke concentration for use in screening. Their use in this role (or for other particle types) would need to be verified against PM_{10} (say TEOM) measurements. Nephelometers might similarly be used as they provide a good surrogate measurement of smoke.

APPENDIX C

GLOSSARY

Air NEPM	National Environment Protection Measure for Ambient Air Quality (26 June 1998)
Airshed	An area in which air quality is subject to common influences from emission, meteorology and topography
API	Airborne Particle Index
CO	Carbon monoxide
GRUB	Generally Representative Upper Bound (referring to a performance monitoring station, as described in the PRC Guideline Paper)
NATA	National Association of Testing Authorities
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NEPM standards	Standards defined in Schedule 2 of the NEPM (refer also to definitions contained in Schedule 2)

Pollutant	Averaging Period	Maximum Concentration	Goal within 10 years; Maximum allowable exceedences
CO	8 hours	9.0 ppm	1 day a year
NO_2	1 hour	0.12 ppm	1 day a year
	1 year	0.03 ppm	none
O_3	1 hour	0.10 ppm	1 day a year
	4 hours	0.08 ppm	1 day a year
SO_2	1 hour	0.02 ppm	1 day a year
	1 day	0.08 ppm	1 day a year
	1 year	0.02 ppm	none
Lead	1 year	0.50 $\mu g\ m^{-3}$	none
PM_{10}	1 day	50 $\mu g\ m^{-3}$	5 days a year

NO	Nitric oxide
NO_2	Nitrogen dioxide
NO_x	Oxides of nitrogen
O_3	Ozone
PM_{10}	Particles which have an aerodynamic diameter less than 10 μm
PMS	Performance Monitoring Station, as defined in the Air NEPM
ppm	parts per million
PRC	Peer Review Committee
SEPP	State Environment Protection Policy
SO_2	Sulphur dioxide
TEOM	Tapered Element Oscillating Microbalance
TSP	Total Suspended Particulate Matter
VOC	Volatile Organic Compounds
$\mu g\ m^{-3}$	Microgram (1 millionth of 1 gram) per cubic metre

Appendix D

A Pilot Study of Air Quality in Darwin, N.T.
for the
Northern Territory Government,
Department of Lands Planning and Environment

Final Report

CSIRO Atmospheric Research
Aspendale, Victoria, Australia

15th March 2001

Project Team

Northern Territory University:
D. Parry,
T. Jong,
N. Munksgaard.

CSIRO Atmospheric Research:
J. Gras,
G. Ayers,
M. Keywood,
K. Boast,
J. Powell,
P. Selleck,
T. Firestone.

For further information contact: Dr. John Gras

Telephone: (03) 9239 4400
Fax: (03) 9239 4444
email: john.gras@dar.csiro.au

Postal address:

CSIRO Atmospheric Research
PMB 1 Aspendale, Vic., 3195
Australia

A Pilot Study of Air Quality in Darwin, N.T .
Final report to the Northern Territory Government, Department of Lands Planning and Environment

1. Air quality in Darwin, Pilot Study design.

Work described in this report was carried out for a pilot study of air quality in Darwin. This was a joint activity of the Northern Territory Government Department of Lands Planning and Environment (DLPE), the Northern Territory University (NTU) and CSIRO Atmospheric Research (CAR). The purpose of the study was to provide scientifically rigorous measurements of selected Air NEPM components in the Darwin area from March 2000 to October 2000, a period including both wet and dry season conditions. At the request of DLPE the study was extended, with particle and gas measurements carried through until 13th December. The main sampling instrumentation was decommissioned on 18th December. Measurements undertaken in the study include airborne mass for particles with aerodynamic diameter less than 10 μm (PM10), airborne lead (in PM10), NO_2, SO_2 and ozone. PM10 determinations include measurement using a tapered element oscillating mass balance (TEOM) as well as gravimetric mass and airborne PM10 lead loadings determined using filter collections. TEOM analyses provided continuous PM10 loadings with a 30-minute time resolution and the filter collections were operated on a one-day-in-six cycle. Passive gas samples were taken as duplicates on a six-day (integral) cycle.
The site at Berrimah was selected by DLPE for the main sampling location to satisfy the requirements of a representative urban location with a secure site and controlled environment for the continuous monitor. An additional filter sampler was operated at the NTU Casuarina campus on a six-day cycle for gravimetric PM10 and particulate lead. Initially this sampler was operated on a one-day-in-six cycle but, because of relatively low lead concentrations in Darwin and the low integrated flow rate with the filter sampler, this was altered on 23rd July to also include a five-day-in-six collection. In this final report, all gas and particle data are reported to the end of October and also data for the November-December study extension period where these have been analysed. Gas concentration data to the end of January 2001 are included. All data will be available in electronic form on completion of the analyses for the study extension period.

2. Equipment & installation

Continuous mass loading was determined at the CSIRO site in Berrimah using a Rupprecht and Patashnick TEOM 1400A series mass balance. This was operated at the "standard" conditions of 50 ºC for the inlet conditioning and a sample flow rate of 3 l min^{-1}. A Rupprecht and Patashnick PM10 size selective inlet was mounted on the roof at the sampling site with the sample flow directed vertically downward to the TEOM mass balance, which was located inside an air-conditioned laboratory, maintained at 19 ºC. A standard Ecotech flow splitter was used to divide the sample

flow after the size selective inlet to the sample line (3 l min^{-1}) and a bypass flow to which a filter sampler was connected (13.67 l min^{-1}). Flow rates were maintained at a constant value by mass flow controllers in the TEOM control chassis. This system was installed at Berrimah on 21st and 22nd February 2000. Data were obtained from 23rd February to 13th December 2000. The inlet sample line in the laboratory was lagged to prevent excessive cooling of the sample flow before the TEOM inlet heater. Subsequent problems indicative of condensation occasionally falling as water droplets into the TEOM (sudden jump in mass and subsequent decay) prompted installation of a second layer of lagging (24th March) and a small heater was constructed at CAR and sent to Darwin for installation on the inlet line. The second layer of lagging and reduction of the absolute humidity with the onset of drier conditions meant that the condensation problem was not evident after about mid-April and that the auxiliary heater was not necessary. Another problem that was encountered was acoustic noise from the sample pump. The pump that was used to provide the main TEOM sample flow (16.7 l min^{-1}) had baffling on the outlet to reduce acoustic noise, but this was insufficient to reduce the noise to a level that was considered low enough to prevent impact on normal office work nearby. An acoustic baffle box was constructed and tested for noise reduction at CAR, it was also tested to ensure that the pump was operating within its design thermal range. The baffle box was shipped to Darwin on 13th May, and installed. This reduced acoustic noise to an acceptable level.

A standard CAR passive sampler mount plate was installed by NTU at Berrimah in late February and an Ecotech MicroVol aerosol sampler was installed at the NTU Casuarina Campus and became operational on 7th March.

3. Operation

The sampling program operated substantially as planned although there were a number of problems. As detailed in Section 2, some minor difficulties occurred with the TEOM and were corrected. A small amount of data loss also occurred in the early stages of the project when the collected mass on the TEOM filter reduced the sample flow rate below the accepted threshold. The NTU MicroVol flow controller malfunctioned between 24th March to 5th May and this unit was replaced for the 11th May sample with a new sampler sent from CAR. Samples obtained during the period when the sensor output was low show low mass loadings and data obtained before 11th May should be considered suspect. An error in the shipping schedule for the passive samplers meant that no ozone samplers were exposed over the March to May period but duplicate NO_2 and SO_2 samples were obtained as planned. The replacement MicroVol showed flow problems from mid September and was replaced with a new unit on 2nd October.

4. Data summary

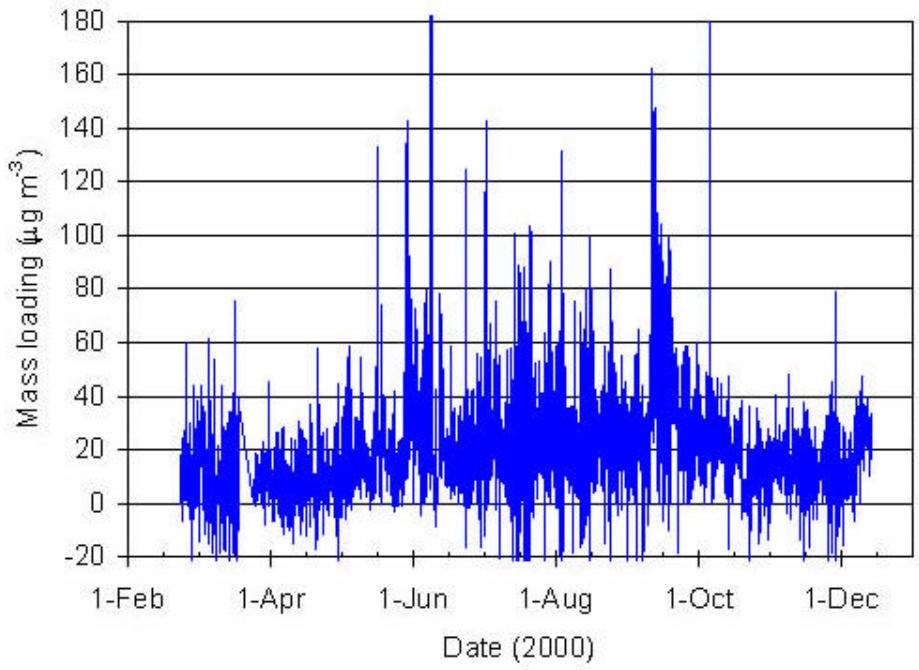
4.1 TEOM PM10 data

Analyses of PM10 data were carried out approximately weekly. Data were recorded as 30-minute, 1-hour, 8-hour and 24-hour mass loadings and integrated collected mass, using the standard TEOM protocol. Data were down loaded to the local PC every six days by the NTU operator and then transmitted to CAR. Primary editing at CAR involved visual inspection of the data and operator comments. Any data that

were known, or appeared, to be invalid were flagged in the data file. Frequently, this included short periods of several hours after changing TEOM filter elements and also included the events that appear to be due to condensation in the inlet line. Mass loadings recorded by the TEOM have a number of "built-in" corrections. These include conversion to the Australian standard measurement conditions of 1 atmosphere and 0 ºC (these parameters are set in the operation firmware) and an empirical correction required for US EPA PM10 equivalence. This latter correction is:

$$PM10 = 1.03 \times \text{mass loading} + 3.0\ \mu g\ m^{-3}.$$

The presence of this correction also needs to be taken into account when comparing the TEOM-derived mass loadings with those from other samplers. Small corrections for the sample and bypass flow must also be included to allow for departures from the nominal 3.0 and 13.67 l min^{-1} flows, as measured using a reference flow meter.



Values of 24-hour mean PM10 were derived from the edited 30-minute loadings for each day. In keeping with normal practice, negative masses were included in the running averages. Figure 1 shows hourly mean mass loadings and the 24-hour mean loadings are shown in Fig. 2 (for days where more than 15 hours of accepted data were collected in the 24-hour period).

Figure 1. PM10 mass loading hourly samples from the Berrimah TEOM, 23rd February – 12th December 2000 (1 atmosphere, 0 ºC, US EPA equivalent)

Mass loadings follow the expected general pattern of increase from the wet season into the dry season with occasionally stronger events. There were two main periods where the 24-hour mean PM10 mass loading exceeded the Air NEPM standard of 50 µg m^{-3}, both associated with local observations of smoke. The first occurred at the end of May, when a single day just exceeded the 50 µg m^{-3} level; the second was in

early September when 5 consecutive days exceeded 50 μg m^{-3}. During this second period the loading reached 69 μg m^{-3} on 11th September and 70 μg m^{-3} on the following day. Another smoky period was also observed near the end of the measurements in December, during a late dry period, although 24-hour loadings reached only about 30 μg m^{-3}.

4.2 Gravimetric mass determinations.

Gravimetric mass loadings as 24-hour integrals were determined from filter collections on the TEOM bypass flow line and also using an Ecotech MicroVol system with a 10-μm size selective inlet operating at the NTU Casuarina Campus. Samples in both cases were collected on pre-weighed (dried) stretched PTFE substrates.

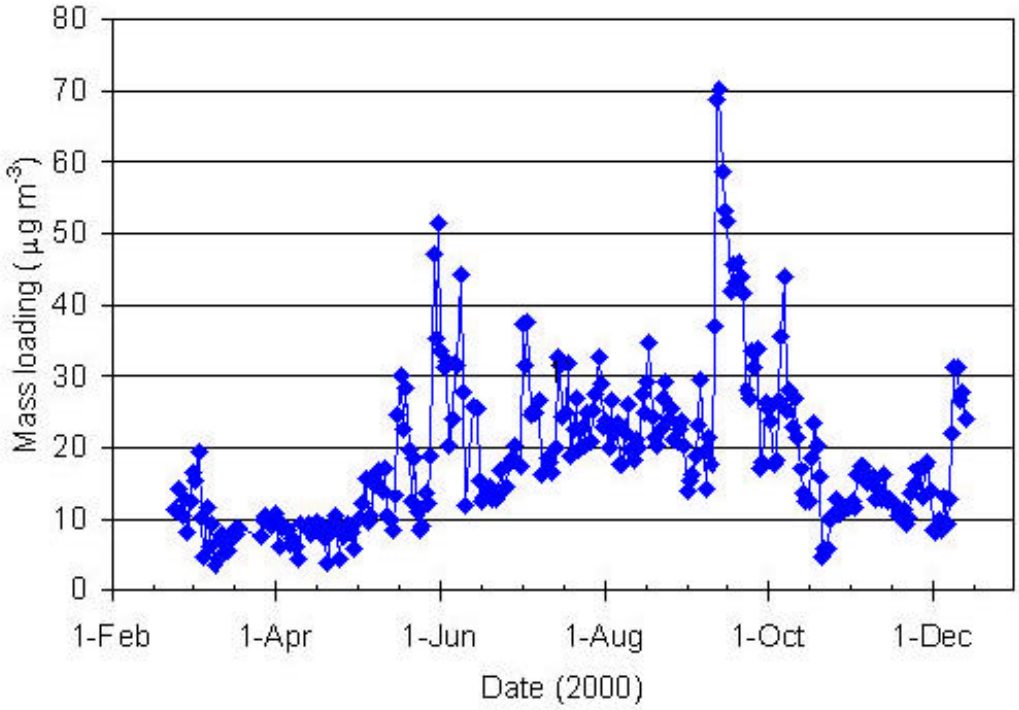


Figure 2. PM10 24-hour mean mass loadings at Berrimah, 23rd February – 12th December 2000 (1 atmosphere, 0 ºC, US EPA equivalent).

On return to CAR Aspendale the collected samples were conditioned for 24 hours at low relative humidity (RH < 20%) and weighed dry using a Mettler UMT2 Ultra-microbalance. Mass loadings from the two filter samplers and from the TEOM for the filter sample periods, without US EPA equivalence correction, are plotted in Fig. 3. MicroVol data for the period prior to 12th May have been excluded.

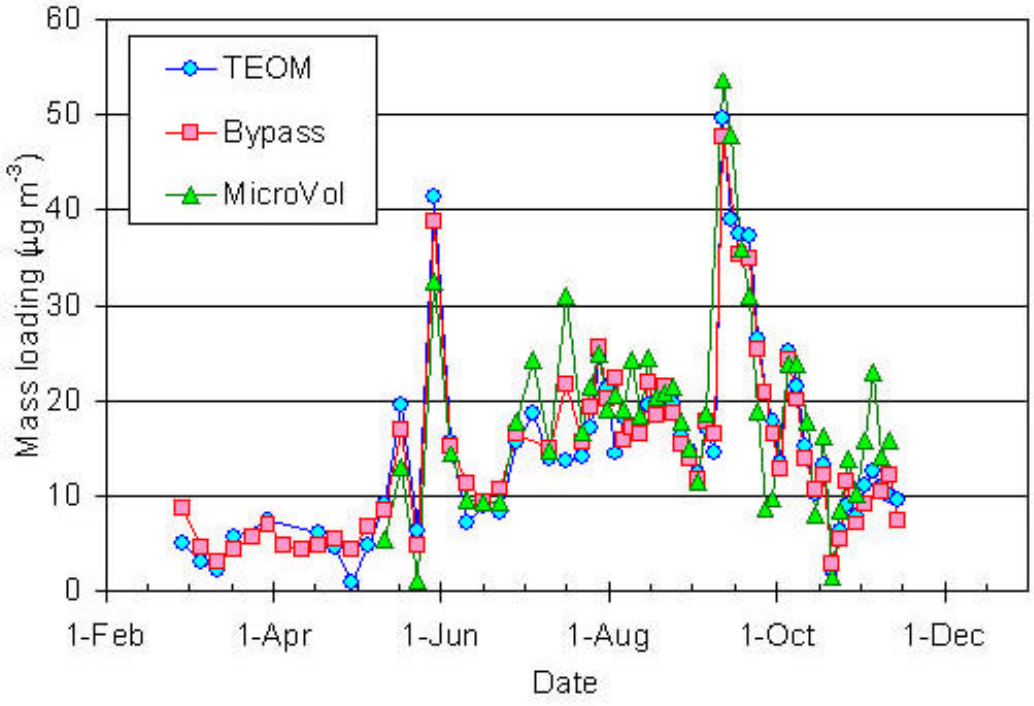


Figure 3. Comparison of integrated mass loading derived from TEOM system, gravimetric determination using the TEOM bypass flow sampler and gravimetric determination using a MicroVol filter sampler at the NTU Casuarina site. All data shown for 1 atmosphere, 0 ºC. For this figure TEOM data are not corrected to US EPA equivalence.

4.3 Comparison of TEOM and gravimetric mass loadings.

Atmospheric mass loadings, derived by integrating the TEOM data for the sample periods of the bypass filter, are also shown in Fig. 4 as a function of the corresponding mass loadings derived using the bypass filter. For this comparison the US EPA equivalence correction was removed from the TEOM data so that, in effect, both estimates of atmospheric mass loading are based on observed mass and the corrected flow at 0 °C, 1 atmosphere. Small empirical corrections for the actual flow rates, determined using a bubble flow meter when the sampler was commissioned in Darwin, are also included. Four outliers with suspected weighing errors have been deleted from Fig. 4. The relationship between the mass loadings is

$$\text{PM10 (TEOM)} = 1.04 \times \text{PM10 (bypass)} - 0.8\ (\mu g\ m^{-3}),$$

with $R^2 = 0.95$. This relationship indicates quite clearly that volatilisation losses of aerosol mass due to heating the inlet to 50 °C in the TEOM inlet is not a problem in Darwin and also raises the question of whether the US EPA equivalence correction of

$$\text{PM10 (reported)} = 1.03 \times \text{PM10 (observed)} + 3.0\ (\mu g\ m^{-3})$$

for the TEOM is appropriate in this location. Empirical equivalence correction is an issue that perhaps should be addressed in establishing an Australian standard procedure for the TEOM. It should be noted that the comparison reported here is not with a co-located Hi-Vol sampler but a low-volume sampler (13.67 l min^{-1}) using the same size-selective inlet.

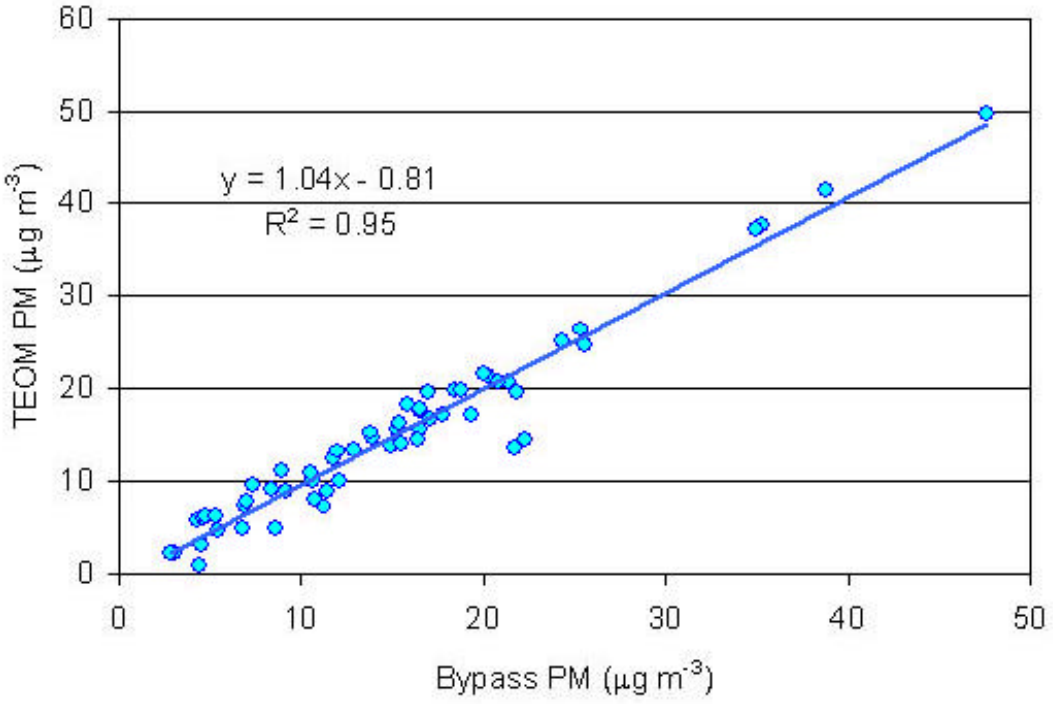


Figure 4. Averaged PM10 mass loading derived from TEOM mass loadings as a function of gravimetric determination using the TEOM bypass flow sampler, for filter sample periods (1 atmosphere, 0 ºC, TEOM data not corrected to US EPA equivalence).

4.3.1 Comparison of MicroVol and TEOM bypass samples

The time series of mass loadings for the discrete filter sampling periods is shown in Fig. 3. This indicates a strong coherence between the different samplers, including the MicroVol sampler, which was located at the NTU Casuarina site. The relationship between the samplers is further examined in Fig. 5, which gives the bivariate relationship between mass loadings of PM10 from the MicroVol at Casuarina and the TEOM bypass filters at Berrimah. Overall the agreement between the two samplers is quite strong, given their 7-km separation. The relationship is given by

$$\text{PM10 (NTU)} = 1.05 \times \text{PM10 (Berrimah)} - 0.9 \ (\mu g\ m^{-3}),\ (r^2 = 0.79).$$

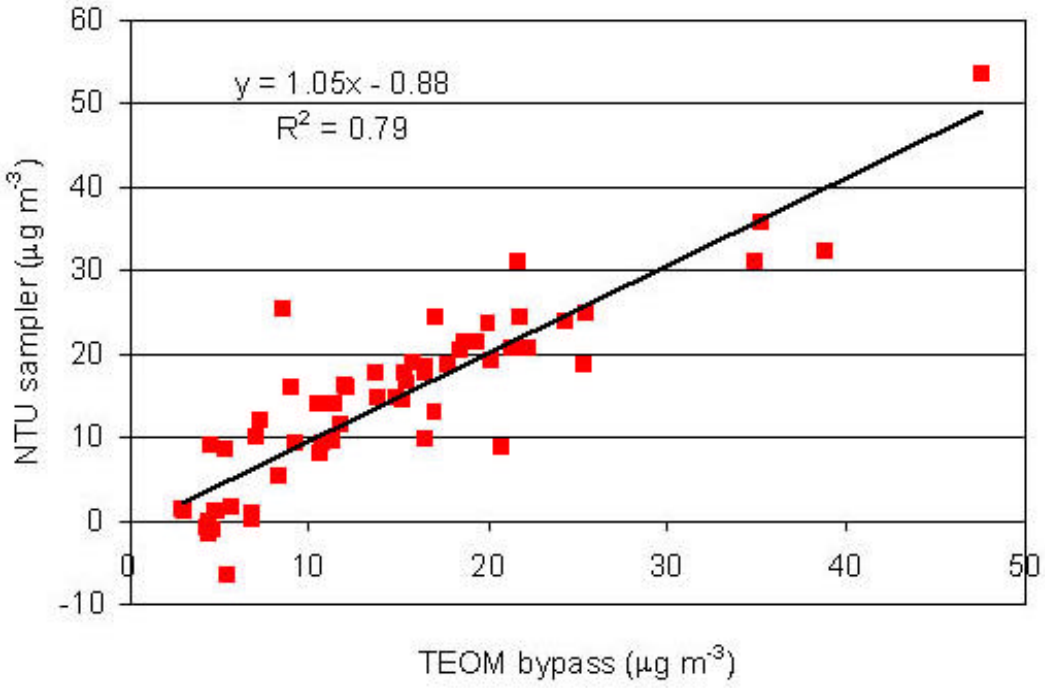


Figure 5. PM10 mass loadings from gravimetric determination on filter samples collected at the NTU Casuarina site and filter samples collected with the TEOM bypass sampler at Berrimah (1 atmosphere, 0 ºC, TEOM data not US EPA equivalent).

4.4 Particulate lead loadings.

Airborne lead in the PM10 fraction was determined at Berrimah using samples collected via the TEOM bypass flow and at the NTU Casuarina site using an Ecotech MicroVol sampler with a PM10 size selective inlet. Initially, samples were taken for 24-hour averages, however from 23rd July the sample period was extended to five days. This change in sampling duration was made because of the very low levels of lead encountered. Exposed filters were first shipped to CAR for determination of gravimetric mass after which they were returned to NTU for determination of lead.

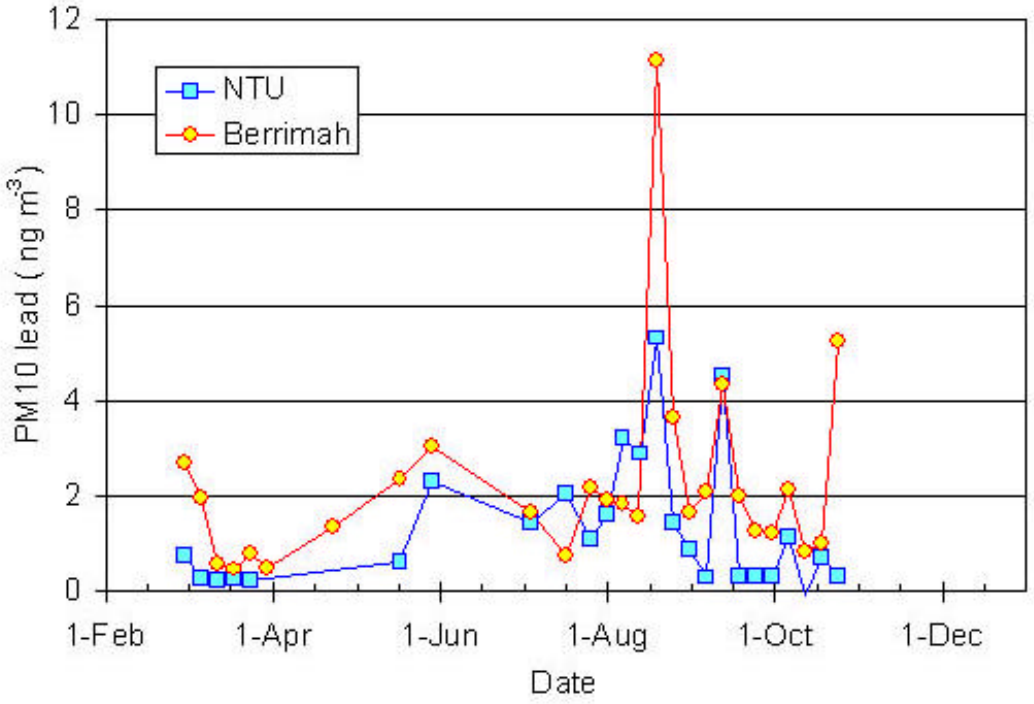


Figure 6. Atmospheric lead loadings in PM10 at the Berrimah and NTU Casuarina sites.

At NTU the filters were digested using nitric acid and then analysed using inductively-coupled plasma – mass-spectrometry (ICP-MS). This procedure has a detection limit of around 2 ng lead per filter. Atmospheric PM10 lead loadings for the Berrimah and Casuarina sites are shown as a time series in Fig. 6. Where samples returned loadings per filter less than the minimum detection level, a value corresponding to one half this minimum detection limit has been plotted. The maximum lead loading observed was 11.1 ng m^{-3}, at the Berrimah site. These concentrations are well inside the Air NEPM standard of 0.5 µg m^{-3} (500 ng m^{-3}) for 24-hour average lead loading. It can also be compared, for example, to Perth in 1994 - 1995 (Gras 1996) where the mean lead loading (in PM2.5) was 85 ng m^{-3}.

4.5 PM10 Zinc and Iron

Zinc and iron, both elements usually associated with mineral aerosol, are also determined using the ICP-MS method. Time series of PM10 zinc loadings at the Berrimah and Casuarina sites are shown in Fig. 7 and a corresponding series of iron loadings in Fig. 8. Iron loadings at the two sites are reasonably similar with a broad dry season maximum and evidence of individual events. Surprisingly, concentrations of zinc at the two sites are quite different. Frequently, airborne concentrations of zinc at the Casuarina site were significantly larger than at Berrimah. Clearly, this points to an intermittent local source for airborne zinc near the NTU Casuarina site.
For the 1994 -1995 period in Perth, the mean PM2.5 iron loading was 36 ng m^{-3} and the corresponding zinc loading was 12 ng m^{-3}. The higher iron values and pattern of temporal variation in Darwin are consistent with a coarse mode (dust) source for the mineral fraction.

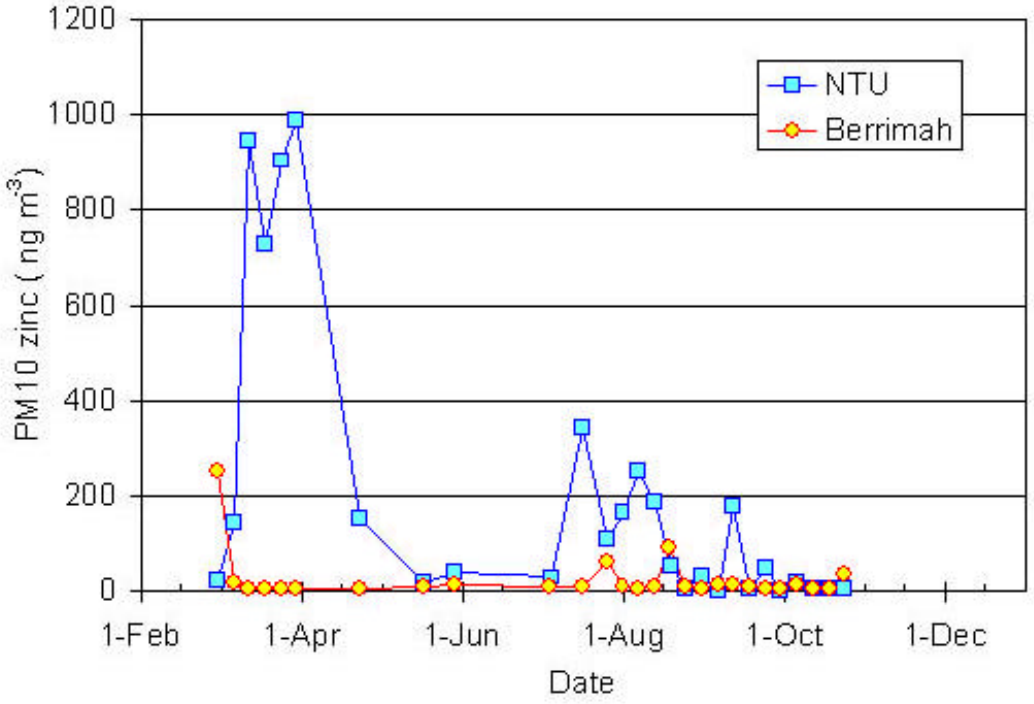


Figure 7. Atmospheric zinc loadings in PM10 at the Berrimah and NTU Casuarina sites.

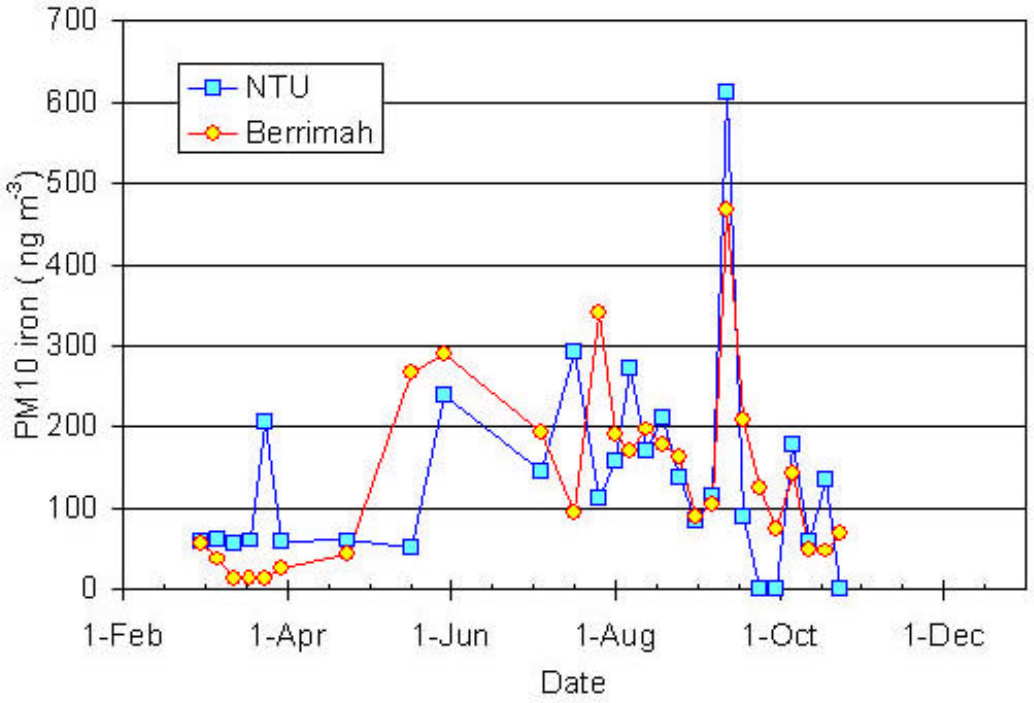


Figure 8. Atmospheric iron loadings in PM10 at the Berrimah and NTU Casuarina sites.

4.6 Diurnal variation of PM10 loading at Berrimah.

Diurnal variation in PM10 mass loadings for the Berrimah site, derived from the edited 30-minute "US-EPA equivalenced" TEOM data, are given in Fig. 9 as a function of time of day. Values plotted are the median concentrations at the particular time of day for the indicated month.

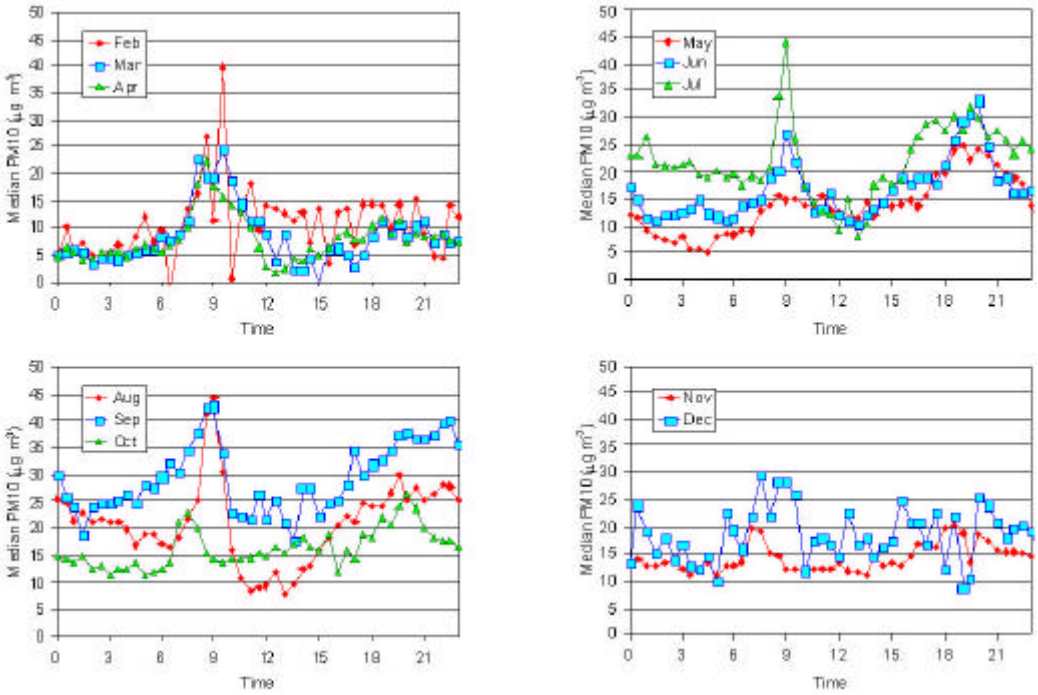


Figure 9. Diurnal variation in PM10 loading as monthly medians of the 30-minute "equivalenced" TEOM data.

Plots from February and December are noisier than the other months due to their shorter sampling periods. These diurnal variations in mass loading demonstrate a number of features that are typically related to local sources and atmospheric stability. This includes the persistent early morning peak at around 08:00 to 09:00 corresponding with the start up of local sources before the onset of convective mixing, and minimum around midday or early afternoon due to the maximum ventilation associated with convective mixing. With progression into the dry season both the early morning and evening mass peaks become more pronounced. This is particularly obvious for the period July to September and is consistent with increased nocturnal stability and reduced ventilation during this period and the seasonal increase in regional aerosol loading. By the end of the sampling period, as shown by the November-December data, the diurnal cycle had returned to a pattern more like that observed at the end of the previous wet season in February-March although the concentrations in general appear to be still elevated. Maximum concentrations both at night and during the day were observed in September. Comparison between typical wet and dry season diurnal cycles can be seen clearly in Fig. 10, which shows the median concentrations for February, March, November and December representing "wet" season and medians for July, August and September representing the "dry" season. For Fig. 10 data from all days of the week are included.

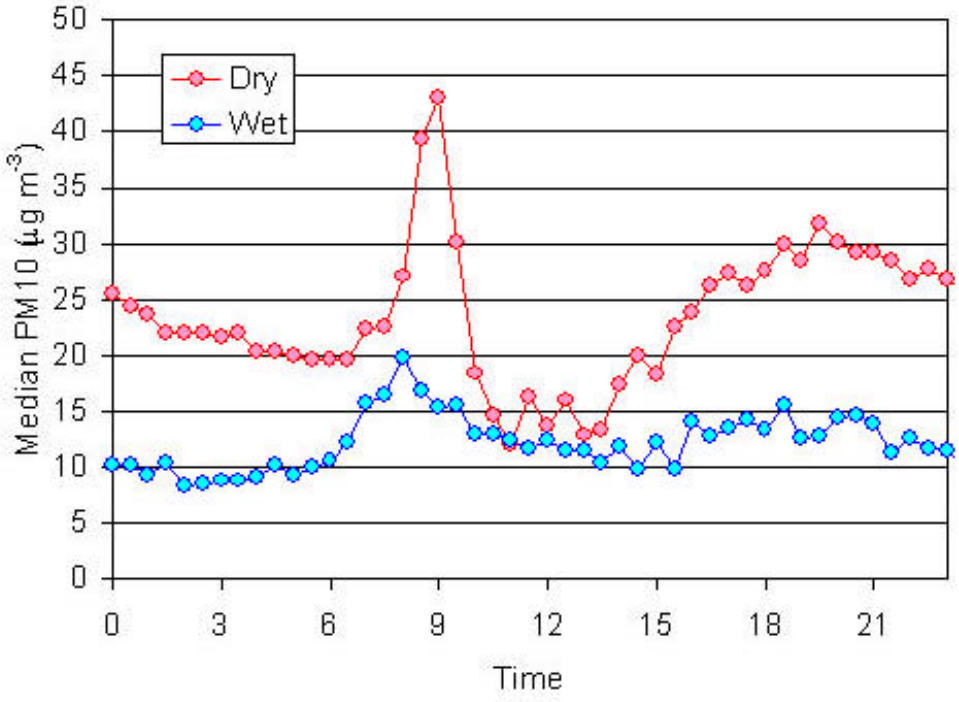


Figure 10. Diurnal variation in 30-minute PM10 loading, using "equivalenced" TEOM data medians representing the dry season (July, August & September) and the wet season (February, March, November & December).

With this level of temporal filtering the main difference appears in the nocturnal concentrations and early morning peak, which is most probably associated with the differences in atmospheric stability and ventilation. Daytime concentrations are quite similar. More noticeable differences can be seen in the monthly medians such as shown in Fig. 9 and even more extreme differences could be expected for individual fumigation events. Individual 30-minute loadings for the 10th to 20th September are plotted in Fig. 11. As is evident in Figs. 1 and 2, this was a period with significant mass loadings. The wide range in loadings from day to day for the 10th to 20th September period can be seen in Fig. 11, but the effect of increased ventilation during the day is also still quite evident. This can be interpreted as an indication that the increased loadings are due to advection to the measurement location mainly at low altitude. During the day the advected material is diluted by mixing. Advection at higher altitudes and mixing down with convection would result in increased loadings during the day. The mass loading data also show some weekday – weekend differences indicating an impact of local (mainly traffic) sources on the mass loading. This can be seen clearly in Fig. 12. Data used in Fig. 12 were separated into weekend (midnight Friday to midnight Sunday) and weekday (midnight Sunday to midnight Friday). The dry season is represented by data from July, August and September, as for Fig. 10. In order to reduce noise in the weekend series for the wet season, data from February to the end of April and October 16 to the end of the record in December were used. All four series shown in Fig. 12 are medians for the selected conditions. The most consistent weekday-weekend difference is in the magnitude of

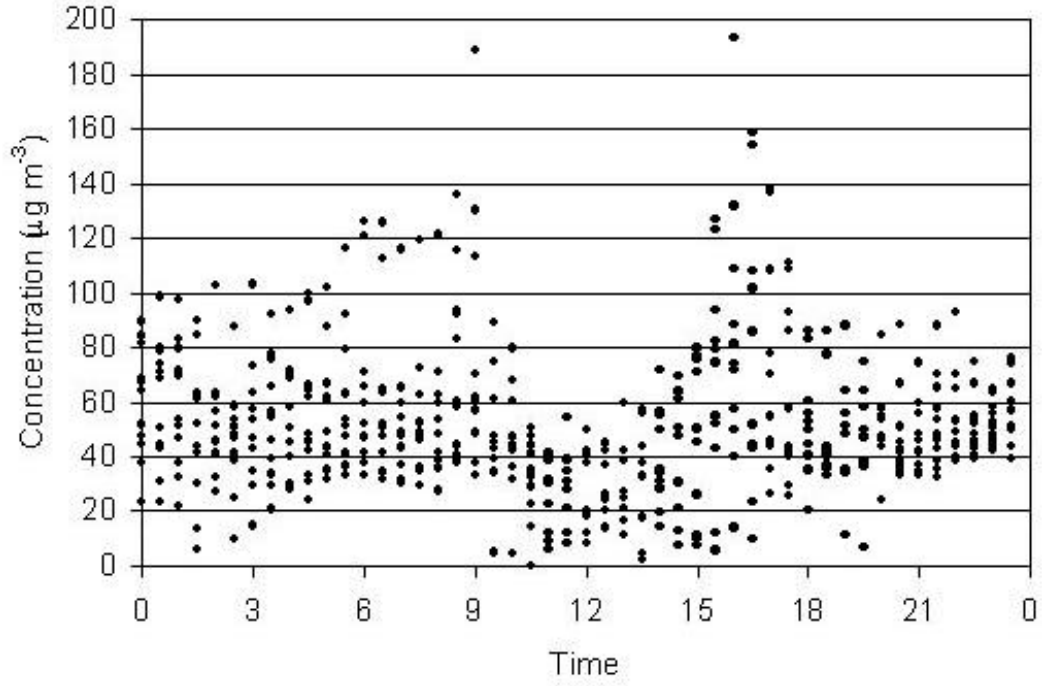


Figure 11. Diurnal variation in PM10 loading as individual 30-minute "equivalenced" TEOM data for the period 10th to 20th September.

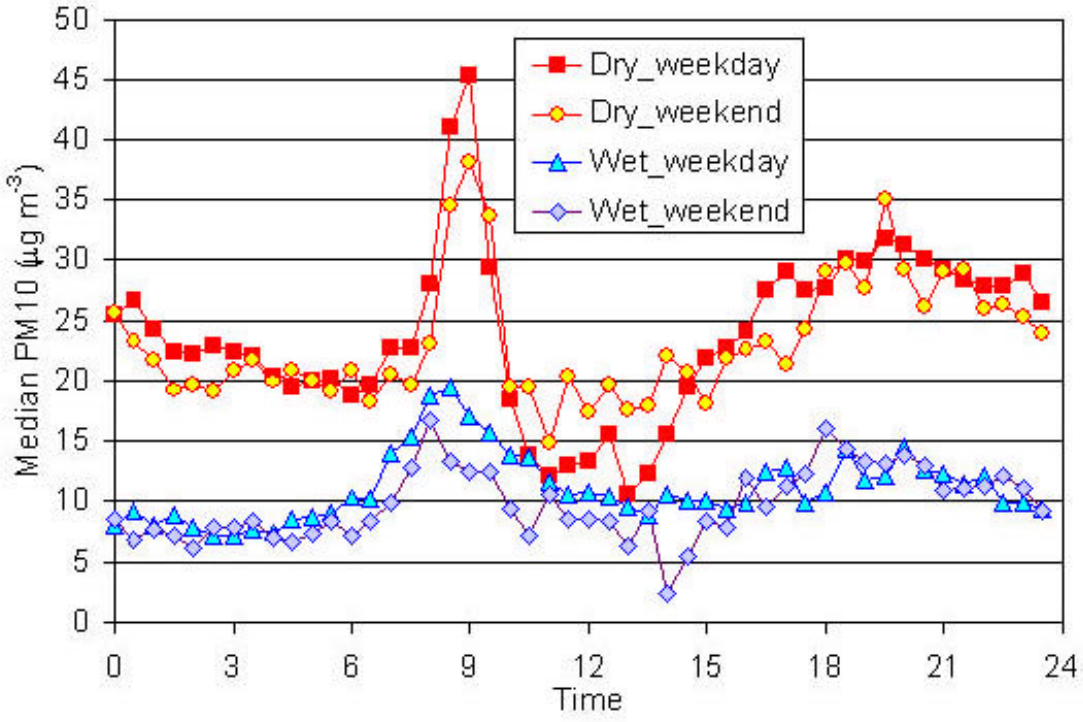


Figure 12. Diurnal variation in 30-minute PM10 loading, using "equivalenced" TEOM data showing weekend – weekday differences for both "dry" and "wet" seasons.

the morning peak, which is clearly greater during weekdays during both the "wet" and "dry" periods.

4.7 Sulfur dioxide, nitrogen dioxide and ozone passive samplers

All concentration data obtained from the duplicate passive samplers at the Berrimah site up to the end of January 2001 are shown in Fig. 13. This represents all data that have been analysed. The concentration of SO_2 was very low throughout the study averaging 0.5 ppbv, with a root-mean-squared (rms) difference of 0.3 ppbv between the paired samples and an overall sample standard deviation of 0.3 ppbv. The maximum concentration (single sample) was 1.3 ppbv. The Air NEPM 24-hour average standard for SO_2 is 80 ppbv. The Berrimah SO_2 concentrations are very similar to the average concentration of 0.8 ppbv obtained at Charles Point, for a 5-year period from 1993 to 1998 using the same passive sampling approach (Ayers, Parry and Gillett, unpublished data).

NO_2 concentrations were generally relatively low, ranging from1 ppbv to 8 ppbv, with an overall mean of 4.3 ppbv. The rms difference between paired samples was 0.8 ppbv. Concentrations show a clear seasonal variation with greater NO_2 during the dry season. Some measurements of NO_2 concentrations have been made at Charles Point. Typical values obtained (in September 1998) were about 1 ppbv with peaks associated with smoke plumes up to several ppbv (M. Meyer, CSIRO Atmospheric Research, personal communication 2001). As well, passive sampling for NO_2 was carried out at Charles Point for the 1993 – 1998 period returning an overall mean concentration of 0.5 ppbv. The longest averaging time specified in the Air NEPM for NO_2 is one hour, and for this, the standard is 120 ppbv. Neither SO_2 nor NO_2 concentrations observed throughout the study suggest cause for concern.

Ozone data are available only from 4th June 2000 and all of the available data are included in Fig. 13. As plotted in Fig. 13, ozone concentrations include an empirical calibration factor based on six months' observation at two sites in Melbourne. At these sites ozone was determined simultaneously using passive samplers and Victorian EPA active ozone monitors. As shown in Fig. 13 ozone concentration shows a complicated but systematic pattern of variation with time, most values being less than 25 ppbv and a period in July-August with concentrations less than 10 ppbv. This latter period of lower ozone concentrations coincides with that where NO_2 concentrations were greatest, but titration of the ozone by NO alone is insufficient to explain the apparent decrease at this time. Ozone concentration was determined at Charles Point from about 1993-1997. These unpublished data show a seasonal cycle in ozone concentration with a dry season maximum of about 25 ppbv (July to October) and a minimum around February to April of about 12 ppbv (M. Meyer, CSIRO Atmospheric Research, personal communication 2001). Concentrations for ozone in the Air NEPM are specified only up to a four-hour average, for which the limit is 80 ppbv. Direct extrapolation of the Berrimah data to shorter measuring periods cannot be justified in the absence of additional data on the frequency distribution of ozone concentrations, but some data from Charles Point may be indicative in this respect. For example, for the period 1993 –1997 maximum hourly concentration data are available for Charles Point, for the month of May. For these

data the maximum hourly concentration reached was 61 ppbv (M. Meyer, CSIRO Atmospheric Research, personal communication 2001).

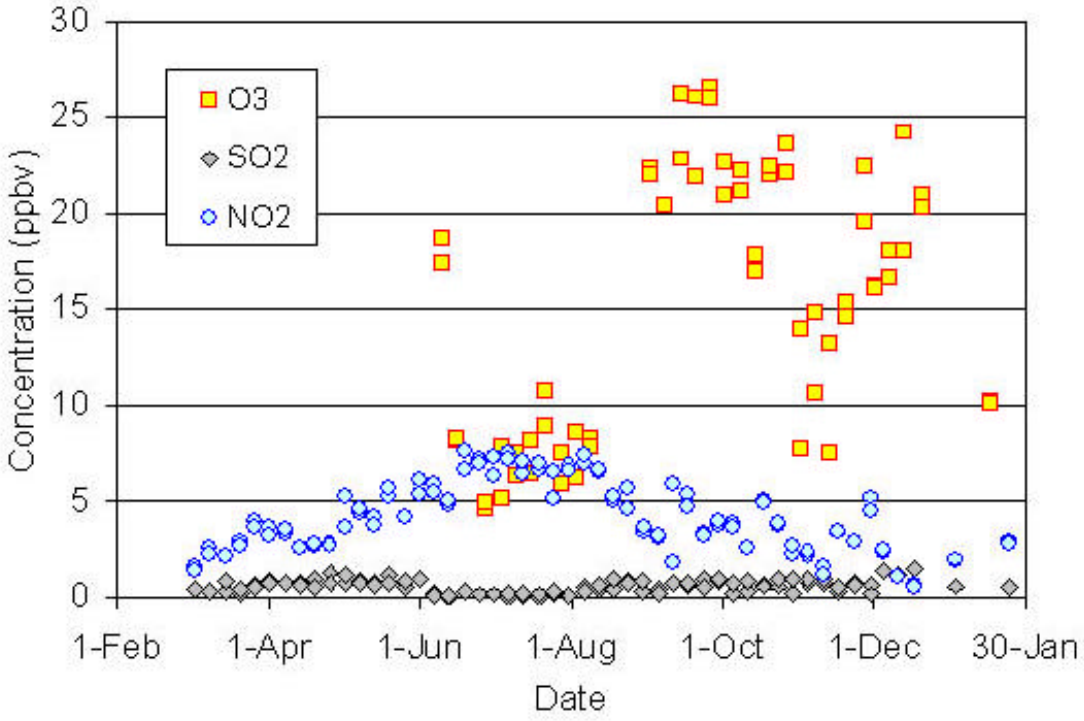


Fig. 13 Time series for concentrations of NO_2, SO_2 and O_3 at the Berrimah site. Data are plotted for the middle of the 6-day sample period.

5. Summary

Initial problems with the TEOM included occasional condensation on the sample filter due to the large difference between ambient and laboratory temperatures. This was overcome by better thermal insulation on the inlet line and auxiliary heating. Any longer-term sampling program should benefit substantially from operation at a more elevated but stabilised laboratory temperature, possibly around 25 ºC. An acoustic noise problem with the sample pump was solved by using a heavily damped and baffled pump box. Other problems included several failures of the flow system in the MicroVol samplers installed at NTU. These appear to have been random, possibly induced by environmental conditions. No ozone samples were collected before 4th June, but ozone and NO_2 sampling continued through until the end of January 2001 to obtain a wet season reference. All data obtained during the study and the extension will be available in electronic form on completion of the analyses.

Aerosol PM10 mass loadings show both a systematic seasonal variation and the presence of a number of enhanced events lasting from one to several days. Mass loadings were minimum in the wet season, when observed values were typically less than 10 µg m^{-3}, increasing significantly to around 20 µg m^{-3} in the dry season. Two main factors contributing to this pattern are expected to be seasonal burning in the surrounding region and increased nocturnal stability reducing ventilation. Even in the absence of additional sources this could be expected to lead to some increase in

loadings. A quite consistent diurnal pattern is evident in the mass loading with a daytime minimum and two maxima. These are a narrow peak at around 08:00 to 09:00 and a broader nocturnal peak. Daytime loadings appear to be similar in the wet and dry season but nocturnal and morning peaks in the dry season have about twice the mass loading as those in the wet season. A number of visually smoky periods were observed during the study. In two of these smoky periods observed PM10 concentrations exceeded the NEPM standard of 50 $\mu g\ m^{-3}$ over a 24-hour period. Such events occurred on six days. The maximum 24-hour PM10 loading was 70 $\mu g\ m^{-3}$ (including the US EPA equivalence correction). The presence of a vehicle contribution to the PM10 mass is evident from weekday – weekend differences in the morning peak (around 09:00) in both the wet and dry seasons.

Overall, very good agreement was observed between mass loadings derived through the TEOM system and samples taken with the same size selective inlet but collected on filters, subsequently dried and subjected to gravimetric determination. This close agreement calls into question the practice of using a US EPA empirical equivalence correction that is "built in" to the TEOM system in Australian conditions. For low mass loadings in Darwin, this "correction" apparently results in a significant overestimation. Mass loadings determined by filter sampler at the NTU Casuarina campus were strongly correlated with those observed at Berrimah, although the distance between the two site locations is about 7 km (the regression analysis gives $r^2 = 0.79$). This points to a largely common variance, or regional pattern, to the temporal variation in mass loading. The PM10 metal concentrations that were determined (lead, iron and zinc) were generally low. The maximum lead concentration of 11.1 ng m^{-3} being well inside the Air NEPM standard of 0.5 $\mu g\ m^{-3}$. The pattern of iron concentrations is consistent with a coarse-mode soil source and some anomalous zinc loadings up to 1 $\mu g\ m^{-3}$ were measured at the Casuarina Campus.

NO_2 concentrations averaged 4.3 ppbv and ranged from 1 ppbv to 8 ppbv. Changes in concentration are consistent with a seasonal increase during the dry season. Concentrations observed in this study are consistent with dry season concentrations previously observed at Charles Point with the expectation of local sources in the present study. SO_2 concentrations throughout the study were very low, having an overall mean of 0.5 ppbv and an rms difference between paired samples of 0.3 ppbv. Neither NO_2 nor SO_2 concentrations suggest reason for concern when judged against the new Air NEPM concentration limits. Ozone concentrations are similar to those previously seen at Charles Point although the cause of relatively lower concentrations in July-August is unclear. The season maximum observed was around 26 ppbv for 6-day samples, considerably short of the Air NEPM 80 ppbv limit for a 4-hour average.

Reference

Gras J.L., 1996. The Perth Haze Study, Final Report. CSIRO Atmospheric Research, Aspendale, Australia.