National Environment Protection Measure for Ambient Air Quality

Monitoring Plan for Western Australia May 2001

This Monitoring Plan has been prepared in accordance with the National Environment Protection Council (Ambient Air Quality) Measure (1998). The Plan describes monitoring which will be undertaken in the State of Western Australia to determine compliance with the Standards and Goal of the Measure.

Summary

The National Environment Protection Measure for Ambient Air Quality (NEPM), made in June 1998, sets standards for six air pollutants, namely:

- carbon monoxide (CO)
- ozone (O_3)
- nitrogen dioxide (NO_2)
- sulfur dioxide (SO_2)
- lead (Pb)
- PM_{10} which is a measure of very small particles.

The NEPM also requires each State or Territory to undertake monitoring according to a specified protocol in order to determine whether the goal of achieving the standards within 10 years is achieved.

This Monitoring Plan has been developed by the Department of Environmental Protection to fulfil the requirements of the NEPM. It identifies five regions, namely:

- Perth (including Kwinana and Rockingham)
- Mandurah
- Bunbury
- Geraldton
- Kalgoorlie

within which monitoring is (or may be) required. The plan presents details of the monitoring program, identifying for each of the regions in turn:

- those pollutants for which monitoring is clearly necessary;
- those pollutants which are unlikely to be significant but which warrant a short "campaign" of measurements for certainty; and
- those pollutants which can be demonstrated by means other than monitoring to be clearly complying with their NEPM standard and therefore do not warrant the expense of monitoring.

The table on the following page summarises Western Australia's plan for monitoring to meet the requirements of the NEPM. Existing or proposed performance monitoring stations are identified by the letter **P** and existing or proposed campaign monitoring by the letter **C**. Trend performance monitoring stations are identified by the letter **T**. The Department of Environmental Protection will continue to monitor air pollutant concentrations at other sites as a part of its existing programs. Monitoring stations planned for Mandurah, Geraldton and Kalgoorlie are scheduled to be operational by no later than the end of 2003.

NEPM Air Quality Monitoring in Western Australia

Pollutants						
Site	**Carbon Monoxide**	**Ozone**	**Nitrogen Dioxide**	**Sulfur Dioxide**	**Lead**	**PM_{10}**
Perth Region						
Caversham		**P / T**	**P / T**			**P**
Duncraig	**P / T**					**P / T**
Queens Building	**P**				**P**	
South Lake	**P**	**P**	**P**	**P / T**		**P**
Swanbourne		**P**	**P**			
Mandurah Region						
Mandurah	**P**	**P**	**P**			**P**
Bunbury Region						
Bunbury	**C**					**C**
Geraldton Region						
Geraldton						**C**
Kalgoorlie Region						
Kalgoorlie	**C**			**P / T**		**P**

Key	
P	Performance Monitoring Station
C	Campaign Monitoring
T	Trend Performance Monitoring Station

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GLOSSARY

ABS	Australian Bureau of Statistics
AMG	Australian Map Grid
AGL	Above ground level
AMSL	Above mean sea level
AGPS	Australian Government Publishing Service
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 emissions, meteorology and topography.
ambient air	The external air environment (does not include the air environment inside buildings or structures).
CO	Carbon monoxide
CBD	Central Business District
DEP	Department of Environmental Protection
GRUB	Generally representative upper bound for community exposure (referring to a performance monitoring station, as described in the technical paper PRC(2000c)).
katabatic	Refers to movements of cold air. Katabatic flows drain down a valley, analogous to storm water flows.
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 exceedances
CO	8 hours	9.0 ppm	1 day a year
NO_2	1 hour 1 year	0.12 ppm 0.03 ppm	1 day a year none
O_3	1 hour 4 hours	0.10 ppm 0.08 ppm	1 day a year 1 day a year
SO_2	1 hour 1 day 1 year	0.20 ppm 0.08 ppm 0.02 ppm	1 day a year 1 day a year none
Lead	1 year	0.50 µg m^{-3}	none
PM_{10}	1 day	50 µg m^{-3}	5 days a year

NO	Nitric oxide
NO_2	Nitrogen dioxide
NOx	Oxides of nitrogen
NMHC	Non-methane hydrocarbons
NPI	National Pollutant Inventory
O_3	Ozone

Pb	Lead
Performance Monitoring Station	A monitoring station used to measure achievement against the Goal specified in the table of NEPM Standards.
PM_{10}	Particles that have an aerodynamic diameter less than 10 µm
$PM_{2.5}$	Particles that have an aerodynamic diameter less than 2.5 µm
ppb	Parts per billion by volume
ppm	Parts per million by volume
PRC	Peer Review Committee
Region	An area within a boundary surrounding population centres as determined by the relevant participating jurisdiction.
Screening procedures	Criteria developed by the PRC that 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.
SO_2	Sulfur dioxide
STP	Standard Temperature and Pressure, being 0 degrees Celsius (273.15 K) and 1 atmosphere (1013.25 hPa).
sub-region	A populated area within a region whose air quality differs from other areas in the region due to the topography, meteorology and sources of pollutants.
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

1. Introduction

On the 26 June 1998, the National Environment Protection Council (NEPC), consisting of Commonwealth, State and Territory Ministers, adopted the National Environment Protection Measure on Ambient Air Quality (NEPC, 1998) (hereafter referred to as the Measure or NEPM). 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.

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 adopting 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 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 air monitoring program of some jurisdictions. The Department of Environmental Protection in Western Australia undertakes air quality monitoring from time to time for various reasons including general assessment of air quality, airshed modelling studies and assessment of the impact of individual or cumulative sources of emissions. Air quality monitoring is also undertaken by some industries as a condition of licence.

This Report represents Western Australia's submission on how it plans to monitor, assess and report 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 (Chapter 2);
- 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 (Chapter 3);
- Siting and instrumentation, including site descriptions, compliance with siting guidelines, instrument standards, data handling procedures and accreditation (Chapter 4); and
- Reporting, including evaluation of performance against the NEPM Standards and Goal, presentation of air quality statistics and determination of exposed population (Chapter 5).

The Report also includes a number of Appendices. Appendix A comprises summary plots of pollutant concentrations from monitoring results. Appendix B summarises the exposed population represented by the performance monitoring stations. Appendix C describes the method used for selecting upper bound monitoring sites for ozone in the Perth airshed. Appendix D provides a summary of emissions in the Perth Region.

2. 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 performance monitoring 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;
- (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.

The PRC has adopted the use of Australian Bureau of Statistics (ABS, 1997) population figures, specifically the "Urban Centre / 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. PRC Strategy Paper titled *Selection of Regions* (PRC, 2000b) provides a discussion of the use of ABS data and issues to consider when classifying regions. This paper includes the following summary comment:

> In summary, whilst the ABS "urban centre" population data may provide a transparent basis for a preliminary assessment of regions for NEPM monitoring, it is important to note that other considerations such as local knowledge of region / airshed population, emission sources, topography and dispersion should also be considered. In applying the formula that guides the number of monitoring sites needed on the basis of population, the actual population in the affected airshed should be estimated by integrating up the ABS data as appropriate. The changes in population that can result from this integration may be substantial. In some instances it may raise the population above the lower threshold where monitoring needs to be considered. Moreover, a narrow application of the ABS population data should not be used as a justification for a lower level of monitoring than would result from a consideration of an airshed concept.

Figure 2.1 is a map of Western Australia showing the capital city Perth and other significant population centres, plus smaller population centres in the vicinity of significant emission sources.

Figure 2.1 Map of Western Australia showing significant population centres.

Table 2.1 gives the ABS Urban Centre / Locality data from the 1996 Census (most recent available) for the population centres shown on Figure 2.1. They are ranked according to size, with all other urban centres in the State being smaller.

Table 2.1 ABS Urban Centre / Locality population data from the 1996 Census.

Urban Centre / Locality	Number of persons
Perth	1,096,829
Rockingham	49,917
Mandurah	35,945
Kalgoorlie-Boulder	28,087
Geraldton	25,243
Bunbury	24,945
Albany	20,493
Kwinana	15,674
Port Hedland	12,846
Broome	11,368
Busselton	10,642
Karratha + Dampier	10,057 + 1,424
Esperance	8,647
Collie	7,194

Bunbury must be assumed to meet the criteria of 25,000 persons. Kwinana will be included in the Perth Region, as will Rockingham (this will be justified later). Albany falls clearly below the criteria but will need to be reviewed in the future. Therefore the Type 1 or Type 3 regions identified from Table 2.1 are Perth / Kwinana / Rockingham, Mandurah, Kalgoorlie-Boulder, Geraldton and Bunbury.

The possible candidates for classification as Type 2 regions in Western Australia have been assessed, as follows:

- There are three major sources of emissions in the vicinity of Collie, namely two coal fired power stations and an alumina refinery. Ambient air quality monitoring in the township and surrounding district is undertaken by the relevant industries and reported to the Department of Environmental Protection (DEP). Neglecting Bunbury (which has already been defined as a region), there are no other significant population centres within what may sensibly be considered to be a "Collie airshed", therefore a Type 2 region does not exist. The emissions from Collie industries will be considered when assessing the monitoring requirements for Bunbury.
- The combined population of Karratha / Dampier and Port Hedland is close to 25,000. However these Pilbara coastal towns are about 200 km apart. Locally generated dust is currently the only significant air quality issue in the Pilbara relevant to the NEPM. These Pilbara towns do not contribute to each other's dust loading. Consequently these towns cannot be considered to comprise a Type 2 region. Monitoring of dust is undertaken by Pilbara industries and reported to the DEP. The DEP is also undertaking a baseline monitoring program including ozone, nitrogen oxides, carbon monoxide, PM_{10} and $PM_{2.5}$, which has confirmed the current low levels of pollutants other than particulates.

In summary, there are no Type 2 regions in Western Australia.

3. Performance Monitoring Requirements of Regions

Part 4 of the NEPM outlines the monitoring protocol to be followed by 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:

$$\mathbf{1.5P + 0.5}$$

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.

Sub-clauses (1) and (2) are self-explanatory. Sub-clause (3) provides to 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 undertaken by jurisdictions. The guidelines identify a range of screening procedures that might 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* (PRC, 2000d), should be read in conjunction with the assessment of monitoring requirements that follows.

The NEPM also specifies, in clause 15, a requirement for trend stations:

Clause 15. Trend Stations

(1) A number of performance monitoring stations in each participating State and participating Territory must be nominated as trend stations.

(2) The number of performance monitoring stations to be nominated as trend stations must be sufficient to monitor and assess long-term changes in ambient air quality in different parts of the jurisdiction.

(3) A trend station must be operated in the same location for one or more decades.

The PRC has recommended that, as general practice, performance monitoring stations should be nominated as trend stations wherever possible. Throughout this report, performance monitoring stations will be nominated as trend stations primarily on the basis of the strategic suitability of the site (discussed below), the expected tenure of the site and the significance of the pollutant relative to the NEPM Standard. The history of monitoring at a site may also enhance its selection as a trend site.

The following extract from a PRC Strategy paper entitled *Monitoring Strategy* (PRC, 2000c) 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 distribution of GRUB 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.

3.1 PERTH METROPOLITAN REGION

3.1.1 Overview description of the region

Region boundaries

Before describing the features of the Perth Region it is necessary to define the extent of the region to the south (namely to determine whether the region encompasses Kwinana, Rockingham and possibly even Mandurah).

Based on detailed monitoring and modelling studies over several years, there is no doubt that Rockingham, Kwinana and the greater Perth metropolitan area should be considered to be part of a single airshed. The sea breeze recirculates pollutants from Kwinana across the greater Perth area and vice versa. Plumes from Kwinana industries can be detected far downstream in the Perth Region. Similarly, the monitoring station at Rockingham has recorded smog events associated with the recirculation of urban emissions.

It is also apparent from modelling studies that photochemical smog events may occur in Mandurah as a result of southward transport of pollutants from Perth and Kwinana. These events are not expected to be frequent. It is very unlikely that significant photochemical smog could be generated near Mandurah from local emissions. Therefore it could be argued that Mandurah is part of the Perth Region too. However this argument is less convincing for pollutants like PM_{10}. The DEP has chosen to consider Mandurah as a separate region for the purposes of the NEPM and is committed to installing a monitoring station there.

For the purpose of the NEPM, the Perth Region boundaries are defined as shown in Figure 3.1. Although there is no functional purpose served in exactly defining the boundary AMG coordinates, these may be taken to be defined by the bottom left corner (350000E, 6415000N) and the top right corner (440000E, 6520000N).

Population and topography

Figure 3.1 shows population density (persons per square km) based on population density data supplied by the ABS (1997). Figure 3.1 also shows the topography of the region. The city of Perth lies on a coastal plain which has gently undulating terrain rising to about 40 metres above sea level. The coastal plain is about 25 kilometres wide and is bounded on its eastern side by the north-south oriented Darling Escarpment, which rises to about 300 metres AMSL. Figure 3.1 clearly illustrates that most of the region’s population lives on the coastal plain, with a clear preference for near-coastal locations. Lot sizes on the escarpment tend to be larger, giving way to forest or agricultural land further east. There is a significant population in the City of Rockingham and Town of Kwinana to the south.

Industry

The Kwinana Industrial Area (KIA) is shown as a grey strip on the coastline in Figure 3.1. (Greater detail will be provided in the section relating to sulfur dioxide emissions.) Almost all of the heavy industry within the region is located in the KIA, including a coal/gas power station, alumina refinery, fuel refinery, titanium dioxide plant, fertilizer works and nickel refinery. Light industrial areas, fuel storage facilities and other such facilities are distributed across the region.

Emissions

An inventory of emissions was compiled during the Perth Photochemical Smog Study (Western Power Corporation and DEP, 1996) and has recently been revised as part of the Perth Air Quality Management Plan (DEP, 2000). These inventories included estimates of CO, SO_2, NO_x, VOC, particles and Pb. In addition, sulfur dioxide emissions from Kwinana industries are routinely reported as a requirement of licence. A summary of the contribution of various source categories to the emission or production of NEPM pollutants is given in Appendix D.

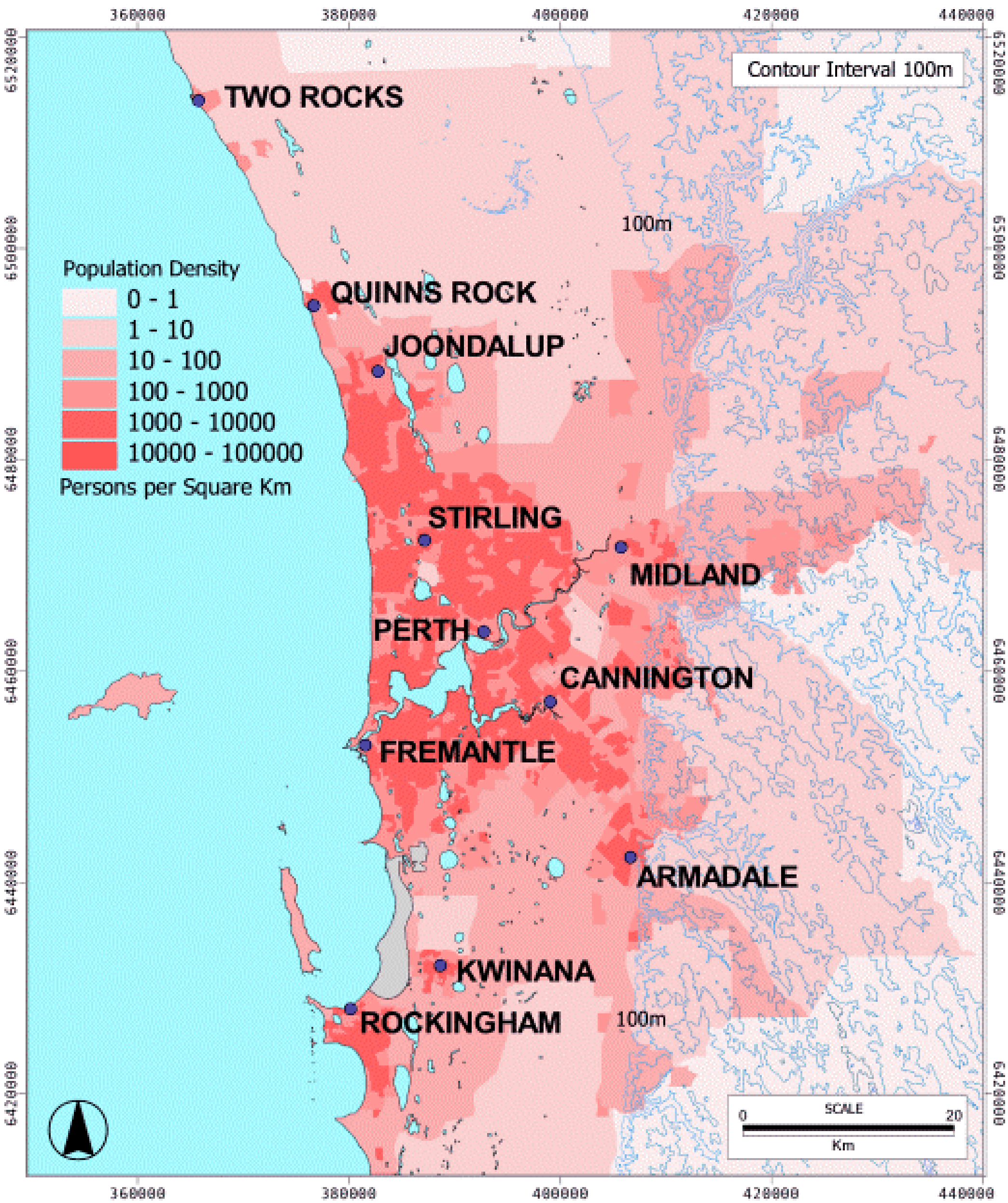


Figure 3.1 Map of the Perth Region, showing population density and topography.

Smoke from wood fires is a significant issue, however it is very difficult to obtain reliable quantitative estimates of emissions. The same is true of smoke from open burning (wildfires and fires for hazard reduction or asset management).

Meteorological features

During warmer months the sea breeze is a regular feature of Perth's meteorology. Pollutants blown offshore within morning easterly winds are frequently recirculated across some part the region in south-westerly sea breezes. Figure 3.2 is a trajectory plot showing recirculation of emissions from Perth and Kwinana. During this recirculation, chemical reactions produce photochemical smog products. The worst smog days occur when a low-pressure trough (another common feature of summer meteorology) is situated just offshore (Western Power Corporation and DEP, 1996).

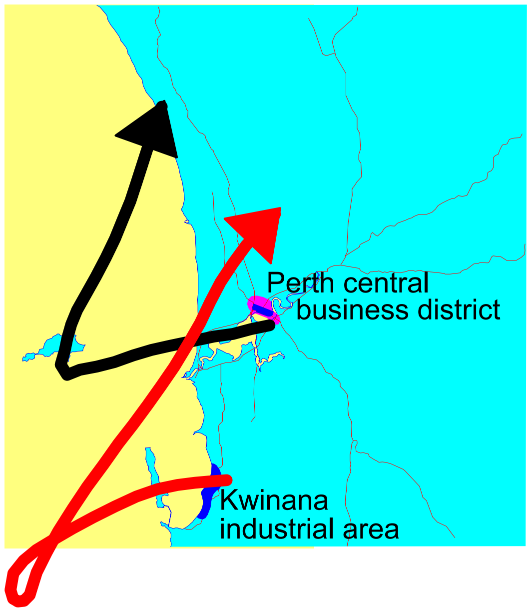


Figure 3.2. The path of air masses offshore, then onshore, on a typical Perth smog day (21 March 1994).

The black line shows the path of air which passed the Perth central business district in the morning, and the shaded line shows that for the air which passed the Kwinana industrial area.

The sea breeze also causes a phenomenon known as shoreline fumigation, whereby plumes from tall chimneys like those at Kwinana cause high ground level concentrations of pollutants further from the source than at an equivalent inland source. This is illustrated in Figure 3.3.

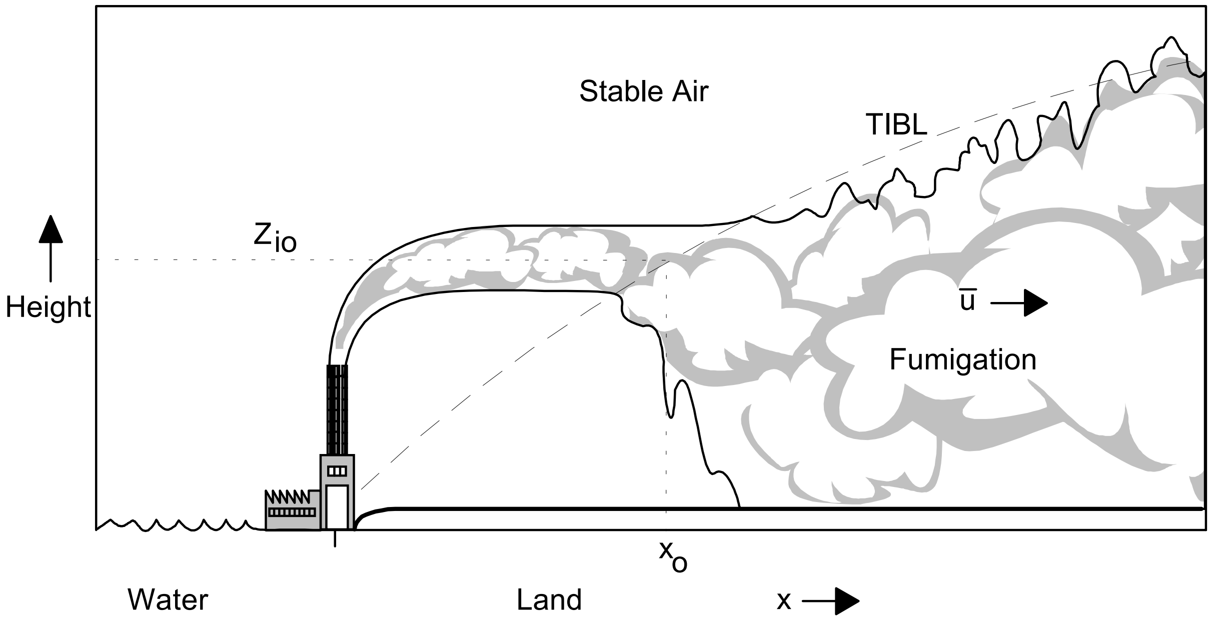


Figure 3.3 Shoreline fumigation of a plume into a thermal internal boundary layer (TIBL). The horizontal dimension is compressed in this illustration.

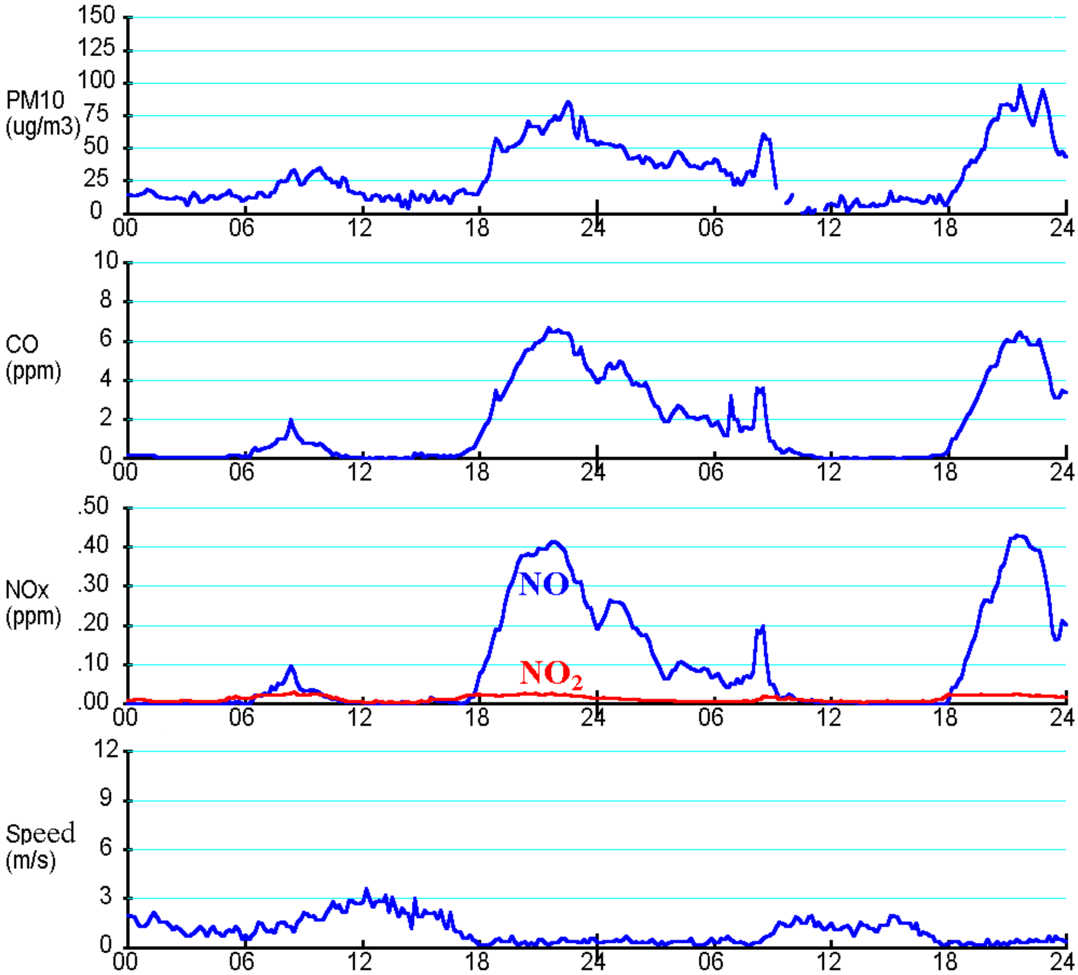


Figure 3.4 Concentrations of NO and NO_2, CO and PM_{10} plus wind speed measured over two days, 4 June to 5 June 1999, at Duncraig.

Winter months in Perth are characterised by the passage of cold fronts bringing rain and strong winds. However there are also many winter nights on which very stable conditions develop (virtually calm under cloudless skies). On such nights, high concentrations of emissions from wood fires and motor vehicles accumulate near ground level, particular in depressions across the coastal plain. This is illustrated in Figure 3.4 which shows concentrations of NO and NO_2, CO and PM_{10} plus wind speed measured over two days, 4 June to 5 June 1999, at Duncraig. Near-calm, very stable conditions occur after sundown on the evening of both days, leading to the rapid accumulation of pollutants.

Figure 3.5 shows the strong seasonal cycle in monthly-maximum 8-hour average concentrations of CO at Duncraig, consistent with our understanding that primary pollutant concentrations at this site (and much of the coastal plain) are strongly governed by the occurrence of stable meteorological conditions. This cycle is not evident at the Queens Buildings site in the CBD, where CO concentrations are dominated by daytime vehicle emissions in the immediate vicinity of the monitor.

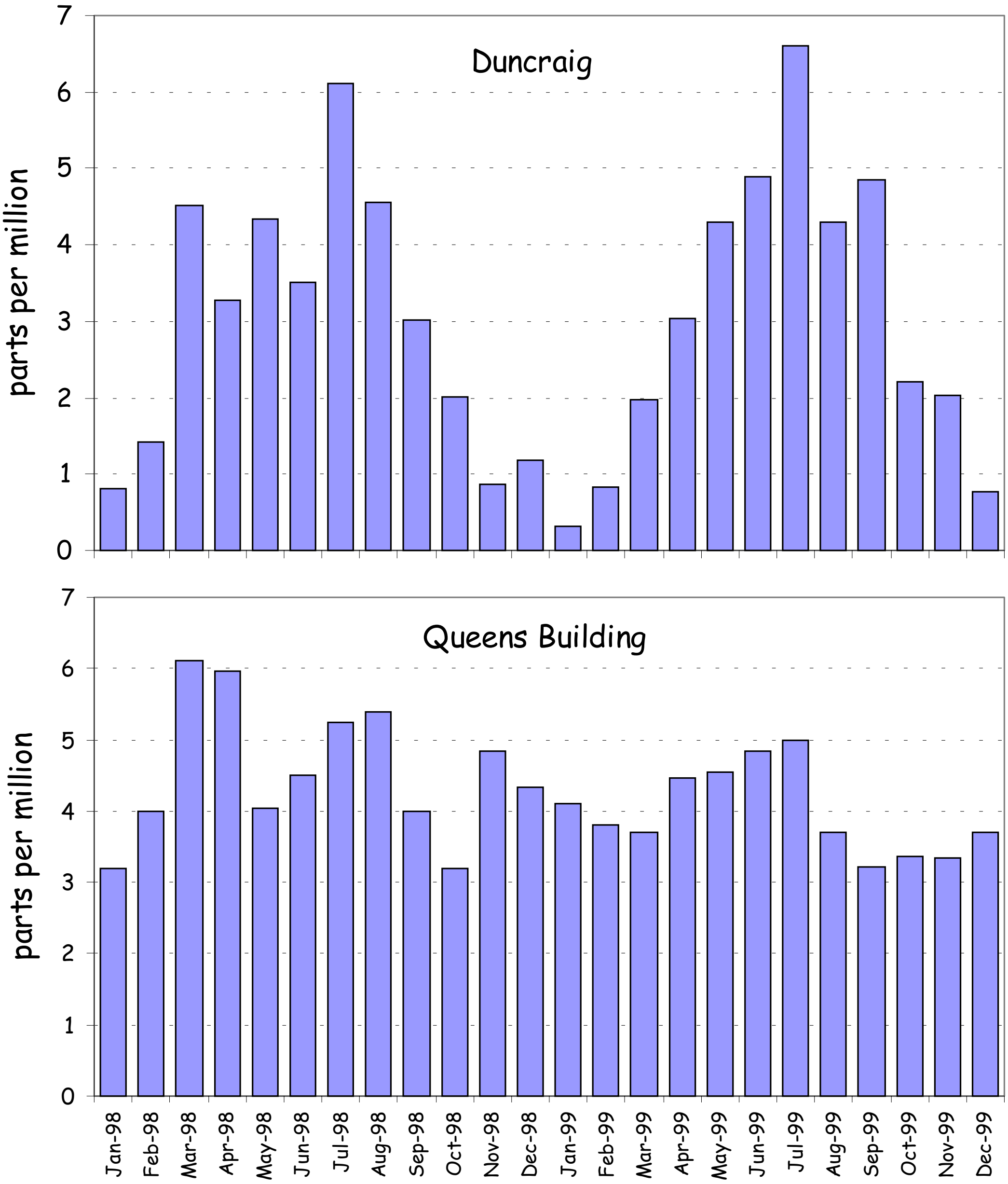
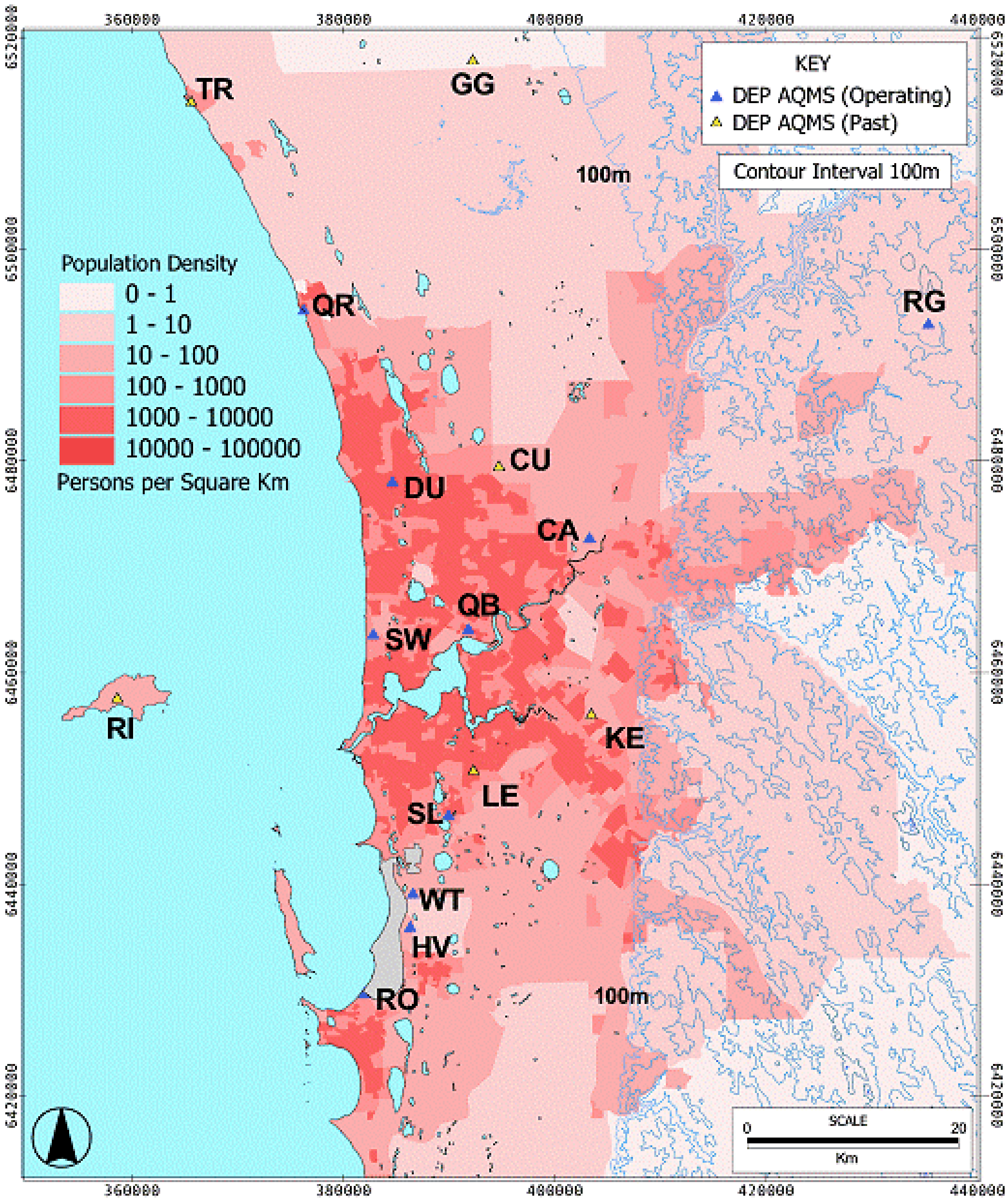


Figure 3.5 Monthly-maximum 8-hour average concentrations of carbon monoxide at Duncraig and Queens Buildings, showing seasonal cycles over two years.

Air quality monitoring history

Figure 3.6 shows air quality monitoring sites that have been operated by the DEP at some stage since 1989. Those that are currently operating are shown as filled triangles, while those that are no longer operating are shown as open triangles. The station shown at South Lake was commissioned in March 2000. (Note that monitoring stations operated by industry at Kwinana are not shown; these will be described in the section on sulfur dioxide.)



CA Caversham	HV Hope Valley	QR Quinns Rock	SL South Lake
CU Cullacabardee	KE Kenwick	RO Rockingham	SW Swanbourne
DU Duncraig	LE Leeming	RG Rolling Green	TR Two Rocks
GG Gingin	QB Queens Building	RI Rottnest Island	WT Wattleup

Figure 3.6 DEP air quality monitoring stations which are either currently operating or have been operated at some stage since 1989.

The monitoring network shown in Figure 3.6 is a combination of networks which were each the subject of careful design for the purposes of the Perth Photochemical Smog Study, the Perth Haze Study and the management of sulfur dioxide in the Kwinana area. Network design was based on the knowledge of emissions sources, pollutant chemistry and important features of the meteorology. CSIRO Atmospheric Research provided advice on monitoring site locations for the Perth Photochemical Smog Study and Perth Haze Study (DEP, 1996).

Table 3.1 provides details of the parameters measured and the time periods of measurement at each of the monitoring stations. Monitoring prior to 1988 was essentially limited to Kwinana, and is not included in Table 3.1.

Table 3.1 Air quality parameters measured at DEP monitoring stations.

Monitoring Site	CO	O_3	NO_2	SO_2	lead	PM_{10} Hi-Vol	PM_{10} TEOM	$PM_{2.5}$ TEOM	Visibil-ity
CA Caversham	08/93 to present	11/89 to present	09/90 to present			05/93 to present		03/94 to present	12/89 to present
CU Cullacabardee		12/92 to 05/95	12/92 to 05/95						07/94 to 10/95
DU Duncraig	08/95 to present		08/95 to present			09/94 to present	06/96 to present	01/95 to present	03/94 to present
GG Gingin		09/94 to 11/95	09/94 to 11/95						
HV Hope Valley	01/90 to 03/91		12/89 to present	12/89 to present					01/89 to present
KE Kenwick		01/93 to 06/95	01/93 to 06/95			05/93 to 10/95			09/93 to 10/95
LE Leeming	10/96 to 01/00		01/97 to 01/00					12/96 to 01/00	10/96 to 01/00
QB Queens Building	08/89 to present		01/90 to present		01/90 to present	01/90 to present			01/90 to present
QR Quinns Rock		11/92 to present	11/92 to present						12/95 to present
RO Rockingham		12/95 to present	12/95 to present	07/88 to present					
RG Rolling Green		01/93 to present	01/93 to present						
RI Rottnest Island		01/93 to 03/96	01/93 to 03/96						
SL South Lake	03/00 to present	03/00 to present	03/00 to present	03/00 to present			03/00 to present		03/00 to present
SW Swanbourne	01/93 to 05/95	01/93 to present	03/93 to present			03/94 to present		06/94 to 07/95	06/94 to present
TR Two Rocks		01/93 to 05/94	01/93 to 03/94						
WT Wattleup				01/88 to present					

Data from selected monitoring stations are plotted in Appendix A and will be discussed as appropriate for each pollutant.

3.1.2 NEPM formula

With a combined population across Perth / Kwinana / Rockingham of 1,183,000, the NEPM formula (clause 14(1)) indicates that three performance monitoring stations are required.

3.1.3 Carbon monoxide

3.1.3.1 Review of data

Figure A1.1 in Appendix A presents data from three monitoring stations, Queens Buildings, Duncraig and Caversham in a form which facilitates an assessment of NEPM monitoring requirements. The NEPM allows an exceedance of the 8-hour 9.0 ppm standard on one day per calendar year. Hence the 2nd highest 8-hour average concentration, on a separate day to the highest, must be below the standard. Figure A1.1 shows the highest, 2nd, 18th and 36th highest daily maximum 8-hour averages for each of several calendar years. The 18th and 36th highest are, approximately, the 95th and 90th percentiles of the daily maximum 8-hour averages respectively (i.e. there are 365 daily maximum 8-hour averages in a non-leap year, one for each day, so the 36th highest is at the 90th percentile level). These percentile values are less "noisy" than the highest or 2nd highest, allowing an assessment of long-term trend.

As can be seen from Figure A1.1, the highest CO values measured in the Perth Region over the past decade have been at the Queens Buildings site. This site is within the Perth CBD in one of the heavily trafficked central streets. The measurement is made via a sample port extended out from the awning of a building at an elevation of about 4.4 metres above the kerb. Hence the station does not measure kerbside (near-exhaust) concentrations but rather the concentrations typical of a busy street canyon. This is arguably the upper limit of expected CO concentrations arising from motor vehicle emissions. Concentrations measured at this site have complied with the NEPM standard since 1991 and the trend, based on measurements and projected emission reductions, is clearly downward.

However the significant concentrations of CO measured at Duncraig, caused by a combination of motor vehicle and wood smoke emissions, indicate a need for performance monitoring of CO in the region for the foreseeable future. It is worth noting that the DEP operated a monitoring station at Leeming, 13 kilometres south of the CBD for three years and measured a pattern of CO concentrations similar to that at Duncraig; hence Duncraig is not atypical. The Leeming station was more distant from major roads than that at Duncraig. The station did not comply with AS 2922 with regard to the proximity of other structures and therefore its data will not be presented here.

The CO monitor at Caversham was installed to study dispersion during the Perth Photochemical Smog Study, not in response to any concern that concentrations of CO might be high. The Caversham station is situated among vineyards about two kilometres beyond the border of an extensive urban area. Sea breezes blow urban emissions across the station. The housing density in the immediate vicinity of the station is low and the nearby traffic is also relatively low. Consequently the station provides a broad-scale measure of urban CO concentration but does not measure high concentrations associated with traffic or wood fire emissions.

3.1.3.2 Nominated performance monitoring stations and trend stations

Duncraig is a good upper bound site for monitoring the combined effects of emissions from vehicles on the nearby Mitchell Freeway and domestic wood fires. The site is about 200 metres from the freeway; hence it is well beyond the distance of "roadside" measurement. By Perth's standards the site is representative of dense population. The site lies in a dunal depression through which the freeway passes, hence the effect of stable air "ponding" in the depression is likely to lead to elevated concentrations. This feature would be found in many other places across the coastal plain.

The new site at South Lake lies in a growing urban area and is likely to see increasing levels of CO from wood fires in particular. It is not as close as Duncraig to major roads and is therefore more typical of a population-average site.

Although there are no immediate plans to remove the Caversham monitor, it is not nominated as a performance monitoring station in view of the low population density in the immediate vicinity.

The DEP proposes to maintain the Queens Buildings station as a performance monitoring station to provide an upper bound measurement of motor vehicle-emitted CO, and to track the improving compliance with the NEPM. Being a CBD site, it represents a special case which will be identified within annual reports. It will not be nominated as a trend site since it does not fit the normal pattern of a GRUB or population-average monitoring site.

In summary, WA proposes to undertake performance monitoring of CO at Duncraig, South Lake and Queens Buildings. Duncraig and South Lake are nominated as trend stations.

3.1.4 Photochemical oxidants (as ozone)

3.1.4.1 Review of data

Figure A1.2 shows the highest, 2nd, 18th and 36th highest daily maximum 1-hour averages of ozone for each of several calendar years at Swanbourne, Caversham and Rolling Green.

It is clear from Figure A1.2 that there is an ongoing potential for the NEPM standard for ozone to be exceeded at various sites in the Perth Region. Selection of upper bound performance monitoring station sites for ozone was the subject of a detailed paper, prepared in 1999, which appears in Appendix C of this report. In brief, this paper identified three important classes of smog events, namely "coastal", "inland" and "far inland". On the basis of this analysis, Swanbourne, Caversham and Rolling Green were nominated as upper bound performance monitoring stations. Swanbourne and Caversham were shown to be typical of coastal and inland stations respectively.

However, subsequent to this analysis being completed, the PRC agreed that outlying sites like Rolling Green, located in areas with low population density, should not be nominated as performance monitoring sites unless they are additional to the number required under the NEPM formula and are appropriately described in NEPM monitoring reports.

3.1.4.2 Nominated performance monitoring stations and trend stations

For the reasons explained in Appendix C, Swanbourne and Caversham are nominated as two of the three performance monitoring stations for the region.

South Lake is nominated as the third performance monitoring station. It has the following desirable attributes:

- it provides spatial spread of stations (it will measure ozone returning onshore in the southern part of the metropolitan area);
- it is a moderate distance inland in a growing urban area, hence it is well classed as a population average station;
- it may occasionally detect the interactions of O_3-rich air with the NO_x -rich plumes from Kwinana industry (potentially giving elevated NO_2 concentrations);
- it will also measure sulfur dioxide (see 3.1.6), providing comprehensive pollutant data.

Caversham, Swanbourne and South Lake are all nominated as trend stations.

The DEP also intends to maintain the stations at Quinns Rocks and Rolling Green for the foreseeable future as part of its wider network. It is less likely that the ozone monitor at Rockingham will be retained now that South Lake has been commissioned, given the proximity of the stations (relative to the broad scale of ozone plumes).

3.1.5 Nitrogen dioxide

3.1.5.1 Review of data

Figure A1.3 shows the highest, 2nd, 18th and 36th highest daily maximum 1-hour averages of nitrogen dioxide for each of several calendar years at Caversham, Duncraig and Queens Buildings.

The data from Queens Buildings indicates that exceedances of the NEPM standard have not occurred since 1992, there being an apparent reduction in highest values over the decade. However there is not a clear trend evident in the 90th percentile data from this site.

As with CO, the Queens Buildings station is arguably well placed to measure the upper limit of NO_x emissions from motor vehicles. The Queens Buildings station is surrounded by heavily trafficked roads and freeways for at least 500 metres in all directions. For a nominal wind speed of 5 metres per second, the air reaching Queens Buildings would have been receiving high emissions of NO for 100 seconds. Given that the reaction of NO and O_3 to form NO_2 is fast, it is likely that the titration of O_3 to form NO_2 would be largely complete near the ground. (For a NO concentration of 0.25 ppm and a rate constant of 26.6 ppm^{-1}min^{-1}, the natural half-life of O_3 at 298K is 9 seconds.)

The highest concentrations at Caversham and Duncraig have only once exceeded half of the NEPM standard, being generally low. Concentrations at Swanbourne have been similar. Measurements at other monitoring stations have been lower.

3.1.5.2 Nominated performance monitoring stations and trend stations

Given that the Queens Buildings monitor provides an upper limit for NO_2 and other sites measure low values, it would be possible to argue for reduced monitoring for NO_2 in the region.

However it is desirable, for purposes of scientific understanding, to monitor NO_x at all stations where O_3 is monitored. Accordingly it is proposed that Caversham, Swanbourne and South Lake be performance monitoring stations for NO_2. This selection of stations provides a good spatial distribution.

Caversham, Swanbourne and South Lake are all nominated as trend stations.

The DEP will continue to measure NO_2 at Quinns Rocks, Rolling Green and Duncraig for the foreseeable future as part of its wider network. The DEP will also continue to measure NO_2 at Queens Buildings in order to determine the long-term trend.

3.1.6 Sulfur dioxide

3.1.6.1 Review of data

Figure 3.7 is a map of the sulfur dioxide monitoring network that surrounds the Kwinana Industrial Area (KIA). Monitoring stations are identified by two-character names, e.g. WT which stands for Wattleup (see the Key to station names). The South Lake monitoring station is marked (SL) near the upper right corner. The map shows the area within which heavy industry is located, shaded grey, with individual industries identified. Urban areas can also be seen (fine-scale road networks). Note that the names “North Rockingham” and “Rockingham” (used previously) refer to the same site.

Figures A1.4(a) and (b) present data from the monitoring stations for the years in which each has operated over the past decade. A single monitoring station was sited at Rhodes Park for one year, then moved to Hillman Primary School for one year, then moved to Henderson Road. Data from these three sites are shown on a single plot in Figure A1.4(b). Wattleup, Hope Valley and Rockingham are DEP stations, whereas the Miguel Road, Henderson Road and Abercrombie Road stations are owned and operated by an industry cooperative.

Sulfur dioxide concentrations in the Kwinana area have reduced markedly since the late 1970s due to the conversion from high to low sulfur fuels and the installation of sulfur dioxide control technology. Emissions are controlled under the provisions of an Environmental Protection Policy (EPP) to ensure that ambient concentrations do not exceed ambient standards set in the EPP. These ambient standards are specified in a manner that makes direct comparison with the NEPM difficult. However the DEP has determined via a detailed analysis (Rayner and Grieco, 1999) that the EPP standard for the rural residential area beyond the buffer zone is a little more stringent than the NEPM standard for SO_2. Hence the maximum allowable emissions from Kwinana industry are currently being controlled to a level consistent with the Goal of the NEPM. As is apparent from the monitoring results in Figure A1.4, some of the Kwinana industries have not been fully utilizing their emissions allowance and there exists an opportunity for further industrial development.

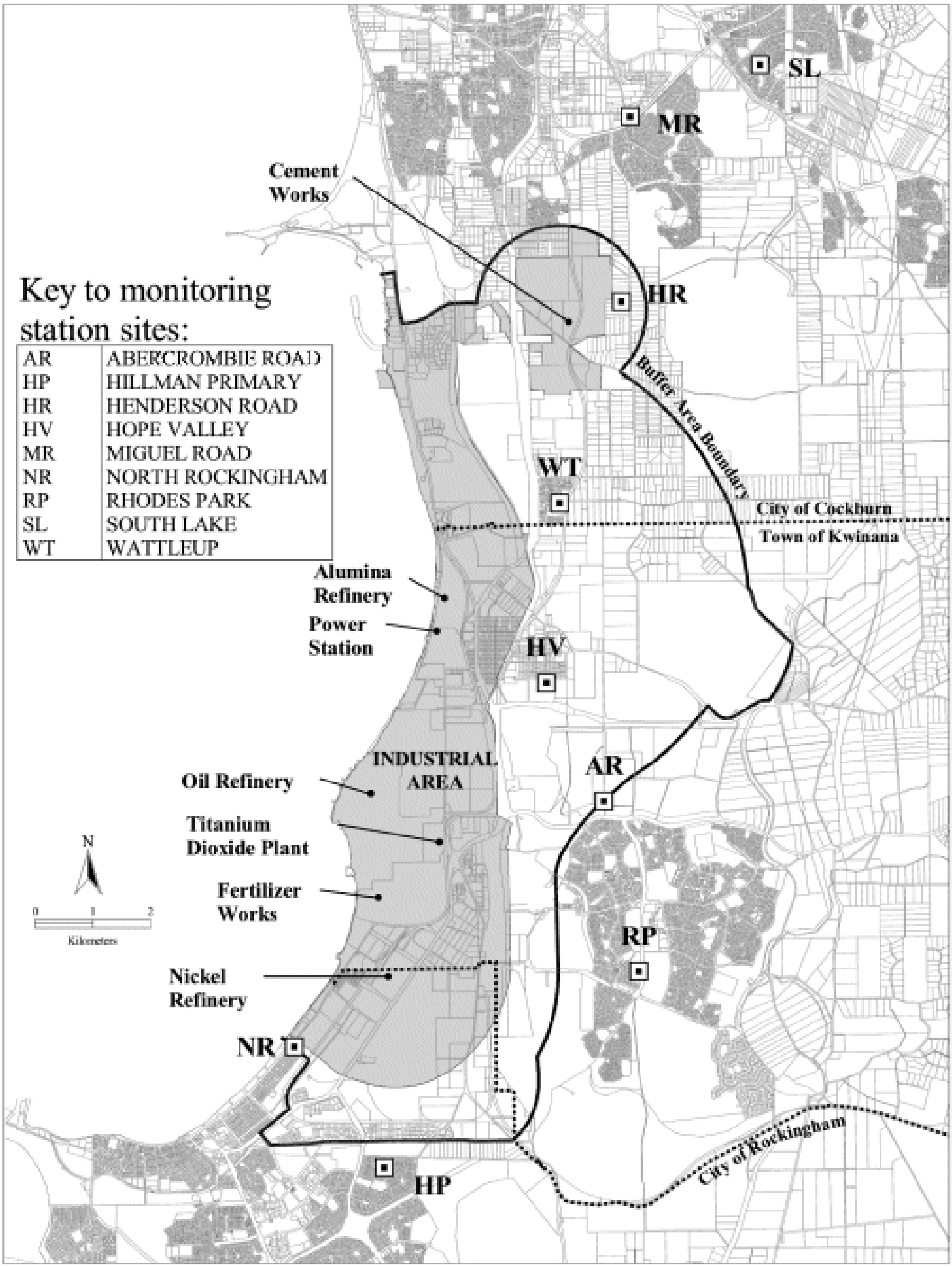


Figure 3.7 Sulfur dioxide monitoring network in the Kwinana Industrial Area. Monitoring stations are marked as box symbols with the accompanying initials explained in the Key.

3.1.6.2 Screening analysis and nominated performance monitoring stations and trend stations

Heavy industries at Kwinana are the only significant sources of sulfur dioxide in the Perth / Kwinana / Rockingham region. Accordingly there is a clear case for application of screening procedures to demonstrate that less than three performance monitoring stations are required in the region.

The following screening procedures described in PRC (2000d) are relevant:

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

Screening Procedure	Acceptance Limit (% of NEPM standard)
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 exceedances 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 exceedances or gain a more representative depiction of pollutant distribution.	55%

The network of six monitoring stations established as a requirement of the EPP will remain in operation for the foreseeable future (unless sulfur dioxide emissions decrease significantly, which is unlikely). The DEP considers these to be "source management" monitoring stations, mostly located at the boundary of or within the sparsely populated buffer zone to ensure compliance with the EPP.

With assistance from the CSIRO, the DEP has developed and refined a computer model called DISPMOD, which simulates the dispersion of sulfur dioxide in the Kwinana area, including the shoreline fumigation phenomenon (Figure 3.3). This model gives good predictions of the statistics of ground level concentrations at Wattleup, Hope Valley, Abercrombie Road and Rockingham and over-predicts the statistics for the more distant stations at Henderson Road and Miguel Road. A contour map of modelled "99.9 percentile hourly average concentrations" (in micrograms per cubic metre), based on 1995 measured or estimated emissions and measured meteorology, is given in Figure 3.8. The locations of the Hope Valley and South Lake monitoring stations are shown for reference. (Note that the definition of percentiles and how averaging is performed differs from the NEPM, however the numerical values of the contours are not important in the context of this argument.) This map shows that the sulfur dioxide concentration is reducing in every direction outward from the buffer zone. Consequently the data from the six monitoring stations may be taken to indicate the upper limit of sulfur dioxide concentrations to which residents may be exposed anywhere in this NEPM region.

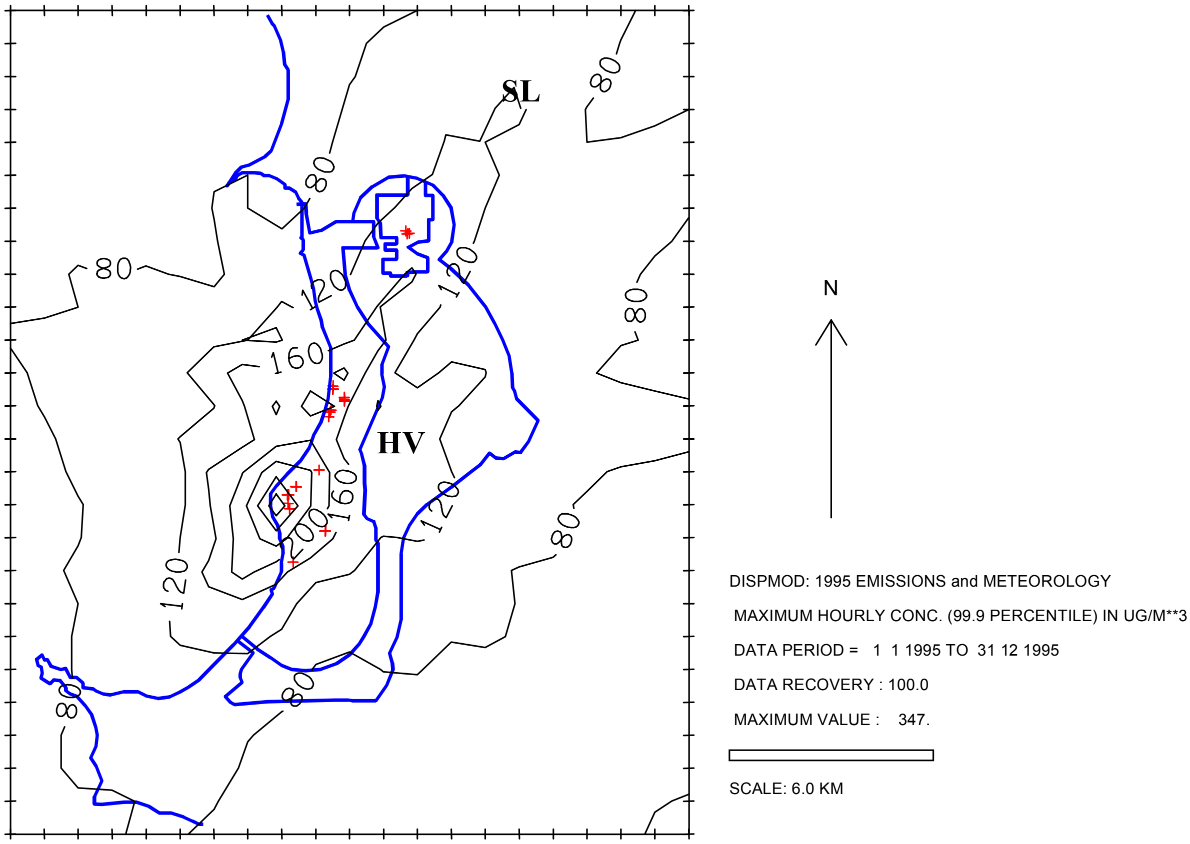


Figure 3.8 Contours of modelled 99.9 percentile hourly average sulfur dioxide (micrograms per cubic metre), based on 1995 measured or estimated emissions and measured meteorology. (Note: the NEPM standard of 0.2 ppm = 570 micrograms per cubic metre at STP)

Each of the current stations has data records of five or more years duration. Inspection of the data over the five years to 1999 shows that the highest 1-hour concentrations have all been below 50% of the NEPM standard (0.2 ppm). Furthermore, the highest 1-day and 1-year concentrations measured at any of the six stations over the five years to 1999 were 0.022 ppm (at Rockingham) and 0.004 ppm (at Wattleup) respectively. These are, respectively, 27% of the 1-day standard and 20% of the 1-year standard. It may be concluded that the whole region has been in compliance over this five-year period by a large margin.

WA proposes to operate one performance monitoring station for sulfur dioxide, while maintaining the source management network described above, which will identify the need for additional performance monitoring stations should that ever arise. This decision, together with the foregoing data and modelling assessments, satisfies the screening procedures B and C above.

It is proposed that the South Lake station be an upper bound performance monitoring station for sulfur dioxide, and a trend station. The Miguel Road station is also somewhat beyond the buffer zone, but a site inspection has revealed that it is not a good long-term candidate for a performance monitoring station site. The South Lake site is near the southern extent of the main urban population and downwind of Kwinana in sea breeze conditions.

3.1.7 Lead

3.1.7.1 Review of data

Figure A1.5 shows the 1-year averages of lead concentrations measured at Queens Buildings over the period 1990 to 1999. As previously discussed, Queens Buildings provides an upper limit on concentrations caused by motor vehicle emissions, which are the only significant source of particulate lead in WA. There has been a dramatic reduction over this period due to the combined effects of the increasing fraction of unleaded petrol vehicles and the reducing lead content of leaded petrol. Leaded petrol ceased to be sold in WA in January 2000.

3.1.7.2 Nominated performance monitoring stations and trend stations

The monitoring plan for lead that follows is consistent with the guideline document entitled *Lead monitoring* (PRC, 2000i).

The Queens Buildings lead measurements will be maintained through 2001, following which the DEP will review the data. If, as expected, the data shows lead concentrations continuing to reduce to levels far below the NEPM standard, a performance monitoring station for lead will not be established. This decision will be supported with reference to the screening procedure below (extracted from PRC (2000d)), the requirements of which are already easily met by the Queens Buildings monitoring record. Monitoring of lead at Queens Buildings may be terminated when concentrations are consistently below 10% of the standard. If, on the other hand, the monitoring in 2001 does not show lead concentrations continuing to reduce far below the NEPM Standard, the need for a performance monitoring station will be considered.

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

3.1.8 Particles as PM_{10}

3.1.8.1 Review of data

Figure A1.6(a) and (b) shows PM_{10} data from the following sources:

(a) High Volume samplers operated on a one day in six cycle at Caversham, Swanbourne and Queens Buildings;

(b) High Volume sampler (one day in six cycle) and a TEOM (continuous operation, data logged every 10 minutes) at Duncraig.

The Hi-Vol statistics must be viewed in light of the once in six day operation of these instruments. These statistics are nevertheless valuable in determining the need for ongoing monitoring.

PM_{10} concentrations in excess of the NEPM standard of 50 micrograms per cubic metre ($\mu g/m^3$), 1-day average, have been measured at all four monitoring sites, by both Hi-Vols and a TEOM. The NEPM Goal sets the maximum allowable exceedances of the standard at 5 days per calendar year. Compliance with this Goal cannot be directly determined from one in six day measurements. The continuous TEOM data indicates compliance at Duncraig.

The highest particulate events recorded by the DEP (PM_{10} or $PM_{2.5}$) have been caused by smoke from either home fires or open burning. With respect to the latter, the impact of smoke from hazard reduction burning has decreased in recent years due to improvements in forecasting of appropriate meteorological conditions.

Figures A1.7 and A1.8 show $PM_{2.5}$ measurements and the observed relationship between Hi-Vol and TEOM measurements of PM_{10} respectively. These figures are not directly relevant to the current discussion but are included for future reference.

3.1.8.2 Nominated performance monitoring stations and trend stations

For the same reasons discussed in relation to CO, Duncraig is a good upper bound performance monitoring station site for PM_{10} caused by the combination of vehicle and home fire emissions during strongly stable meteorological conditions.

Caversham, Duncraig and South Lake are all nominated as trend stations.

Likewise, the new site at South Lake is expected to measure significant PM_{10} concentrations from wood fires. It will also measure PM_{10} emissions from the Kwinana Industrial Area, although these are expected to be low.

The Caversham station has the longest particulate monitoring record in WA and will be maintained as a performance monitoring station, providing a good spatial distribution of monitoring stations. The spatial distribution is important in providing the capacity to map the impact of smoke plumes from remote fires.

The three performance monitoring stations will be equipped with continuous PM_{10} monitors, presumed at this stage to be TEOMs.

PM_{10} measurement by Hi-Vol at Queens Buildings will be reviewed in conjunction with a review of lead monitoring (as previously mentioned). It is not likely that a Hi-Vol will be maintained at Swanbourne.

3.1.9 Summary of monitoring proposed for the Perth Region

Table 3.2 summarises the monitoring proposed for the Perth Region.

Table 3.2 Monitoring in the Perth Region.

Site:	**CO**	**O_3**	**NO_2**	**SO_2**	**Pb**	**PM_{10}**
QB - Queens Building	P		DEP		P(1)	
DU - Duncraig	T		DEP			T
SL - South Lake	P	P	P	T		P
CA - Caversham	DEP	T	T			P
SW - Swanbourne		P	P			
QR - Quinns Rock		DEP	DEP			
RG - Rolling Green		DEP	DEP			
HV – Hope Valley				DEP		
WT - Wattleup				DEP		
RO - Rockingham				DEP		

Key to symbols:
P – performance monitoring station
P(1) – performance monitoring for lead will not be maintained after the annual average concentration reduces to less than 10% of the NEPM standard
T – trend performance monitoring station
DEP – station will be maintained by DEP for the foreseeable future

3.2 MANDURAH REGION

3.2.1 Overview description of the region

Region boundaries

Figure 3.9 shows the nominal boundaries of the Mandurah Region. The northern boundary, which is shared with the Perth Region, is shown as a dashed line. Performance monitoring will be restricted to the main urban area of Mandurah for the following reasons:

- there is not expected to be significant generation of photochemical smog products (ozone, nitrogen dioxide, etc.) due to Mandurah's emissions which would warrant monitoring further from the city (this point will be further discussed below);
- representative measurements of CO and PM_{10} will be obtained within urban areas;
- pollutants from the Perth Region will be widely dispersed on the occasions when they are transported to Mandurah. Hence a single monitoring station at Mandurah will be representative of the region whatever its size (within sensible limits).

Population

Figure 3.9 shows the population densities within the Mandurah Region, based on data from ABS (1997). Mandurah is characterised by single residential dwellings (including canal developments) with very few two or three storey apartment blocks and no high-rise residential development. The city population includes a large proportion of retirees. Many people commute to the Perth / Kwinana Region for employment.

Industry

There is no heavy industry at Mandurah itself. The closest heavy industry is at Kwinana, 35 km to the north, and at Pinjarra (see Figure 3.9) where there is an alumina refinery.

Emissions

There are no emissions estimates available for Mandurah sources. Perth Region emissions (including Kwinana) are known and the Pinjarra refinery emissions can be estimated if required.

Smoke from wood fires is likely to be a significant source of particles, however it is very difficult to obtain reliable quantitative estimates of these emissions. The same is true of smoke from open burning (wildfires and fires for hazard reduction or asset management).

The monitoring plan for Mandurah will not rely on emissions estimates, therefore emissions will not be quantified in this report.

Meteorology and topography

The meteorology of Mandurah, as it affects air quality, can be taken to be the same as that of coastal portions of the Perth Region. The topography is similar, with the Darling Escarpment about 25 km to the east. As indicated on Figure 3.9, the region is very flat.

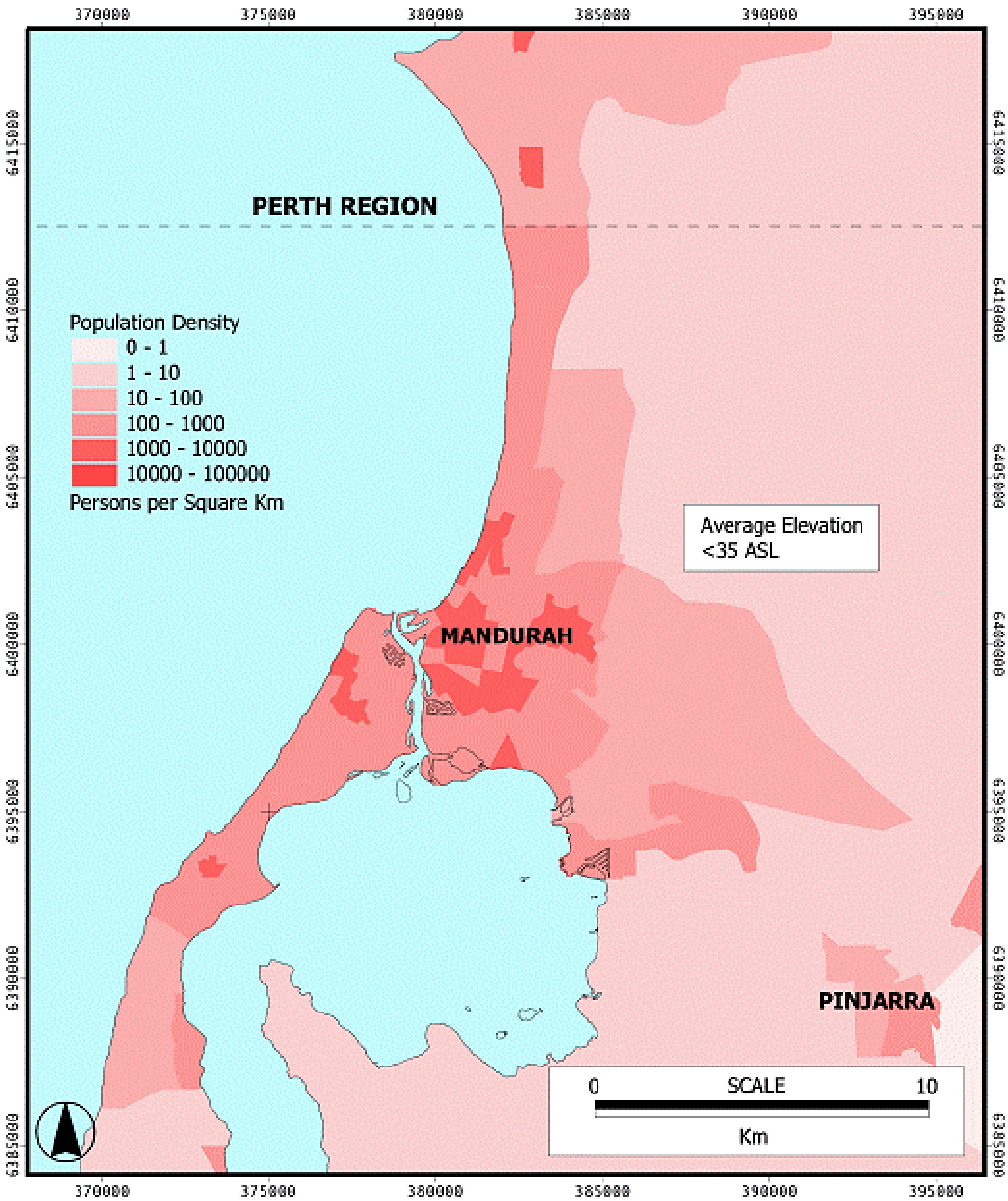


Figure 3.9 Map of the Mandurah Region, showing population density and topography.

Air quality monitoring history

There has been no air quality monitoring at Mandurah. At the time of writing, plans are in hand to locate a monitoring station within the main urban area shown on Figure 3.9, ideally close to the coast (for reasons described in section 3.2.4).

3.2.2 NEPM formula

With a population of 35,945, the NEPM formula (clause 14(1)) indicates that one performance monitoring station is required in the Mandurah Region.

Since it is likely that ambient concentrations of all NEPM pollutants will be low relative to the NEPM standards, the DEP will not nominate the Mandurah performance monitoring station as a trend station at this time.

3.2.3 Carbon monoxide

The concentration of carbon monoxide caused by motor vehicles is expected to be low. There is expected to be some level of contribution from wood fires. This pollutant will be monitored. The monitoring site (selected primarily for ozone – see below) will measure a reasonable representation of CO concentrations in calm conditions or stable, light easterly drifts.

3.2.4 Photochemical oxidants (as ozone)

As previously mentioned, it is considered likely that Mandurah will be the recipient of ozone from the Perth and Kwinana plumes, notably on days when the low pressure trough crosses the coast on its passage inland. On such days, the wind has been observed to swing from north-east through north to westerly, before backing more southerly as the trough passes inland. Hence the transport of reacting emissions is to the south-west, into the light wind region of the trough, then back onshore south of Perth.

The preferred Mandurah monitoring station site is close to the coast, in order to measure ozone concentrations before any significant titration with fresh nitric oxide occurs and before convective mixing over the land causes significant dilution. North-south concentration gradients are likely to be small.

3.2.5 Nitrogen dioxide

NO_x will be measured at Mandurah to assist in interpreting the O_3 events. However there is no expectation that NO_2 concentrations will approach the NEPM standard at any time, given the generally low values measured in the Perth Region.

3.2.6 Sulfur dioxide

Figure A1.4(a) shows that sulfur dioxide concentrations at the Rockingham monitoring station have in recent years been in the order of 25 to 30% of the NEPM standard. Concentrations at Mandurah, 30 km further south, will obviously be considerably less. Furthermore, the sulfur dioxide concentrations at the Rockingham monitoring station are managed under an Environmental Protection Policy for the Kwinana Industrial Area. The Kwinana Environmental Protection Policy is designed to ensure that standards equivalent to the NEPM standard for sulfur dioxide will not be contravened.

The alumina refinery at Pinjarra burns North-West Shelf natural gas and therefore has negligible sulfur dioxide emissions.

Accordingly, screening procedure F from Table 1 of PRC (2000d) can be employed as follows:

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

Screening Procedure	**Acceptance Limit (% of NEPM standard)**
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential[(2)].	40%

Based on this criterion and the safeguard provided by the Kwinana Environmental Protection Policy, sulfur dioxide will not be monitored at Mandurah.

3.2.7 Lead

The very low and reducing lead concentrations in the Perth CBD (section 3.1.7) provide a clear basis for not measuring lead in small cities like Mandurah.

3.2.8 Particles as PM_{10}

PM_{10} particles will be measured at Mandurah. Wood fires, wildfires and prescribed burning, sea salt and, to a lesser extent, vehicles are likely sources. Secondary particles in smog plumes from the Perth Region may also be measured.

As with CO, the preferred coastal monitoring site will measure a reasonable representation of PM_{10} concentrations in calm conditions or stable, light easterly drifts. Any site in the region would be acceptable for measuring the impact of broad plumes from forest fires. There are very large areas of State forest in the south-east quadrant, hence the Mandurah monitoring station will be used to test assumptions used in screening for other cities in relation to:

- the O_3 generating capacity of bushfire smoke in the absence of anthropogenic NO_x;
- CO in bushfire plumes.

3.2.9 Summary of monitoring proposed for the Mandurah Region

Table 3.3 summarises the monitoring proposed for the Mandurah Region.

Table 3.3 Monitoring in the Mandurah Region.

Site:	**CO**	**O_3**	**NO_2**	**SO_2**	**Pb**	**PM_{10}**
MA - Mandurah	P	P	P			P

Key to symbols:
P – performance monitoring station

(2) Pollution potential must take into account meteorology and topography.

3.3 BUNBURY REGION

3.3.1 Overview description of the region

Region boundaries and population

Figure 3.10 shows the nominal boundaries selected for the Bunbury Region, based on the following considerations:

- there is not expected to be significant generation of photochemical smog products (ozone and nitrogen dioxide) due to Bunbury's emissions which would warrant monitoring further from the city (this point will be further discussed below);
- representative measurements of CO and PM_{10} will be obtained within urban areas;
- the impact of emissions from industries outside the region will be considered;
- while Busselton (45 km south-west of Bunbury) experiences the impact of bushfire smoke and smoke from local wood burning similar to that experienced at Bunbury, there is no reason to view Busselton's air quality as depending on, or affecting, Bunbury's air quality. Therefore Busselton is not included in the Bunbury Region. It should be noted that the DEP monitors smoke levels at Busselton as part of its ongoing air quality management activities.

Figure 3.10 shows the population densities within the Bunbury Region, based on data from the ABS (1997).

Industry

Industries in the immediate vicinity of the City of Bunbury are not major sources of the NEPM pollutants. However there are a number of industries beyond the NEPM region with significant emissions of one or more NEPM pollutants that may need to be considered in assessing monitoring requirements. These industries (and locations relative to Bunbury) include:

- two coal fired power stations near Collie, 60 km E;
- an alumina refinery at Worsley, 35 km ENE;
- a titanium dioxide plant and a silicon smelter at Kemerton, 18 km NNE;
- a synthetic rutile plant near Capel, 20 km S.

Emissions

There has not been a comprehensive emissions inventory undertaken for Bunbury. The only emissions estimates that will be directly used in the assessment of monitoring requirements are those for industries (see above).

In general terms, it is known that smoke from wood fires is a significant issue, however it is very difficult to obtain reliable quantitative estimates of emissions. The same is true of smoke from open burning (wildfires and fires for hazard reduction or asset management). Bunbury experiences high concentrations of bushfire smoke on occasions, due to its proximity to regions of State forest in the south-west of the State.

Meteorology and topography

Bunbury has a Mediterranean climate that can be compared to that of Perth and Geraldton. Due to the city's more southerly location, it is a degree or two cooler, and with the lack of a long coastline to the south, its local sea breezes are weaker and more westerly. Figure 3.11 shows this, as a greater frequency of south-westerly and west-south-westerly winds. Also noticeable is a greater frequency of winds from the south-east, which corresponds to the regular incursion of sea breezes from the south coast.

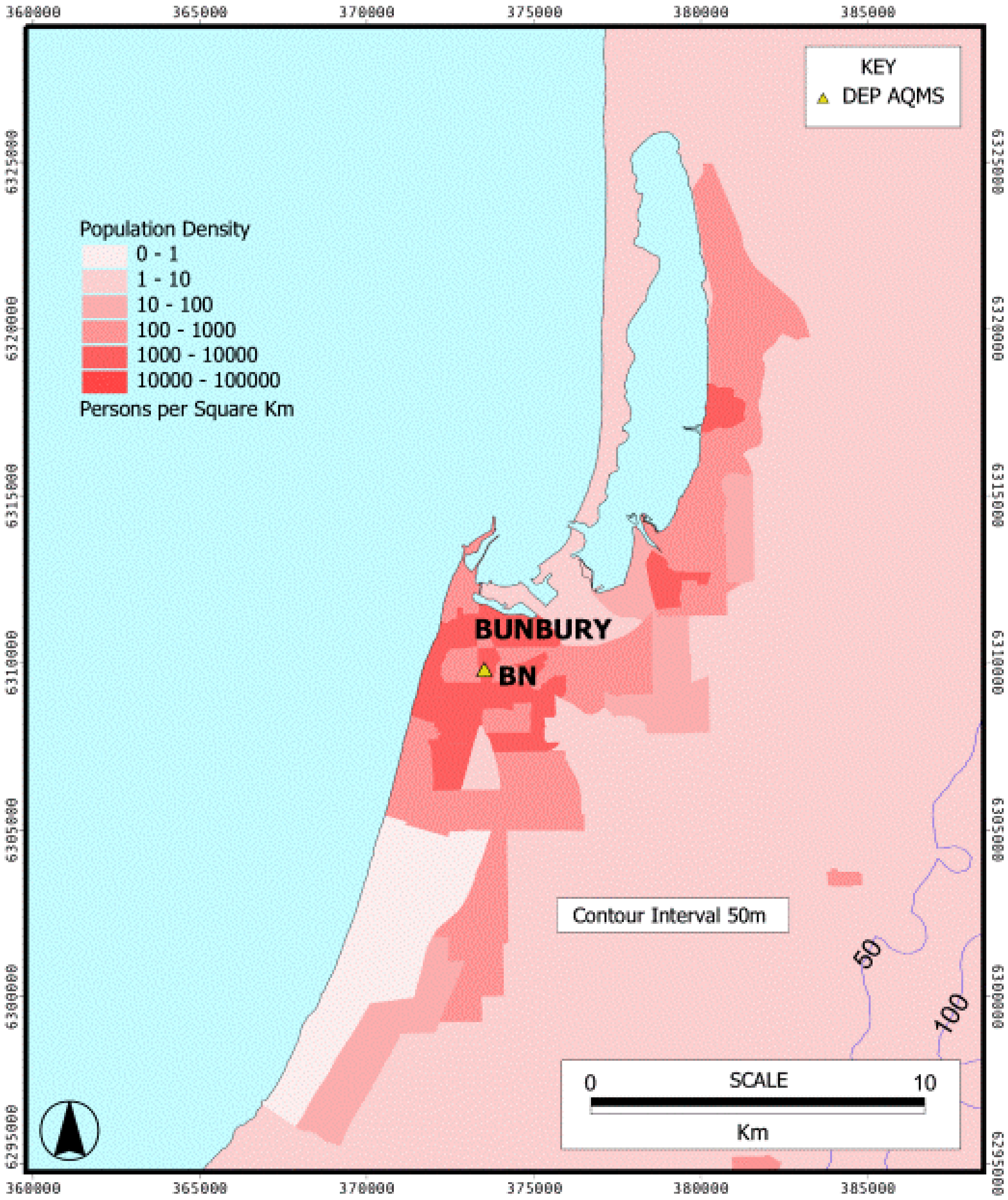


Figure 3.10 Map of the Bunbury Region, showing population density and topography.

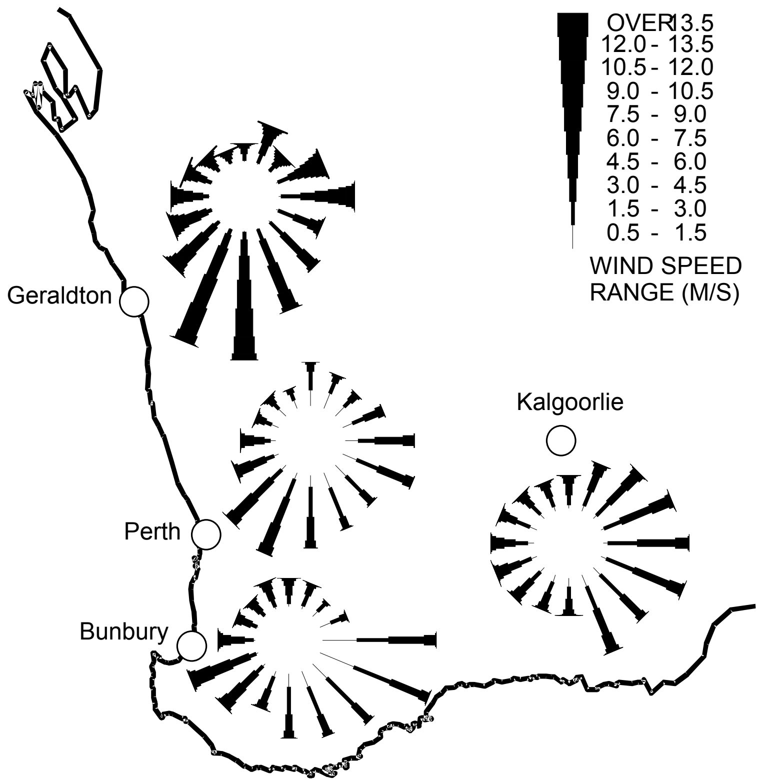


Figure 3.11. Wind roses for Geraldton, Perth, Bunbury and Kalgoorlie.
The width of each section of an arm corresponds to its speed range (see legend) and the radius encompassed by it corresponds to the frequency of winds in that range. The total length of each arm indicates the frequency of all winds from the indicated direction.

Figure 3.10 shows that Bunbury lies on a nearly flat coastal plain. However there are several features that affect the meteorology of the Bunbury Region:

- As shown in the Bunbury Airshed Study (Tarlowski and Rye, 1982), turbulent eddies and katabatic flows from the Darling Scarp affect easterly winds within a few kilometres of the scarp edge.
- The coastline in the vicinity of Bunbury includes Leschenault Inlet. Wind field analyses during the Bunbury Airshed Study also showed that the inland movement of the sea breeze was enhanced in the northern part of the region, to the extent that the eastern coastline of the inlet could be taken to approximate the effective coastline (Figure 3.12). The formation of land breezes also responded to the inlet, with offshore flows forming on the inner inlet coastline and the coastline south of Bunbury at about the same time. However, in winter, the effective coastline was closer to the ocean coastline.
- The coastal dunes located on the coast south of the city tend to channel winds on their inland side, maintaining wind direction from a south-south-westerly direction during stable conditions at night-time.

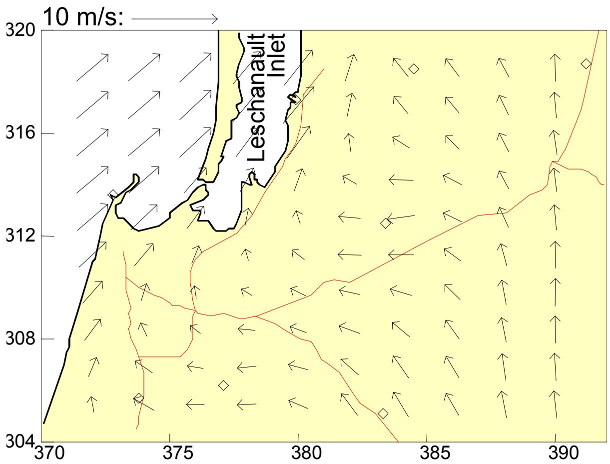


Figure 3.12. Wind field for a typical sea breeze incursion over the Bunbury Region (24 February 1982, at 2pm), showing the enhanced inland penetration due to Leschenault Inlet.

Air quality monitoring history

A monitoring station was installed at Bunbury in February 1997, measuring visibility only (via a nephelometer). The location of the station is marked by the site code BN on Figure 3.10. A TEOM measuring $PM_{2.5}$ was added in April 1997. Carbon monoxide and PM_{10} (TEOM) monitors were added in March 1999 and May 1999 respectively. The focus of this monitoring has been elevated levels of particles due to smoke from wood fires and various forms of open burning. As a point of interest, visibility is also measured at Busselton.

The Bunbury monitoring station is centrally located next to a primary school, surrounded by single residences, with heavily trafficked roads at least 200 metres distant. The site complies with AS2922. The site may be considered an upper bound site for CO, PM_{10} and probably also for NO_2.

3.3.2 NEPM formula

With a population of approximately 25,000, the NEPM formula (clause 14(1)) indicates that one performance monitoring station may be required in the Bunbury Region.

3.3.3 Carbon monoxide

The DEP does not intend to undertake performance monitoring for CO at Bunbury, based on application of the following screening procedures extracted from PRC (2000d):

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
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential(2).	40%

With respect to screening procedure A, the DEP has collected almost 12 months' data on CO concentrations at the Bunbury monitoring station. The data, plotted as monthly maximum 8-hour averages in Figure A3.1, shows the expected annual cycle with highest concentrations occurring in winter, associated with stable meteorology. The highest concentration measured in 1999 was 2.68 ppm, which is 30% of the NEPM standard. This clearly meets the acceptance limit for 1 year of monitoring. It is planned at this stage to maintain the CO monitor for a total of two years before removing it. This will allow a review of the screening decision.

Screening procedure F above is redundant (given the successful application of A) however it is worth noting that the CO monitoring results from Mandurah are likely to provide a basis for application of procedure F to small cities like Bunbury.

3.3.4 Photochemical oxidants (as ozone)

The DEP does not intend to undertake performance monitoring for O_3 at Bunbury, based on application of the following screening procedures extracted from PRC (2000d):

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

Screening Procedure	Acceptance Limit (% of NEPM standard)
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%

With respect to screening procedure E, the DEP is awaiting the results of a study being conducted by the CSIRO, in which the model TAPM is to be employed to determine the smog-

(2) Pollution potential must take into account meteorology and topography.

forming potential of cities of various sizes under adverse meteorological conditions. With respect to screening procedure F, the monitoring data from the larger Mandurah Region (excluding smog events associated with southward transport of emissions from the Perth Region) will be used to confirm the determination from procedure E.

The CSIRO study will consider biogenic VOC emissions but may not adequately consider the effects of bushfire smoke plumes. The smoke includes highly reactive VOCs, and experience in the Perth Region has shown that their reaction with urban emissions may generate significant ozone concentrations. A clear example occurred in the Perth Region on 13 January 1993 (Figure 3.13). A characteristic of these events at inland sites like Caversham is the long duration and relatively slow rise of high ozone concentrations within the broadly distributed smoke cloud.

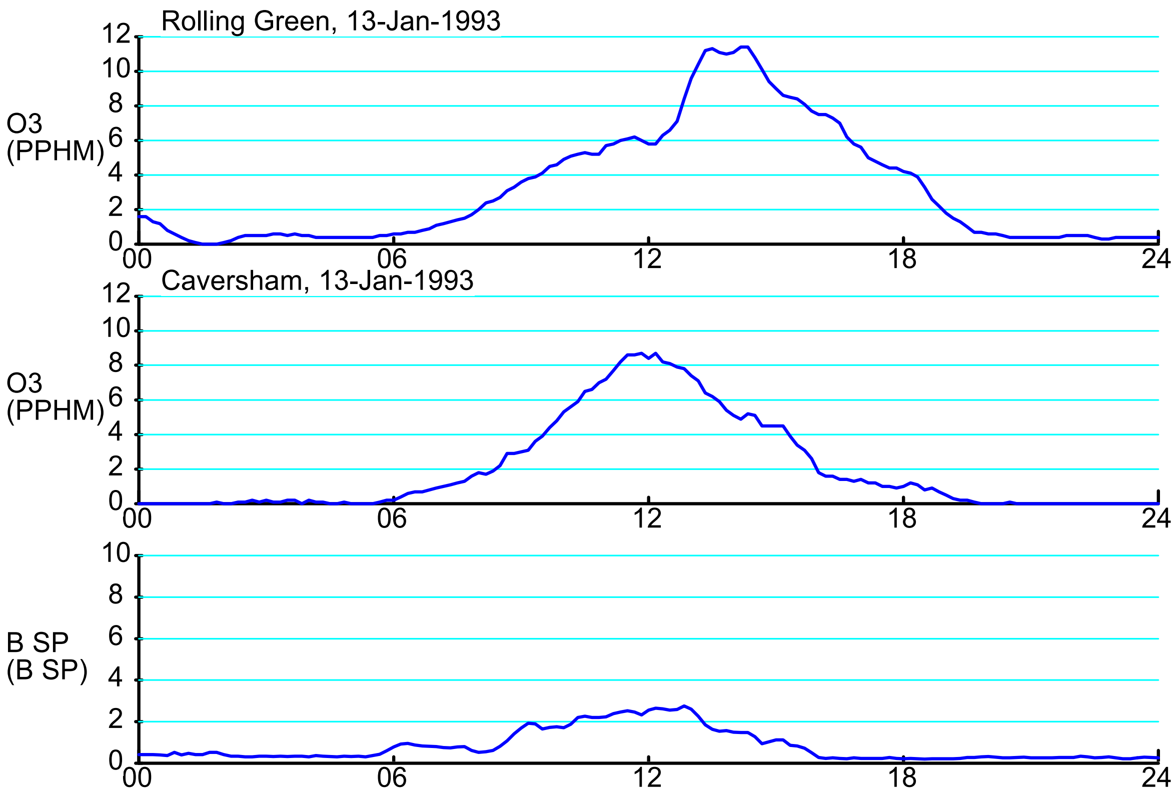


Figure 3.13 Ozone concentrations (parts per hundred million) at Caversham and Rolling Green on 13 January 1993, plus nephelometer readings at Caversham revealing the presence of bushfire smoke.

The important issue in relation to smaller cities like Bunbury is the extent to which ozone events associated with bushfire smoke depend on anthropogenic emissions (notably NO_x). If the dependency is high, such events may be of much less significance over small cities (where total emissions are low).

The DEP has employed the CIT photochemical smog model over a number of years to investigate and simulate smog events. Ozone concentrations observed during the 13 January 1993 event have been simulated reasonably well by setting the background VOC level to generate the observed reactivity, and using the Perth Photochemical Smog Study emissions inventory for other emissions. This simulation provides a base case for assessment of the role of anthropogenic emissions. Contours of ozone concentration from the base case simulation are plotted in Figure 3.14(a). The contours plotted in (b) and (c) of that figure are model simulations that used the same reactivity and biogenic emissions, but with all other anthropogenic emissions (vehicles, industry, area sources) set at 50% and 10% of the base case respectively. This roughly simulates the ozone that would be expected if the Perth population were 500,000 or 100,000, with all emissions scaled proportionately.

As can be seen, peak concentrations reduce to levels about 75% and 30-40% of the base case respectively. Note that the background ozone is about 20% of the base case peak. On the basis of this simulation it is considered very unlikely that a city with a population less than 100,000 people would experience ozone concentrations associated with bushfire smoke which would approach the NEPM standard, unless there were other large sources of emissions nearby.

Bunbury, with a population of 25,000 and low VOC and NO_x emissions nearby, would appear to have little prospect of significant ozone concentrations associated with normal biogenic emissions or bushfire smoke. The only issue that warrants further assessment is the possibility of ozone forming in the plumes from the power stations at Collie, which may at times impact Bunbury and other residential areas. Ozone formation in these plumes would depend on biogenic VOC and may be accelerated by VOC in bushfire smoke. The DEP will investigate this issue, using appropriate modelling methods. Noting that these plumes are released from tall chimneys 40 km from Bunbury, the likelihood of significant ozone concentrations is considered to be small.

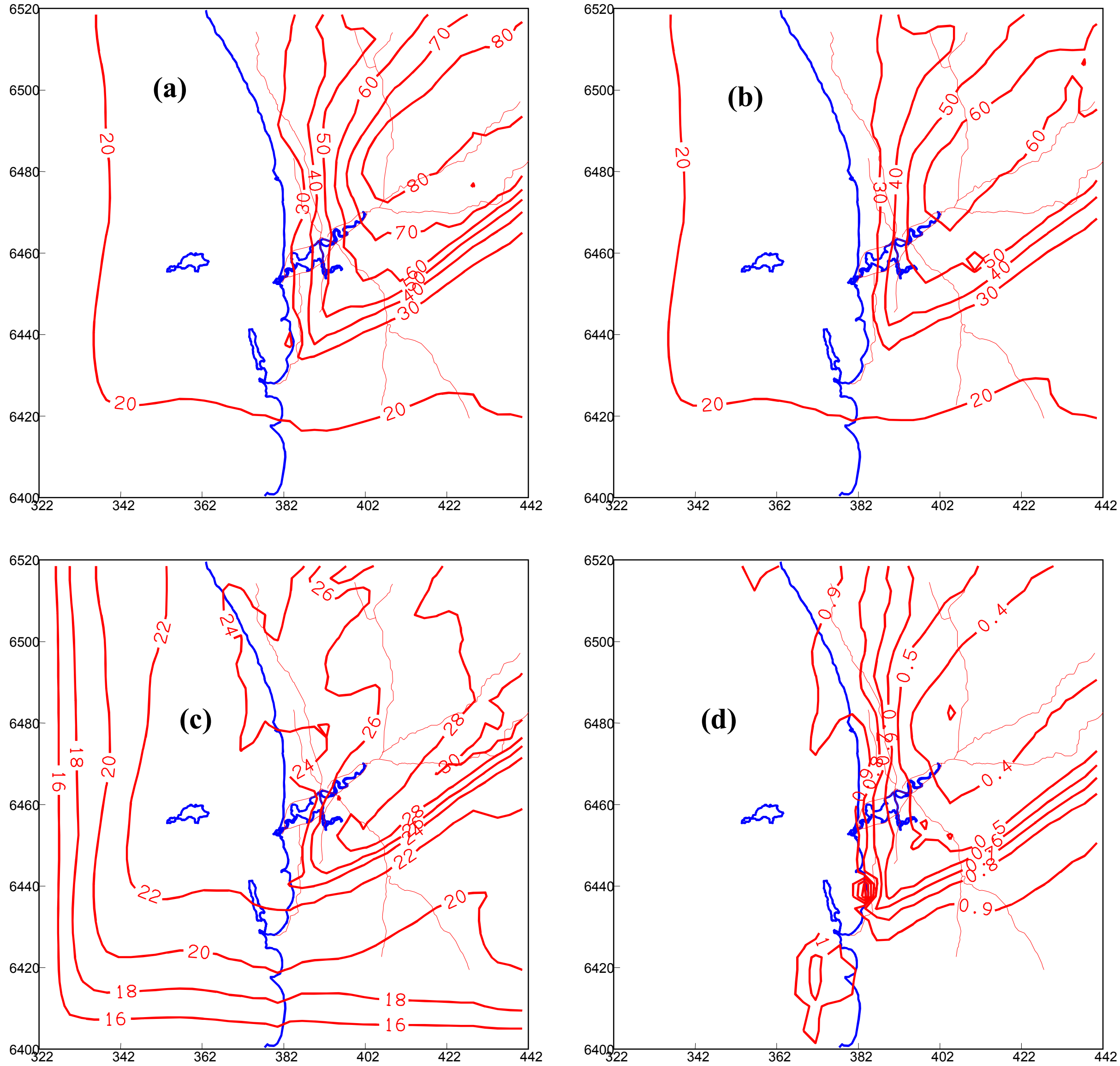


Figure 3.14 Model assessment of the role of anthropogenic emissions in the formation of ozone in bushfire smoke, based in the 13 January 1993 event in the Perth Region:

- **a) peak hourly average ozone for base case (as per known emissions);**
- **b) anthropogenic emissions halved;**
- **c) anthropogenic emissions one tenth of base case;**
- **d) ratio of peak hourly ozone for the one tenth case compared to the base case.**

All contours in (a), (b) and (c) are in parts per billion (ppb) of ozone.

3.3.5 Nitrogen dioxide

The DEP does not intend to undertake performance monitoring at Bunbury, based on application of the following screening procedures extracted from PRC (2000d):

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

Screening Procedure	Acceptance Limit (% of NEPM standard)
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.	35%
As above in combination with F.	45%
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential[2].	40%

With respect to screening procedure E, the DEP is awaiting the results of a study being conducted by the CSIRO, in which the model TAPM is to be employed to determine the smog-forming potential of cities of various sizes under adverse meteorological conditions. With respect to screening procedure F, the monitoring data from the larger Mandurah Region (excluding smog events associated with southward transport of emissions from the Perth Region) will be used to confirm the determination from procedure E.

The only residual question in relation to NO_2 at Bunbury will be whether the plumes from power stations at Collie cause significant concentrations of NO_2 at Bunbury, 40 km away. It is worth noting that NO_x from Kwinana industry plumes (including the Kwinana Power Station) does not cause high NO_2 levels in Perth suburbs. The DEP will investigate this issue using a model that accounts for transformation of NO to NO_2 in the atmosphere.

[2] Pollution potential must take into account meteorology and topography.

3.3.6 Sulfur dioxide

The DEP does not intend to undertake performance monitoring at Bunbury, based on application of the following screening procedures extracted from PRC (2000d):

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

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%

Data on the emissions of sulfur dioxide from industries in the Bunbury Region and surrounding areas (see section 3.3.1) will be used in a model (Gaussian or 3-D prognostic) to simulate concentrations at Bunbury. This will be supported by SO_2 monitoring data collected at Collie.

3.3.7 Lead

The acceptable and improving lead monitoring results for the Perth CBD (section 3.1.7) provide a clear basis for not measuring lead in small cities like Bunbury.

3.3.8 Particles as PM_{10}

As previously discussed, PM_{10} is currently being monitored at Bunbury using a TEOM, operated continuously – this may be considered to be campaign monitoring for the purposes of the NEPM. The data collected thus far is plotted in Figure A3.1. The DEP intends to continue to monitor PM_{10} for a full year and decide at the end of that time whether to undertake performance monitoring for this pollutant at Bunbury. On the basis of data collected thus far it appears that performance monitoring will be necessary.

3.3.9 Summary of monitoring proposed for the Bunbury Region

Table 3.4 summarises the monitoring proposed for the Bunbury Region.

Table 3.4 Monitoring in the Bunbury Region.

Site:	**CO**	**O_3**	**NO_2**	**SO_2**	**Pb**	**PM_{10}**
BN - Bunbury	C					P? - current campaign monitoring

Key to symbols:
P – performance monitoring station
C – campaign monitoring

(1) Validation means demonstrated satisfactory correlations between observations and predictions in the same or similar airshed.

3.4 GERALDTON REGION

3.4.1 Overview description of the region

Region boundaries, population and topography

Figure 3.15 shows the boundaries selected for the Geraldton Region. As with Bunbury, the region does not extend far beyond the fringes of the city for the following reasons:

- there is not expected to be significant generation of photochemical smog products (ozone and nitrogen dioxide) due to Geraldton's emissions which would warrant monitoring further from the city (this point will be further discussed below);
- representative measurements of CO and PM_{10} will be obtained within urban areas;
- the impact of emissions from industries outside the region will be considered.

Figure 3.15 also shows the population densities within the Geraldton Region, based on data from the ABS (1997), plus contours of the local topography.

Industry

There are a number of industries in the NEPM region and beyond with emissions of one or more NEPM pollutants that may need to be considered in assessing monitoring requirements. These industries (and locations relative to Geraldton) include:

- a gas turbine 5 km E;
- a synthetic rutile plant at Narngulu, 8 km SE;
- a proposed iron and steel project at Oakajee, 20 km N.

Emissions

There has not been a comprehensive emissions inventory undertaken for Geraldton. The only emissions estimates that will be directly used in the assessment of monitoring requirements are those for the industries above.

In general terms, it is known that smoke from open burning (wildfires and fires for hazard reduction or asset management) is an issue of concern at times, as is wind blown dust.

Meteorological features

Geraldton experiences a climate which is similar to, but in some aspects more extreme, than Perth. Temperatures are generally a degree or two warmer, and rainfall is less.
The most notable difference between the climates of Geraldton and Perth is in the mean wind speeds. Although Geraldton's maximum wind gusts are noticeably less than Perth's, its mean wind speed is not only greater, but is also greater than on the coast near Perth (at Swanbourne) during the summer and early autumn (Figure 3.16). The cause is the much greater regularity and strength of the sea breeze at Geraldton. As can be see from Figure 3.11, there is a clear predominance of strong S to SSW winds in the wind rose for the area (the wind rose was constructed from Oakajee data).

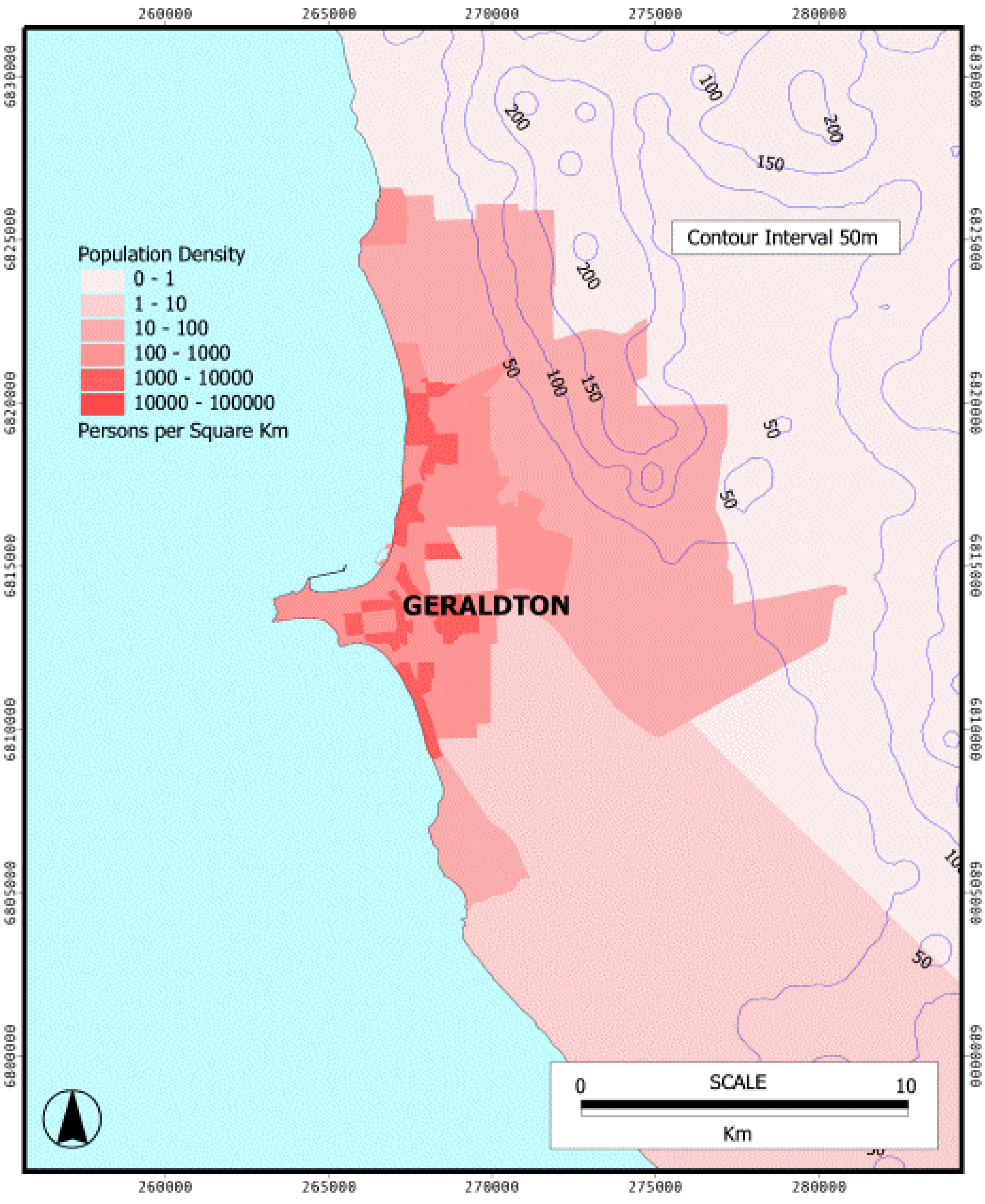


Figure 3.15 Map of the Geraldton Region, showing population density and topography.

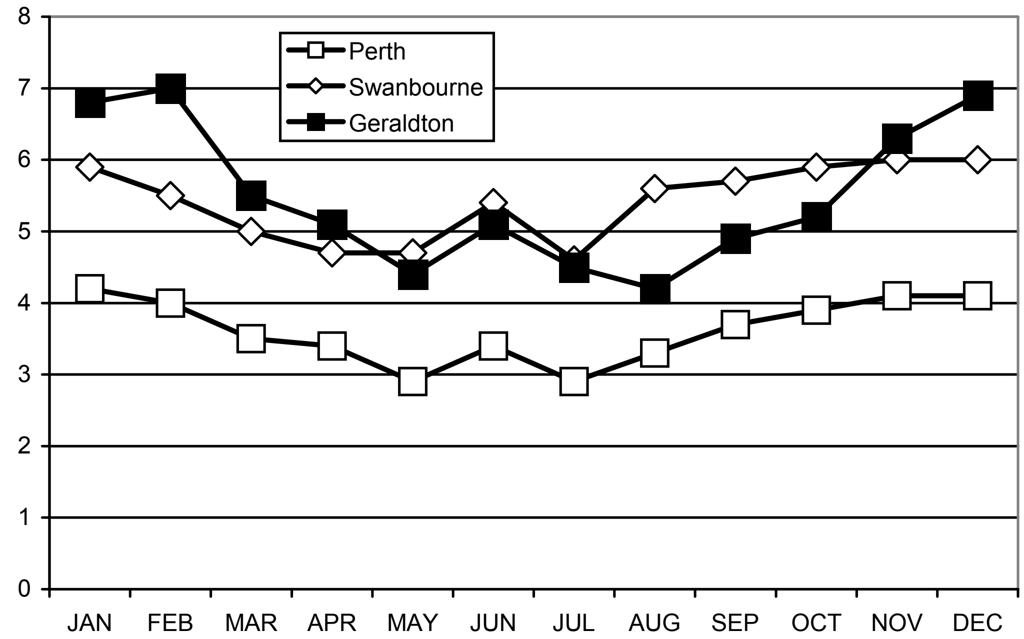


Figure 3.16. Monthly average wind speeds for Perth, Swanbourne (coastal site near Perth) and Geraldton Airport, for the year 1998 (data provided by Bureau of Meteorology).

Air quality monitoring history

The DEP has not conducted air quality monitoring at Geraldton to date.

3.4.2 NEPM formula

With a population of 25,243, the NEPM formula (clause 14(1)) indicates that one performance monitoring station is required in the Geraldton Region.

3.4.3 Carbon monoxide

There is little likelihood of significant CO concentrations in Geraldton, for the following reasons. Firstly, emissions of CO from motor vehicles and industrial emissions would be no greater than those for Bunbury, and emissions of CO from wood fires may be expected to be less than for Bunbury in light of the warmer climate. Secondly, the frequency of stable conditions at Geraldton is low; the wind speed is 3 m/sec or less for only 2% of the time (Oakajee data) compared to 13% at Kalgoorlie and 17% at Bunbury. Stable conditions are essential for significant accumulation of CO to occur. Noting that the CO concentrations measured at Bunbury are low relative to the NEPM standard, it may be safely concluded that CO concentrations at Geraldton will be much less than the NEPM standard.

In accordance with the following screening procedures extracted from PRC (2000d), the DEP does not intend to monitor CO at Geraldton, based on the interim argument above and the forthcoming results of campaign monitoring at Bunbury and Kalgoorlie. If necessary, modelling will be undertaken to demonstrate the greater dispersion potential at Geraldton.

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

Screening Procedure	Acceptance Limit (% of NEPM standard)
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential(2).	40%

3.4.4 Photochemical oxidants (as ozone)

The DEP does not intend to undertake performance monitoring at Geraldton, based on application of the following screening procedures extracted from PRC (2000d):

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

Screening Procedure	Acceptance Limit (% of NEPM standard)
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%

With respect to screening procedure E, the DEP is awaiting the results of a study being conducted by the CSIRO, in which the model TAPM is to be employed to determine the smog-forming potential of cities of various sizes under adverse meteorological conditions. With respect to screening procedure F, the monitoring data from the larger Mandurah Region (excluding smog events associated with southward transport of emissions from the Perth Region) will be used to confirm the determination from procedure E.

3.4.5 Nitrogen dioxide

The DEP does not intend to undertake performance monitoring at Geraldton, based on application of the following screening procedures extracted from PRC (2000d):

(2) Pollution potential must take into account meteorology and topography.

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

Screening Procedure	**Acceptance Limit (% of NEPM standard)**
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%

With respect to screening procedure E, the DEP is awaiting the results of a study being conducted by the CSIRO, in which the model TAPM is to be employed to determine the smog-forming potential of cities of various sizes under adverse meteorological conditions. The relatively small industrial NO_x emissions will be considered in the application of this study to Geraldton. With respect to screening procedure F, the monitoring data from the larger Mandurah Region (excluding smog events associated with southward transport of emissions from the Perth Region) will be used to confirm the determination from procedure E.

3.4.6 Sulfur dioxide

Industrial emissions of SO_2 in the Geraldton Region are very small. It is expected that SO_2 concentrations in residential areas will be very small compared to the NEPM standard. This will be confirmed via a modelling, using the Oakajee meteorological data or suitable alternative, in accordance with the following screening procedure.

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

Screening Procedure	**Acceptance Limit (% of NEPM standard)**
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%
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential[(2)].	40%

[(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.

3.4.7 Lead

The very low and reducing lead concentrations in the Perth CBD (section 3.1.7) provide a clear basis for not measuring lead in small cities like Geraldton.

3.4.8 Particles as PM_{10}

There are two likely sources of significant PM_{10} concentrations in the city of Geraldton:

- wind blown crustal material;
- smoke from bushfires, hazard reduction or stubble burning and possibly home fires.

The DEP proposes to install a PM_{10} monitor (most likely a stand-alone TEOM) for the purpose of campaign monitoring over a period of two years, following which a determination will be made on the need for ongoing performance monitoring.

A site for campaign monitoring has not been selected.

3.4.9 Summary of monitoring proposed for the Geraldton Region

Table 3.5 summarises the monitoring proposed for the Geraldton Region.

Table 3.5 Monitoring in the Geraldton Region.

Site:	**CO**	**O_3**	**NO_2**	**SO_2**	**Pb**	**PM_{10}**
Geraldton						**C**

<u>Key to symbols:</u>
C – campaign monitoring

3.5 KALGOORLIE REGION

3.5.1 Overview description of the region

Region boundaries and population

The Kalgoorlie Region defined for the purpose of this NEPM is shown in Figure 3.17. It is centred on the city of Kalgoorlie-Boulder and extends outward to include three major industries that have the capacity to cause significant concentrations of sulfur dioxide in the city.

Kalgoorlie-Boulder is a mining city, situated immediately adjacent to a large open pit gold mine and ore processing plants. The population of 28,000 lives in the residential area shaded grey on Figure 3.17.

Industry

From an air quality viewpoint, by far the most significant industries are those which emit sulfur dioxide. These industries, which are shown on Figure 3.17, are:

- the Gidji Gold Roaster;
- the Kanowna Belle Gold Roaster;
- the Kalgoorlie Nickel Smelter.

Other significant industries identified in the Kalgoorlie Trial of the National Pollutant Industry (DEP, 1999) are:

- gold mining and ore processing;
- lime manufacturing;
- gas turbines at two locations.

Emissions

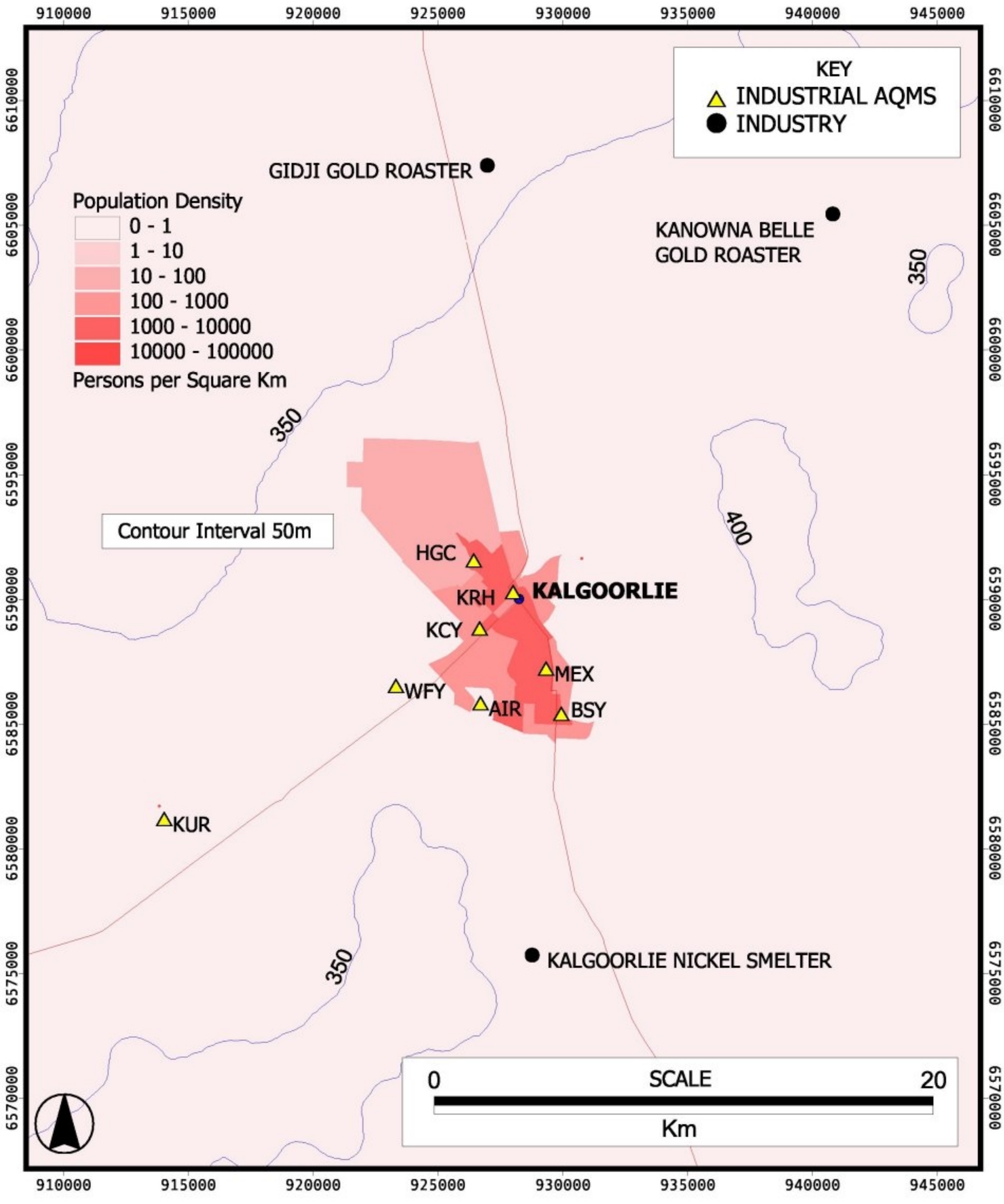
The Kalgoorlie Trial of the National Pollutant Industry provides a comprehensive assessment of NEPM pollutant emissions which can be used if necessary to support modelling assessments of the need for NEPM monitoring.

Meteorology and topography

The Kalgoorlie Region is relatively flat (see Figure 3.17) and its climate is typical of an inland site in Australia. In the absence of the moisture, winds and moderating effects on temperatures of a neighbouring ocean, the climate is one of extremes. For example, as shown in Figure 3.18, while winter maximum and summer minimum temperatures are similar for Kalgoorlie and Perth, summer maxima and winter minima are both more extreme for Kalgoorlie.

Those aspects of Kalgoorlie's climate affecting air quality are also subject to extremes. High summer temperatures ensure that strong convection develops during the daytime, while low minima are related to the frequent occurrence of strong nocturnal temperature inversions, with calm conditions near the surface.

Kalgoorlie receives frequent summer sea breezes, due to their deep inland penetration from the south coast. These normally arrive in the evening, when a nocturnal inversion may be forming,



KEY to monitoring station codes:

HGC Hannans Golf Course	AIR Kalgoorlie Airport
KRH Kalgoorlie Regional Hospital	MEX Metals Exporation site
KCY Kalgoorlie Council Yard	BSY Boulder Shire Yard
WFY Westrail Freight Yard	KUR Kurrawang

Figure 3.17 - Map of the Kalgoorlie Region, showing the three major sources of sulfur dioxide emissions and the locations of sulfur dioxide monitoring stations.

and possess a direction close to easterly. It is common in these cases for the sea breeze flow to persist above the nocturnal inversion, while surface winds decrease. This can give rise to jetstream-like vertical wind profiles, with near-calm conditions near the surface and stronger winds from a different direction within and above the nocturnal inversion (Figure 3.19). In turn, this means that the management of pollutant plumes at the levels where inversions occur cannot rely solely on measurements of winds near the surface.

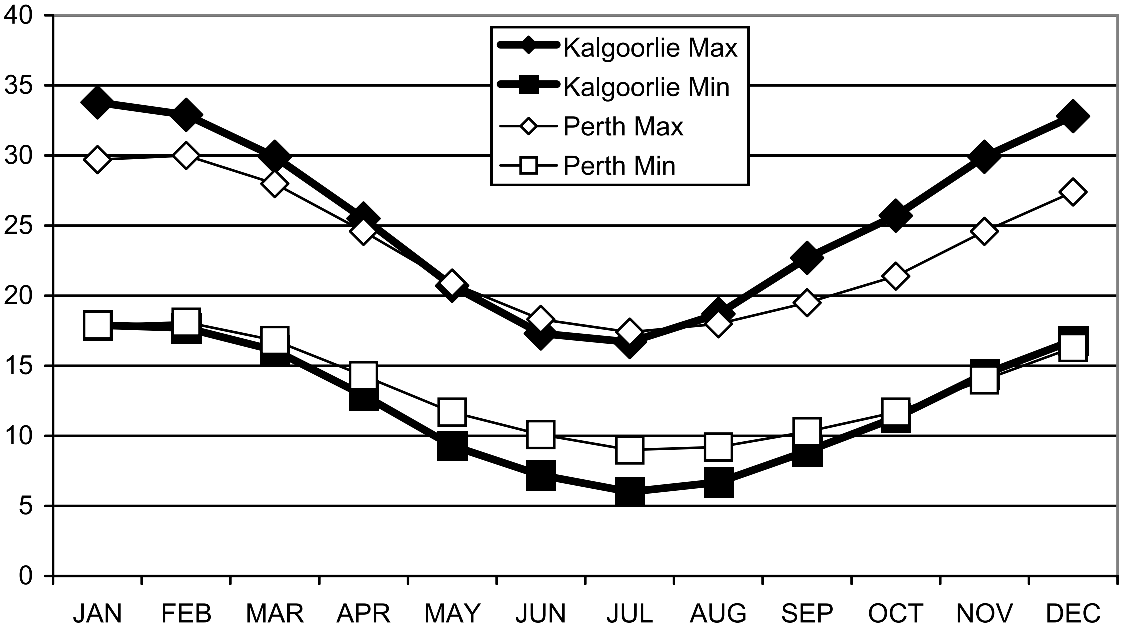


Figure 3.18. Comparison of monthly average maximum and minimum temperatures for Kalgoorlie and Perth (Source: Bureau of Meteorology).

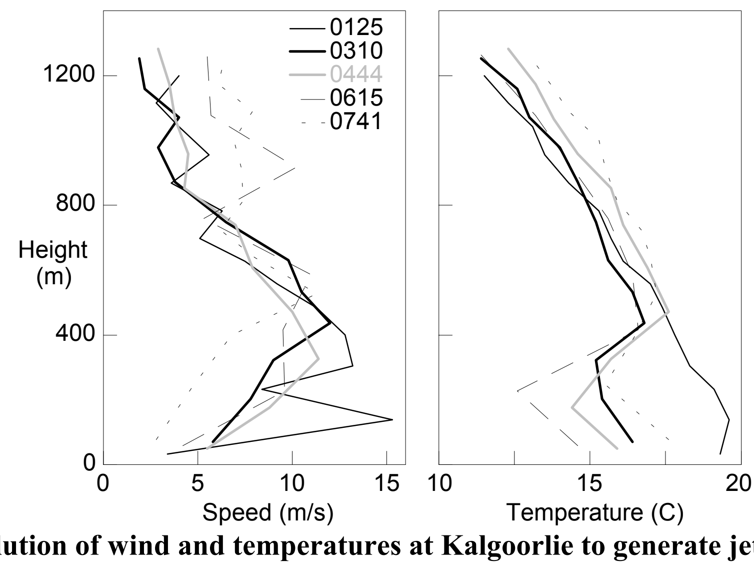


Figure 3.19. Evolution of wind and temperatures at Kalgoorlie to generate jetstream-like vertical wind profiles on the morning of 12 November 1984.

While surface wind speeds are generally moderate, the pattern of peak winds reveals a significant aspect of Kalgoorlie's climate. While Perth's two highest monthly peak gust recordings occurred in July and August (obviously associated with winter storms), the two highest in Kalgoorlie occurred in November and January (Bureau of Meteorology information).

The source of these gusts was summer thunderstorms. Such high winds in the dry season are known to cause major dust storms, which contribute significantly to particulate concentrations in the region.

Air quality monitoring history

Monitoring of sulfur dioxide commenced at the Kalgoorlie Regional Hospital in 1982, with two more monitoring stations added over the following two years. The monitoring network has evolved and grown since that time, with Kalgoorlie industries now responsible for the operation of a network of seven monitoring stations within, or in the immediate vicinity of, the Kalgoorlie-Boulder residential area, as shown on Figure 3.17. The industries also operate three stations at remote locations (the location or direction of these is also shown on Figure 3.17). A summary of the data is given in the section on sulfur dioxide below.

3.5.2 NEPM formula

With a population of approximately 28,087, the NEPM formula (clause 14(1)) indicates that one performance monitoring station may be required in the Kalgoorlie Region.

3.5.3 Carbon monoxide

The DEP propose to undertake campaign monitoring of CO in Kalgoorlie, for a period of at least one year, to determine whether performance monitoring is warranted.

This decision has been taken in light of the uncertainties in estimating CO emissions from wood fires and in modelling CO ambient concentrations in calm or near-calm conditions, which are known to occur in the Kalgoorlie Region.

3.5.4 Photochemical oxidants (as ozone)

The DEP does not intend to undertake performance monitoring at Kalgoorlie, based on application of the following screening procedures extracted from PRC (2000d):

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

Screening Procedure	Acceptance Limit (% of NEPM standard)
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.	58%
As above in combination with F.	66%

The CSIRO study employing TAPM will provide an estimate of the maximum ozone concentrations associated with a city the size of Kalgoorlie. It should be noted however that Kalgoorlie does not experience sea breeze recirculation events, which are a critical factor in smog events. Recirculation of pollutants in the region may occur, but without the restricted marine air mixing depths which yield high smog concentrations. The DEP will undertake a supporting assessment to confirm that the meteorology of Kalgoorlie is not conducive to the formation of significant ozone concentrations.

3.5.5 Nitrogen dioxide

The DEP does not intend to undertake performance monitoring at Kalgoorlie, based on application of the following screening procedures extracted from PRC (2000d):

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

Screening Procedure	Acceptance Limit (% of NEPM standard)
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.	35%
As above in combination with F.	45%
F. In a region with no performance monitoring, comparison with a NEPM compliant region with greater population, emissions and pollution potential[(2)].	40%

The CSIRO study employing TAPM will provide an estimate of the maximum NO_2 concentrations associated with a city the size of Kalgoorlie. With respect to screening procedure F, the monitoring data from the larger Mandurah Region (excluding smog events associated with southward transport of emissions from the Perth Region) will be used to confirm the determination from procedure E.

Industrial emissions of NO_x at Kalgoorlie are moderate. The largest of these emissions are from power generation and are therefore mostly NO (initially) within elevated buoyant plumes. When the results of the CSIRO study are available, the DEP will determine whether, for the sake of completeness, a supplementary modelling assessment of NO_2 from industrial sources is warranted. Professional judgement, supported by evidence from the Perth-Kwinana Region, suggests that there is little likelihood of significant NO_2 concentrations.

3.5.6 Sulfur dioxide

Figures A5.1(a) and (b) present data from six Kalgoorlie monitoring stations, identified in Figure 3.17, for the years in which each has operated since 1985. Data are presented as the highest, 2^{nd}, 18^{th} and 36^{th} highest daily maximum 1-hour averages of SO_2 for each year of operation.

Historically there have been severe SO_2 pollution problems at Kalgoorlie. Environmental Protection Policies have been applied since 1988 to control and improve this situation. There

(2) Pollution potential must take into account meteorology and topography.

have been two events that have improved the air quality in Kalgoorlie-Boulder residential areas. The first, which occurred during the period 1989-91, was the closure in succession of the three gold roasters operating on the Golden Mile immediately to the east of residential areas. The effect can be seen in the plot for the Kalgoorlie Regional Hospital in Figure A5.1 (and in the data from other monitoring stations since discontinued). The second event was the commissioning in late 1996 of a sulfuric acid plant in the Kalgoorlie Nickel Smelter. The dramatic effect of this event can be seen in all plots in Figure A5.1. Since 1998, all monitoring stations in the city of Kalgoorlie-Boulder have shown compliance with the NEPM. Nevertheless, there remain very large emissions of sulfur dioxide in the region, with the potential for high concentration in the city if plume management strategies fail.

Accordingly, performance monitoring for sulfur dioxide will be undertaken at a suitable location (yet to be determined) within the Kalgoorlie-Boulder residential area. This monitoring station will be nominated as a trend station for sulfur dioxide in the Kalgoorlie Region.

3.5.7 Lead

The acceptable and improving lead monitoring results for the Perth CBD (section 3.1.7) provide a clear basis for not measuring lead in small cities like Kalgoorlie. The tiny emission of lead from the Kalgoorlie Nickel Smelter (less than 1 gram per minute) is insignificant (causing a concentration increment that is a minute fraction of the NEPM standard).

3.5.8 Particles as PM_{10}

There has not been monitoring of PM_{10} at Kalgoorlie to date. There has been a long history of complaints about dust from tailings disposal areas, which have been investigated with dust deposit gauges and High Volume samplers measuring TSP. Dust from mining operations and general background dust levels may also be high at times. It is likely that there is a significant PM_{10} fraction in the dust from tailings disposal.

There is also anecdotal evidence of high smoke concentrations on calm winter nights associated with home fires.

Accordingly, performance monitoring for PM_{10} will be undertaken at Kalgoorlie. Monitoring results over the first two years will determine whether the station is to be nominated as a trend station.

3.5.9 Summary of monitoring proposed for the Kalgoorlie Region

Table 3.6 summarises the monitoring proposed for the Kalgoorlie Region.

Table 3.6 Monitoring in the Kalgoorlie Region.

Site:	CO	O_3	NO_2	SO_2	Pb	PM_{10}
Kalgoorlie	C			T		P

Key to symbols:
P – performance monitoring station
T – trend performance monitoring station
C – campaign monitoring

4. Siting and Instrumentation

4.1 DETAILS OF MONITORING STATIONS

Table 4.1 lists all current and proposed Air Quality Monitoring Stations in Western Australia. Each station has been listed under one of the five regions identified in foregoing sections.

Each monitoring station has been characterised as representing a certain Site Type (second column). The Site Type codes are defined as follows. The Central Business District (CBD) of Perth is dominated by high-rise commercial and retail premises separated by street canyons. Residential (R) sites are characteristic of typical low to medium density suburbs. These comprise mainly single storey owner-occupied dwellings with little or no industry. Residential/Industrial Buffer sites (R/IB) refer to residential areas (Hope Valley and Wattleup) located within the Kwinana Environmental Protection Policy buffer area. Semi-Rural (SR) sites are located on the outskirts of the suburban area where the land use is typically small farms or wineries.

Table 4.1 shows which pollutants are measured at a given monitoring station by showing the date (month/year) on which monitoring commenced. The schedule for the commencement of monitoring is shown in italics. The mode of monitoring (Performance, Trend or Campaign) is indicated by shading. Measurement methods are indicated by codes (under each pollutant heading) which are defined in the table Key. Other relevant measurements ($PM_{2.5}$ and visibility) are also shown in Table 4.1. All pollutants except PM_{10} (HIVOL) and lead are measured and stored as 10-minute averages.

Table 4.2 provides details of meteorological parameters measured in conjunction with air quality parameters. Monitoring is being and will be undertaken in accordance with the PRC strategy paper *Meteorological Measurements* (PRC, 2000f).

4.2 MONITORING STATION SITE COMPLIANCE

Monitoring station siting compliance, as shown in Table 4.3, is based on a thorough analysis of all air quality monitoring sites in which all the parameters noted in the table were quantitatively checked. The table list was compiled using *Australian Standard AS2922 – 1987 – Ambient Air – Guide for the Siting of Sampling Units* as a basis. As Table 4.3 shows, the majority of stations comply fully with the Australian Standard. There are a few cases however where nearby trees or other structures result in non-compliance, and no further action can be taken to remedy this.

The Mandurah, Geraldton and Kalgoorlie sites will be selected, and equipment installed, by the dates shown in Table 4.3. Site compliance information will be provided to the PRC.

The Queens Building Performance monitoring site is sited in the Perth CBD (see Figures 4.1 and 4.2) and as such does not comply with a number of requirements of AS2922 such as minimum distance to support structures, clear sky angle and minimum distance to roads. The site, located in William Street, Perth, has a sample inlet terminating 4.4 metres above the kerb.

Traffic flow in William Street during 1992-93 was approximately 27,500 vehicles per week.

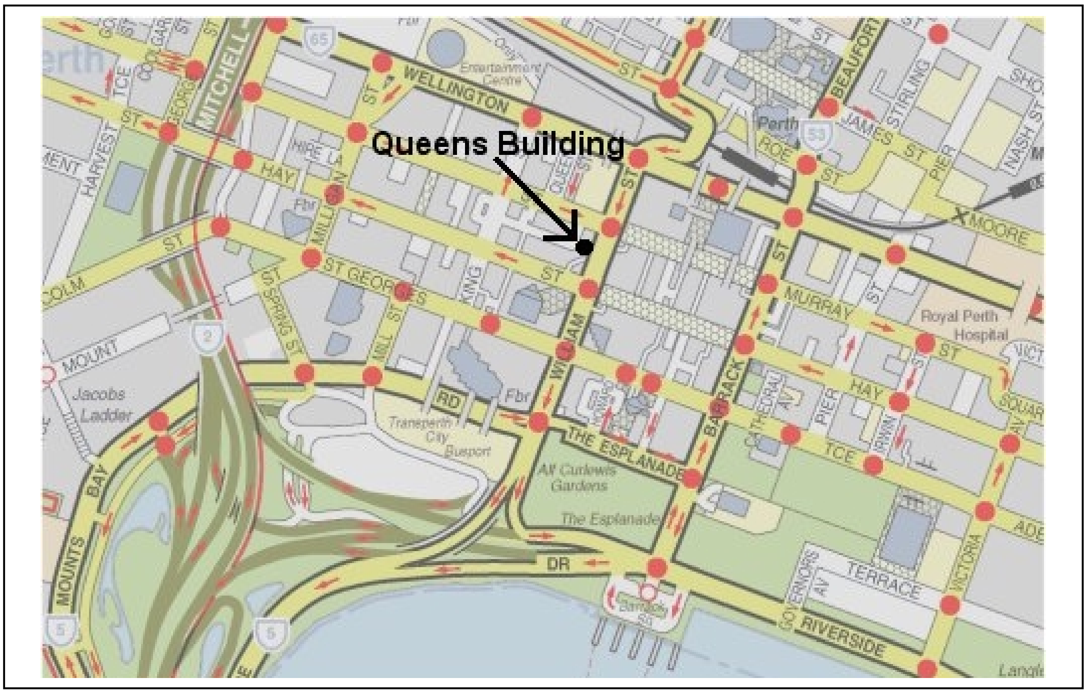


Figure 4.1. Map indicating the location of the Queens Building Performance Monitoring Station. The filled red dots indicate the location of traffic lights.

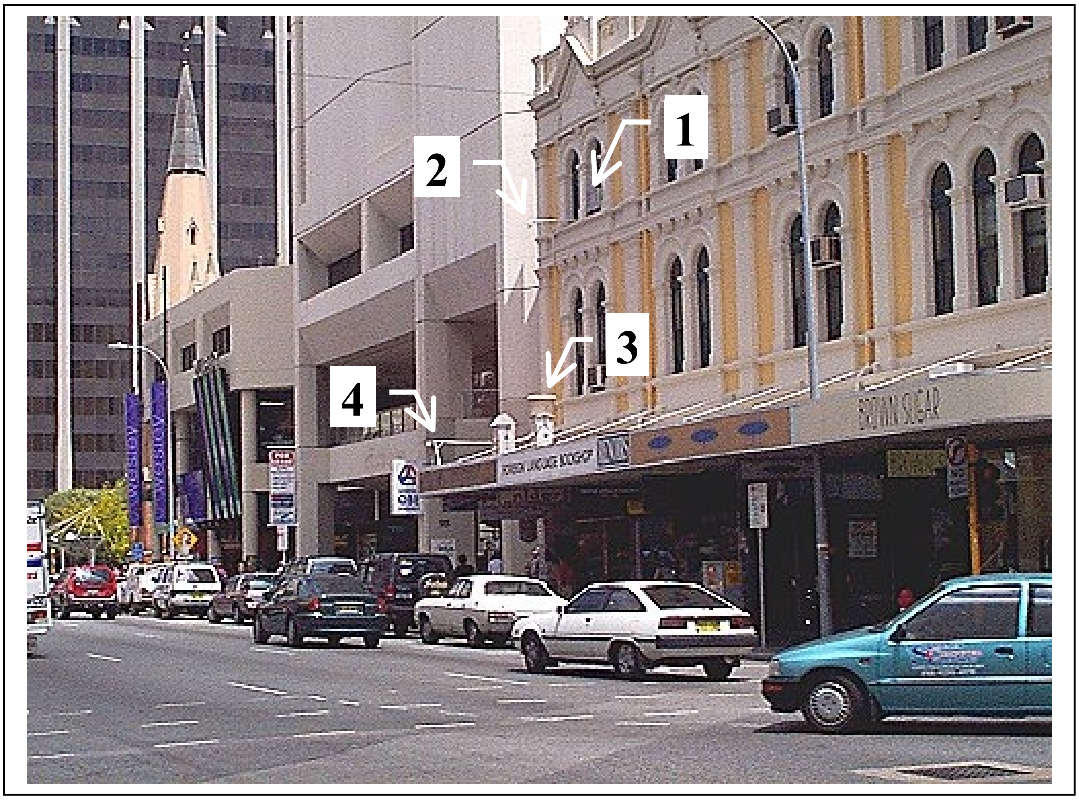


Figure 4.2. External aspect of the Queens Building Performance Monitoring Station: **[1] is the actual monitoring room, [2] is the nephelometer inlet, [3] is the PM_{10} sampler and [4] is the inlet sample tube.**

The detailed information on sites and instrumentation used to assess station site compliance is currently held in the form of internal documentation only. This information will be incorporated into the NATA accreditation process as it progresses.

4.3 INSTRUMENT STANDARDS

The instruments used in the Western Australian network are all in accordance with the relevant Australian standard as shown in Tables 4.4 and 4.5. The methods shown in Table 4.4 are for those instruments used for NEPM reporting purposes whilst Table 4.5 describes methods used for other measurements made within the network.

4.4 DATA HANDLING PROCEDURES

The DEP has contributed to the development of data handling procedures by the PRC. At the date of writing the PRC technical paper (PRC, 2000e) has yet to be finalised, nevertheless the DEP is confident of being able to comply with all the requirements of this guideline.

4.5 ACCREDITATION

The DEP is committed to providing NATA accredited data for NEPM reporting purposes and is currently working to that end. Zero air generators and multi-gas calibrators have been ordered and will be progressively installed at all existing monitoring sites upon their receipt to enable full compliance with Australian Standard methods. Data loggers are scheduled to be replaced with more advanced types, and all operational procedures will be updated to meet relevant Australian Standards and NATA laboratory practices.

As future funding for the specific purpose of attaining NATA accreditation of monitoring activities remains uncertain, it is difficult to accurately predict when accreditation will be achieved. Notwithstanding this uncertainty, the DEP has set itself the goal of commencing operation of air quality monitoring activities in accordance with NATA accredited practices by the end of 2003. If this target is met, it is reasonable to expect to be audited by NATA and, assuming no major problems are found, achieving formal registration by the end of 2004. Regardless of the date of formal registration, a successful audit would mean that NATA accredited data could be reported from the date that operation under the audit conditions commenced, which, as stated earlier, is intended to be by the end of 2003.

Table 4.1: Air Quality Monitoring Sites in Western Australia.

Site	Site Type	CO (IR GFC)	O_3 (UV A)	NO_2 (GPC)	SO_2 (UV F)	Lead (XRF)	PM_{10} (TEOM)	PM_{10} (HIVOL)	$PM_{2.5}$ (TEOM)	Visibility (N)
Perth Region										
Caversham	SR	08/93	11/89	09/90			proposed	05/93	03/94	11/89
Duncraig	R	08/95		08/95			06/96		01/95	03/94
Hope Valley	R/IB			12/89	12/89					01/89
Queens Building	CBD	08/89				01/90 (1)		01/90		
Quinns Rocks	R		11/92	11/92						12/95
Rockingham	R		12/95	12/95	08/88					
Rolling Green	SR		01/93	01/93						
South Lake	R	03/00	03/00	03/00	03/00		03/00			
Swanbourne	R		01/93	03/93				03/94		06/94
Wattleup	R/IB				01/88					
Mandurah Region										
Mandurah	R	*12/03*	*12/03*	*12/03*			*12/03*			
Bunbury Region										
Bunbury	R	03/99					06/99		04/97	02/97
Geraldton Region										
Geraldton	R						*12/03*			
Kalgoorlie Region										
Kalgoorlie	R	*12/03*			*12/03*		*12/03*			

All pollutants except PM_{10} (HIVOL) and lead are measured and stored as 10-minute averages.

(1) Performance monitoring of lead will not be maintained if the annual concentration is less than 10% of the NEPM Standard.

Key

Station Type:

- Performance (red hatched)
- Trend Performance (grey shaded)
- Campaign (horizontal lines)

Monitoring Method:

IR GFC	Infra-Red Gas Filter Correlation
UV A	Ultra Violet Attenuation
GPC	Gas Phase Chemiluminescence
UV F	Ultra-Violet Fluorescence
XRF	X-ray Fluorescence
HI-VOL	High Volume Sampler with size selective inlet
TEOM	Tapered Element Oscillating Microbalance
N	Light Scattering Nephelometer

Site Type:

CBD	Central Business District
R	Residential
SR	Semi Rural
R/IB	Residential / Industrial Buffer

Table 4.2: Meteorological Monitoring Sites in Western Australia.
Numbers in the table indicate measurement height. Brackets indicate proposed monitoring.

		Meteorological Monitoring							
Site	Site	WND	AT	DT	RH	SR	NR	R	AP
Perth Region									
Caversham	SR	10	10	10/2	10	3	2.5	0.3	1.5
Duncraig	R	10	4						
Hope Valley	R/IB	10	10	10/2	10	3			
Queens Building	CBD		4						
Quinns Rocks	R	10	10						
Rockingham	R								
Rolling Green	SR	10	10						
South Lake	R	10	10						
Swanbourne	R	10	10						
Wattleup	R/IB	10	10						
Mandurah Region									
Mandurah	R	(10)	(10)						
Bunbury Region									
Bunbury	R	10	10						
Geraldton Region									
Geraldton	R	(10)	(10)						
Kalgoorlie Region									
Kalgoorlie	R	(10)	(10)						

Key

4	Instruments at 4 metres
10	Instruments at 10 metres
WND	Wind Speed, Direction and Sigma
AT	Air Temperature
DT	Temperature difference between 10 and 2 metres
RH	Relative Humidity
SR	Solar Radiation
NR	Net Radiation
R	Rainfall
AP	Air Pressure
( )	Proposed instruments

Site Type:

CBD	Central Business District
R	Residential
SR	Semi-Rural
R/IB	Residential / Industrial Buffer

Meteorological monitoring will conform so far as practicable with "Meteorological Measurements" (PRC, 2000f).

Table 4.3: Station siting compliance.

	Height above ground	Min. distance to support structures	Clear sky angle of 120°	Unrestricted airflow of 270°/360°	20m from trees	No boilers or incinerators nearby	Minimum distance from road or traffic	Sample line material	Sample line length	Comments
Perth Region										
Caversham	☑	☑	☑	☑	☑	☑	☑	☑	☑	
Duncraig	☑	☑	☒	☑	☒	☑	☑	☑	☑	6 metres to medium sized trees and presence of power pole.
Hope Valley	☑	☑	☑	☑	☑	☑	☑	☑	☑	
Queens Building	☑	☒	☒	☒	☑	☑	☒	☑	☑	City canyon with high traffic volume.
Quinns Rocks	☑	☑	☑	☑	☒	☑	☑	☑	☑	15 metres to small to medium size trees. Surrounding area dominated by low scrub.
Rockingham	☑	☑	☑	☑	☒	☑	☑	☑	☑	12 metres to trees. Northern vector dominated by grain storage facility.
Rolling Green	☑	☑	☑	☑	☑	☑	☑	☑	☑	
South Lake	☑	☑	☑	☑	☑	☑	☑	☑	☑	
Swanbourne	☑	☑	☑	☑	☑	☑	☑	☑	☑	
Wattleup	☑	☑	☑	☑	☒	☑	☑	☑	☑	10 metres to medium to large eucalyptus trees.
Bunbury Region										
Bunbury	☑	☑	☑	☑	☒	☑	☑	☑	☑	15 metres to small to medium eucalyptus trees.
Mandurah Region										
Mandurah										Installed and operational by 12/03
Geraldton Region										
Geraldton										Installed and operational by 12/03
Kalgoorlie Region										
Kalgoorlie										Installed and operational by 12/03

Table 4.4: Methods used in Western Australia for NEPM monitoring and reporting.

Pollutant	Standard	Title	Method Used
Carbon Monoxide	AS 3580.7.1-1992	Ambient Air - Determination of Carbon Monoxide – Direct Reading Instrument Method	Gas Filter Correlation /Infra-Red
Nitrogen Dioxide	AS 3580.5.1-1993	Ambient Air - Determination of Oxides of Nitrogen – Chemiluminescence Method	Gas Phase Chemiluminescence
Photochemical Oxidant (Ozone)	AS 3580.6.1-1990	Ambient Air - Determination of Ozone – Direct Reading Instrument Method	Non-Dispersive Ultra-violet
Sulfur Dioxide	AS 3580.4.1-1990	Ambient Air – Determination of Sulfur Dioxide – Direct Reading Instrument Method	Pulsed Fluorescence
Lead *	AS 2800-1985	Ambient Air – Determination of Particulate Lead - High Volume Sampler of Gravimetric Method	X-ray Fluorescence
PM_{10}	AS 3580.9.8-2001	Ambient Air – Determination of Suspended Particulate Matter - PM_{10} Continuous Direct Mass Method using a Tapered Element Oscillating Microbalance Analyser	Tapered Element Oscillating Microbalance (TEOM)

* uses a TSP selective inlet operating on a one in every six day cycle.

Table 4.5: Methods used in Western Australia for monitoring pollutants that will not be used for NEPM reporting purposes.

Pollutant	Standard	Title	Method Used
PM_{10}	AS3580.9.6-1990	Ambient Air – Determination of Suspended Particulate Matter PM_{10} – High Volume sampler with Size Selective Inlet Gravimetric Method	Size Selective Inlet (one in six day cycle)
$PM_{2.5}$	AS in preparation	Manufacturers Method	Tapered Element Oscillating Microbalance (TEOM)
Light Scattering (visibility)	AS2724.4-1987	Ambient Air – Particulate Matter – Determination of Light Scattering Integrating Nephelometer Method	Light Scattering/ Nephelometry

5. Reporting

At the time of writing a PRC technical paper on reporting was still in preparation (PRC, 2000h). Western Australia will comply with the requirements of this guideline. The discussion that follows indicates how Western Australia intends to meet and possibly exceed the requirements of the guideline.

The NEPM clauses 17 and 18 describe the requirements for evaluation of performance and reporting. To meet these requirements, the Department of Environmental Protection will prepare Annual Reports that include the components described below.

5.1 BACKGROUND INFORMATION

The Report will reference the Monitoring Plan (this document) which 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 clear as a stand-alone document.

A map of Western Australia, showing the regions subject to assessment under the NEPM, will be included.

Maps of each region will be included, showing population distribution and the location of each performance monitoring station that operated during the reporting year. If campaign monitoring was undertaken at other sites during the year, these sites will also be shown. A table will accompany each map, identifying the pollutants measured at each performance monitoring station, a linear graph showing when valid data was collected for each pollutant and the associated percentage data recovery for each pollutant for the reporting year. Other monitoring undertaken by DEP within the region that is not performance monitoring (for NEPM purposes), but nevertheless conforms to NEPM accreditation requirements, will also be identified in the table and on the map.

5.2 DETERMINATION OF EXPOSED POPULATION

In accordance with clause 17, the table for each region will also include, for each pollutant at each performance monitoring station, an estimate of the "exposed population … represented by the station". This concept of "exposed population represented" is very subjective and open to widely varying interpretations. For instance, at one extreme, if the intent is to identify how many people in the area surrounding a performance monitoring station experience the same day-by-day sequence of pollutant levels to within (say) 10% or 20% of the measured concentration, the number may be quite small. (Carbon monoxide and particle concentrations are localised in nature, being dependent on local sources.) At the other extreme, it is reasonable to argue that a well-sited GRUB station "represents" a large portion of the population in that it provides a basis for assurance that the concentrations experienced by almost all of the exposed population in its part of the region will be below the measured values. An intermediate interpretation would be to attempt to estimate the number of people who would experience annual statistics of pollutant concentrations similar to that measured at a particular performance monitoring station (ignoring day-to-day comparisons) by virtue of similarities in local meteorology, topography, local emissions, etc. For example, a single coastal monitoring station in the Perth Region provides an estimate of the number of exceedances of the NEPM O_3 standard that is representative of many coastal suburbs, even though southern coastal suburbs may experience an exceedance on a different day to northern coastal suburbs. Similarly, even though concentrations of CO and PM_{10} at the low-lying Duncraig monitoring station may be relatively localised, they would be representative of concentrations experienced in many similar low-lying areas across the Perth Region.

As implied above, a single quantitative determination of exposed population would be flawed due to the very different spatial distribution of NEPM pollutants (varying from localised for CO to broadly distributed for O_3). If the ultimate purpose of determining this “exposed population” is to facilitate extended analysis of population exposure, it would be better to simply provide the pollutant and population data, allowing more sophisticated techniques to be employed (e.g. model-driven interpolation of measurements).

Pending clarification of the intent of this requirement, and in accordance with deliberations of the Peer Review Committee, the Department of Environmental Protection has followed the “intermediate interpretation” described above (i.e. people who would experience annual statistics of pollutant concentrations similar to that measured at a particular performance monitoring station). Procedures for presenting this information (possibly via mapping) will be developed to accompany reporting under the NEPM clause 18. As an initial indication, Appendix B provides, in tabular form, a brief qualitative description of the portion of the populated area within each region that would be expected to be represented by the measurement of each of the pollutants at the selected performance monitoring stations.

5.3 EVALUATION OF PERFORMANCE AGAINST STANDARDS AND GOAL

In addition to tables that describe performance against standards and goal in the various regions, there will be:

- an analysis of the extent to which the standards of this Measure are, or are not, met in the jurisdiction;
- a statement of the progress made towards achieving the goal.

5.4 ANNUAL AIR QUALITY STATISTICS

In addition to tables showing air quality statistics, Western Australia will include graphical presentations, along the lines in Appendix A of this report. All available years will be plotted to give a visual representation of trends.

References

Australian Bureau of Statistics (ABS), 1997, *Census 96*.

Australian Standard AS2922 – 1987, *Ambient Air – Guide for the Siting of Sampling Units*. Standards Association of Australia, North Sydney, NSW.

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Department of Environmental Protection (DEP), 1999, *National Pollutant Inventory: Kalgoorlie NPI Trial*. Commonwealth of Australia.

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PRC, 2000a *Checklist for Monitoring Plans*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 1, November 2000.

PRC, 2000b *Selection of Regions*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 2, November 2000.

PRC, 2000c *Monitoring Strategy*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 3, November 2000.

PRC, 2000d *Screening Procedures*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 4, November 2000.

PRC, 2000e *Data Handling*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 5, November 2000.

PRC, 2000f *Meteorological Measurements*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 6, November 2000.

PRC, 2000g *Accreditation*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 7, November 2000.

PRC, 2000h *Annual Reports*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 8, November 2000.

PRC, 2000i *Lead Monitoring*, National Environment Protection Council (Ambient Air Quality) Measure Technical Paper No. 9, November 2000.

Rayner, K. and Grieco, A. 1999, *Comparing the NEPM and Kwinana 1-hour standards for* *sulfur dioxide*. Department of Environmental Protection Technical Note.

Rye, P., 1996, *Meteorological and source analysis of smog events during the Perth Photochemical Smog Study*. Department of Environmental Protection, Technical Series 83.

Tarlowski, C. and Rye, P., 1982, *Report on the Bunbury Airshed Study*. Curtin University School of Physics and Geosciences Report SPG 415 / 1985 / AP 119.

Western Power Corporation and Department of Environmental Protection (DEP), 1996, *Perth Photochemical Smog Study*. Western Power Corporation Report CS20/96, Department of Environmental Protection Report 16.

Appendix A: Plots of Pollutant Concentration

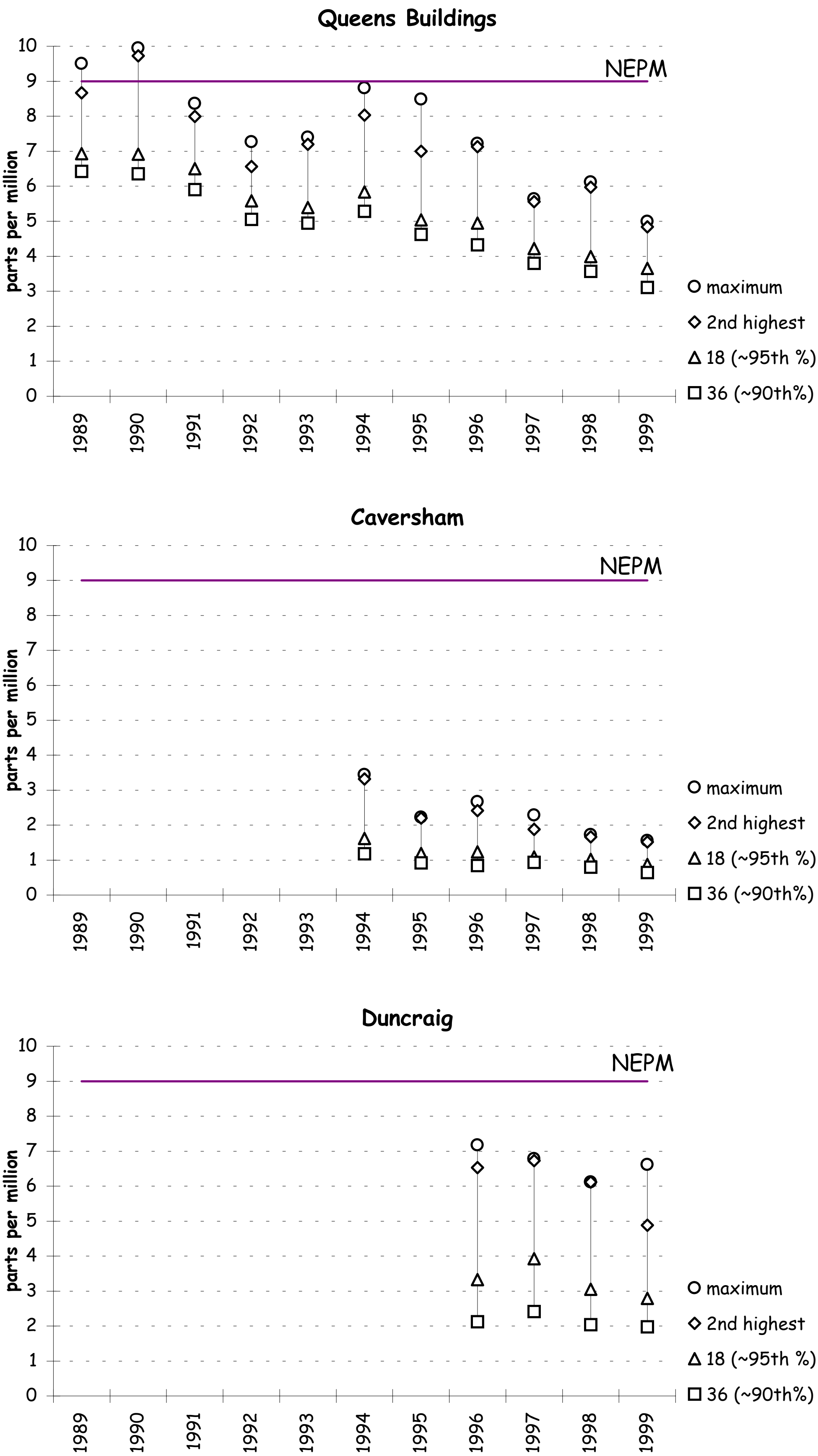
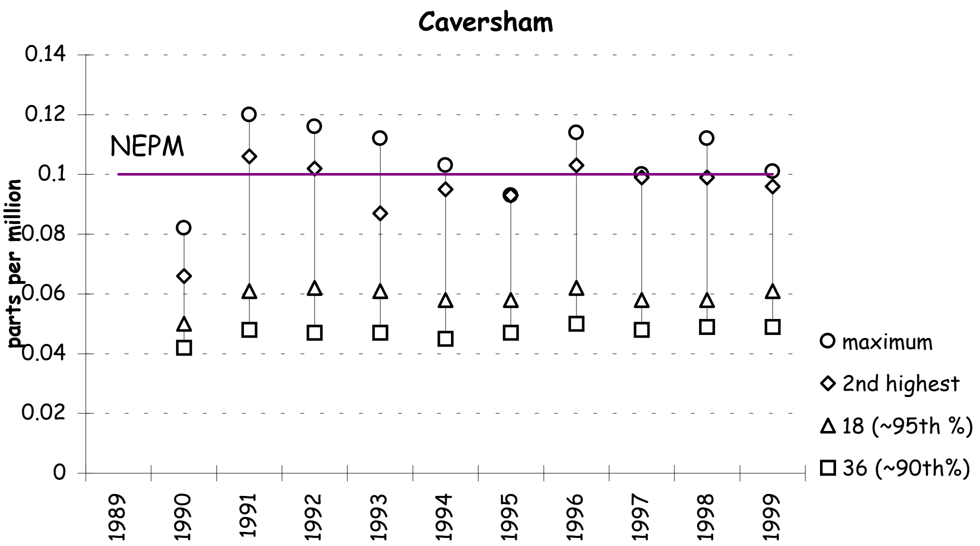
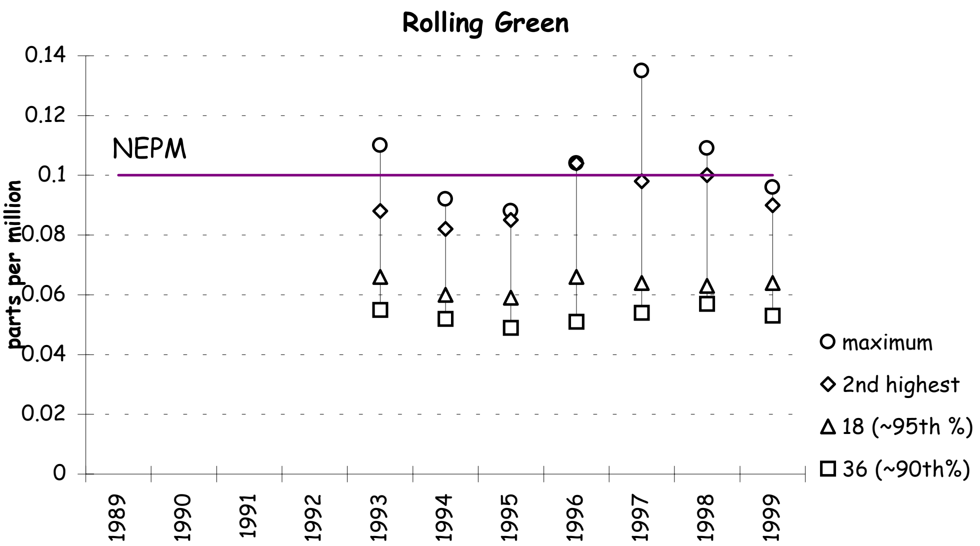


Figure A1.1 Highest, 2nd, 18th (95th percentile) and 36th (90th percentile) highest daily maximum 8-hour averages of CO for each of several calendar years in the Perth Region.





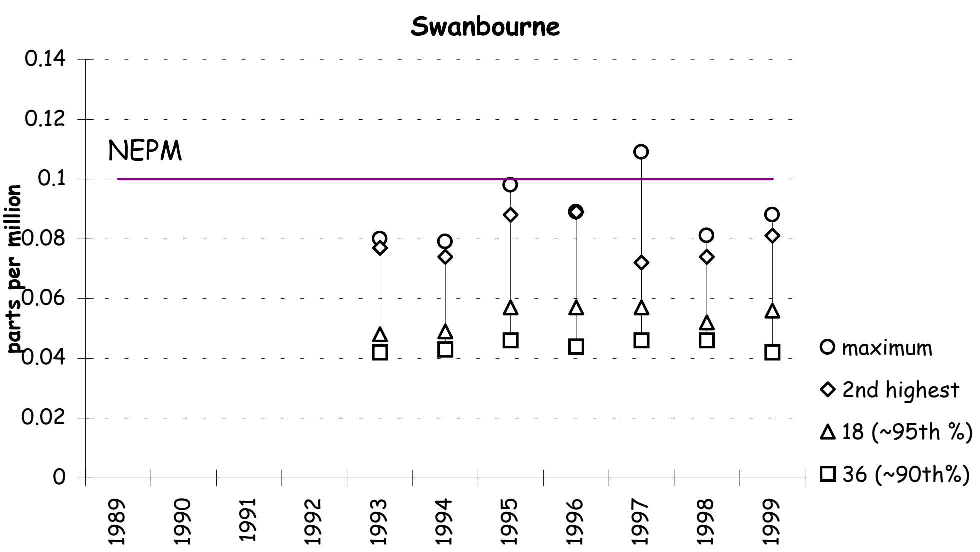
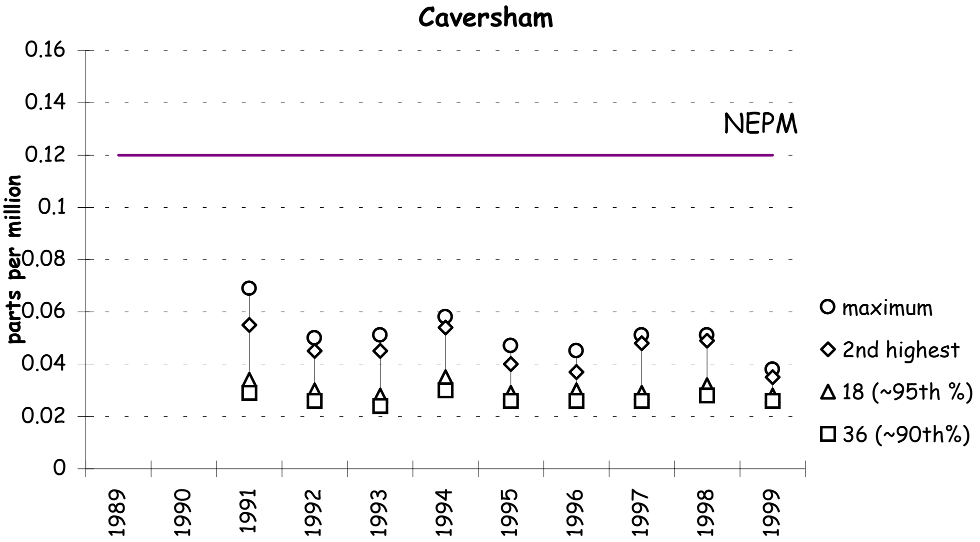
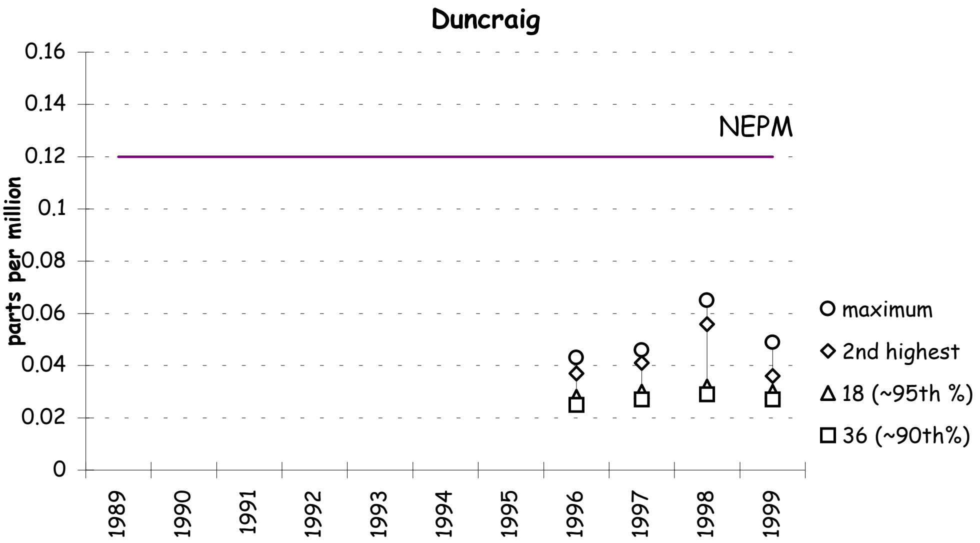


Figure A1.2 Highest, 2nd, 18th (95th percentile) and 36th (90th percentile) highest daily maximum 1-hour averages of O_3 for each of several calendar years in the Perth Region.





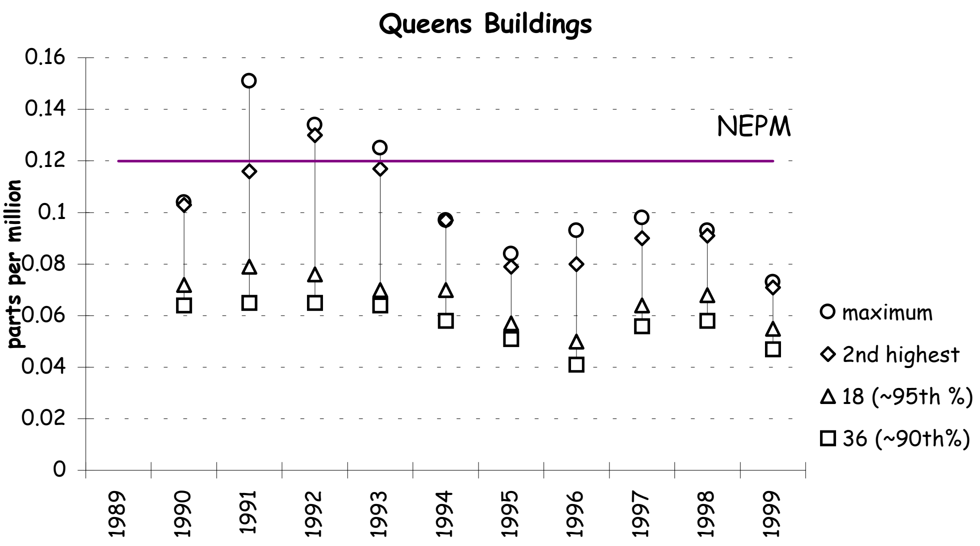
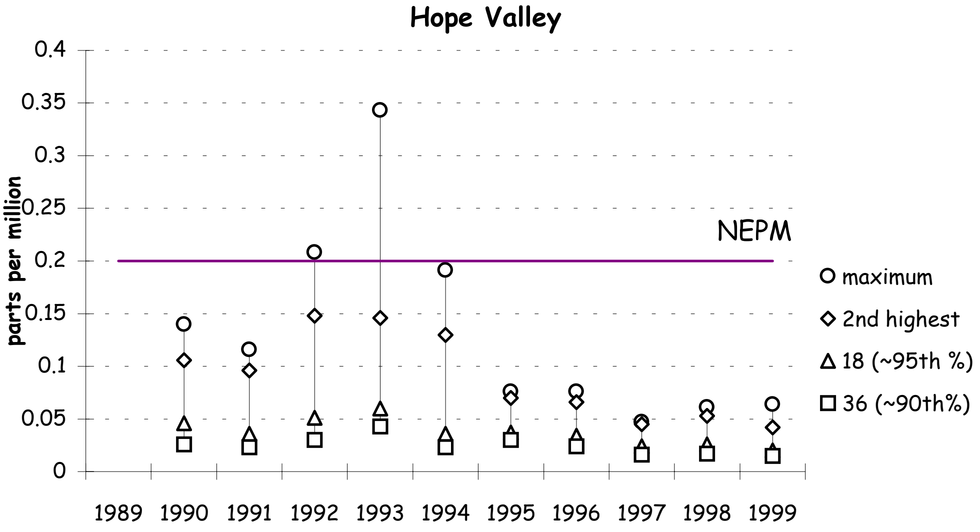
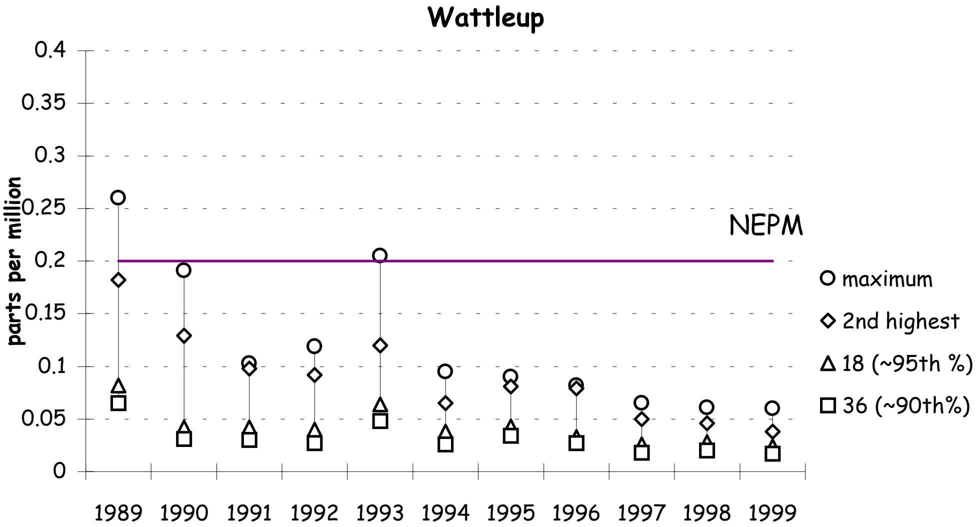


Figure A1.3 Highest, 2nd, 18th (95th percentile) and 36th (90th percentile) highest daily maximum 1-hour averages of NO_2 for each of several calendar years in the Perth Region.





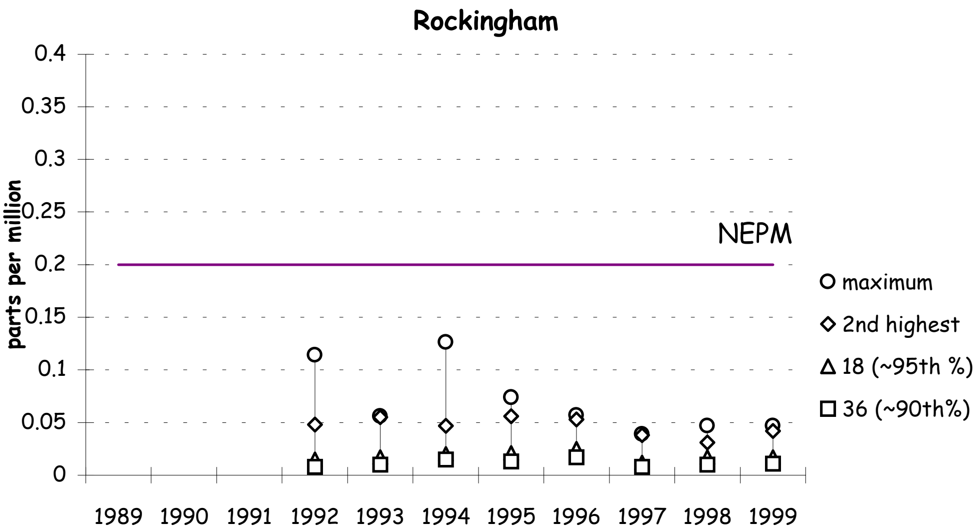


Figure A1.4(a) Highest, 2nd, 18th (95th percentile) and 36th (90th percentile) highest daily maximum 1-hour averages of SO_2 for each of several calendar years in the Perth Region.

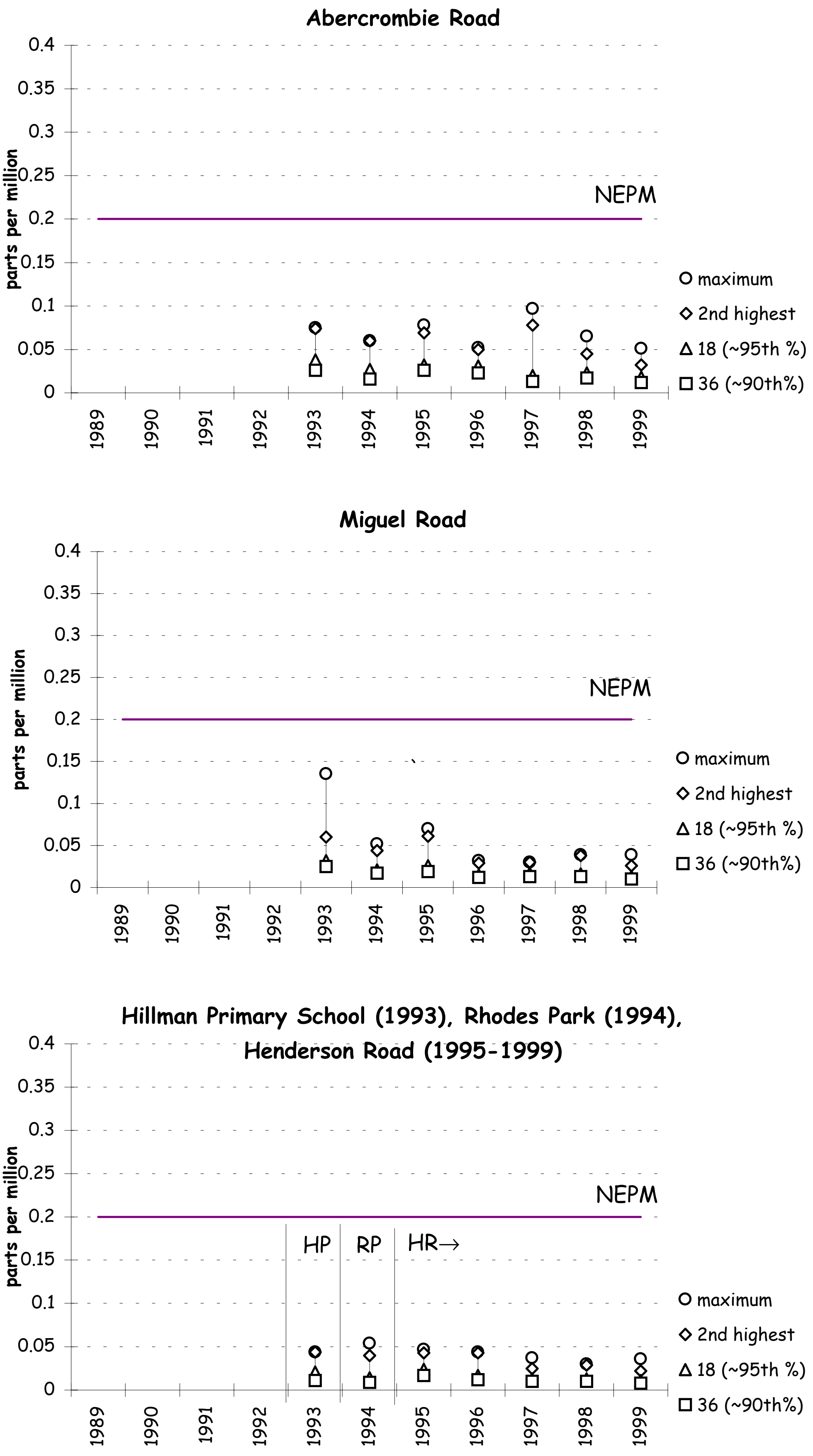


Figure A1.4(b) Highest, 2nd, 18th (95th percentile) and 36th (90th percentile) highest daily maximum 1-hour averages of SO_2 for each of several calendar years in the Perth Region.

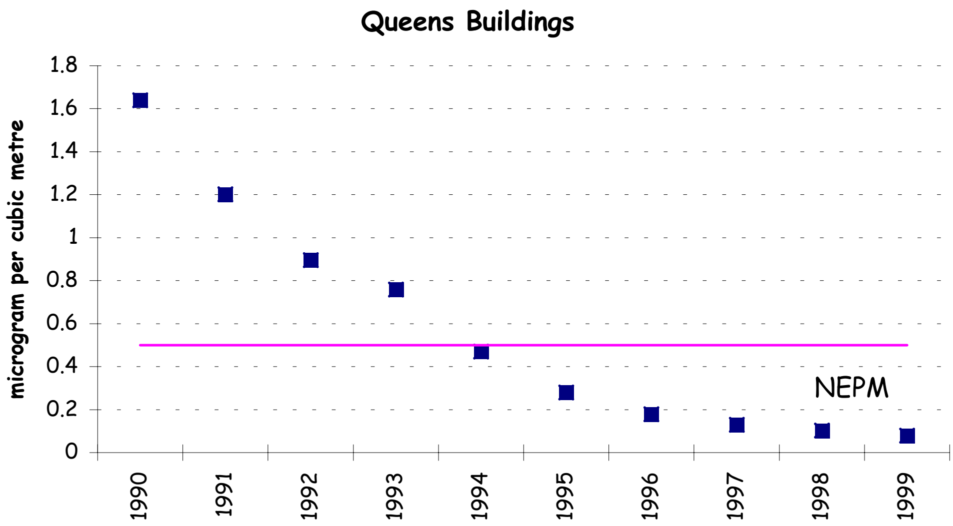
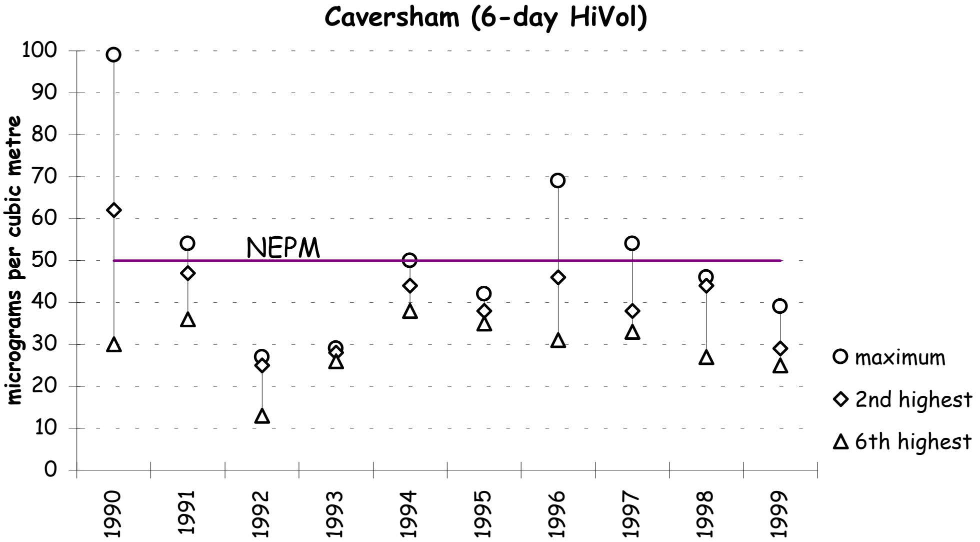
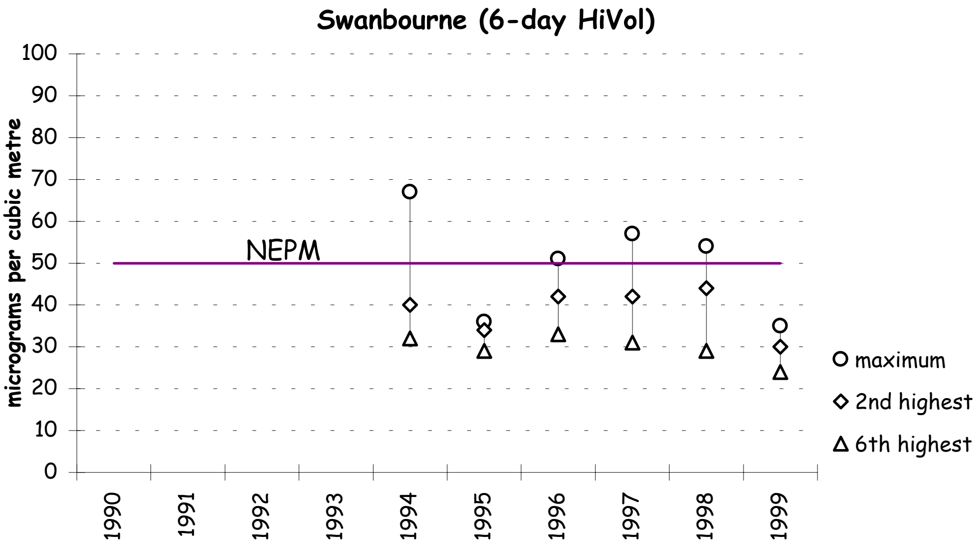


Figure A1.5 1-year averages of lead concentrations measured at Queens Buildings in the Perth Region over the period 1990 to 1999.





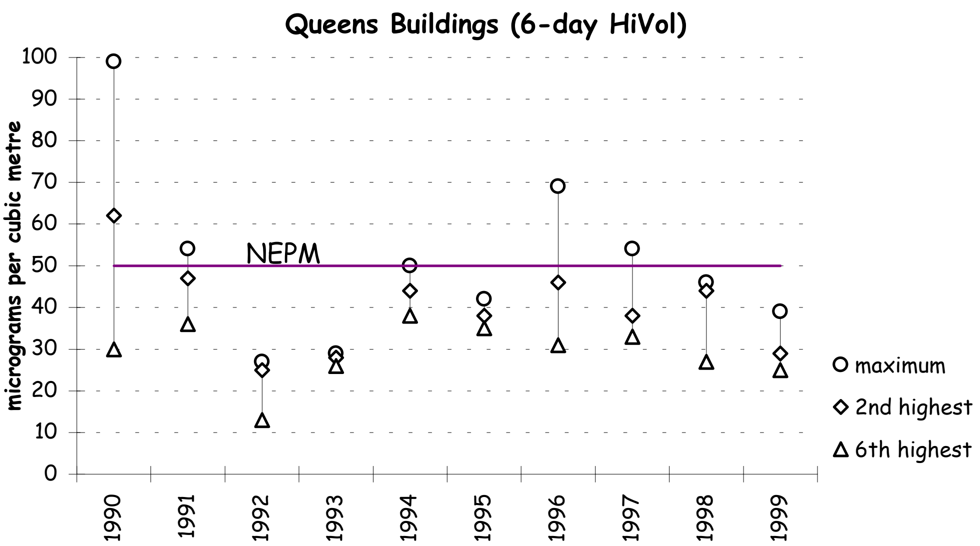
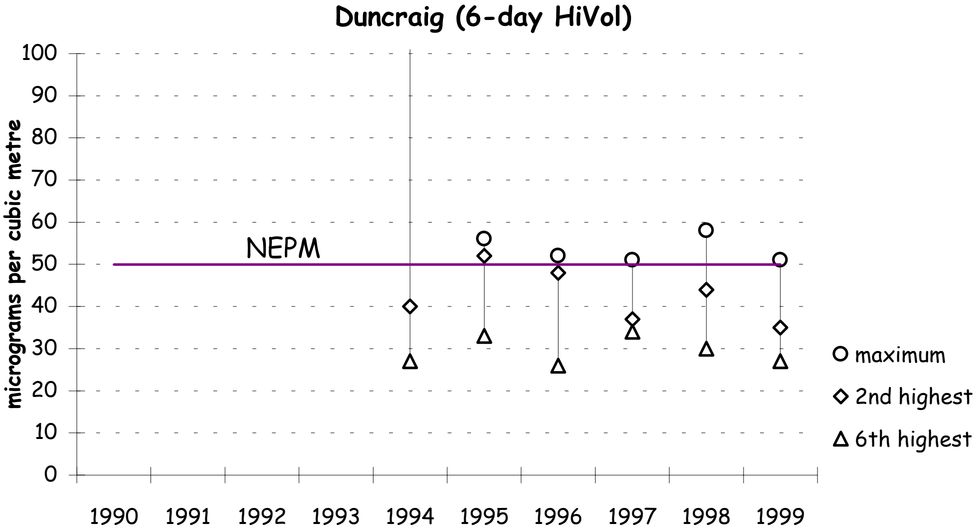


Figure A1.6(a) Highest, 2nd and 6th highest 1-day averages of PM_{10} for each of several calendar years in the Perth Region (Hi-Vol samplers operated on a one day in six cycle).



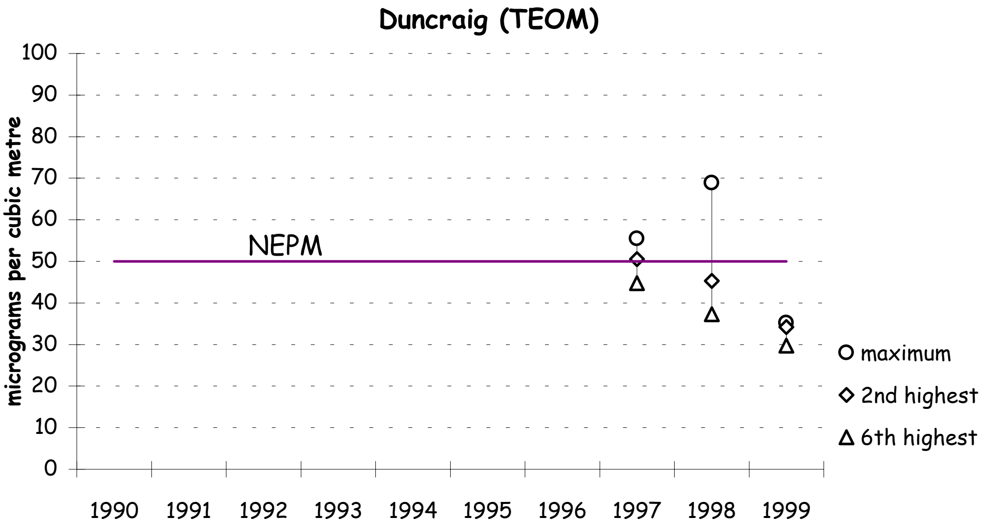
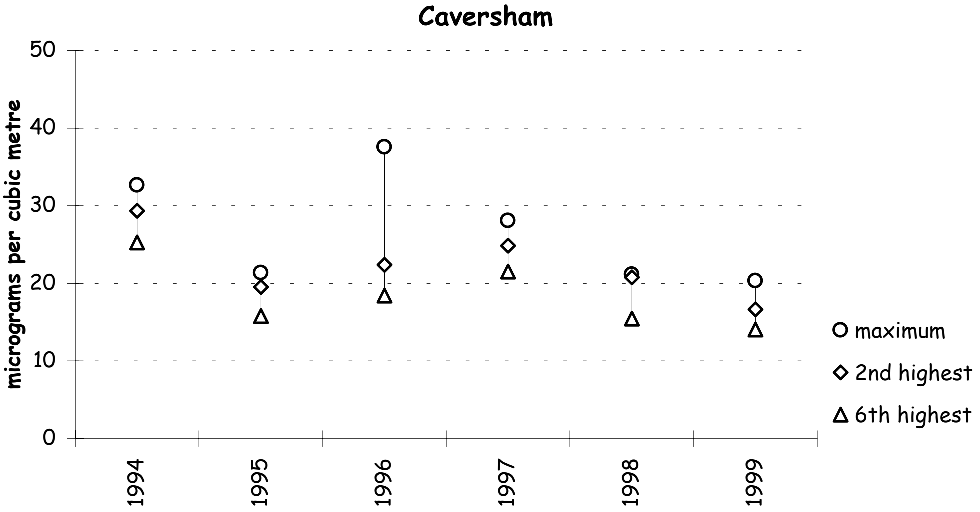
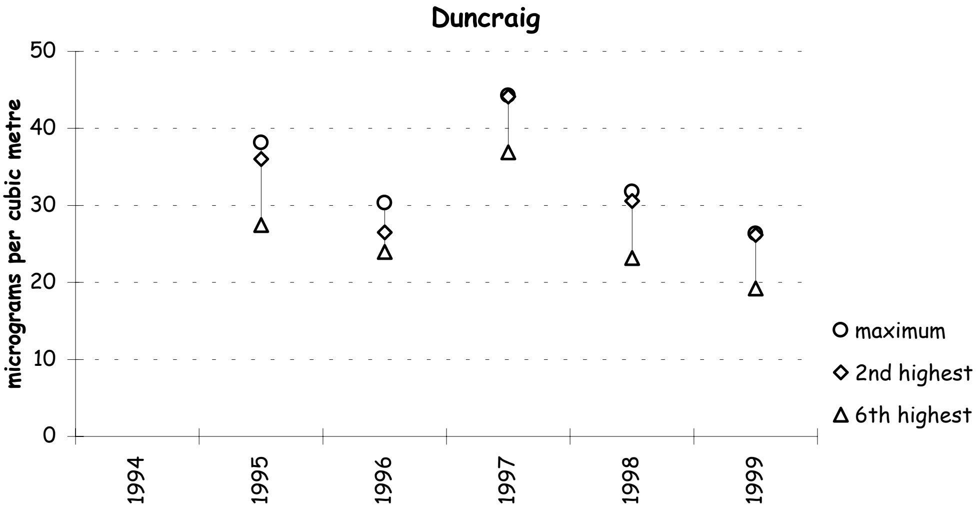


Figure A1.6(b) Highest, 2nd and 6th highest 1-day averages of PM_{10} for each of several calendar years at Duncraig in the Perth Region.

(Note: the Hi-Vol sampler was operated on a one day in six cycle, whereas the TEOM was operated continuously – hence the results are not directly comparable.)





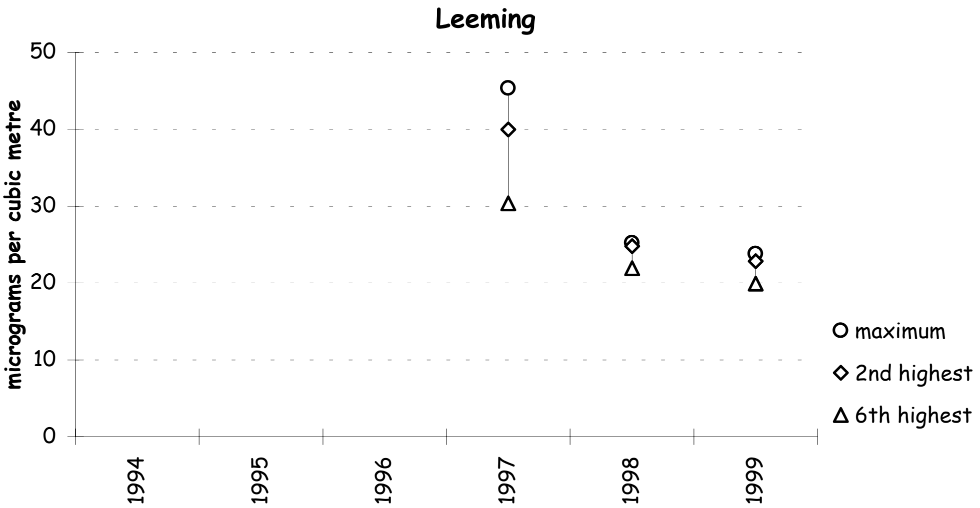


Figure A1.7 Highest, 2nd and 6th highest 1-day averages of $PM_{2.5}$ for each of several calendar years in the Perth Region, measured by TEOM instruments operated continuously.

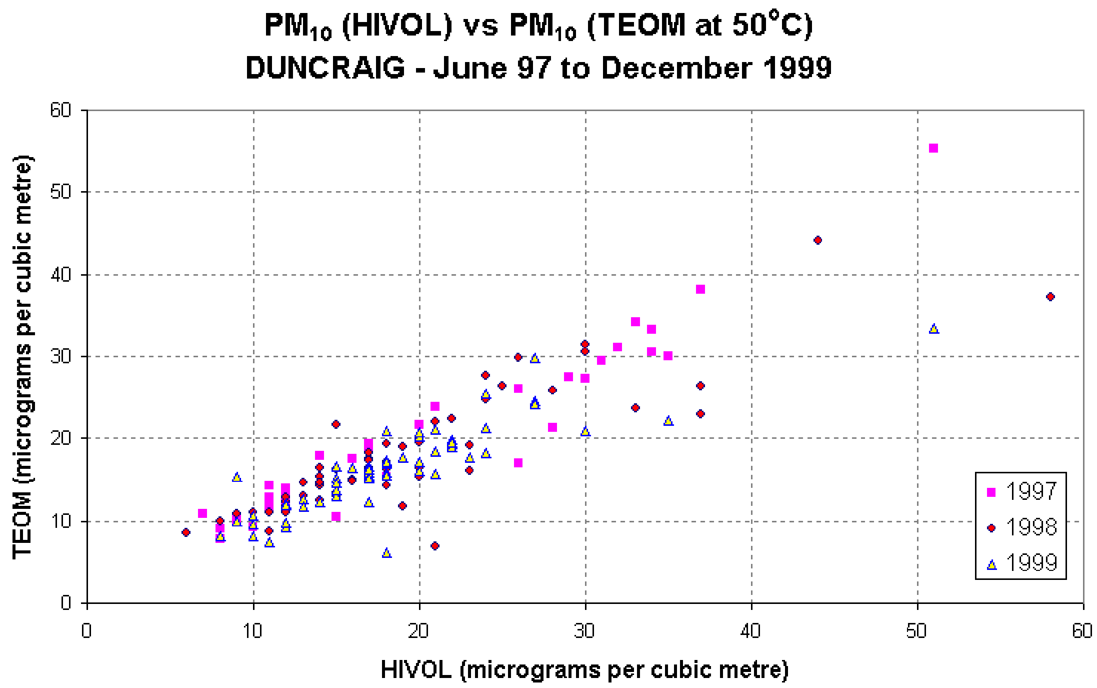
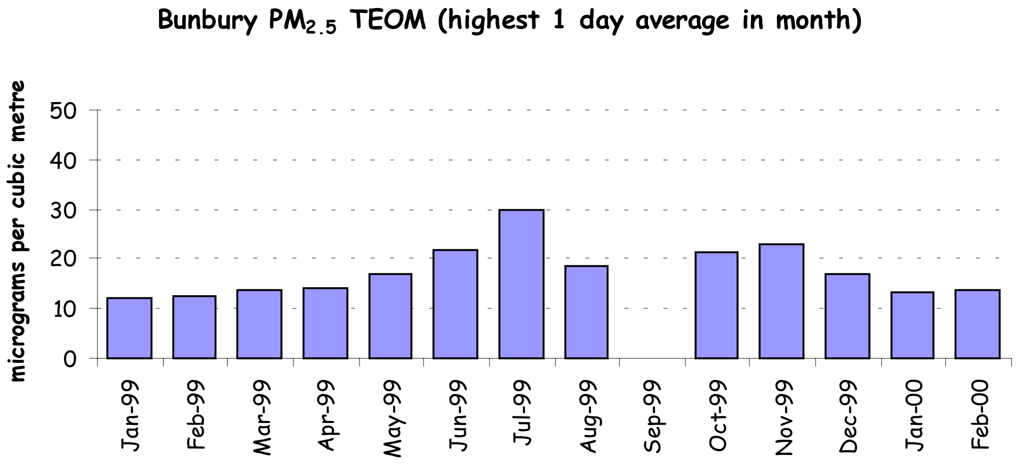
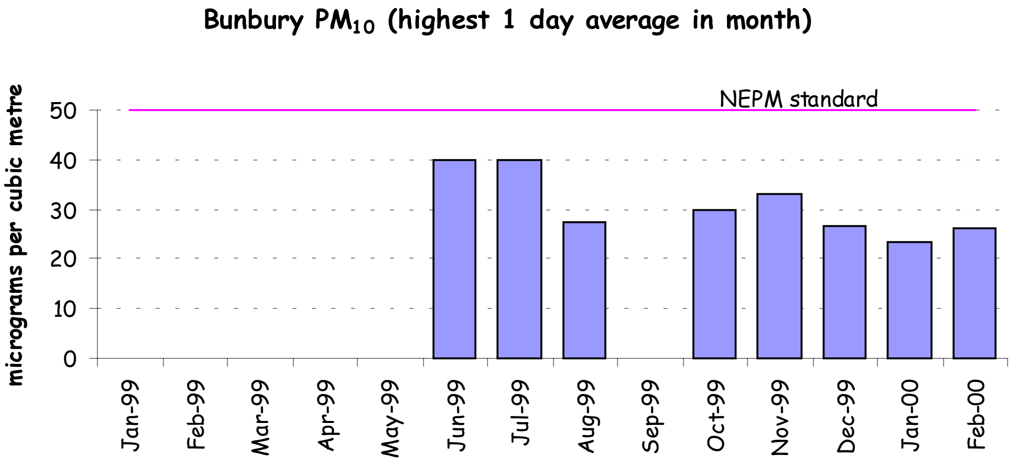


Figure A1.8 Coincident measurements of 1-day averages of PM_{10} via Hi-Vol sampler and TEOM at Duncraig, over four and a half years.





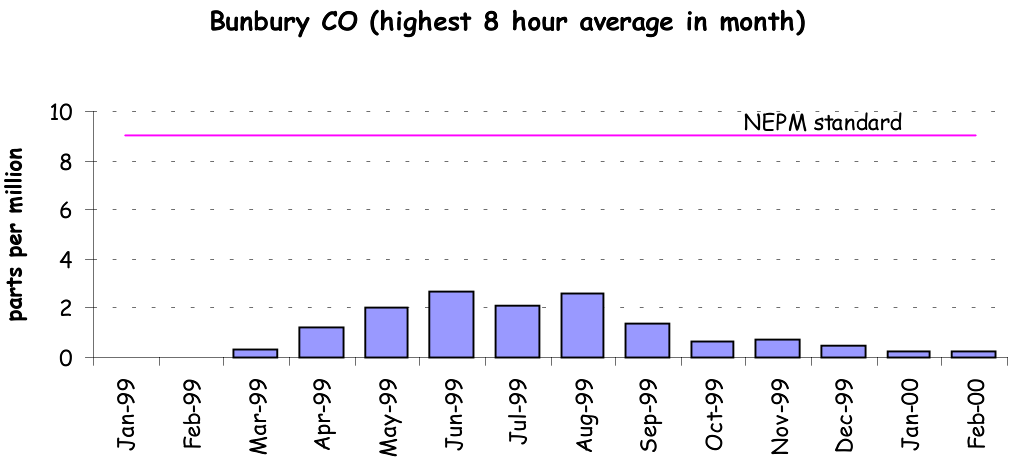
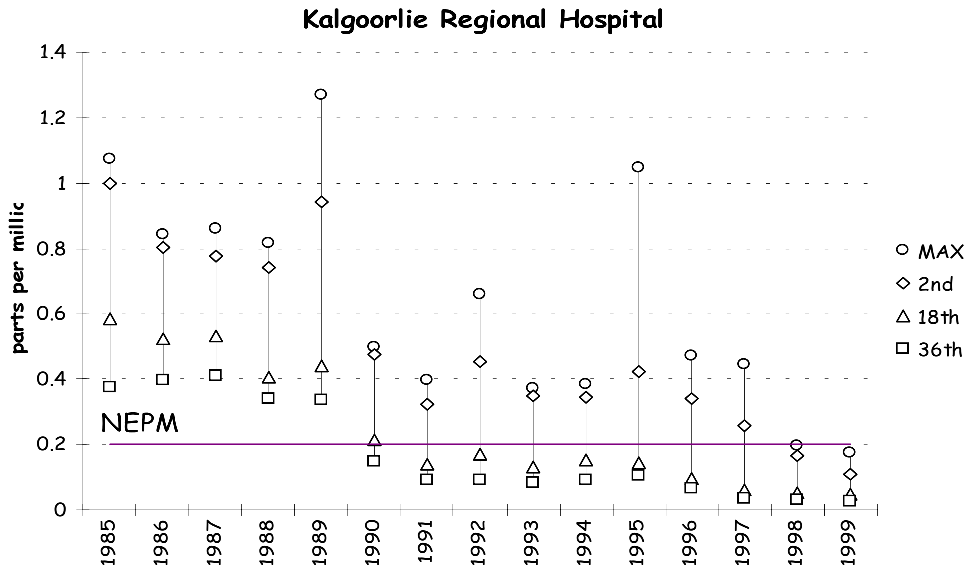
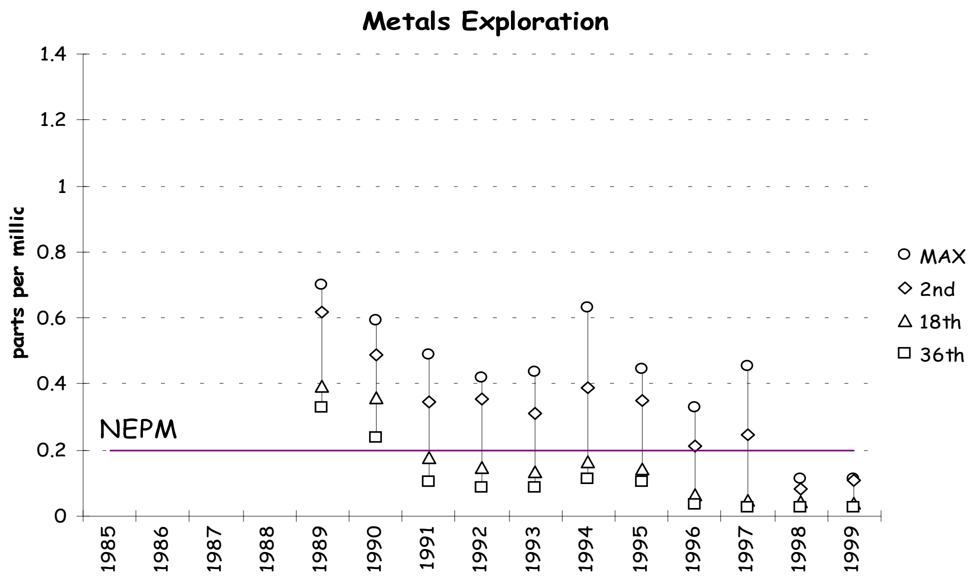


Figure A3.1 Monitoring results from the Bunbury monitoring station, showing the highest value in each month of 1-day averaged $PM_{2.5}$ and PM_{10} (measured by co-located TEOMs) and 8-hour averaged CO.





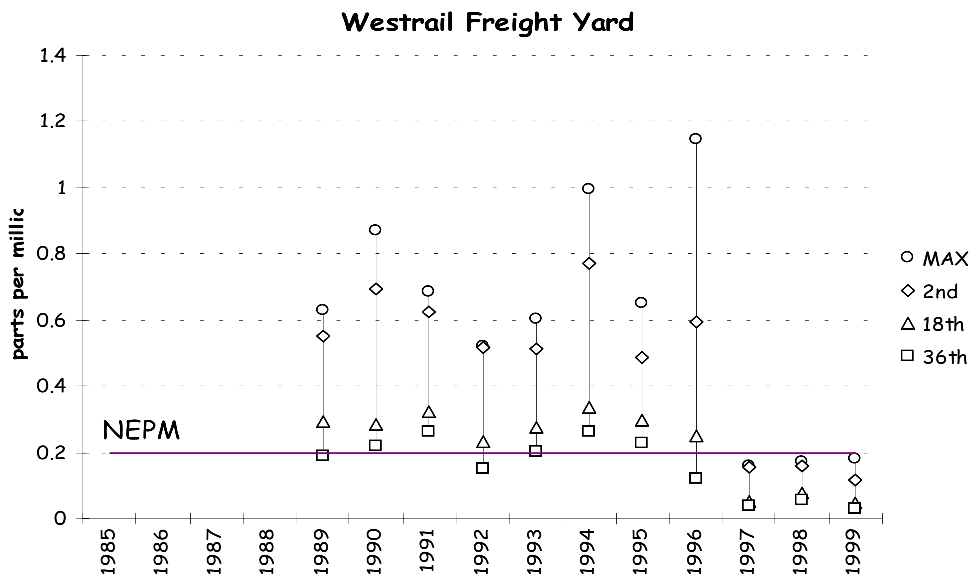


Figure A5.1(a) Highest, 2nd, 18th (95th percentile) and 36th (90th percentile) highest daily maximum 1-hour averages of SO_2 for several calendar years in the Kalgoorlie Region.

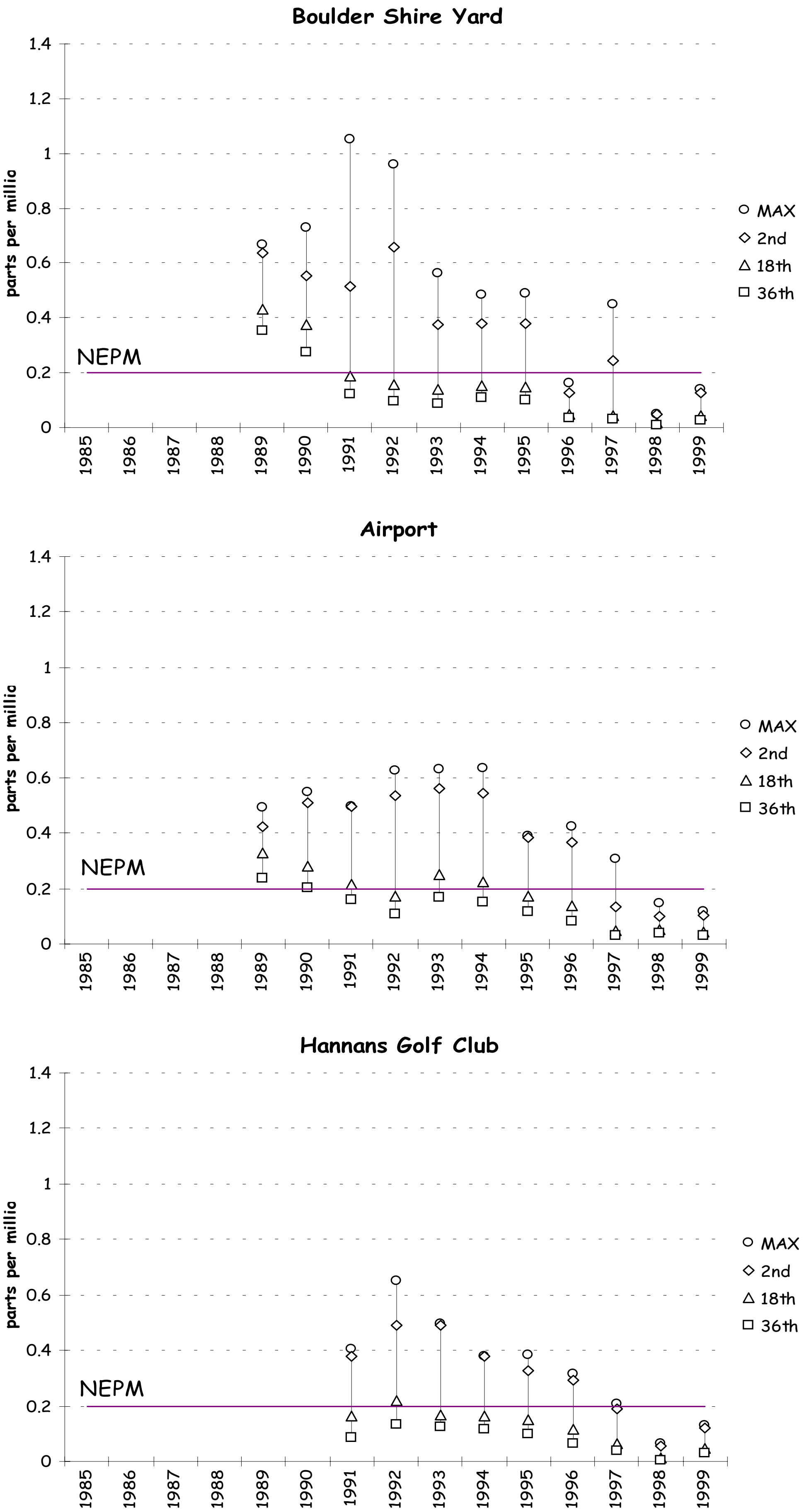


Figure A5.1(B) Highest, 2nd, 18th (95th percentile) and 36th (90th percentile) highest daily maximum 1-hour averages of SO_2 for several calendar years in the Kalgoorlie Region.

Appendix B: Exposed Population Represented by Performance Monitoring Stations

Exposed Population Represented By Performance Monitoring Stations

Station / Pollutant		Exposed Population
Perth Region:		
Caversham	O_3	suburbs in the middle to eastern side of the coastal plain (upper bound)
	NO_2	suburbs in the middle to eastern side of the coastal plain
	PM_{10}	represents low density suburban areas without significant density of local sources (roads, wood fires)
Duncraig	CO	low-lying areas with high population density relatively close to major roads (upper bound)
	PM_{10}	low-lying areas with high population density relatively close to major roads (upper bound)
Queens Buildings	CO	upper bound for vehicle emissions (compliance here ensures compliance everywhere in the region)
	lead	upper bound for vehicle emissions (compliance here ensures compliance everywhere in the region)
South Lake	CO	represents general population average, not strongly influenced by major roads
	O_3	suburbs between the coast and city
	NO_2	suburbs between the coast and city, with possible influence of Kwinana
	SO_2	southern suburbs which receive emissions from Kwinana in the sea breeze
	PM_{10}	represents general population average, not strongly influenced by major roads
Swanbourne	O_3	coastal suburbs (central, north and south)
	NO_2	coastal suburbs (central, north and south)
Mandurah	CO	represents the whole city
	O_3	represents the influence of Perth's emissions on the whole city
	NO_2	represents the whole city
	PM_{10}	represents the whole city
Bunbury	CO	represents the whole city
	PM_{10}	represents the whole city
Geraldton	PM_{10}	represents the whole city
Kalgoorlie	CO	represents the whole city
	SO_2	represents the whole city
	PM_{10}	represents the whole city

Appendix C: Selecting Upper Bound Monitoring Station Sites for Ozone in the Perth Region

Ken Rayner, Arthur Grieco
December 2000

Selecting upper bound monitoring station sites for ozone in the Perth Region

Ken Rayner, Arthur Grieco   December 2000

1. Introduction

This paper was prepared in April 1999 as a model for selection of upper bound monitoring sites for ozone. Subsequently, the Peer Review Committee prepared the paper entitled *Monitoring Strategy* (PRC, 2000c) which explained the requirement for "generally representative upper bound for community exposure (GRUB)" stations plus, as required, additional stations to achieve adequate representation of population-average concentrations. This paper deals only with the selection of GRUB stations in the Perth region. It has been modified only slightly from the April 1999 version to note the view of the PRC that monitoring stations in areas well beyond the main areas of urban population should not be nominated as performance monitoring stations.

This paper employs one of the approaches identified by the PRC for selecting sites for GRUB stations, namely analysis of a sufficiently large data set of routine measurements over a sufficiently dense network of monitors, coupled with an analysis of the meteorological patterns associated with ozone events in various parts of the region. Much of the data collection and analysis was completed during the Perth Photochemical Smog Study (Western Power Corporation and DEP, 1996).

2. Monitoring during the Perth Photochemical Smog Study

Figure 1 shows the location of monitoring stations operated either continuously or at various stages during the Perth Photochemical Smog Study (1992 to 1995).

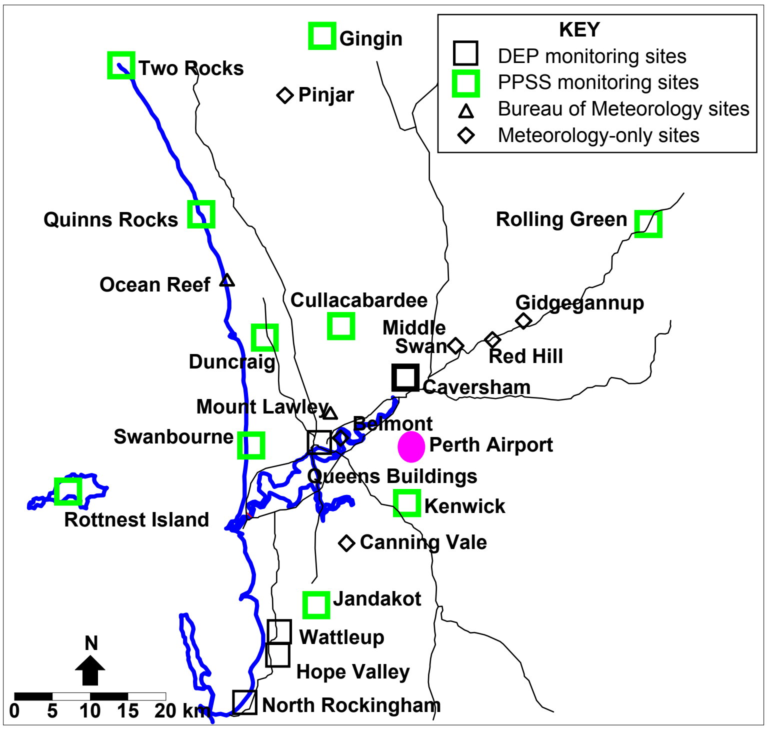


Figure 1. Measurement sites used in the Perth Photochemical Smog Study.

The rationale for selection of monitoring sites was as follows:

- **Rolling Green** was chosen as representative of the region likely to receive Perth's smog in the late afternoon. The study team was aware of findings from Sydney and Melbourne that peak smog levels could occur many tens of kilometres from the source of emissions.
- **Quinns Rocks** and **Two Rocks** were selected to detect recirculation over northern residential areas of the previous day's smog after it had been blown inland, and to measure the inflow of smog when the sea breeze returned it to the northern beaches.
- **Swanbourne** was chosen as a measurement site for two reasons. The first was the need to obtain a regular sample of the offshore flow of the city's morning emissions, before photochemical smog had started to form. The location was also expected to be the site which often received the first inflow of smog with the afternoon sea breeze.
- **Cullacabardee** was chosen on the basis of CSIRO modelling, which showed a strong possibility of the smog mass passing north-west of Caversham on days when the sea breeze did not penetrate well inland. Monitoring confirmed that this did happen.
- **Kenwick**, located to the south-east of the city, was selected to ensure that the effects of smog carried by occasional north westerly sea breezes were measured, and that there was a site which would measure smog originating from Kwinana industry during onshore winds.
- **Rottnest Island** was the only location where it was possible to measure smog development offshore. It was selected on the basis of a strong impression (proven correct) that the data from this site would be of great value in developing an understanding of Perth's smog events.

The sites listed above were the original seven. After monitoring across two summer periods at Two Rocks, the study team was satisfied that a clear decline in smog concentrations occurred north of Quinns Rocks, so that continued monitoring at Two Rocks was not a high priority. Other stations were established for shorter periods in the course of the study to investigate specific issues, as follows:

- **Gingin.** The Two Rocks station was moved to the Gingin airfield in September 1994 to measure the effect of the Pinjar gas turbine power station.
- **Jandakot.** This station was established in March 1994 to measure the plume from Kwinana, close to the source.
- **North Rockingham.** This existing DEP station was equipped with monitors for ozone and nitrogen oxides for a portion of the summer of 1993-1994, to see whether smog recirculation southward of the major emissions sources could be detected.

Figure 1 also shows the DEP stations at **Queens Buildings** in the Perth central business district and **Hope Valley** near Kwinana. Both stations are in the immediate vicinity of large emissions of nitrogen oxides. This parameter was measured at the stations but ozone was not.

3. Analysis of ozone events (Perth Photochemical Smog Study and beyond)

With the possible exception of bushfire events, the only occasions, in the Perth Region, when ozone concentrations rise significantly above background involve the inland advance of the sea breeze. Peak ozone concentrations occur just after the passage of the sea breeze front. The highest concentrations are measured when a morning easterly wind carries urban emissions offshore, and a south-westerly sea breeze brings the reacting air mass back over the city.

Figure 2 shows ozone concentrations at Swanbourne, Caversham and Rolling Green on 21 November 1996. Concentrations at the two inland sites climb sharply following the arrival of the sea breeze front. It is interesting to note that the ozone concentration at Rolling Green exceeds that at Caversham, despite the additional dispersion that would have occurred, indicating

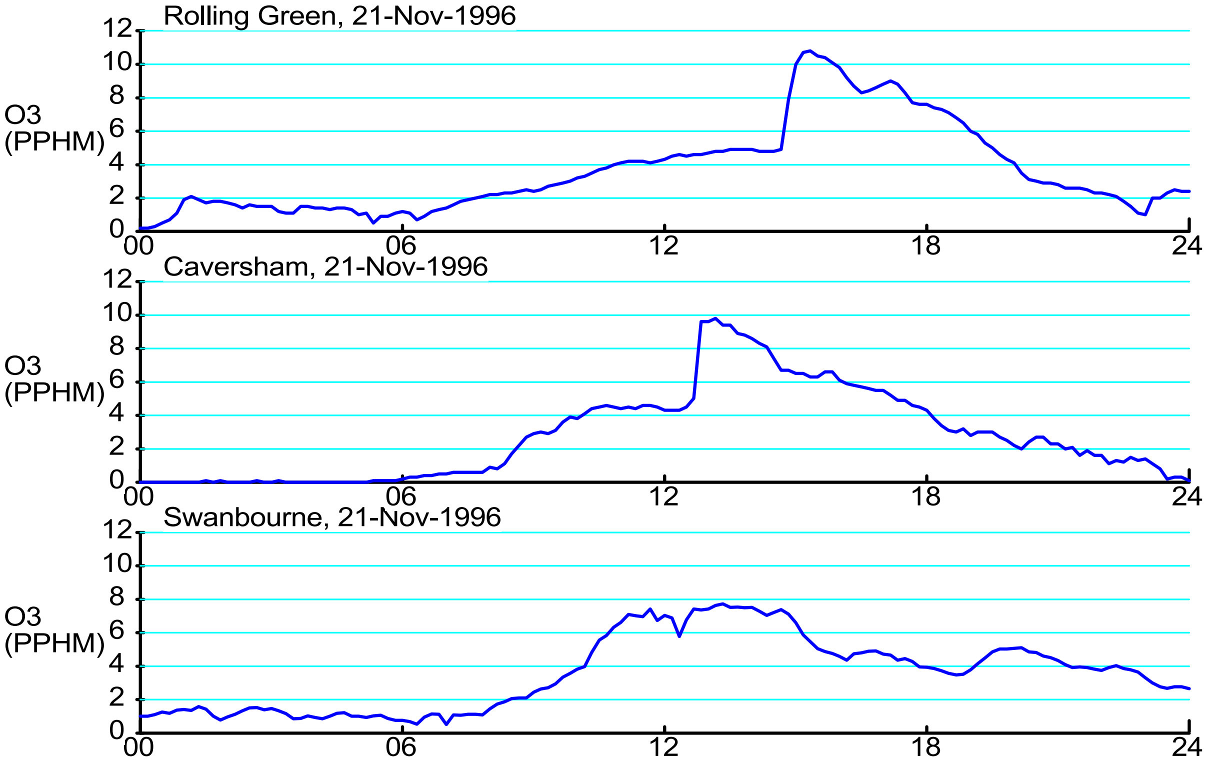


Figure 2. Ozone event on 21 November 1996 showing the inland advance of the sea breeze.

that smog reactions were incomplete at Caversham. This is one of many examples which could be given to support the requirement for monitoring at one or more sites many tens of kilometres downwind of the source of emissions. In this instance, morning peak hour emissions have travelled offshore before returning over the city and beyond to Rolling Green.

Over the full sample of smog events recorded during the Study, Rye (1996) identified four main classes (two of which were very similar) giving rise to the highest ozone concentrations, and a few others that were sufficiently different to these to justify separate grouping. For the purposes of this paper, the four most important classes will be explained.

3.1 Inland Events

Days on which ozone concentrations inland were significantly greater than at the coast, consistent with further progress of smog chemistry as the air mass moved inland. The meteorology of the day normally involves a cool inflow, with low mixing depths persisting inland. The event in Figure 2 above falls into this category.

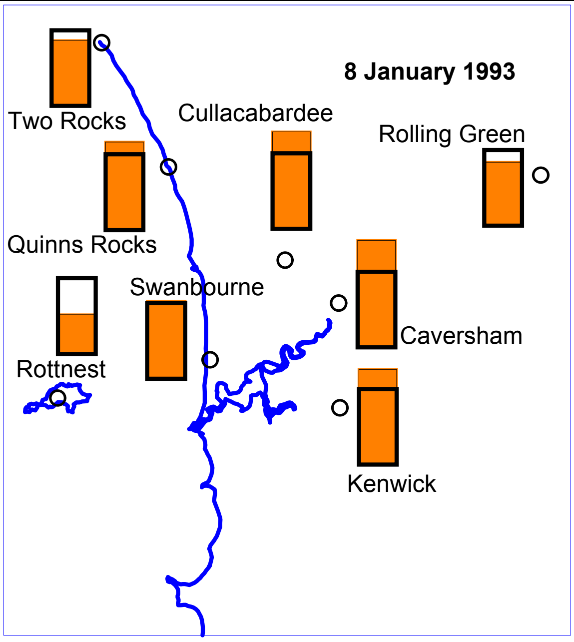


Figure 3. Ozone concentrations on 8 January 1993. The black box indicates 0.08 ppm.

3.2 Kwinana Events

These are identified when trajectories to inland sites lead back to the Kwinana Region, as well as passing across the city or suburbs. Coastal sites may also receive high ozone levels, sometimes due solely to emissions from the Kwinana Region. These cases show more southerly winds, otherwise a meteorological regime similar to the "inland" class. An event on 8 January 1993 was a good example. Figure 3 shows bar graphs on a map which indicate widespread high ozone concentrations. Figure 4 shows the time series of ozone concentrations at Quinns Rocks and Caversham. Trajectory analyses indicate that the Caversham event was due to the morning Kwinana and urban emissions, whereas the much earlier event at Quinns Rocks appears to have been caused by Kwinana emissions from the previous evening.

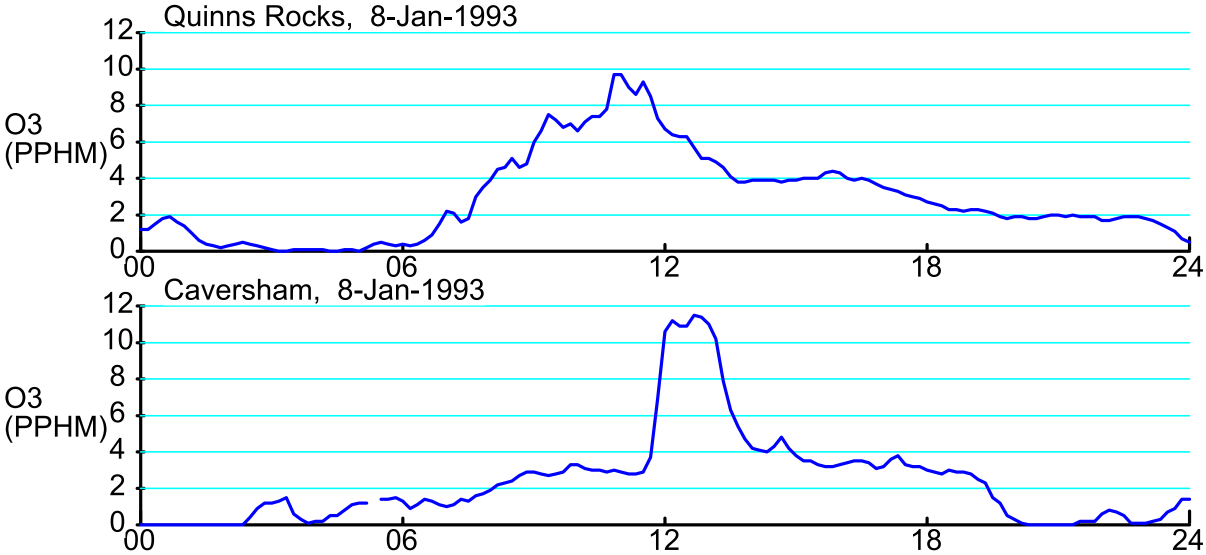


Figure 4. Ozone concentrations at Quinns Rocks and Caversham on 8 January 1993.

3.3 Coastal Events

These are characterised by highest concentrations at the coast. Most commonly, the meteorological regime comprises a fresh easterly gradient wind, followed by passage inland of the coastal trough or sea breeze. The decreased concentrations inland are probably the combined result of dilution as mixing depth increases, along with the late arrival of smog at the coast, so that the smog-producing chemical reactions were already close to completion. An extreme example of this class occurred on 19 February 1994 (see Figure 5).

An accumulation of urban emissions formed the previous evening in light winds, and was carried well offshore by morning. The day began with north to north-easterly winds, and

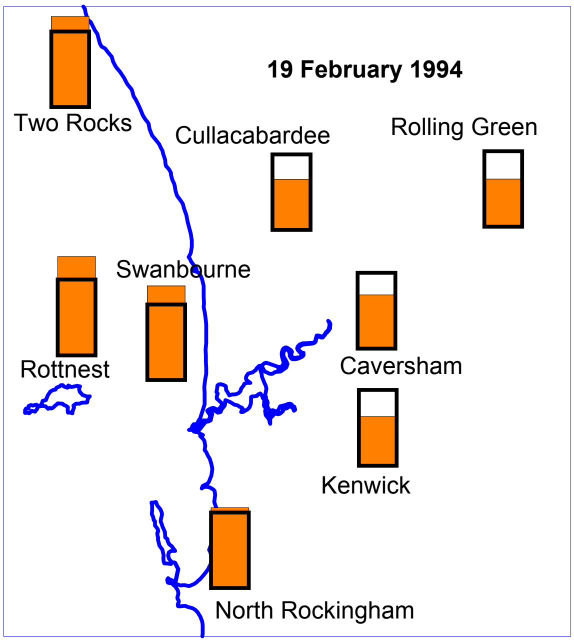


Figure 5. Ozone concentrations on 19 Feb 1994. The black box indicates 0.08 ppm.

a weak trough offshore. The sea breeze was initially north-westerly, arriving about 10:30am and bringing with it smog formed from the morning's emissions, giving an hourly peak at the Rockingham site just over 0.08 ppm (see Figure 6). The trough subsequently passed inland across the coast at about 1:30pm. Then from 3pm the trough passage brought high concentrations (believed to arise from the previous day's emissions) to the whole coastline, from Rockingham to Two Rocks (Figure 6). Quinns Rocks data are missing due to an equipment failure. Concentrations had decreased by the time the inland sites were reached.

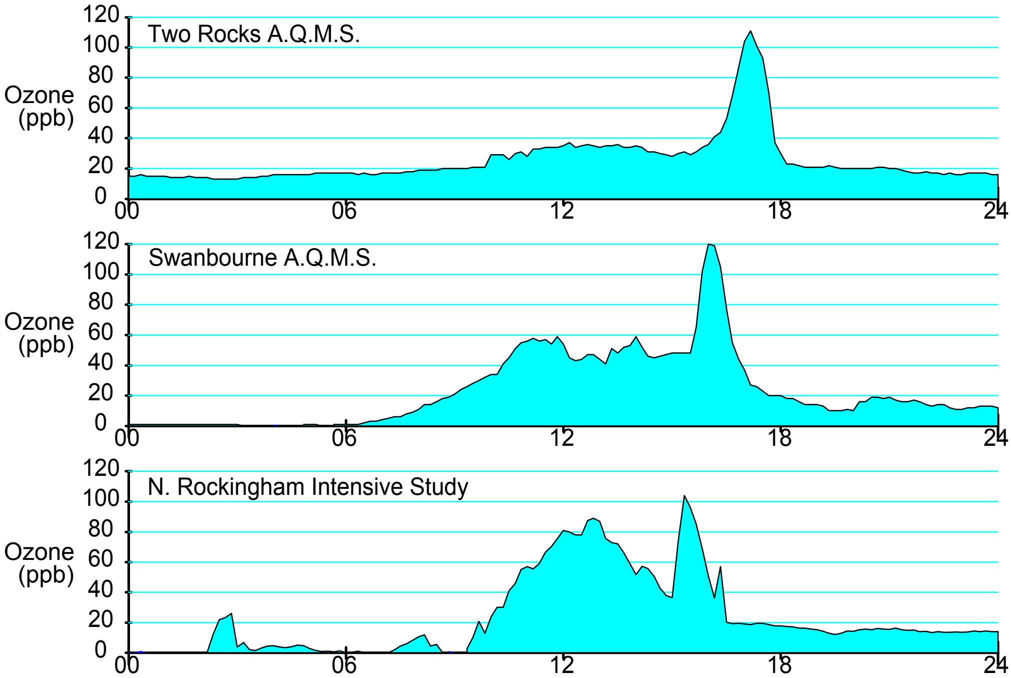


Figure 6. Ozone measurements at three of the coastal monitoring sites on 19 February 1994. North Rockingham and, to a lesser extent, Swanbourne show ozone returned to the coast by the sea breeze as well as the later trough passage.

3.4 Bushfire Smoke Events

These occur when smoke from controlled burns or other bushfires is brought across the urban area in daytime. The smoke includes highly reactive VOCs, and experience has shown that their reaction with urban emissions generates ozone concentrations similar to those generated by urban emissions alone. The significant difference is that these events can occur in periods of persisting south-westerly winds, when smog levels would normally be low. A clear example occurred on 13 January 1993 (Figure 7). A characteristic of these events at inland sites like Caversham is the long duration and relatively slow rise of high ozone concentrations within the broadly distributed smoke cloud.

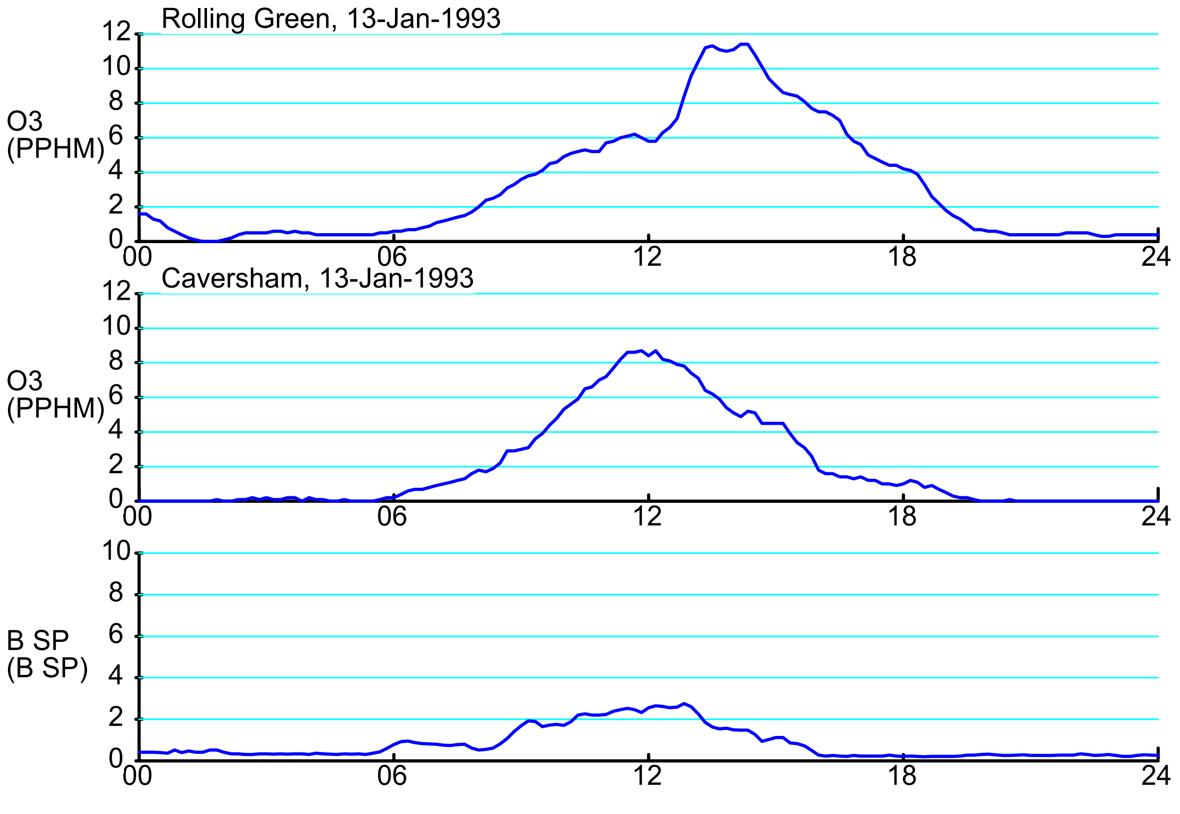


Figure 7. Ozone concentrations at Caversham and Rolling Green on 13 January 1993, plus nephelometer readings at Caversham revealing the presence of bushfire smoke.

4. Current ozone monitoring network

Following the Perth Photochemical Smog Study, the Department of Environmental Protection (DEP) rationalised the number of monitoring stations. The objective was to reduce operating costs while retaining a network of stations that would record the range of smog events known to occur.

Ozone measurements of smog events at Kenwick and Cullacabardee were found to be strongly correlated with those from Caversham and generally of lower magnitude; consequently Kenwick and Cullacabardee were decommissioned. Two Rocks was strongly correlated with Quinns Rocks but measured lower concentrations and was therefore decommissioned. The specific-purpose stations at Jandakot, Rottnest and Gingin were shut down at the end of the study. Measurements at Rockingham were of sufficient interest for an ozone monitor to be permanently installed in 1995.

Consequently the current ozone monitoring network consists of stations at Rockingham, Swanbourne, Quinns Rocks, Caversham and Rolling Green, plus the new site at South Lake which has not yet generated data and is therefore not referred to in the following analysis.

5. Number of performance monitoring stations required under the NEPM

The NEPM specifies a formula for the number of performance monitoring stations within a region of population P million, as follows:

$$N = 1.5P + 0.5 \quad \text{with N rounded up to the next whole number.}$$

For the purposes of this paper we will consider a region extending south past Rockingham, north past Two Rocks and east past Rolling Green. The number of monitoring stations required for this region according to the above formula is:

$$N = 1.5 \times 1.147 + 0.5 = 2.22 \quad \text{rounded up to 3}$$

6. Selection of performance monitoring station sites for ozone

Given that the monitoring network across the region has, in the past, been extensive and (in the context of ozone) reasonably dense, the DEP has an obvious preference to be able to nominate and employ some of its existing monitoring stations as performance monitoring stations. This will be valid so long as it is apparent that the nominated stations provide "upper bound" measurements that are representative of the major ozone event categories identified in Section 3.

The notion of a monitoring station being representative needs to be clarified. Consider for example the category of events called "coastal events" in section 3. The coastline within the Perth / Rockingham Region extends approximately 100 km north-south. It is obvious that various "coastal events" will bring high concentrations to different locations along the coastline, such that a single monitoring station will not record the highest concentrations associated with every "coastal event". Nevertheless, by examining the statistics of concentrations recorded by coastal monitoring stations it may be possible to select a single station that is representative of coastal sites (i.e. concentrations at various percentiles are equal to or greater than those at other coastal stations). Such a station can then be considered to be an "upper bound coastal station" so long as there is no evidence, or reason to believe, that significantly higher concentrations might occur at another coastal site.

Selection of a performance monitoring station in this way would appear to meet the intent of the NEPM clause 13(2). However, "determination of the exposed population in the region or sub-region represented by the station" as required under NEPM clause 17, is open to interpretation.

Figures 8 and 9 show, for each July to June year since 1992-93, a comparison of ozone measurement statistics, for 1-hour and 4-hour averages respectively, for each monitoring station operating during the year. (The choice of July to June years is made simply to increase the amount of data available.) Four concentration levels are shown for each station, being the 1st, 2nd, 5th and 10th highest measurements, each of which occurred on a different day (ensuring that each of these four concentrations represent the maximum of four independent ozone events). The spread from 1st to 10th is chosen to give an indication of whether high concentration events are common or rare.

A further point to note is that the 1-hour and 4-hour averages in Figures 8 and 9 are rolling averages based on 10-minute averages. This has been done to remove the distortion introduced by averaging over clock hours that degrades our ability to compare the magnitude of ozone events at various sites. Consider for example the ozone event on 19 February which is depicted in Figures 5 and 6. Table 1 below shows the maximum 1-hour averages at Two Rocks, Swanbourne and Rottnest Island calculated on a rolling 10-minute basis and a clock hour basis (end times of the averaging periods are given).

Table 1. Concentrations at three monitoring sites calculated on a rolling 1-hour average and a clock hour average basis.

Monitoring station:	Maximum rolling 1-hour based on 10 minute averages	Maximum 1-hour average based on clock hours
Two Rocks	.094 ppm @ 1740	.074 ppm @ 1800
Swanbourne	.098 ppm @ 1630	.073 ppm @ 1700
Rottnest Island	.103 ppm @ 1600	.103 ppm @ 1600

As can be seen from Figures 5 and 6, and the rolling averages in Table 1, the events at the three sites were very similar in magnitude. The event at Rottnest coincides with a clock hour, hence the two averages have the same value. However, because the ozone events at Two Rocks and Swanbourne both have their peak (10-minute average) values close to an hour mark, the maximum clock hour average is significantly less (0.020 ppm or more) than the maximum rolling 1-hour average. We are not suggesting that the NEPM definitions be revisited, however there is a strong argument for using rolling averages for special purposes such as event comparison.

The monitoring stations may be grouped as follows:

- Coastal stations (Two Rocks, Quinns Rocks, Swanbourne, Rockingham);
- Middle distance (15 to 20 km) inland (Gingin, Cullacabardee, Caversham, Kenwick);
- Far inland (Rolling Green).

Examination of Figures 8 and 9 lends support to the decisions, described in section 4, to terminate some of the monitoring stations. Two Rocks shows lower concentrations than Quinns Rocks and Swanbourne. Gingin, Cullacabardee and Kenwick show lower concentrations than Caversham.

Inspection of the statistics for the coastal sites, Quinns Rocks, Swanbourne and Rockingham indicates there is little difference over the long term. The DEP's decision is to select Swanbourne as a performance monitoring station but to maintain monitoring stations at Quinns Rocks and at or near Rockingham for the foreseeable future, as resources allow.

Given that Caversham is situated between Cullacabardee and Kenwick, there is reason to be confident that Caversham represents an upper bound, middle distance, inland site. Accordingly Caversham is selected as a performance monitoring station site.

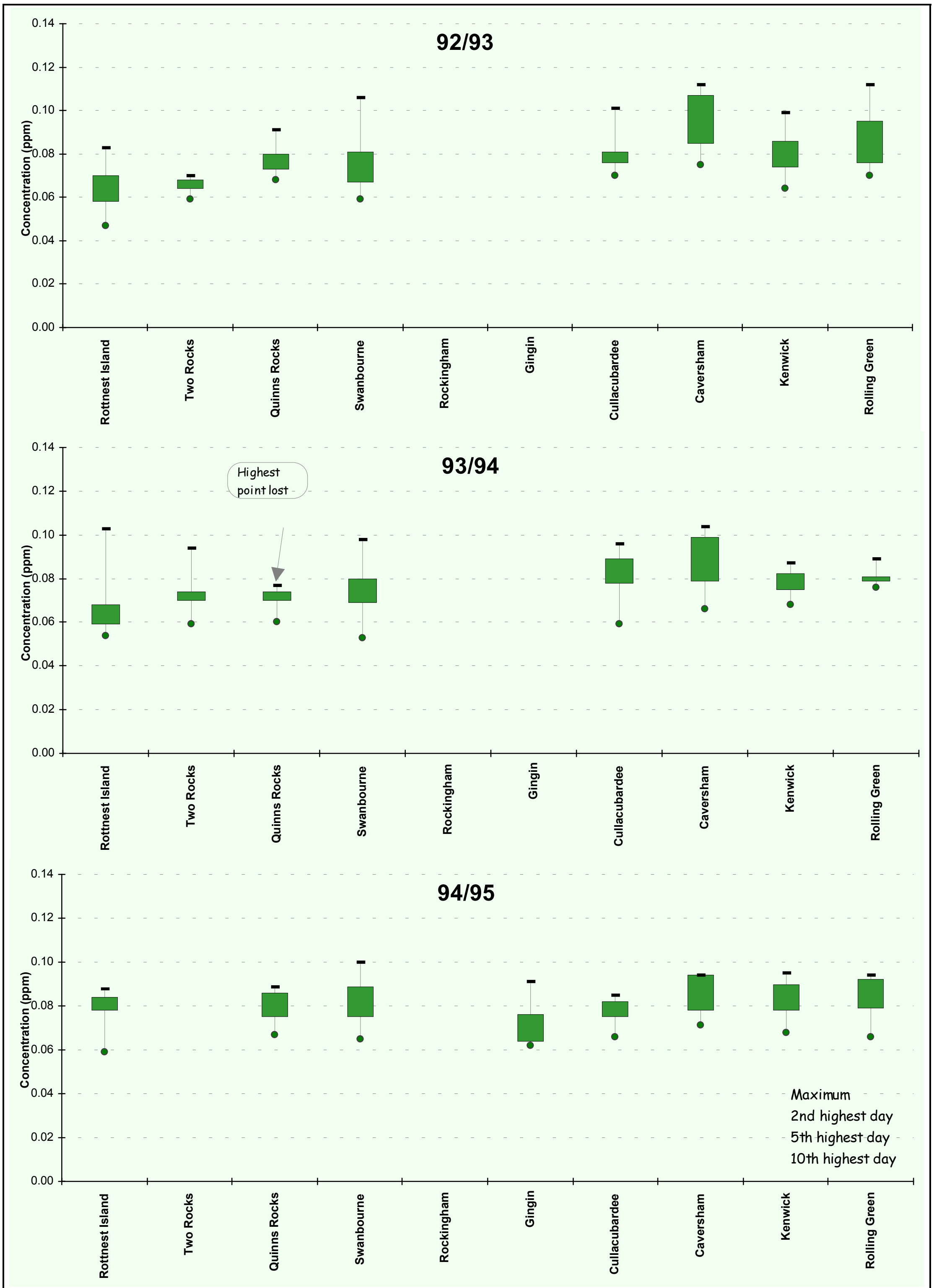


Figure 8(a). Rolling 1-hour average ozone concentrations for the highest, 2nd, 5th, and 10th highest ozone events (separate days) over July to June years.

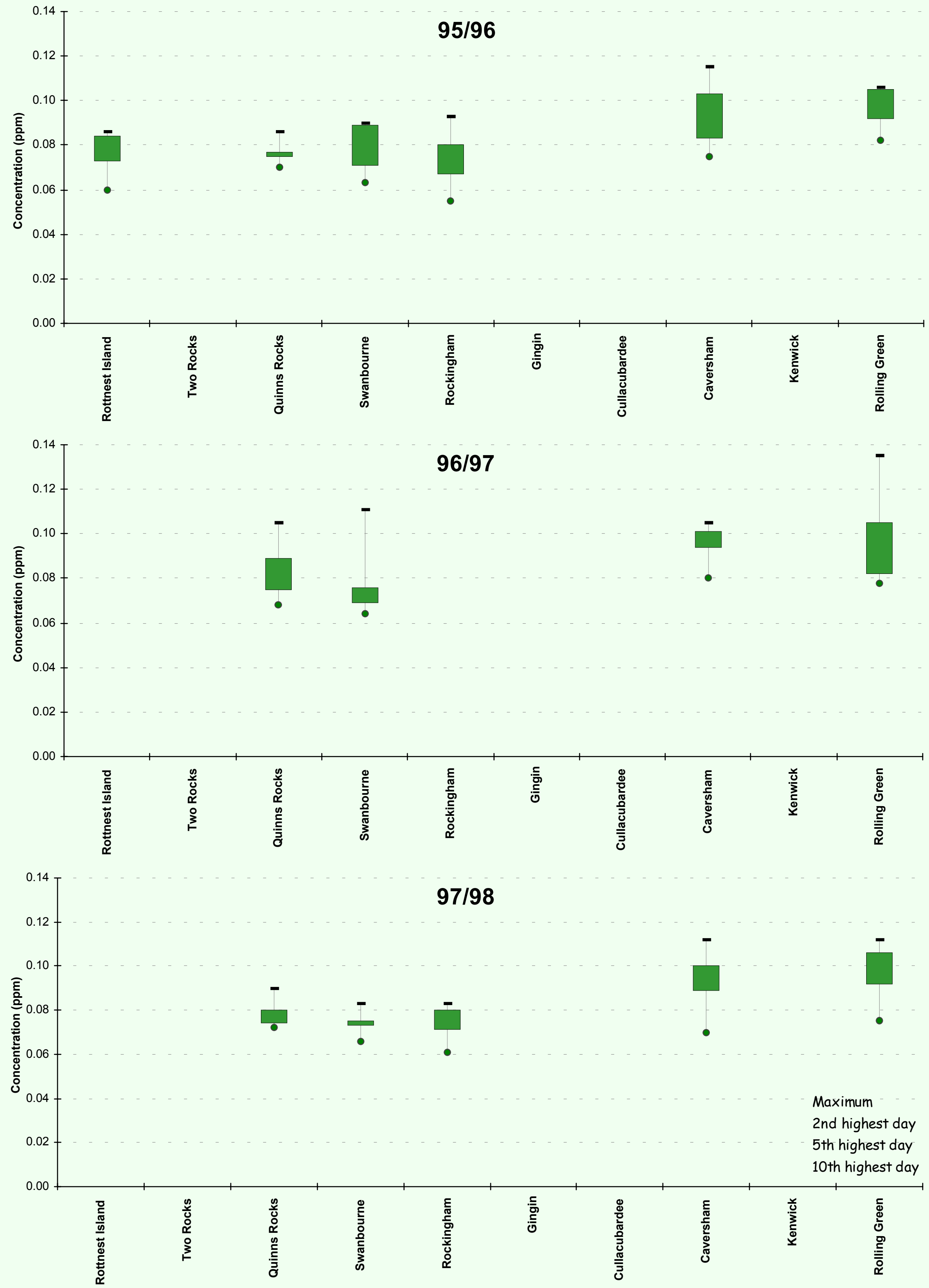


Figure 8(b). Rolling 1-hour average ozone concentrations for the highest, 2nd, 5th, and 10th highest ozone events (separate days) over July to June years.

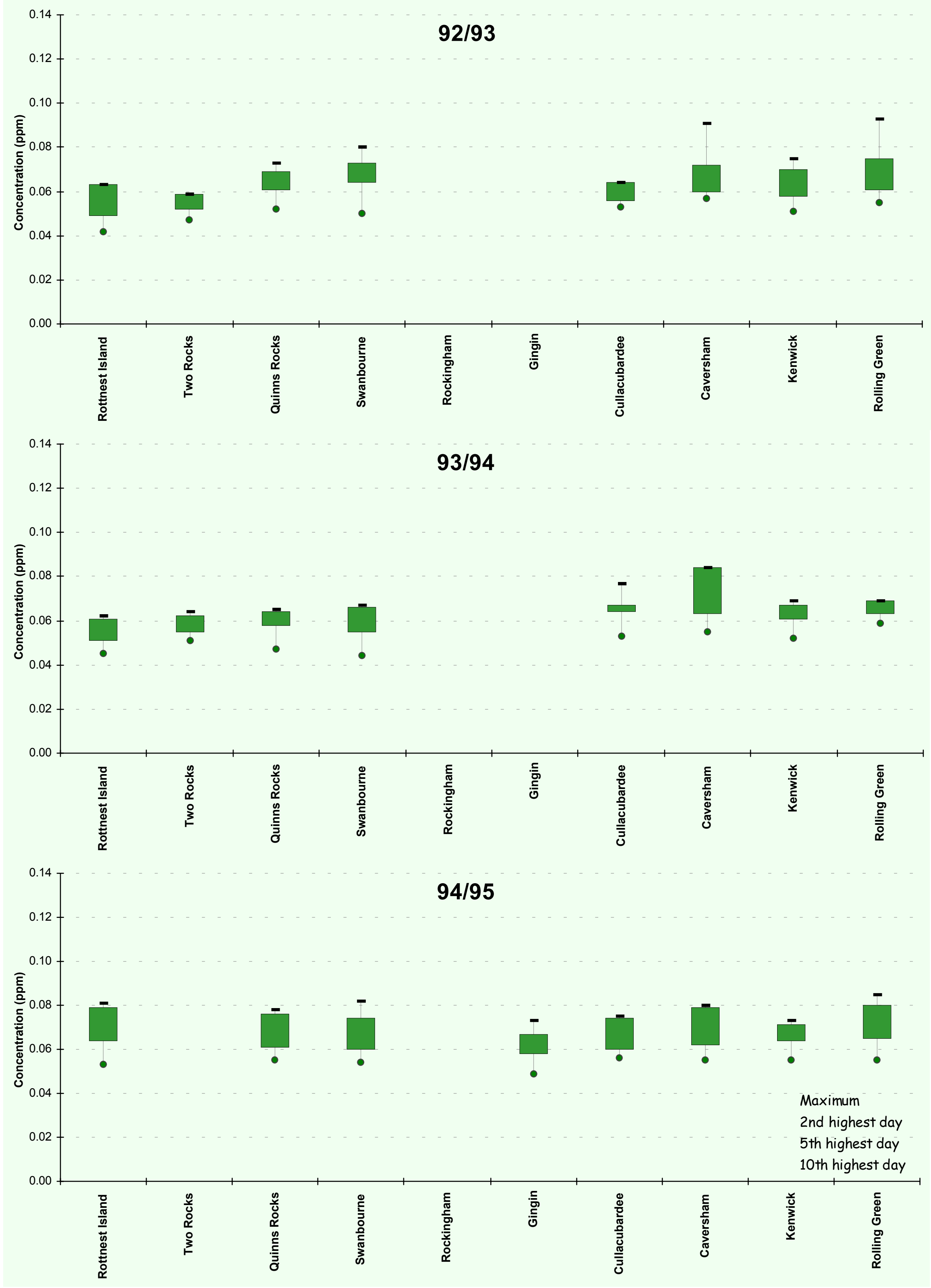


Figure 9(a). Rolling 4-hour average ozone concentrations for the highest, 2nd, 5th, and 10th highest ozone events (separate days) over July to June years.

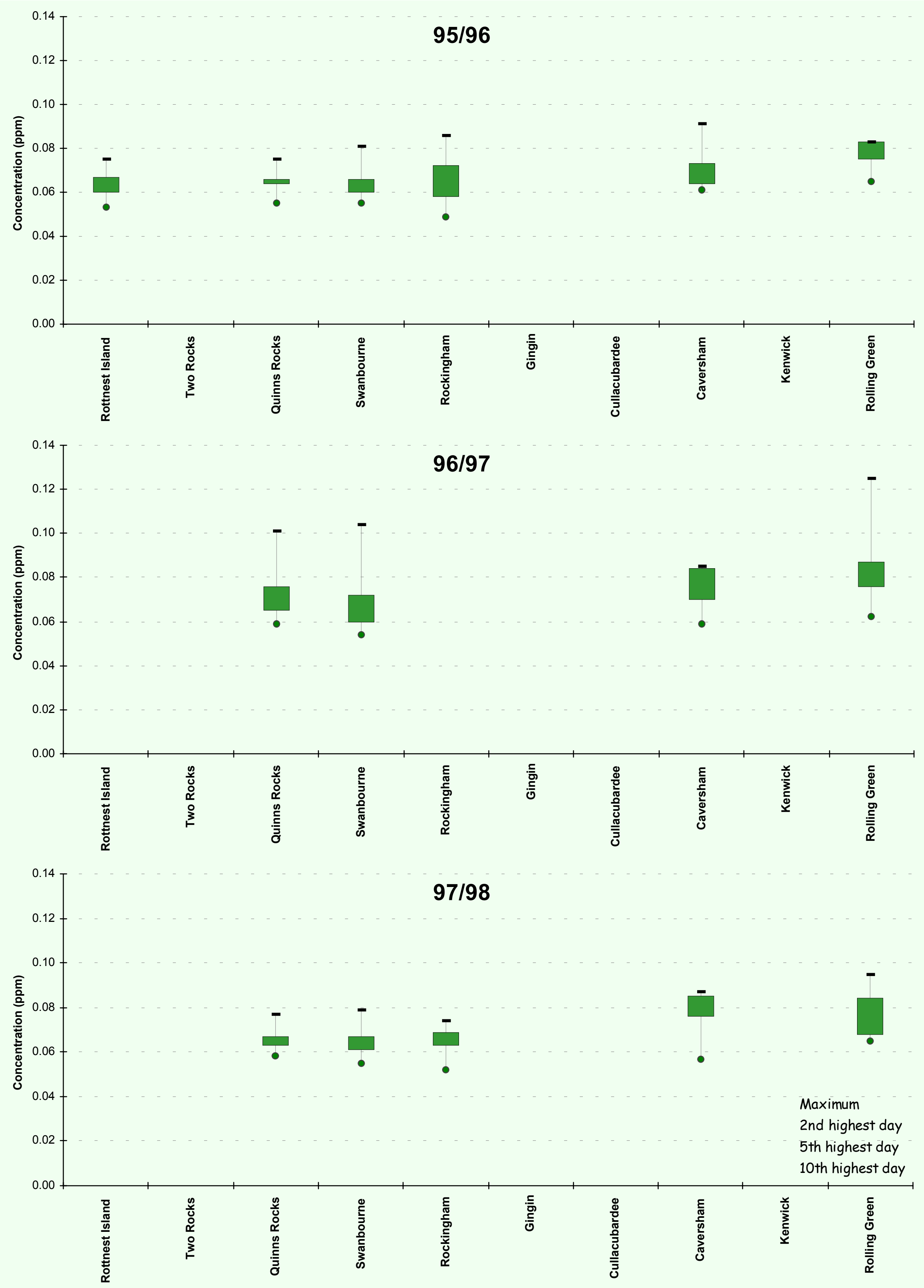


Figure 9(b). Rolling 4-hour average ozone concentrations for the highest, 2nd, 5th, and 10th highest ozone events (separate days) over July to June years.

Finally, we need to confirm our understanding that Caversham does not adequately represent ozone concentrations well inland, in the vicinity of Rolling Green. Figure 10 is a type of cumulative frequency diagram, showing the percentage of ozone events during the Perth Photochemical Smog Study for which the IER Extent parameter, E, exceeded the values shown on the horizontal axis. For the purpose of this diagram, an ozone event was defined as an event with a 1-hour ozone concentration greater than 0.05 ppm.

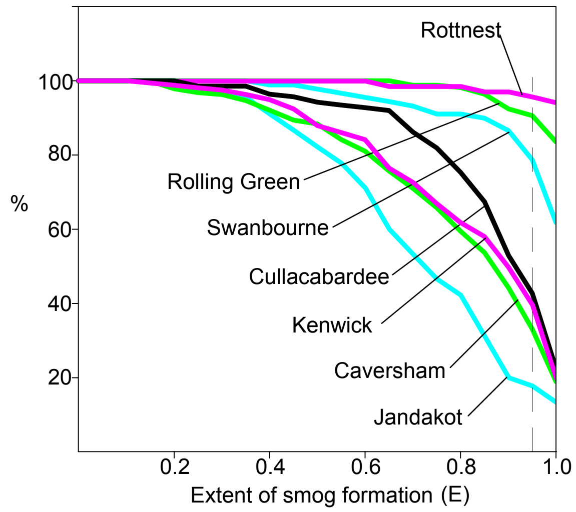


Figure 10. Percentage of ozone events during the Perth Photochemical Smog Study for which the IER Extent parameter, E, exceeded the values shown on the horizontal axis. An ozone event was defined as an ozone concentrations greater than .05 ppm.

As explained in the final report of the Perth Photochemical Smog Study, a value of E=0.95 is considered to represent the point of transition from light-limited to NOx-limited conditions. As can be seen from Figure 10, 90% of smog events at Rolling Green have E equal to or greater than 0.95, while the corresponding figure at Caversham is only 35%. This implies that:

- Caversham ozone measurements cannot be considered to represent Rolling Green, because smog reactions are frequently not complete in the air mass passing over Caversham;
- there is little to be gained from siting a monitoring station further east than Rolling Green as ozone production is almost always complete or nearly complete in the air mass reaching Rolling Green.

The biggest ozone event recorded in the Perth Region (27 February 1997) was observed at Rolling Green, on a day when very light north-easterly winds in the morning were followed by a moderate strength sea breeze. The rolling average can be seen in Figures 8 and 9. The clock hour averages (as per the NEPM) were 0.135 ppm (1-hour) and 0.124 ppm (4-hour).

In summary, Swanbourne and Caversham are clearly suitable and necessary GRUB performance monitoring sites. Rolling Green represents a “far inland” upper bound site. However, as explained in the Monitoring Plan for Western Australia, the population density around Rolling Green is too low for it to be considered representative for NEPM monitoring purposes and hence the South Lake monitoring site has been developed. Rolling Green will be retained for the foreseeable future as a part of the DEP’s ongoing monitoring activities.

Appendix D: Summary of Emissions in the Perth Region

Summary of Emissions in the Perth Region

The Department of Environmental Protection conducted a comprehensive emissions inventory for the 1998-99 fiscal year within the Perth airshed. The study region encompassed an area of approximately 8,600 square kilometres and included the extremities of metropolitan Perth, incorporating all industrial and commercial premises that were expected to influence Perth's air quality.

Emissions estimates were calculated for five source categories. These source categories are:

- *area based* – 13 domestic and commercial source groups;
- *industrial* – 272 industrial and commercial facilities and premises;
- *motor vehicles* – the Perth motor vehicle fleet;
- *other mobile sources* – railways, shipping/recreational boating, aircraft and off-road vehicles;
- *biogenic sources*.

The contribution of these sources categories to the total emissions of NEPM pollutants and precursors is summarised in Figure 1.

An estimated 72,129 tonnes of oxides of nitrogen (NO_x) were emitted into the Perth airshed during the 1998-99 fiscal year. The major emissions of NO_x were from motor vehicles (42%) and industrial processes (38%). Since the previous (1992-93) inventory, emissions of NO_x have increased by 17,252 tonnes. Emissions from all source categories have increased. The increase in NO_x emissions from motor vehicles is predominantly a result of an increase in the number of vehicles and the distance they travel annually. Similarly, the increase in industrial NO_x emissions is partially explained by the increased number of facilities included in the more recent inventory. Other mobile emissions have significantly increased since the 1992-93 inventory, although they still provide minor contributions to overall NO_x emissions. This increase is primarily from boating and off-road vehicles (these are thought to be underestimated for 1992/93).

The Kwinana Environmental Protection Policy set limits for sulfur dioxide (SO_2) emissions from industries in the Kwinana Industrial Area. Emissions from Kwinana industries still account for 86% of the total SO_2 released into the Perth airshed. When results from the 1998-99 and 1992-93 inventories are compared, it is apparent that there has been a significant increase in SO_2 emission estimates from marine craft and a moderate emissions increase from other mobile sources. It is likely that this increase is primarily a result of more accurately determining the sulfur content in the fuel. Annual SO_2 emissions for the 1998-99 fiscal year were estimated to be 19,051 tonnes and 18,386 tonnes in 1992-93.

Motor vehicles emissions contribute 80% of the total carbon monoxide (CO) emissions within the Perth airshed. A similar percentage contribution was also highlighted in the results of the 1992-93 inventory and this is consistent with other Australian cities. Emission controls such as ADR 37/00 and 37/01 for light vehicles, plus the introduction of new technology, have enabled a reduction in CO emissions from motor vehicles over time. The reduction in motor vehicle and other mobile CO emissions is the major reason for the slight decrease in total annual emissions, from 286,139 tonnes in 1992-93 to 283,356 tonnes in 1998-99.

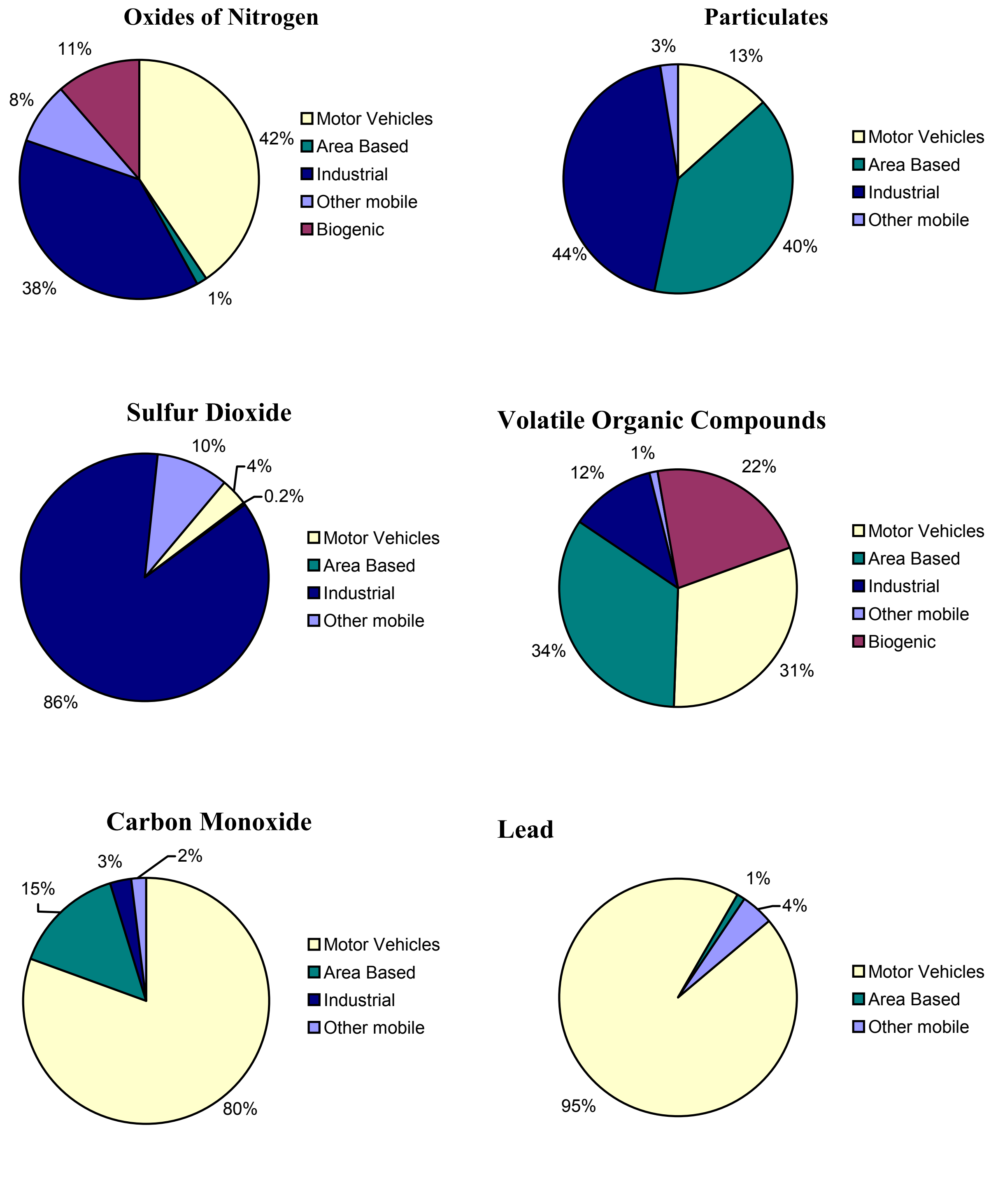


Figure 1. Emissions Estimates of NEPM Pollutants and Precursors in the Perth Airshed during 1998-99

Estimates of CO emissions from area-based and industrial sources have increased by comparison with those of 1992-93. Estimation of emissions from wildfires and prescribed burning yielded additional area-based CO emissions. However, the introduction of new technology and regulations for domestic wood heaters lowered the associated emissions, limiting the total CO emissions from the area-based category. The increased CO emissions from industrial sources may be related to the increase in fuel usage due to the introduction of new industry and plant expansions. Otherwise, the aging of equipment or the introduction of low NO_x burners (some of which achieve reduced NO_x emissions at the expense of CO emissions) may have also increased CO emissions estimates.

The most significant sources of particulate (PM_{10}) emissions in the Perth airshed during 1998-99 were industrial (44%) and area-based (40%) sources. It was estimated that 10,692 tonnes of PM_{10} were emitted during 1998/99, whereas the 1992-93 inventory estimated 13,956 tonnes were emitted. Industrial emissions estimates were significantly reduced in the 1998-99 inventory, as a result of updated emission factors. The emission factors that were specifically available for 'Brick Works' when the previous inventory was undertaken appeared to have significantly over-estimated emissions, so an alternative method of estimation was utilised, giving results that corresponded closely to monitoring data.

Emissions from area-based sources were the most significant (34%) contributor to total volatile organic compounds (VOCs) emissions during 1998-99. During this fiscal year it was calculated that 72,444 tonnes of VOCs were emitted into the airshed, which is lower than the estimate of 81,058 tonnes for the 1992-93 fiscal year. When the previous inventory (1992-93) was undertaken it was determined that motor vehicles were the major source of VOCs in the Perth airshed. Reduced motor vehicle emissions are a result of better emission control associated with ADR 37/01. A significant reduction in industrial emissions was also noted, primarily due to emissions control measures undertaken at the BP Kwinana refinery.

An estimated 44.6 tonnes of lead was emitted into the Perth airshed during the fiscal year of 1998-99, which is much less than the 1992-93 lead emissions estimate of 351 tonnes, reflecting the reduced emission of lead from motor vehicles. This decrease is due to the greater market penetration of unleaded petrol and the reduced lead level in leaded petrol. Emissions from motor vehicles were the dominant source (95%) of lead within the Perth airshed. Leaded petrol ceased to be sold in WA in January 2000, hence it is clear that lead emissions will have reduced to very small levels since the inventory was completed.