Department of
Environment

The Department of Environment is an amalgamation
of the former Water and Rivers Commission
and the Department of Environmental Protection.

References to the Department of Environmental Protection (DEP)
throughout this report were correct at the time of the study.

PILBARA AIR QUALITY STUDY
SUMMARY REPORT

prepared by

Air Quality Management Branch

Department of Environment

DEPARTMENT OF ENVIRONMENT

TECHNICAL SERIES

REPORT No. 120

AUGUST 2004

Acknowledgments

CSIRO Atmospheric Research was contracted to undertake an assessment of the meteorology of the Pilbara coastal region, as it relates to air pollutant dispersion, and to evaluate the capability of computer models for use in the assessment of air pollutant emissions from various sources. The study greatly benefited from the expert knowledge and modelling capability of the CSIRO. In particular, the efforts of Dr Bill Physick are gratefully acknowledged.

The DEP acknowledges the following valuable contributions:

- Woodside carried out air quality monitoring in support of the DEP's monitoring, assisted with radiosonde (weather balloon) releases, and contributed funds to finalise the study;
- LandCorp and the Department of Resources Development undertook meteorological monitoring on the Maitland and Boodarie industrial estates, and contributed funds to finalise the study;
- Hamersley Iron approved the siting of monitoring stations on its leasehold land and contributed funds to finalise the study;
- BHP Billiton, as part of its ongoing monitoring activities, provided valuable air quality and meteorological data from its monitoring stations at the Boodarie industrial estate and Port Hedland, and contributed funds to finalise the study.

Recommended reference

The recommended reference for this publication is: Department of Environment 2004, *Pilbara Air Quality Study – Summary Report*, Department of Environment, Technical Series No. 120.

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ISBN 1 920947 35 3
ISSN 1328-7230

August 2004

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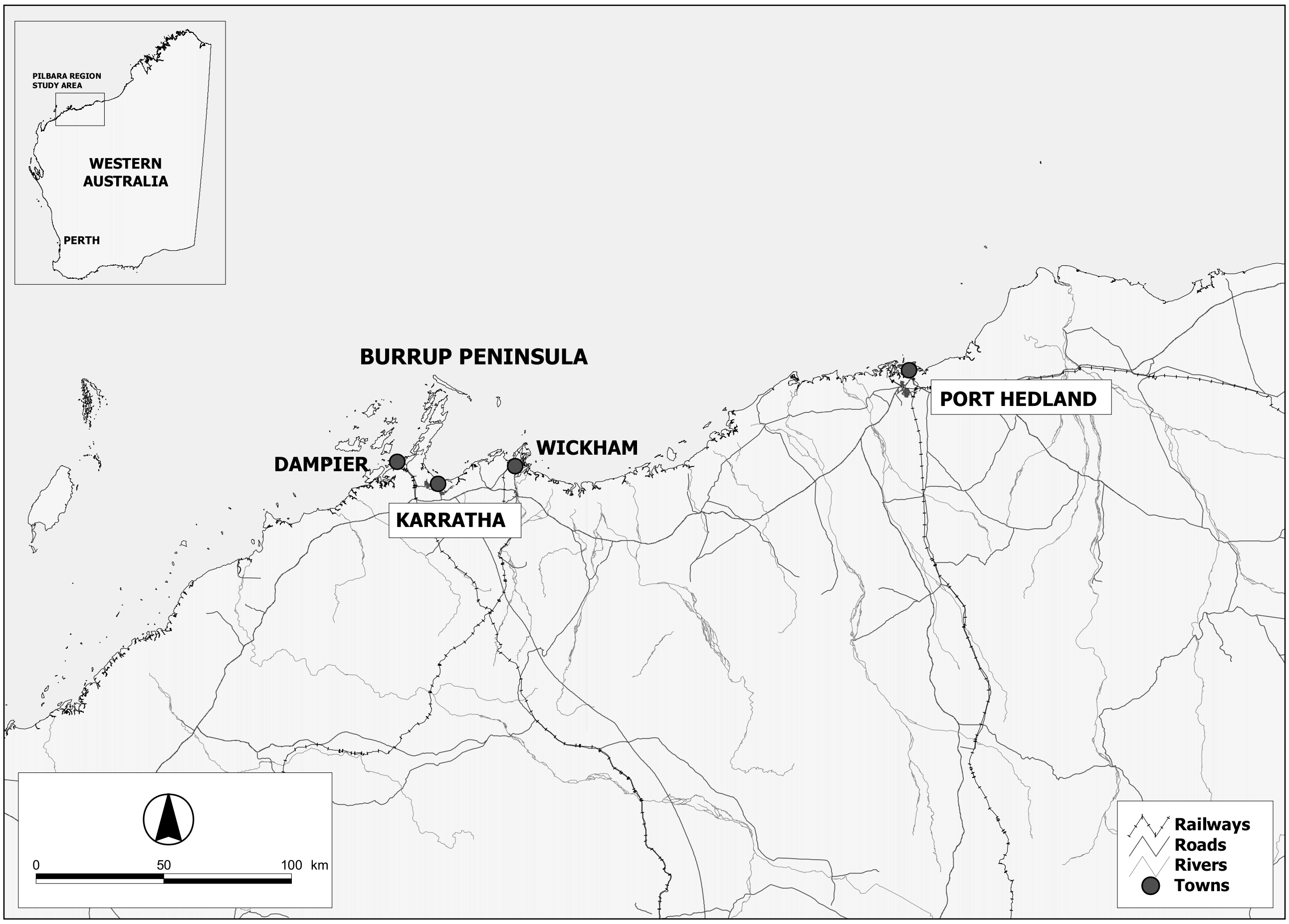


Figure 1.1 Location of study region

1 Introduction

The Pilbara Air Quality Study was proposed in 1996 and initiated in 1998 to provide a foundation for air quality assessment and management in the Pilbara coastal centres of Karratha-Dampier, Wickham-Cape Lambert and Port Hedland. These centres are shown in Figure 1.1. Inland centres in the Pilbara region have not been included in the study, although some of the findings in relation to dust are of direct relevance to those centres.

There is a variety of industrial activities in the above-mentioned coastal centres which may impact on air quality. Dampier, Cape Lambert and Port Hedland each have major port facilities for iron ore shipment, with associated issues of dust management and emissions from ships. Boodarie Iron, operated by BHP Billiton, processes iron ore at its hot briqetted iron (HBI) plant near Port Hedland. At the Woodside Energy Limited onshore treatment plant on the Burrup Peninsula there are emissions from the combustion and processing of natural gas. Natural gas is burned in Hamersley Iron's Dampier power station and in gas turbines near Port Hedland. A number of industries using natural gas as feedstock and fuel are planned for the Burrup Peninsula.

In light of the potential for industrial development, it became apparent to the Environmental Protection Authority (EPA) and Department of Environmental Protection (DEP) in 1996 that there was a need for reliable information on the existing air quality and relevant meteorology of the region, particularly for the Karratha to Cape Lambert area. The time required to measure and analyse an adequate quantity of such information is generally at least two years, well beyond the time-frame within which developers and the Government require advice on the environmental acceptability of proposed projects.

Accordingly, the Government provided funding through the DEP to undertake the Pilbara Air Quality Study. In light of the development pressures on the Burrup Peninsula, the primary focus of the study was the Karratha-Dampier-Burrup Peninsula area. However, with contributions of monitoring data and funds from other agencies and companies, it has been possible to gather information to provide a foundation for air quality assessments in all three coastal centres.

The objectives of the Pilbara Air Quality Study were to develop and present:

- an understanding of the air quality in the study centres;
- an understanding of the meteorology which governs the transport and dispersion of air pollutants from the various points of emission in the region;
- estimates of emissions of key pollutants in the Karratha-Dampier-Burrup Peninsula area;
- computer models, with associated input data files, which may be used to assess the acceptability of emissions from proposed industrial developments.

To assist in achieving these objectives, the DEP employed the services of the CSIRO Division of Atmospheric Research.

The objectives of the study have been met, as described in this summary report and scientific reports referenced herein.

Publication of this Summary Report has been delayed in order to include computer modelling results using corrected emissions information as discussed in section 6.

2 Air quality and meteorological monitoring programs

Monitoring of ambient air quality and meteorology during the Pilbara Air Quality Study is described in detail in DEP (2002a). A summary of that report follows.

2.1 Historical monitoring activities

Before considering the range of monitoring required in this study, a review of previous monitoring activities was undertaken. The issue of asbestos, which is specific to Pt Samson and Roebourne, was not considered.

With respect to air pollutants, the only substance which appears to have been monitored in the ambient environment to any significant extent prior to the current study is dust. In particular BHP has had an established program of dust monitoring and management over many years (BHP, 1996). Directional dust gauges were employed in the 1970s, yielding monthly samples. These were replaced near the end of that decade with High Volume Samplers yielding 24-hour averaged measurements of Total Suspended Particulates (TSP). From 1995 onwards, BHP has also monitored PM_{10} (particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less) and more recently $PM_{2.5}$ at selected sites. Meteorological data has also been monitored.

Hamersley Iron has run High Volume Samplers collecting 24-hr TSP every sixth day at the two stockpiling-ship loading ports, East Intercourse Island and Parker Point, and at two sites within Dampier, since 1993. These

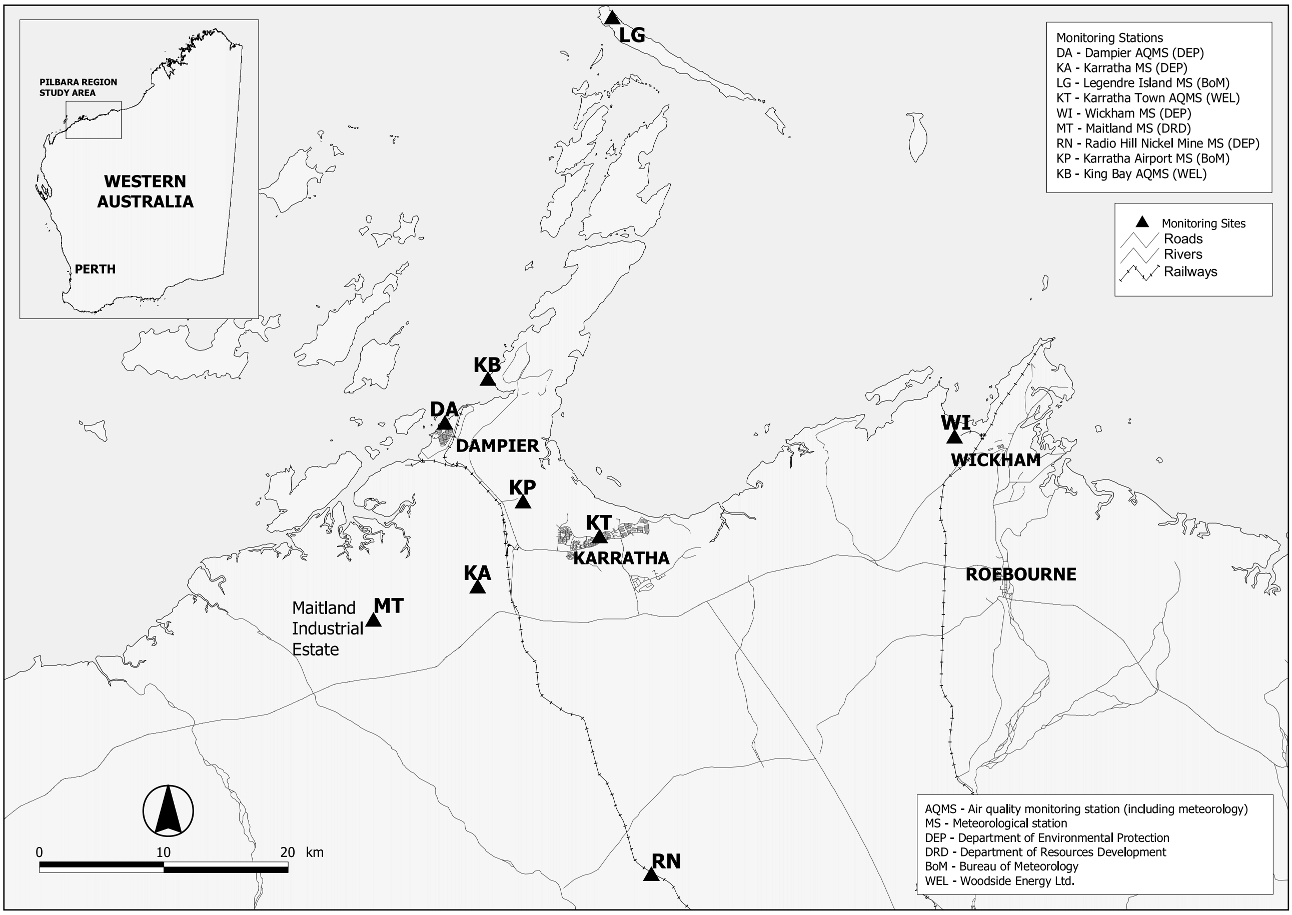


Figure 2.1 Monitoring stations in the study region (western portion)

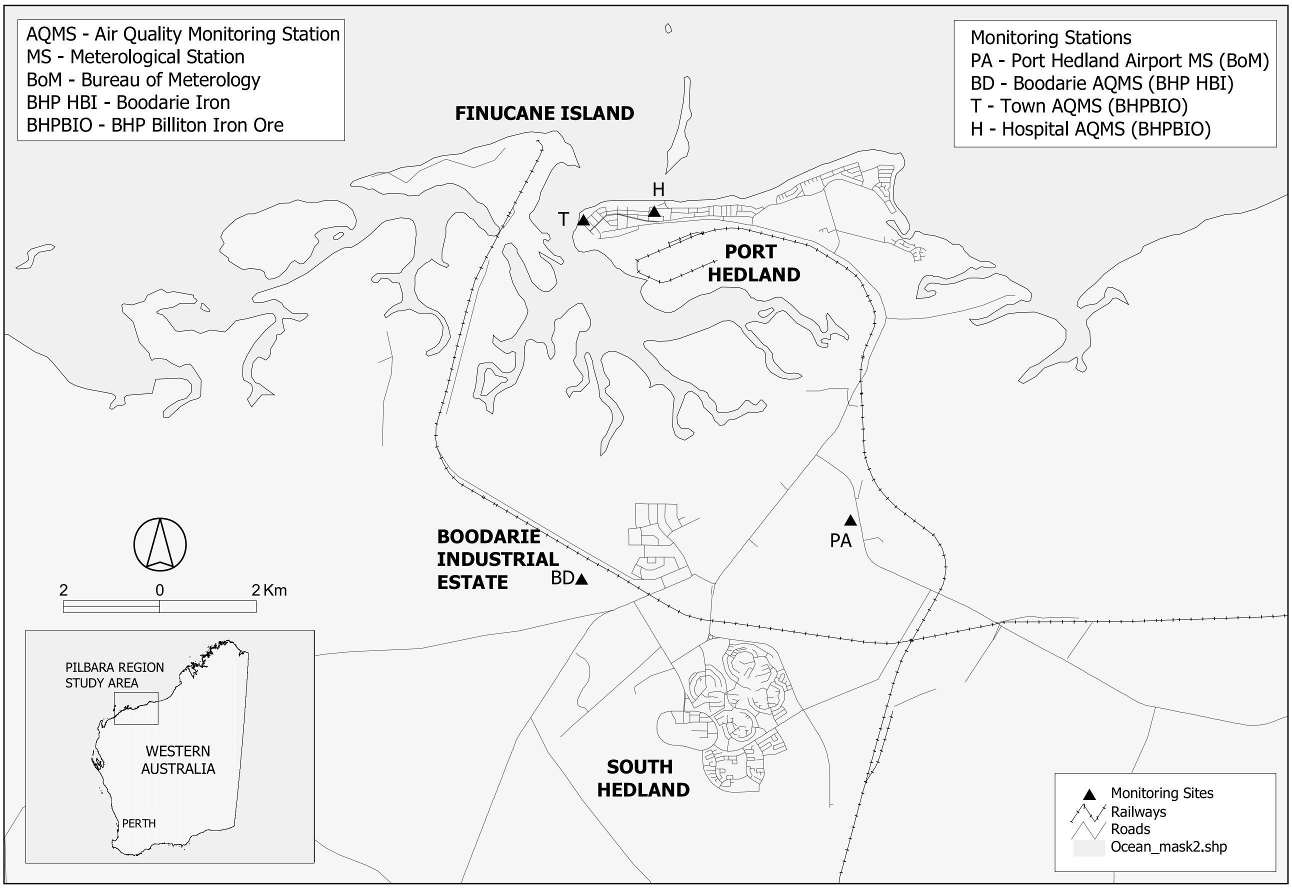


Figure 2.2 Monitoring stations in study region (eastern portion)

measurements have been supplemented with occasional spot monitoring as and when required using photography, dust deposition and hand-held PM_{10} / $PM_{2.5}$ monitors together with increased frequency of data collection (one day in three) at existing stations. Subsequent to this Study, Hamersley Iron have installed additional particulate monitors including continuous recording instruments at Dampier Primary School and Karratha.

Prior to 1996 there appears to have been no significant ambient monitoring of pollutant gases such as oxides of nitrogen, ozone, hydrocarbons, carbon monoxide or sulfur dioxide in the Pilbara region. Monitoring after 1996 is described in the next section.

Woodside and its consultants conducted meteorological monitoring in the early-mid 1980s, providing data for modelling of air quality. These data are not adequate for current purposes and have not been widely available.

Bureau of Meteorology weather stations have been present in the Pilbara for many years (e.g. at the Dampier Salt facility, established 1969). Stations with manual observations taken several times per day have been progressively replaced with automatic stations, providing time-continuous data in computer format. The Bureau of Meteorology currently operates automatic stations at the Karratha and Port Hedland airports and Legendre Island.

2.2 The study monitoring program

The Pilbara Air Quality Study monitoring network was established to support the investigation of coastal meteorology and dispersion, while at the same time gathering a record of current (1998-2000) air quality at Dampier. Particulate monitoring by Hamersley Iron and BHP was not duplicated, apart from one instrument at Dampier. The network and associated activities are summarised below to provide an overview and rationale of the monitoring program.

Figures 2.1 and 2.2 are maps of the Karratha-Dampier-Wickham and Port Hedland areas respectively, showing two-letter codes for the monitoring sites referred to throughout this report. The Burrup Peninsula extends north-east from Dampier, as seen in Figure 2.1.

Figure 2.3 Dampier air quality monitoring station

A baseline air quality monitoring station was established in Dampier (DA). The station, seen in Figures 2.3 and 2.4, is next to the ocean, with no road between it and the ocean. A primary purpose of this monitoring station was to measure secondary pollutants (ozone and nitrogen dioxide) which were expected to be blown onshore in sea breezes (recirculated from emissions released earlier in offshore winds). The absence of upwind roads ensured that concentrations of ozone would not be depleted by nitric oxide emitted by motor vehicles. This station was also sited appropriately to measure the direct impact of industrial emission on the township, and fine particulate matter from the two iron ore loading facilities (having line of sight to both). Meteorological data was also collected at the site. The site was not ideal for meteorological measurements (there being some wind sheltering effects). Woodside installed a meteorological station near its plant on the Burrup Peninsula to provide data applicable to the peninsula area, but this unfortunately did not occur soon enough to provide data for the main study period. There remains a need for high quality meteorological data on the Burrup Peninsula, particularly in view of the proposed industrial developments.

A second air quality monitoring station, owned and operated by Woodside, was sited at King Bay (KB) for the period November 1998 to October 1999, and then moved to a site to the north of the Karratha township (KT) for the period November 1999 to October 2000, in order to obtain a more detailed picture of the distribution of primary and secondary pollutants. This was not considered to be a baseline monitoring station and its data has not been analysed as such. Rather, the purpose of the station was to gather data over periods of time adequate for model testing purposes. The station also monitored wind.

In the Port Hedland area, an air quality monitoring and meteorological station, owned by Boodarie Iron (BHP Billiton), has been operated on the Boodarie industrial estate (hereafter "Boodarie" or site BD) since December 1996 (meteorological parameters have been measured at this site since 1992). This station measures concentrations of primary air pollutants, including both PM_{10} and $PM_{2.5}$. Particulate matter (TSP, PM_{10} and $PM_{2.5}$) and basic meteorology are also monitored at other sites around Port Hedland to assess the impact of BHP Billiton's iron ore facilities.

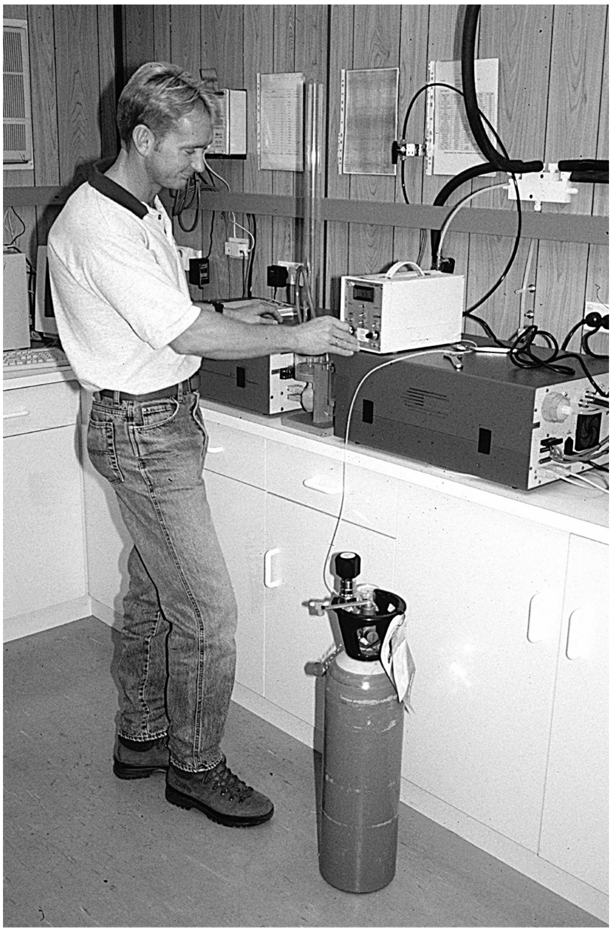


Figure 2.4 Calibration of instruments in the Dampier air quality monitoring station

Figure 2.5 Karratha Station meteorological station

A comprehensive meteorological station (KA) was sited on Karratha Station 12 km to the west south west of Karratha townsite (Figures 2.5). This station was located remote from towns and from sources of noise to allow the operation of a sodar, which measures wind speed and direction at equally spaced height intervals (50 metres in this case) up to several hundred metres above ground level. The site was close to the Maitland industrial estate, and is representative of the near-coastal meteorology of the region. In addition to the measurement of upper air winds, other less common measurements valuable for modelling purposes were made at KA, including net radiation and air temperature difference (2 to 10 metres). The mast was located a few metres south of the shed to obtain representative measurements of air temperature difference in offshore flow.

Information on the wind patterns of the region was of prime importance. In addition to the meteorological measurements described above, wind and other meteorological parameters were obtained from the following:

- Automatic weather stations at Karratha Airport (KP), Port Hedland Airport (PA), and Legendre Island (LG), operated by the Bureau of Meteorology.

- Meteorological stations at Wickham (WI), and at Radio Hill Nickel Mine (RN) south of Karratha, operated by the DEP. The Wickham station provided data for the Cape Lambert area of the study region, and the Radio Hill station location was chosen mainly to provide data on the inland advancement of sea breezes.

- A meteorological station on the proposed Maitland industrial estate (MT), operated by the Department of Resources Development (DRD).

Vertical profiles of wind were measured by the sodar at Karratha Station (KA), as described above. In addition, vertical profiles of both wind and temperature were routinely obtained from radiosonde releases by the Bureau of Meteorology at Port Hedland (PA). The Bureau of Meteorology also assisted the CSIRO and DEP with extra

Table 2.1 Summary of the monitoring program

SITE	Code	Start Date	End Date	O_3	NOx	CO	SO_2	PM_{10}	$PM_{2.5}$	WS	WD	AT10	AT02	RH/DP	SRad	NRad	Pres	Sodar
Dampier [1]	DA	05/98	01/01	●	●	●		●		●	●	●		●	●		●	
King Bay [2]	KB	12/98	10/99	●	●		●			●	●							
Karratha Townsite [2]	KT	11/99	10/00	●	●		●			●	●							
Karratha Station [1]	KA	02/98	04/01							●	●	●	●	●	●	●	●	●
Maitland [3]	MT	09/98	09/99							●	●	●		●				
Radio Hill [1]	RN	09/99	12/00							●	●	●		●				
Karratha Airport [4]	KP	01/96	Cont.							●	●		●	●			●	
Legendre Island [4]	LG	01/96	09/99							●	●		●				●	
Wickham [1]	WI	12/98	12/00							●	●	●		●				
Boodarie [5]	BD	06/97	Cont.		●		●	●	●	●	●	●	●	●	●		●	
Port Hedland Airport [4]	PA	09/98	Cont.							●	●		●	●			●	

KEY

1 – Department of Environmental Protection
2 – Woodside
3 – Department of Resources Development
4 – Bureau of Meteorology
5 – BHP

O_3	Ozone
NOx	Nitrogen dioxide
CO	Carbon monoxide
SO_2	Sulfur dioxide
PM_{10}	Particles less than 10 micrometres in diameter
$PM_{2.5}$	Particles less than 2.5 micrometres in diameter
WS	Wind speed at 10 metres
WD	Wind direction at 10 metres
AT10	Air temperature at 10 metres
AT02	Air temperature at 2 metres or similar
RH/DP	Relative humidity or dew point temperature
Pres	Air pressure
SRad	Solar radiation
NRad	Net radiation
Sodar	Doppler acoustic sounder
Cont.	Monitoring is continuing

radiosonde releases during two intensive field measurement programs, and conducted additional releases on request.

A summary of the monitoring program is given in Table 2.1. This table indicates, for each of the monitoring sites mentioned above, the parameters measured and the start and end dates of measurement. Radiosonde information is not included, as the table relates only to continuously measuring instruments. Except for Bureau of Meteorology automatic weather stations, all monitoring stations measured and logged data as 10-minute averages. DEP (2002a) provides a detailed description of monitoring stations operated by the DEP and provides information on the reliability and percentage recovery of data. Significant points relating to data reliability and recovery were:

- The TEOM (Tapered Element Oscillating Microbalance) PM_{10} monitor at Dampier failed during three periods totalling 43 days, due to high humidity levels causing condensation problems (requiring custom-made modifications).
- Due to an error in data logger programs, wind speeds recorded prior to 12 March 1999 are correct below 11 metres per second but not above. This error is not important for most air pollutant dispersion applications. Bureau of Meteorology data can be substituted in windy periods.
- Temperature difference measurements at Boodarie were generally unreliable. Temperature difference data at Karratha Station also showed a drift in accuracy for a period of five months from mid October 1999.
- Operation of the sodar at the remote Karratha Station site was problematic, due to instrument failure and a need to shut the instrument down during the cyclone season. Data from this instrument, although intermittent, has nevertheless been valuable in understanding the regional meteorological patterns.

Various other comments on instrument problems and data reliability are contained in DEP (2002a).

3 Emissions in the Karratha Region

An inventory of emissions to air in the Karratha Region was undertaken to provide input data for the evaluation of computer models. The inventory is described in detail in DEP (2004a) and summarised here.

The inventory of emissions for the Karratha-Dampier-Burrup airshed was compiled for the 1999 calendar year. The study region encompassed an area of approximately 1,023 square kilometres and included the townships of Karratha and Dampier, the Burrup Peninsula and a section of the North West Coastal Highway.

The pollutants evaluated for this emission inventory were:

- Carbon monoxide (CO);
- Oxides of nitrogen (NO_x);
- Volatile organic compounds (VOCs);
- Sulfur dioxide (SO_2);
- Particles (as PM_{10}) (limited inventory, as explained below).

Emissions were estimated for five source categories. These source categories were:

- *On-road motor vehicles*
  – motor vehicles registered for on-road use;
- *Other mobile sources*
  – railways and ore handling, shipping and aircraft;
- *Biogenic sources*
  – vegetation, soil and the ocean;
- *Industrial sources*
  – Woodside and Hamersley Iron facilities;
- *Area based sources*
  – domestic and commercial / light industrial fuel combustion;
  – architectural surface coatings and thinners;
  – automotive refinishers;
  – park management;
  – service station and refuelling;
  – cutback bitumen;
  – dry cleaning.

It is important to note that PM_{10} emissions from natural sources (notably wind blown dust and bushfire smoke) have not been estimated as part of this inventory. These sources are very significant in the study area, however due to a lack of data and appropriate emission factors they have not been quantified.

The annual emissions from the five source categories are summarised in Table 3.1. The relative contributions of these sources to total emissions are summarised in Table 3.2.

Table 3.1 Annual emission (tonnes/year) from source categories during 1999

Emission Source Category	CO	NO_x	VOCs	SO_2	PM_{10}
Area Based	11	2	78	ne	0.1
Other Mobile	268	1225	51	647	867
Motor Vehicles	2046	367	386	9	33
Biogenic	0	679	2697	0	0
Industry	566	10567	61088	92	12
Total airshed emissions)	2891	12840	64300	748	912

Note: ne = negligible

Table 3.2. Contribution (%) of source categories to total airshed emissions

Emission Source Category	CO	NO_x	VOCs	SO_2	PM_{10}
Area Based	0.4%	0.02%	0.1%	ne	0.01%
Other Mobile	9.3%	9.5%	0.1%	86.5%	95.1%
Motor Vehicles	70.8%	2.9%	0.6%	1.2%	3.6%
Biogenic	0%	5.3%	4.2%	0%	0%
Industry	19.6%	82.3%	95%	12.3%	1.3%

Note: ne = negligible

Based on these five source categories, Other Mobile sources contributed most of the sulfur dioxide (86.5%, mostly from shipping) and particulate (95%) emissions to the Karratha-Dampier-Burrup airshed. On-road Motor Vehicles were estimated to contribute the largest proportion of carbon monoxide (70.8%) to the study area. However, Industry was the single largest contributor to emissions in the airshed, contributing 95% of the volatile organic compounds, 82.3% of the oxides of nitrogen and 19.6% of the carbon monoxide. The bulk of Other Mobile emissions is also associated with industrial activity or servicing.

The above results are presented as pie charts below with the exception of PM_{10} (it would be misleading to chart PM_{10} since the dominant sources are not quantified).

There is always uncertainty in emissions inventories and, for this reason, there is a need to review estimates as better information or estimation procedures become available. The relative significance of emissions from various source needs to be assessed not simply on the basis of quantity, but also on the basis of the impact on ambient concentrations in the region, as predicted by computer models. Persons intending to use the study emissions inventory should check with the DEP to determine the current status of emissions estimates and obtain advice on how these estimates should best be employed in computer models.

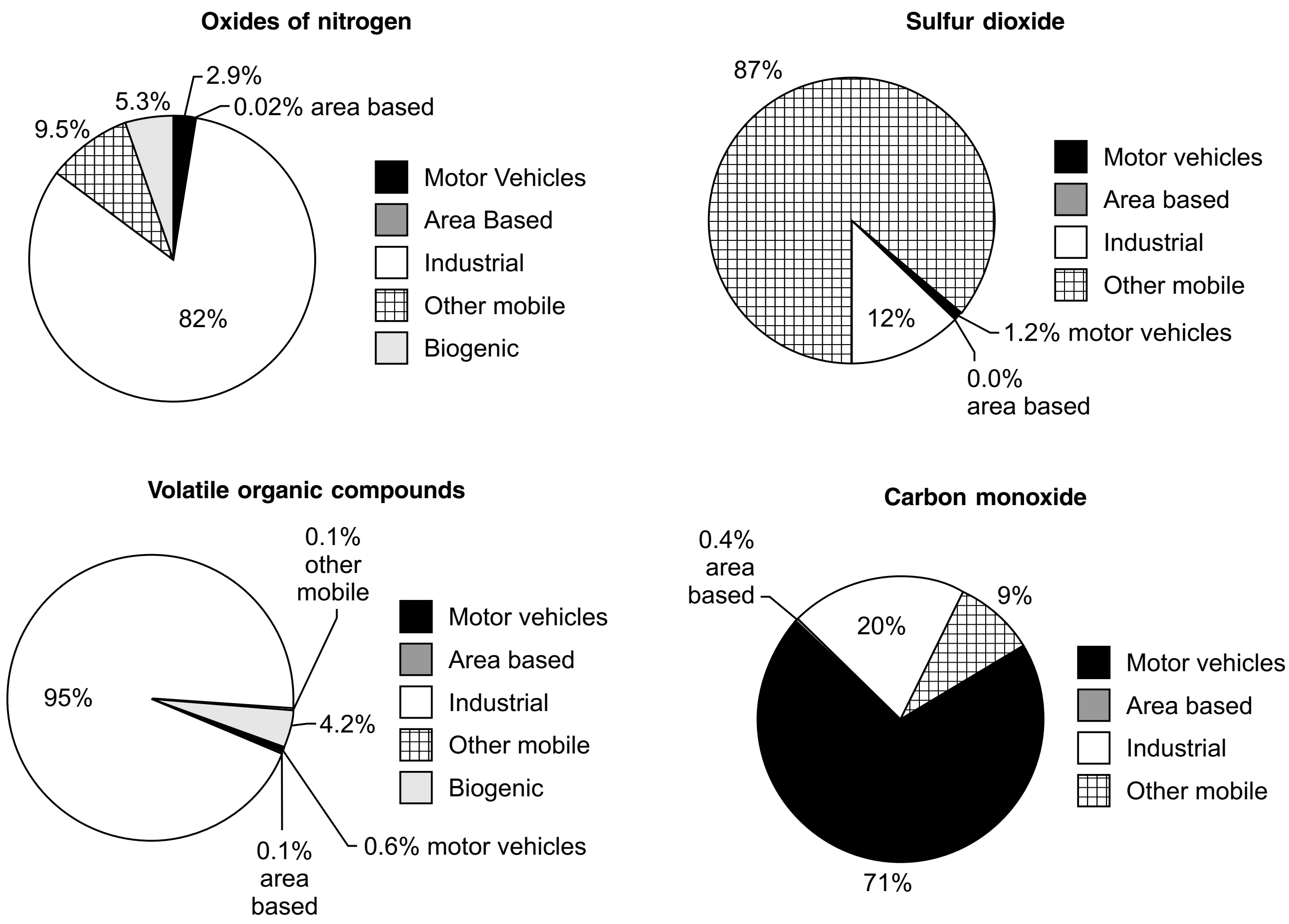


Figure 3.1 Contribution (%) of source categories to total airshed emissions

4 Overview of current air quality

The National Environment Protection Measure for Ambient Air Quality (hereafter "NEPM"), established in 1998, sets standards and a goal for six common air pollutants. These are as listed in Schedule 2 of the NEPM, a copy of which appears in Appendix A.

A review of the health effects of the six NEPM pollutants is given in the NEPM Impact Statement (NEPC, 1998). A review of the health effects of particulate matter is given in the document 'Impact Statement for $PM_{2.5}$ Variation' (NEPC, 2002) which addresses the need for a $PM_{2.5}$ standard in Australia. Both documents are available from http://www.ephc.gov.au. Health effects will not be reviewed in this report.

The Dampier and Boodarie monitoring stations provide a measure of air quality in the Karratha-Dampier-Burrup and Port Hedland areas, having operated for two and three calendar years at these sites respectively during the study period. The various pollutants monitored at these stations are examined below, generally in the order of current significance, and assessed against the relevant NEPM standards. High Volume Sampler measurements of PM_{10} and $PM_{2.5}$ around Port Hedland are included in the assessment.

4.1 Particulate matter measured as PM_{10}

Figure 4.1 shows that concentrations of PM_{10} measured by TEOM instruments at both the Boodarie and Dampier monitoring stations are high, with the NEPM standard of 50 micrograms per cubic metre being exceeded more than the goal of 5 times in each year except for 1999 at Dampier.

The NEPM standard was exceeded 10 times at Boodarie in 1998, 8 and 3 times at Boodarie and Dampier in 1999 respectively, and 12 and 18 times at Boodarie and Dampier in 2000 respectively.

Boodarie Iron (BHP), in its year 2000 Annual Environmental Report (BHP HBI, 2000), identified all except one of the exceedences of the NEPM standard at the Boodarie station as being caused by either dust storms or bushfires. Seven of the exceedences occurred in October 2000. BHP and DEP staff have independently used available satellite images to confirm the presence of very large bushfire smoke plumes which caused high PM_{10} concentrations in October 2000 (see DEP 2002a Appendix D). Images from the NASA Total Ozone Mapping Spectrometer (TOMS) on the Earth Probe satellite provide a measure of UV-absorbing tropospheric aerosols (solid and liquid particles). The example in Figure 4.2 shows a smoke plume across the Pilbara coastal area on 10 October 2000 due to inland fires. The 24-hour average PM_{10} concentrations for this day were 80.8 micrograms per cubic metre at Dampier and 98.3 micrograms per cubic metre at Boodarie, both exceeding the NEPM standard.

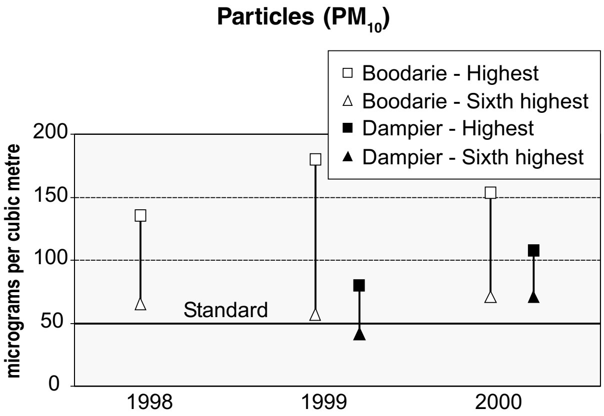


Figure 4.1 Summary of PM_{10} data from the Boodarie and Dampier monitoring stations, showing the highest and sixth highest 24-hour average concentration measured at each site each year. The sixth highest must be less than the standard to achieve compliance with the NEPM.

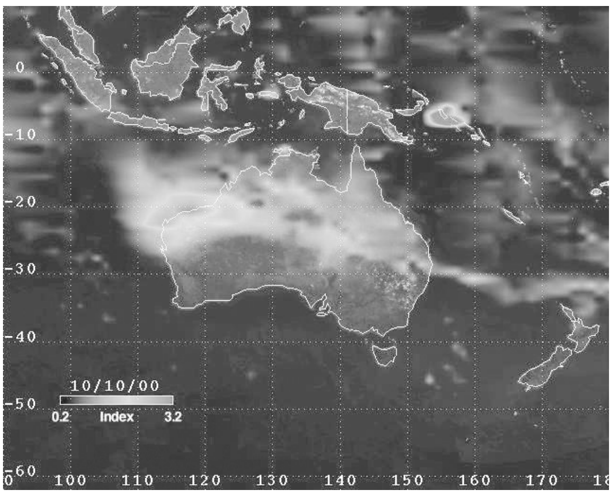
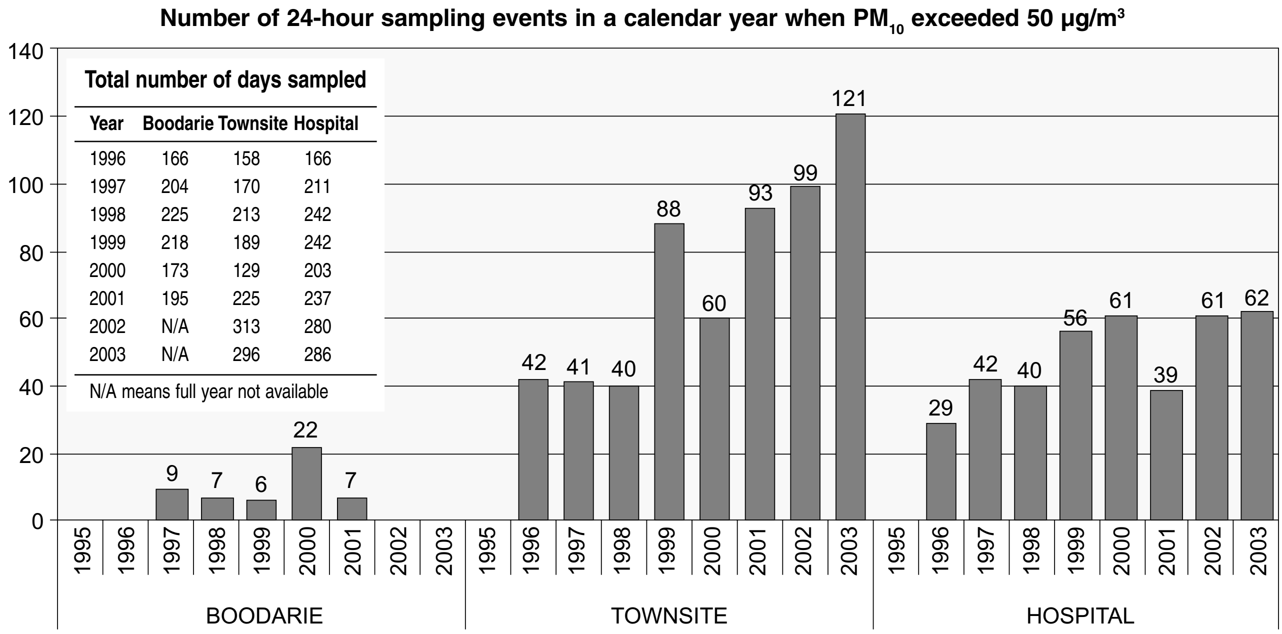


Figure 4.2 Smoke from inland bushfires detected by the NASA Total Ozone Mapping Spectrometer (TOMS) on the Earth Probe satellite for 10 October 2000.



Year	Boodarie	Townsite	Hospital
1996	166	158	166
1997	204	170	211
1998	225	213	242
1999	218	189	242
2000	173	129	203
2001	195	225	237
2002	N/A	313	280
2003	N/A	296	286

N/A means full year not available

Figure 4.3 Number of days in each calendar year on which the 24-hour average PM_{10} concentration exceeded the NEPM standard of 50 micrograms per cubic metre. Note that the number of exceedences is related to the number of days sampled (see inset table). The Townsite increase in 2003 reflects the greater number of days sampled.

The maximum daily averages of PM_{10} during the October 2000 fires occurred on 18 October 2000, being 152 and 107 micrograms per cubic metre at Boodarie and Dampier respectively.

Independent of the TEOM PM_{10} measurements undertaken by Boodarie Iron at the Boodarie monitoring site, BHP Billiton Iron Ore has measured PM_{10} at three sites (Town, Hospital and the Boodarie monitoring station) over several years via High Volume Samplers (BHPBIO, 2002). These sites are shown on Figure 2.2. Figure 4.3 shows the number of exceedences of the NEPM standard out of the total number of days sampled each year (see inset table).

The number of exceedences of the 24-hour NEPM standard at both the Town and Hospital sites is very large for all years compared to the NEPM goal of 5 per year. In fact, at the Town monitoring station, the annual average PM_{10} for both 1999 and 2000 exceeded 50 micrograms per cubic metre, more than twice the annual average at Boodarie. The number of 24-hour average exceedences at the Boodarie monitoring station was also much lower, the highest being 22 in 2000 as measured by a High Volume Sampler compared to 12 exceedences as measured by the nearby TEOM. As results from Boodarie Iron showed that only one of the 12 days was caused by dust from the plant stockpiles, with the remaining 11 being caused by regional or local fires, it is possible that most of the 22 High Volume Sampler exceedences could be similarly explained. The disparity between TEOM and High Volume Sampler exceedences warrants further investigation, but it is likely to be explained at least in part by the loss of semi-volatile aerosols by the TEOM during bushfire smoke events.

To investigate the extent to which the dust concentrations within the town of Port Hedland are dominated by local sources (iron and other metal ore stockpiles, other industry and associated traffic, etc.), a simple analysis was performed as follows. The Boodarie High Volume Sampler is obviously influenced to some extent by local anthropogenic (man-made) dust (whether from the HBI operations or other local sources), but for the sake of argument we will assume it measures only regional (background) dust, smoke and other particles. For every day on which High Volume Sampler data is available for both the Town and Boodarie stations, the measured Boodarie PM_{10} concentration has been subtracted from the Town concentration, to indicate approximately what concentration must be attributable to sources within and immediately adjacent to Port Hedland. Figure 4.4 shows the number of exceedences at the Boodarie and Town sites for the reduced number of days during which both were operating (the graphs may be compared to Figure 4.3) and also the number of exceedences which remain at the Town site after day by day subtraction of Boodarie concentrations.

The analysis demonstrates that even if there was zero background PM_{10}, the local sources of PM_{10} affecting the

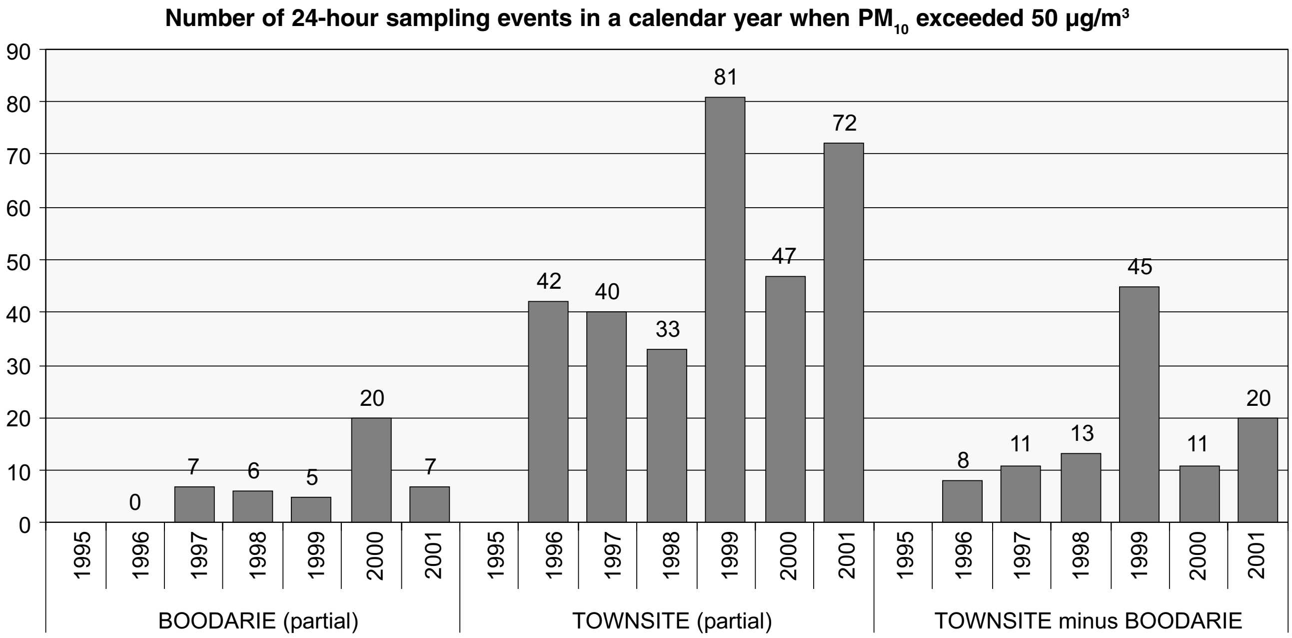
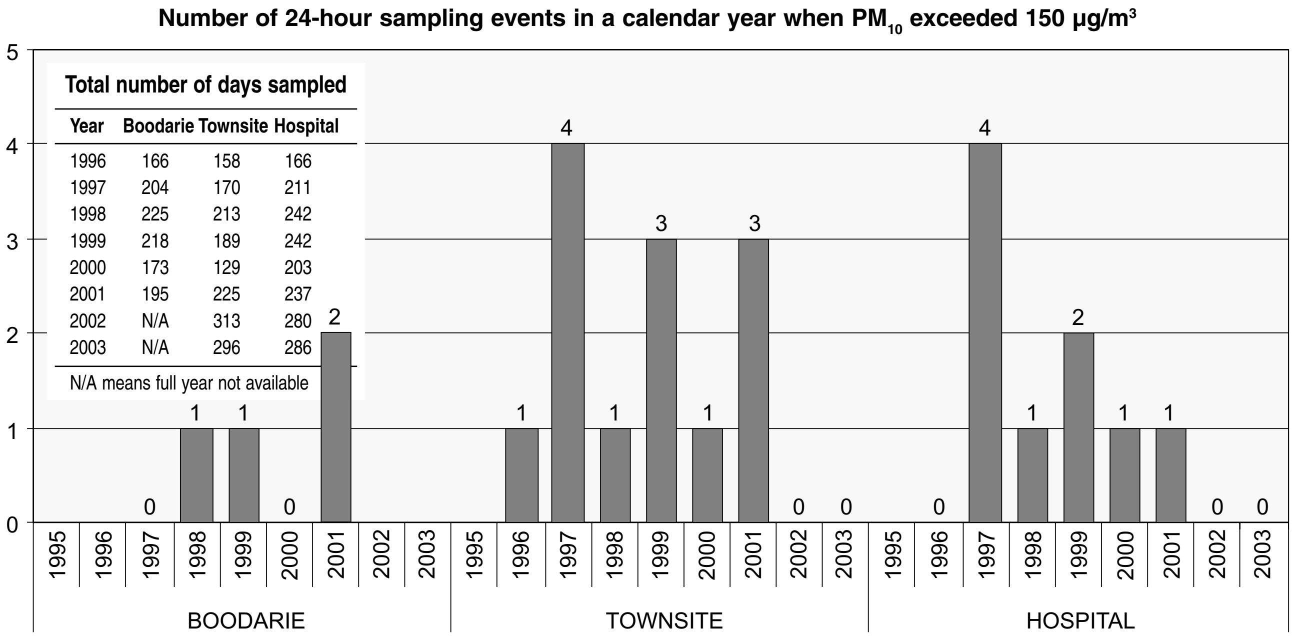


Figure 4.4 For days on which both the Boodarie and Town High Volume Samplers were operating, this graph shows the number of days in each calendar year for which the 24-hour average PM_{10} concentration exceeded the NEPM standard of 50 micrograms per cubic metre for the two monitoring sites, and for the Town site after day by day subtraction of the concentration from the Boodarie site.



Year	Boodarie	Townsite	Hospital
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1997	204	170	211
1998	225	213	242
1999	218	189	242
2000	173	129	203
2001	195	225	237
2002	N/A	313	280
2003	N/A	296	286

Figure 4.5 Number of days in each calendar year for which the 24-hour average PM_{10} concentration exceeded 150 micrograms per cubic metre.

Town High Volume Sampler would cause the NEPM goal of 5 days per year to be exceeded. The analysis underestimates the local contribution by being constrained to use data for days when both samplers are operating (about half the days in a year) and by including the local anthropogenic contribution of PM_{10} at Boodarie in the assumed background level.

A High Volume Sampler measuring PM_{10} was installed at the Bureau of Meteorology (BoM) station near the Port Hedland Airport in mid 2002 (see site PA in Figure 2.2). In the first full year, 2003, there were 15 exceedences of the NEPM standard at this site. The site may reasonably be assumed to represent natural background concentrations.

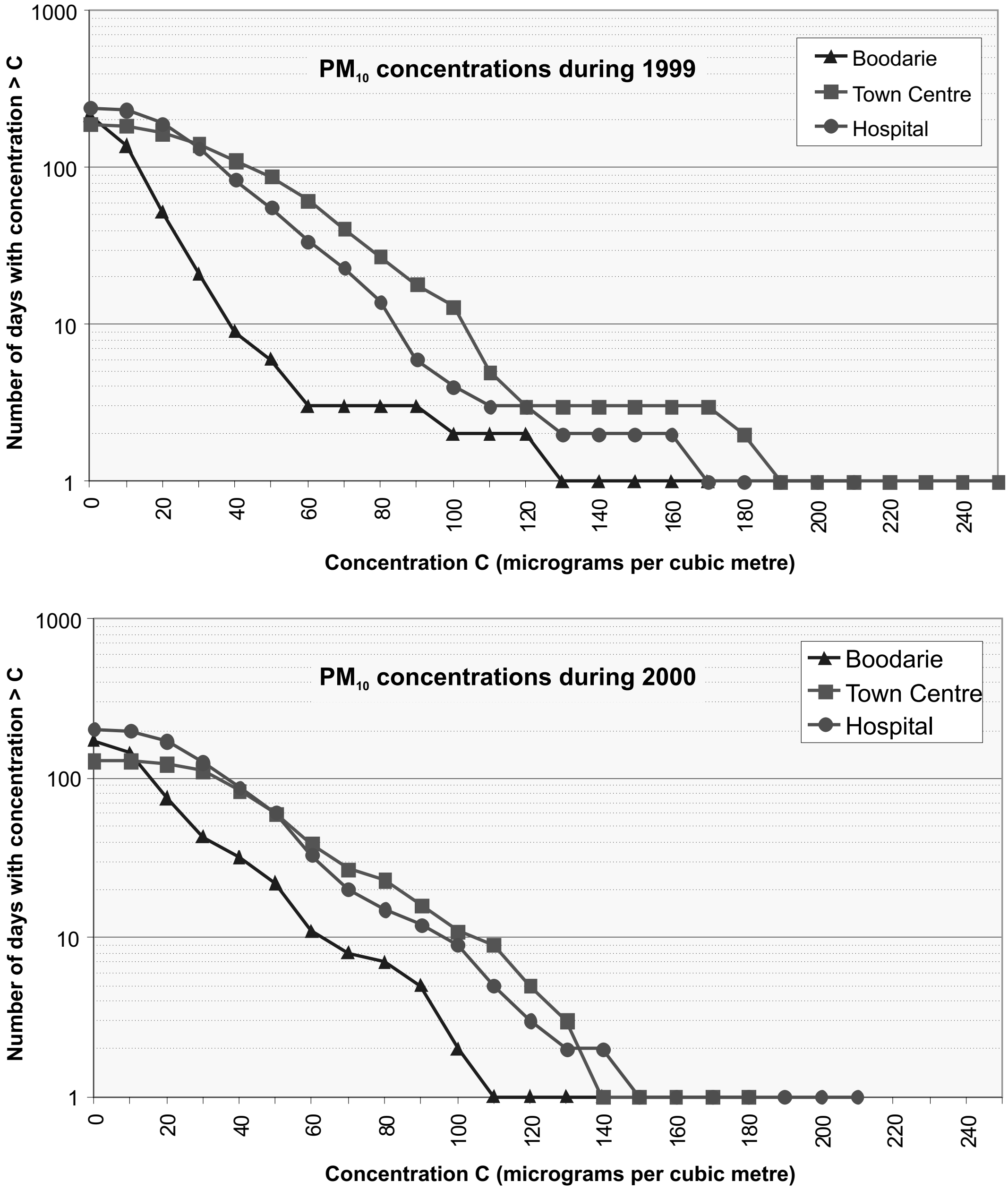


Figure 4.6 Cumulative frequency graphs showing, for three monitoring stations during 1999 and 2000, the number of days with 24-hour averaged concentration greater than the value shown on the horizontal axis.

BHP Billiton Iron Ore has a target for PM_{10} of 150 micrograms per cubic metre averaged over 24 hours. This target has historically been exceeded a small number of times per year as shown in Figure 4.5. The target was not exceeded at any site in 2002 or 2003.

The cumulative frequency graphs for two years in Figure 4.6 provide an alternative way to look at the comparison of data from the three PM_{10} monitoring sites. The number of day's data for each site is listed in Figure 4.3. Noting that the vertical axes have log scales, the greater overall 24-hour average PM_{10} particulate loading at the two sites in Port Hedland can be clearly seen.

In summary, despite the large contribution of natural events (bushfires and wind-blown dust) to PM_{10} levels in the Pilbara region, it is clear that overall concentrations of PM_{10} in the Port Hedland town area are dominated by dust from local sources (ore handling facilities and other activities in the immediate vicinity of the town).

The contribution of dust from ore handling facilities to the PM_{10} concentrations measured at the Dampier monitoring station is also significant. This can be seen from the "pollution rose" in Figure 4.7, which is a polar plot of the annual average of PM_{10} concentrations measurements in each of 72 five degree wind direction sectors for 1999. The lobes in the plot, centred on the directions of approximately 40 and 260 degrees, point to

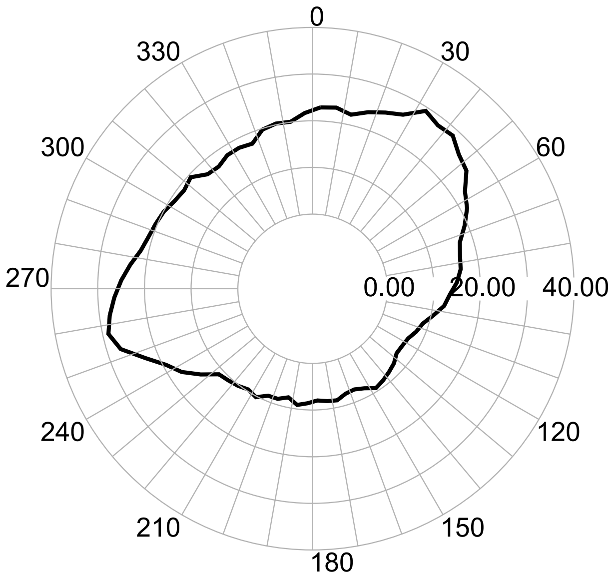


Figure 4.7 Polar plot, for the Dampier monitoring station, of the annual average of PM_{10} concentrations measurements in each of 72 five degree wind direction sectors for the 1999 calendar year.

the iron ore handling facilities at Parker Point and East Intercourse Island respectively.

Management of PM_{10} particulates from iron ore operations in Port Hedland and Dampier is clearly an ongoing priority for the respective companies. Both BHP and Hamersley Iron have dust management programs in place.

4.2 Particulate matter measured as $PM_{2.5}$

The National Environment Protection Council made a variation to the NEPM on 23 May 2003 to include advisory reporting standards and a goal for particles as $PM_{2.5}$ (NEPC, 2003). The advisory reporting standards for $PM_{2.5}$ are 25 µg/m^3 for a 1 day average, and 8 µg/m^3 for an annual average. The goal is to gather sufficient data nationally to facilitate a review of the advisory reporting standards as part of the review of the NEPM scheduled to commence in 2005.

A summary of $PM_{2.5}$ standards from other countries is contained in the Impact Statement for $PM_{2.5}$ Variation (NEPC, 2002). This document and the NEPM variation are available from the Environment Protection and Heritage Council website http://www.ephc.gov.au.

Figure 4.8 shows data from the TEOM at the Boodarie monitoring station measuring $PM_{2.5}$, presented in the same form as previously shown for PM_{10}, i.e. highest and sixth

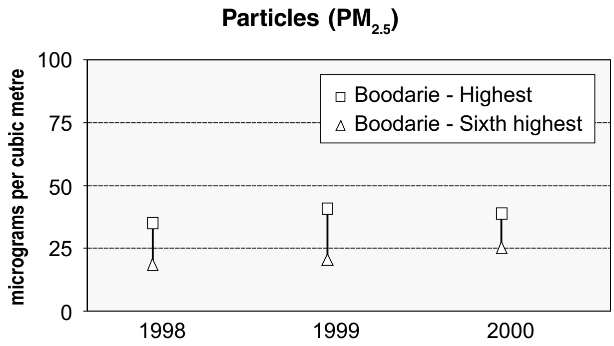


Figure 4.8 Summary of $PM_{2.5}$ data measured by a TEOM at the Boodarie monitoring station, showing the highest and sixth highest 24-hour average concentration each year.

highest 24-hour averages for each year of operation. The sixth highest average has been included solely to assist comparison with PM_{10}; it is not part of the proposed NEPM variation.

The highest recorded 24-hour averages exceeded the proposed advisory reporting standard of 25 µg/m^3 (24-hour average) in each year. The annual average $PM_{2.5}$ concentrations measured via TEOM at Boodarie for the years 1998 to 2000 were 7.6, 7.8 and 9.0 respectively.

BHP Billiton Iron Ore commenced monitoring $PM_{2.5}$ via High Volume Sampler at the Town site in 2001. Monitoring of $PM_{2.5}$ via High Volume Sampler also commenced at the BoM station (site PA) in 2002. Data from these two sites for the available full calendar years are plotted in Figure 4.9 as cumulative frequency graphs, in the same form as Figure 4.6.

As can be seen from Figure 4.9, the $PM_{2.5}$ concentrations measured at the Town site are much greater than at the BoM site. In the year 2003 at the Town site (298 measurement days), 24-hour averaged $PM_{2.5}$ concentrations exceeded 25 micrograms per cubic metre 122 times, 30 micrograms per cubic metre 86 times, 50 micrograms per cubic metre 23 times and 70 micrograms per cubic metre 4 times. The annual average of the $PM_{2.5}$ concentrations at the Town site in 2003 was 26 micrograms per cubic metre.

The ratio of $PM_{2.5}$ to PM_{10} is of interest, given the focus on $PM_{2.5}$ in relation to health effects. In urban areas such as Perth, the annual average ratio is typically 0.5 to 0.6. At the Duncraig monitoring station (suburban Perth) where PM_{10} and $PM_{2.5}$ TEOMs run side by side, the ratio exceeds 0.9 during high particulate events caused by domestic wood fires in winter or smoke from remote bushfires. The ratios determined from the Boodarie TEOM monitors over three years are shown in Table 4.1.

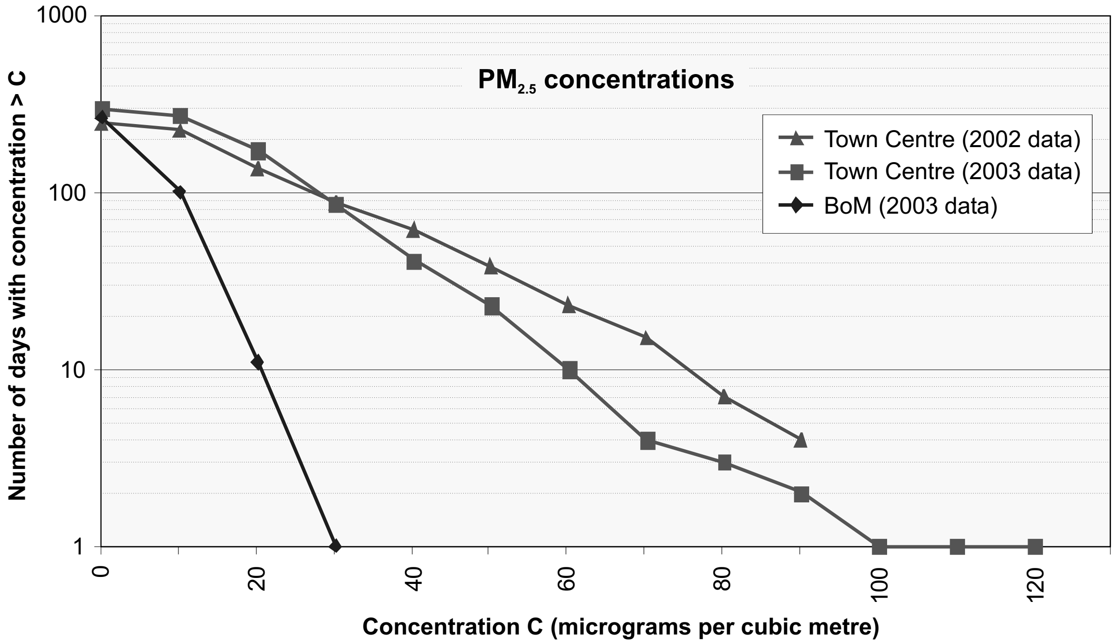


Figure 4.9 Cumulative frequency graphs showing, for the Town site (2002 and 2003) and Bureau of Meteorology site (2003), the number of days with 24-hour averaged $PM_{2.5}$ concentration greater than the value shown on the horizontal axis.

Table 4.1 Annual average particle concentrations at Boodarie.

Year	PM_{10}	$PM_{2.5}$	Ratio $PM_{2.5}/PM_{10}$
1998	19.4	7.6	0.39
1999	18.9	7.8	0.41
2000	20.1	9.0	0.45

These ratios are lower than those found in Perth, reflecting greater contribution of coarser particulate matter from crustal material in the Pilbara. The Boodarie data for 2000 have been plotted as a scatter graph in Figure 4.10 to show the distribution of time-paired 24-hour measurements of $PM_{2.5}$ and PM_{10}. The line on the graph shows a ratio of 1.0.

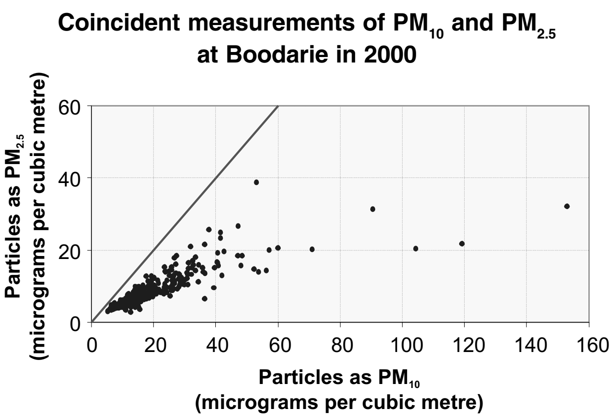


Figure 4.10 Time-paired 24-hour measurements of $PM_{2.5}$ and PM_{10} at the Boodarie monitoring station for the year 2000.

Recalling that 2000 was a year with significant bushfire events, it is interesting to note the small number of data points with high ratios. There appears to be data from the High Volume Samplers at the Town site showing higher ratios, however further analysis of these data is required.

4.3 Nitrogen dioxide

Figure 4.11 shows the 1-hour average concentration of nitrogen dioxide (NO_2) at the Boodarie and Dampier monitoring stations.

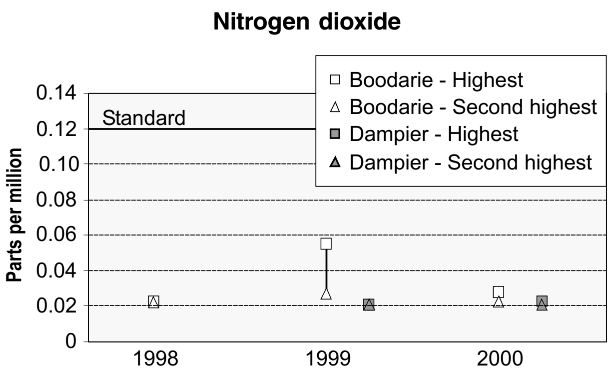


Figure 4.11 Summary of NO_2 data from the Boodarie and Dampier monitoring stations, showing the highest and second highest 1-hour average concentration measured at each site each year. The second highest must be less than the standard to achieve compliance with the NEPM.

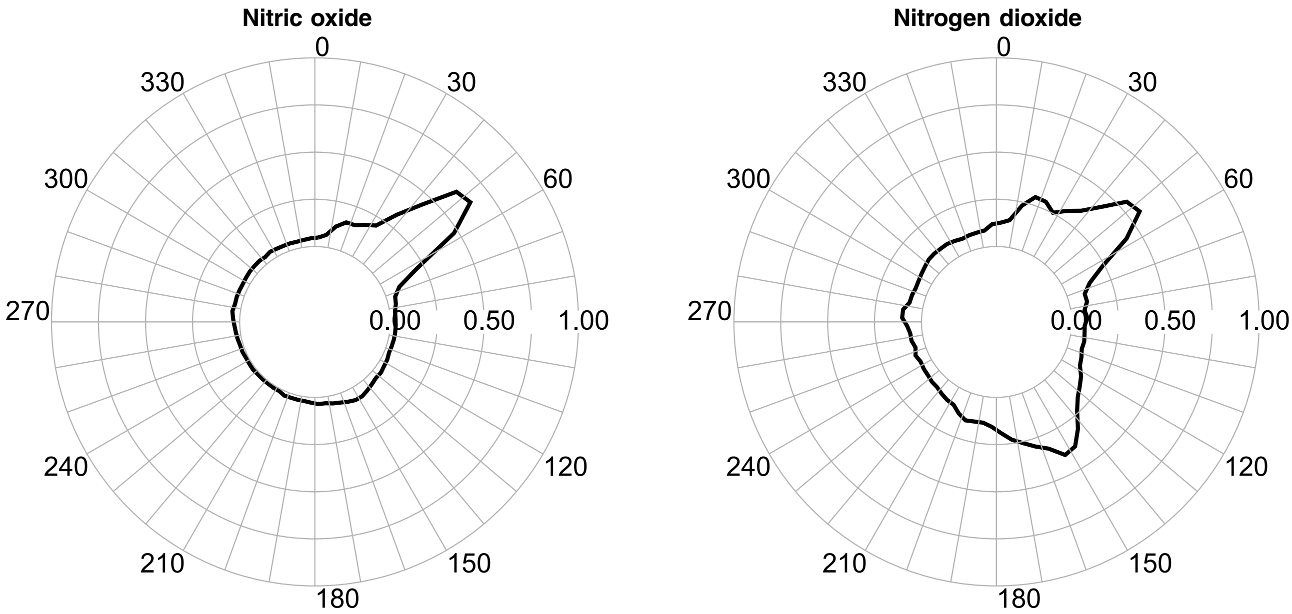


Figure 4.12 Pollution roses for average concentrations of nitric oxide and nitrogen dioxide (parts per hundred million) in each of 72 five degree wind direction sectors for the 2000 calendar year, measured at the Dampier monitoring station.

NO_2 concentrations measured at Boodarie and Dampier were well below the NEPM standard in 1999 and 2000, but still reflect large NO_x emissions from industrial and other sources. Annual averages of NO_2 at Dampier and Boodarie for the two years were all 0.002 ppm, far below the NEPM standard of 0.03 ppm.

Figure 4.12 shows pollution roses for average concentrations of NO and NO_2 at Dampier for the year 2000. Concentration units are parts per hundred million (1 part per hundred million equals 0.01 part per million). The lobe in the NO rose points towards the existing Hamersley Power station and Woodside facility, these being the dominant sources of fresh NO_x emissions. The NO_2 rose shows a lobe towards these industries, but also shows a lobe towards the south east which is likely to be due to a combination of emissions from locomotives, road traffic and aircraft.

Physick and Blockley (2001) showed via modelling that NO_2 concentrations higher than those monitored at Dampier could occur within the region due to photochemical processes. New industries which use gas for fuel and production processes will add to the NO_2 load, reinforcing a need for ongoing surveillance of emissions.

4.4 Ozone

Ozone monitoring was included in the monitoring program with the expectation that ozone concentrations would be relatively low at the current time, due to the relatively low photochemical reactivity of current industrial VOC emissions (mainly methane and other alkanes).

Figure 4.13 shows the 1-hour average concentration of ozone (O_3) at the Dampier monitoring station.

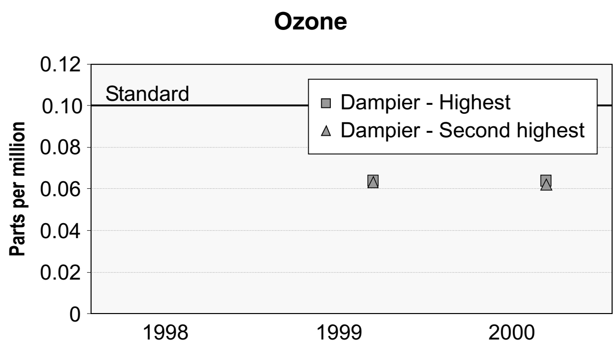


Figure 4.13 Summary of O_3 data from the Dampier monitoring station, showing the highest and second highest 1-hour average concentration measured each year. The second highest must be less than the standard to achieve compliance with the NEPM.

The highest and second highest 1-hour concentrations for the two years at Dampier exceeded 0.06 ppm, which is an appreciable level of ozone (well above natural levels). These ozone events occurred on 30/09/99, 28/11/99, 14/09/00 and 16/09/00. Examination of these four events and associated data, notably PM_{10}, revealed that they were each caused by production of ozone within smoke from bushfires. In each case the winds were moderate, excluding wind blown dust as an significant cause of the elevated

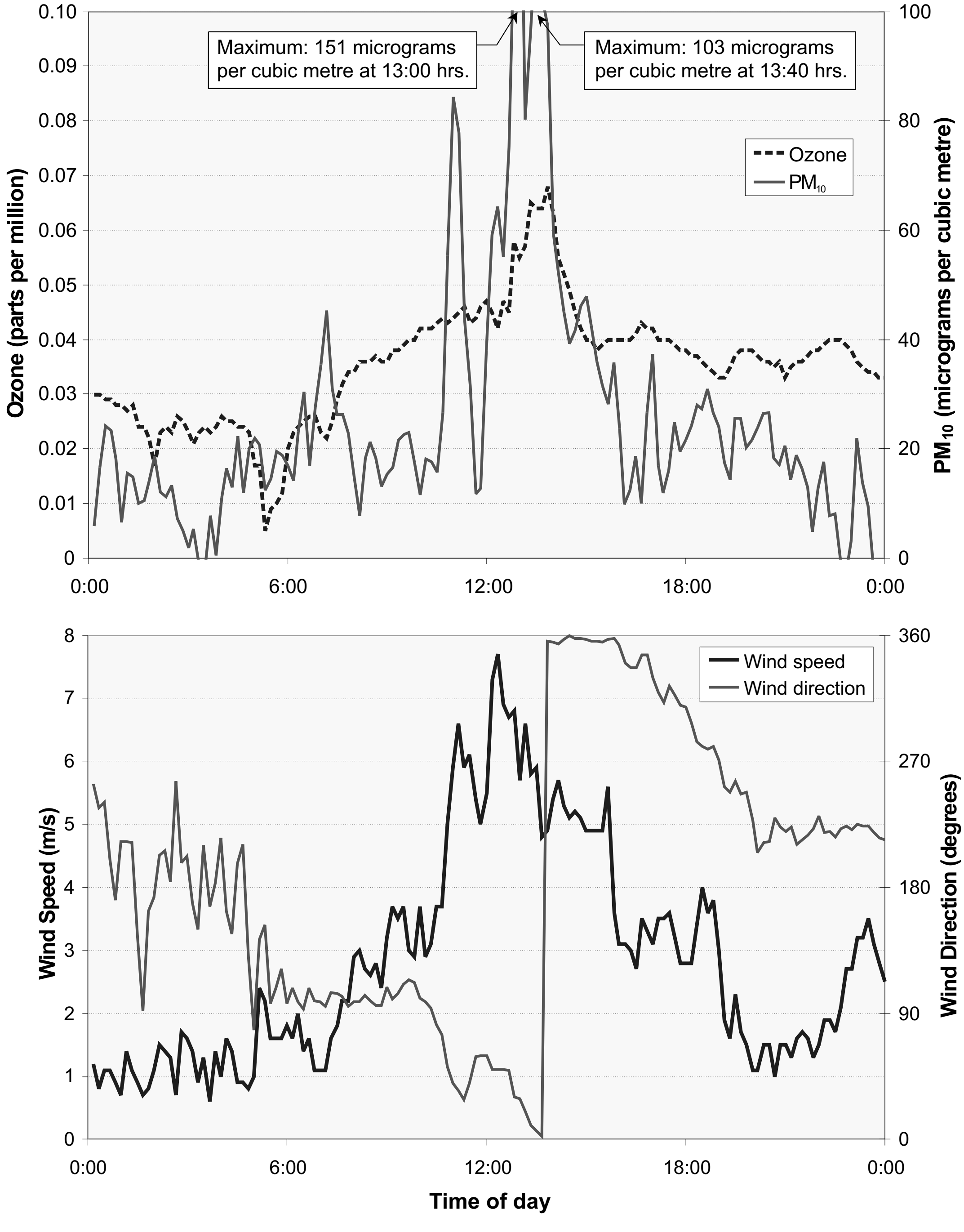


Figure 4.14 Ozone concentration for the 14 September 2000, together with PM_{10}, wind speed and wind direction. Each parameter is graphed from 10-minute average data.

PM_{10} concentrations. The winds on all of these days exhibited the same pattern; starting from west or south at midnight then rotating through south and east to northerly by midday or soon thereafter, followed by a continued rotation through west to west or south by the midnight. The significance of this type of wind pattern for the recirculation of airborne pollutants is discussed in the next section.

By way of example, the ozone concentration for 14 September 2000, on which the highest 1-hour concentration for 2000 occurred, is graphed in Figure 4.14 together with PM_{10}, wind speed and wind direction. Peak concentrations of ozone and PM_{10} (smoke) coincide in the early afternoon.

Extensive fires are quite common in the Pilbara region, especially in the spring months. In 1999, smoke was reported by the Bureau of Meteorology station at Port Hedland on 31 days in the period from September through to November, while haze was reported on a further 29 days. Fires produce both NO_x and VOC emissions that lead to ozone production. Physick and Blockley (2001) analysed the Dampier monitoring data and determined that peak values are increased by up to 20 ppb in smoky air. For the purpose of air quality assessments in the Karratha-Dampier-Burrup area, it is clearly important to consider the cumulative effects of bushfires and anthropogenic emissions. Modelling results presented in section 6 demonstrate that O_3 concentrations in the absence of bushfires can approach 0.06 ppm in the Karratha residential area.

The NEPM also specifies a 4-hour average standard for O_3 of 0.08 ppm. The highest recorded 4-hour average O_3 in 1999 and 2000 at Dampier were 0.062 and 0.057 respectively, both being significant fractions of the standard and both occurring within bushfire smoke.

4.5 Sulfur dioxide

Sulfur dioxide emissions in the region are very small due to the sulfur content of natural gas being extremely low, with consequent low emissions from industries. The emissions inventory for Karratha-Dampier-Burrup determined that the bulk of SO_2 emissions in the area came from ships, mainly when in transit. These emissions are widely distributed and relatively small in total, hence there is little likelihood of significant SO_2 concentrations in the environment. This is supported by data from the King Bay monitoring site (DEP, 2002a). The two isolated high events at the Karratha town site in July 2000, reported in DEP (2002a), have been determined to be incorrect. Otherwise, SO_2 concentrations at the Karratha town site were very low.

Sulfur dioxide has been monitored at Boodarie to determine the ambient concentrations associated with the use of an additive, dimethyl disulfide, in the HBI process (which also causes the emission of small amounts of hydrogen sulfide). Figure 4.15 shows SO_2 concentrations are very low relative to the NEPM standard.

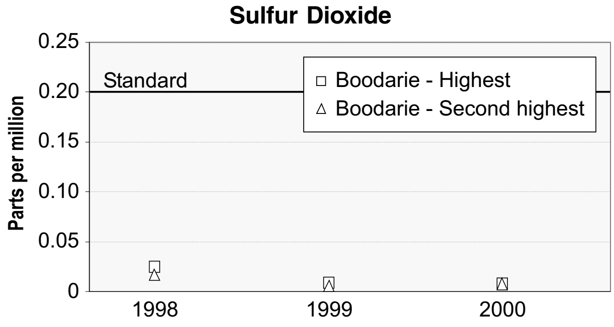


Figure 4.15 Summary of SO_2 data from the Boodarie monitoring station, showing the highest and second highest 1-hour average concentration measured each year. The second highest must be less than the standard to achieve compliance with the NEPM.

4.6 Carbon monoxide

As seen in Figure 4.16, 8-hour average carbon monoxide levels measured at Dampier are extremely low relative to the NEPM standard, reflecting the low traffic density and lack of any other sources of incomplete combustion in the area. It is unlikely the carbon monoxide will ever become an ambient pollutant issue. Carbon monoxide levels in the immediate vicinity of industries can be managed by good design and operating practice.

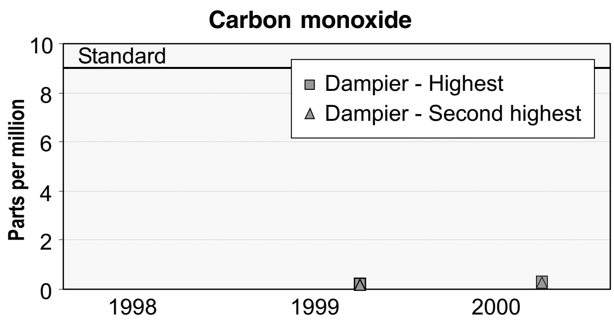


Figure 4.16 Summary of CO data from the Dampier monitoring station, showing the highest and second highest 8-hour average concentration measured each year. The second highest must be less than the standard to achieve compliance with the NEPM.

5 Air pollution meteorology

Assessment of the meteorology as it affects air pollutant dispersion, and processing of meteorological data in support of this assessment, proceeded at two levels in the Study. CSIRO Atmospheric Research, with the assistance of the DEP and other organisations, undertook a detailed field and modelling investigation of the regional meteorology. This work is described by Physick (2001) and Physick and Blockley (2001). As a separate task, the DEP processed available meteorological data for use in conventional dispersion models.

5.1 Assessment of regional meteorology

5.1.1 Phase 1

The primary objective of the first phase of work undertaken by CSIRO was to:

- Document and obtain an understanding of the year-round meteorology in the coastal area extending from the Burrup Peninsula to Port Hedland. Particular attention will be paid to those mesoscale characteristics of the meteorology (like sea breezes) which are important for the dispersion of emissions from local industry.

A summary of findings in relation to this objective, reported by Physick et al. (2000) and Physick (2001), is as follows.

For each wind monitoring site, monthly averages of wind speed and direction at 1-hourly intervals were calculated for the period February 1998 through to January 1999. This is an efficient way to examine both the seasonal behaviour of the surface winds in the region and the variability between sites.

While the analysis shows a strong seasonal variation of the monthly-averaged winds at each site, there is little difference in the winds from site to site for any given month. This is especially so for wind direction, and is probably a consequence of the flat terrain and long relatively-straight coastline. Strongest winds occur in spring and early summer, with weaker winds in autumn and winter. Sea breezes occur on 50% of days in winter and on 80% in summer, where a sea breeze is defined here as an onshore wind.

The diurnal variation in the monthly-mean direction is most interesting, and is observed at all sites. There are three dominant wind regimes, illustrated for the Karratha Station (KA) site in Figure 5.1. In the warmer months, October through to February, the mean direction is from

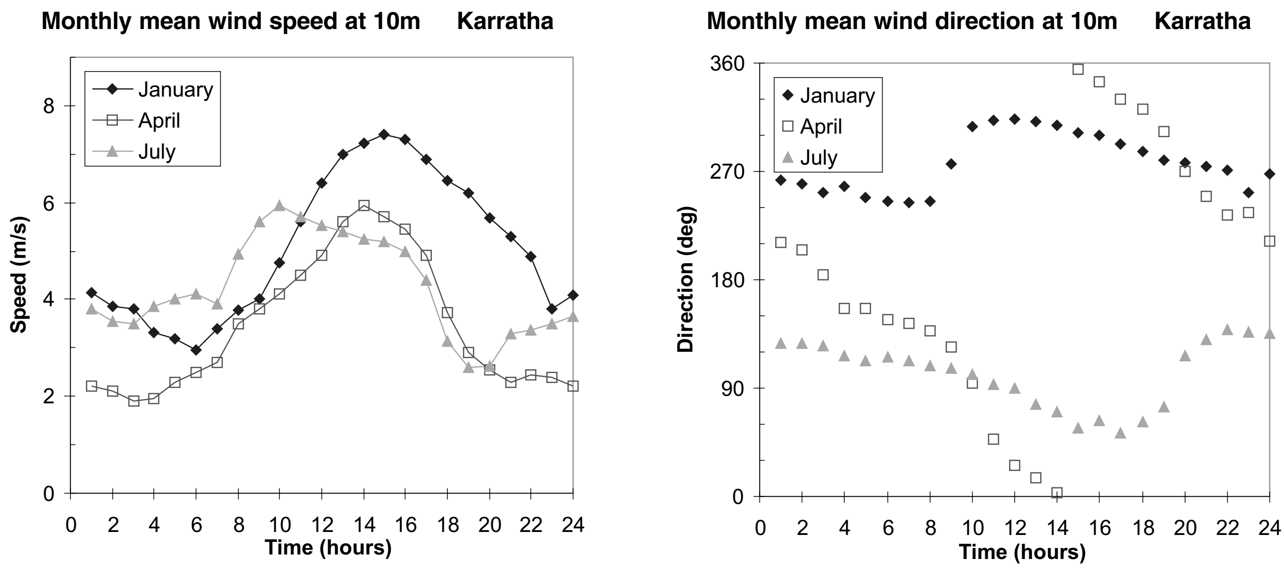


Figure 5.1 Monthly mean wind speed and direction at a height of 10 m at Karratha Station for January 1999, April 1998 and July 1998.

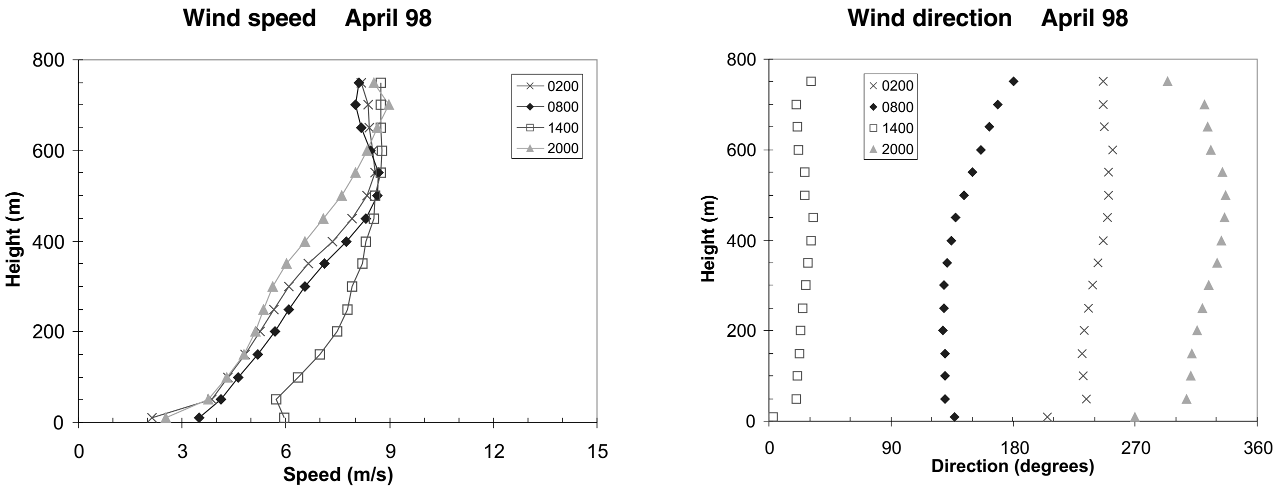


Figure 5.2 Mean wind profiles at 0200, 0800, 1400 and 2000 WST for April 1998 at Karratha Station, measured by the sodar.

the two western quadrants over the diurnal period, switching to onshore (and to its most northerly direction) by mid- to late morning as the land warms. The direction then slowly backs through west until it is offshore again by midnight. This type of day constitutes by far the majority of days in this period, but some days do exhibit the direction behaviour shown for April in Figure 5.1.

Similar, but converse, behaviour is observed in May, June and July when the mean direction is from the two easterly quadrants with a switch to onshore mid-morning, but a switch back to offshore winds by early evening. Also, the most northerly direction is reached in mid-afternoon, in contrast to that in the warmer months.

In the transition months March, April, August and September (and October at two sites), the behaviour of the mean wind direction can be termed ‘around the clock’, meaning that it steadily rotates in an anti-clockwise direction with a 24-hour period. At midnight, the wind is typically from a south-southwest direction for each site. This type of day constitutes the majority of days in these months, but days with westerly and easterly regime winds also occur.

The finding that the vast majority of days exhibit daytime onshore winds, indicates that the thermal internal boundary layer (TIBL) in this region is likely to be an important factor in the dispersal of pollutants from near-shore sources. The formation of TIBLs and their effect on chimney plumes (fumigation or trapping) is described in DEP (2000). Also important are the days exhibiting ‘around the clock’ behaviour for the wind direction, as the recirculation of pollutants, already found in Australia’s major coastal cities, is quite likely.

For the recirculation of pollutants, it is important to know the variation of the offshore/onshore wind pattern with height. Monthly mean sodar winds to a height of 750 m are shown in Figure 5.2 for April 1998. The diurnal rotation of the winds, previously found in the analysis of the surface winds, is also evident to the upper limit of the sodar. Similar behaviour is found for the March, August and September mean fields. There is very little directional shear with height, leading to the conclusion that in the coastal region of the Pilbara on many single and consecutive days of the year there is a mass of air at least 750 m deep rotating with the diurnal period.

Analysis of daily 0700 WST and 1900 WST radiosonde flights from Port Hedland in January 1999 revealed that the sea-breeze circulation is about 2000 m deep, with a speed maximum at a height between 200 and 400 m and a minimum between 1200 and 1400 m. The 0700 WST temperature profiles showed a surface-based mixed layer on every day except one (which occurred when the low-level wind was from the northeast). The most common depth of the mixed layer was 500 m.

The 1900 WST profiles all showed a mixed layer below a strongly stable layer. On the majority of days the depth was the same as found for the 0700 WST profile.

From the profiles of wind, temperature and relative humidity for two January days on which sondes were released from both Dampier and Port Hedland, it was concluded that for this month there are no important differences in the dispersion meteorology between Dampier and Port Hedland. Given the similarity in the surface winds at both locations for November through to February, the above conclusion could perhaps be extended to these months too, although it was recommended that further fine-resolution radiosonde flights at both locations be carried out.

Coastal fumigation was identified as an important process for the dispersion of plumes from elevated sources.

The other objectives of the first phase of work by the CSIRO were to:

- summarise the air quality data from the monitors at Dampier and Boodarie, and to relate any elevated levels to the prevailing meteorology;
- assess the adequacy of the current meteorological and air quality network;
- select days that can be used as worst-case scenarios for the evaluation of models, and for modelling the impact of modified or additional sources in the region; and
- discuss which models are suitable for impact assessments in the region, and whether there are restrictions on the conditions under which they may be valid.

These objectives were met (see Physick (2001)) and contributed to planning for the remainder of the study.

5.1.2 Phase 2

The second phase of work by CSIRO (Physick and Blockley, 2001) also included field and associated model investigations.

The first field investigation was undertaken to gain a better understanding of vertical wind and temperature structure during the rotational wind cycles described above. It was surmised that the wind behaviour on such days may lead to recirculation of coastal emissions back to the source region. This was supported by some preliminary simulations by the CSIRO model TAPM in phase 1. In order to understand further the vertical structure of these winds and associated temperatures, and to provide data for model evaluation, radiosondes were released from the Bureau of Meteorology's station at Port Hedland at 6-hourly intervals over a period of 10 days (14 – 23 August 1999). On four of these days, early afternoon sonde flights were also undertaken at Dampier. An early morning flight was also done on one day. Figure 5.3 shows a radiosonde balloon ready to be released at Dampier by an employee of Woodside.

The ten day special observing period at Port Hedland was carried out under a south-easterly (offshore) surface pressure gradient, a weather pattern that is dominant from April to September in the Pilbara region, and can also occur at other times of the year. The main findings were:

Figure 5.3 A radiosonde balloon ready to be released at Dampier

- Diurnal variation of the wind and temperature fields was limited to a height of 1000 m, and on occasions was below 500 m.
- A sea breeze reached the Port Hedland Airport site (7 km inland) each day as the wind turned to the north.
- The thermal internal boundary layer associated with the sea breeze ranged in depth from 100 m to 200 m, and was capped by a stable layer beneath the daytime mixed layer.
- The wind returned to the southeast (through east) by 1900 local time (LT) on two occasions, and on the other days slowly rotated through west and south, returning to southeast by early morning.
- Strong low-level jets (at about 200 m) formed at night once the wind had an easterly component.

TAPM was able to reproduce the above features well, including the vertical structure associated with the thermal internal boundary layer, although with a time lag of one to two hours.

The objective of the second field investigation was to determine the stability profile in the sea breezes that develop under the two dominant synoptic weather patterns for the region (easterlies and westerlies). The stability in the onshore flow is an important parameter for input to the DEP's model DISPMOD.

Two six-day periods of field observations were carried out at Port Hedland: 28 March to 2 April 2000, and 14 to 19 November 2000. Throughout each day, radiosondes were released simultaneously at the coastline, and at the Bureau of Meteorology station 7 km inland. Profile data at both locations give insight into the growth of the thermal internal boundary layer.

The most interesting finding from the coastal radiosonde flights in March/April was the different structure of the onshore-flow temperature profiles at the beginning of the observing period compared to those at the end. This was a direct result of the temperature of the mixed-layer air flowing offshore in the morning (and returning later in the sea breeze) being cooler or warmer than the sea-surface temperature. Two stability-profile classifications were developed to describe characteristic days during this period. The main finding from the November data under westerly synoptic winds was that the onshore flow (generally north-westerly) was unstable in the lowest few hundred metres at all times. Consequently one stability classification was derived for days typical of this period, making a total of three generic profile categories into which all days of the year were classified.

5.2 Processing meteorological data for Gaussian plume models

Processing of data from the Karratha Station (KA) site was undertaken using procedures employed for Kwinana and other areas in the state. The range of meteorological parameters measured at the site (see Table 2.1) allowed the calculation of turbulent heat flux and friction velocity, atmospheric stability (derived via the method of Golder (1972)) and offshore flow mixing height (using the Port Hedland radiosonde data which were considered representative of the region). Calculation of onshore flow mixing depth (TIBL height) is done within the model DISPMOD using categorised estimates of the temperature profile in the onshore flow, as described in the previous section. Cloud data are not collected at Karratha, so direct application of conventional methods to calculate stability is not possible, however the net radiation data could be used to infer cloud cover (this has not been done to date). Results of the foregoing calculations are presented by DEP (2004b).

Processing of the Dampier meteorological data for model input is more problematic. None of the calculations described for deriving atmospheric stability at Karratha Station are valid under onshore winds at the Dampier site due to its proximity to the water. Furthermore there is a fundamental problem with assuming that meteorological data from a single near-shore site can be used to model dispersion of pollutants across a complex coastal region. A more rigorous approach to modelling this type of three dimensional situation is to employ a prognostic meteorological model like the CSIRO model TAPM, coupled to either a prognostic dispersion model (as included in TAPM) or a plume-puff model like the USEPA-approved model CALPUFF.

Nevertheless, a processed data file has been produced using the Dampier data together with data from Karratha Station to calculate night-time stability. This processed data file should be used with caution (i.e. with a thorough assessment, in each case, of whether the errors associated with the use of the data file in a Gaussian plume model are acceptable). DEP (2004b) showed that this data file, and a corresponding file derived from the output of TAPM, produce reasonably similar results when used in the DEP's model DISPMOD for two examples. This result should not be taken to be a green light for use in other cases.

Since the study started, there have been a number of proposals to develop new industries on the Burrup Peninsula, notably in the east-west valley adjacent to Hearson Cove. Meanwhile there have been no proposals to develop industry on the Maitland Estate. A comprehensively equipped automatic weather station should be installed at a suitable site to provide reliable meteorological data for assessing and confirming the air quality impacts of industrial developments on the Burrup Peninsula.

6 Assessment of air pollutant dispersion models

Three computer models, TAPM, DISPMOD and AUSPLUME, were evaluated to determine their capability to simulate dispersion of emissions in the region. Meteorological results from TAPM and ground-level concentrations from year-long simulations (1999) with all three models are compared with NO_x observations from the monitoring station at Dampier and the Woodside monitor at King Bay (Figure 2.1). TAPM predictions of O_3 and NO_2 are also compared to data from the Dampier station.

TAPM (Hurley, 2002) was developed at CSIRO Atmospheric Research and consists of prognostic meteorological and air pollution modules that can be run for multiple-nested domains. The meteorological module is an incompressible, hydrostatic or non-hydrostatic, primitive equation model for three-dimensional simulations. It predicts the three components of the wind, temperature, humidity, cloud and rainwater, turbulent kinetic energy and eddy dissipation rate, and includes a vegetation/soil scheme at the surface and radiation effects. The model is driven by the Bureau of Meteorology's LAPS (Limited Area Prediction System) analysis fields (on a 75 km-spacing grid) of winds, temperature and specific humidity, which account for the larger-scale synoptic variability. TAPM is run for much finer grid spacings and predicts the meteorology at smaller scales.

The air pollution module of TAPM solves prognostic equations for pollutant concentration using predicted wind and turbulence fields from the meteorological module. It includes gas- and aqueous-phase chemical reactions based on an extended version of the Generic Reaction Set (GRS) developed at CSIRO Energy Technology, a plume-rise module, and wet and dry deposition effects.

DISPMOD is a Gaussian-plume based air quality model for coastal regions, and was designed to simulate the downward fumigation of an elevated plume as it intersects a growing thermal internal boundary layer (TIBL) within onshore flow (Rayner and Blockley, 2000). It was developed as an aid in setting emission limits for industry in the Kwinana industrial complex, situated on the coast south of Perth. As input, it needs surface winds at hourly or shorter intervals, stability parameters and a thermal stability profile when winds are onshore. For offshore winds, it uses the more traditional Gaussian-plume algorithms and needs mixed layer heights at intervals of one hour or less as input. The meteorological inputs required by DISPMOD are collected at a single point and then applied over the entire model domain.

AUSPLUME is a standard Gaussian-plume based air quality dispersion model. It was developed by the Victorian EPA (Lorimer, 1986) and is widely accepted and used for regulatory purposes within Australia. Its input requirements are hourly wind speed, wind direction, temperature, mixed layer height, and stability parameters. AUSPLUME does not have any explicit algorithms for simulating fumigation of elevated plumes.

Physick and Blockley (2001) described the configuration of the three models and details of the input data, and provided a detailed evaluation of model performance. A summary of findings from this work was given by Physick et al. (2002). The report by Physick and Blockley (2001) was provided to consultants assessing the air quality impacts of proposed industries on the Burrup Peninsula from mid 2001 onwards.

There were notable unsatisfactory features of the modelling results reported by Physick and Blockley (2001) and Physick et al. (2002). All models showed significant under-predictions of NO_x at the Dampier monitoring station, where the measurements were known to be reliable. For example TAPM and DISPMOD were about 40% low at the 99.9 percentile level (approximately the 9th highest hourly concentration in the year). On the other hand, the models gave results higher than the measurements at the King Bay monitoring station, about which there was less confidence.

In early 2003, Woodside advised the DEP that it had underestimated NO_x emissions from its plant for a number of years including 1999. The estimated annual emission in 1999 were 10 200 tonnes rather than 5 800 tonnes as previously advised. It was clear that this new information provided the explanation for the model underestimation at Dampier, but exacerbated the apparent overestimation at King Bay.

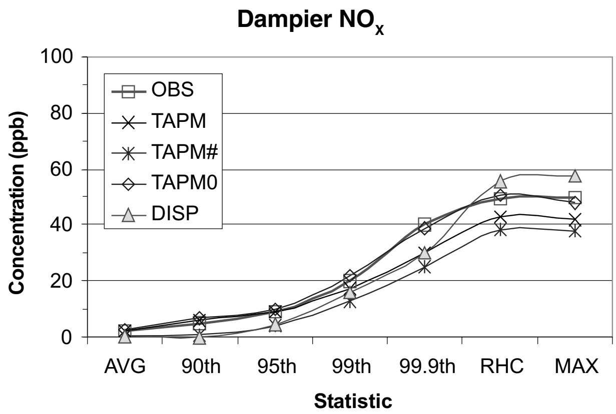
Further assessment of the King Bay data by Woodside and CSIRO Atmospheric Research revealed problems in the data which were addressed (Hurley et al., 2004), but did not explain the apparent overestimation by the models.

Woodside employed the services of CSIRO Atmospheric Research in 2003 to re-model the emissions from Woodside and other existing and potential sources. This work repeated the TAPM modelling described in Physick and Blockley (2001) and Physick et al. (2002) to assess the model's performance against 1999 measurements at Dampier and King Bay. For this work, the latest version of TAPM was used and, employing the greater computer power available, the model was run at much finer resolution. Details of the modelling, including model configuration and assumptions, are given in Hurley et al. (2004). The following discussion of model performance is based on Hurley et al. (2004) and work done by the DEP to reassess DISPMOD and AUSPLUME.

TAPM V2.5 was used for the study with the following assumptions:

- Building wakes are unimportant for the Woodside plumes – the plumes are very buoyant;
- Coastal and terrain effects are important – these are automatically handled by TAPM;
- Buoyancy enhancement for the Woodside plumes is important – this is modelled;
- The reactivity of the VOC species emitted from the Woodside stacks is important – reactivity coefficients have been updated;
- Biogenic and area sources need to be included – the DEP gridded emission inventory has been used (DEP, 2004a);
- Fine-scale resolution needs to be included – modelling is performed down to a 250-m pollution grid spacing;
- Assimilation of local wind observations is not justified.

Figure 6.1 presents predictions by TAPM and DISPMOD, together with measurements (OBS), of NO_x concentrations at Dampier and King Bay for various percentile levels and the robust highest concentration (RHC, defined by Hurley et al., 2004). DISPMOD was run using the meteorological file described in section 5.2 and onshore flow lapse rates derived from the generic profile categories described in section 5.1. TAPM used estimates of all emissions sources described in section 3, whereas DISPMOD and TAPM# used only industrial emissions (DISPMOD is designed for point sources only). This has the effect, seen in Figure 6.1, of causing under-predictions by TAPM# and DISPMOD which are proportionally greatest at the mean and low percentiles and of limited significance at high percentiles.



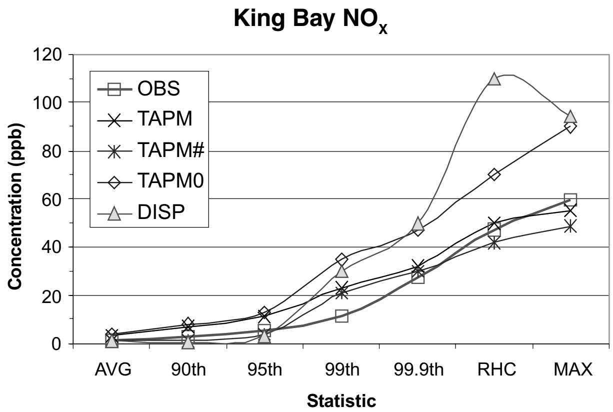


Figure 6.1 Annual mean, maximum, robust highest concentration (RHC) and percentile statistics for modelled (0.25-km grid for TAPM) and observed NO_x at Dampier and King Bay for 1999.

Definitions: OBS – measurements; TAPM – TAPM as per text; TAPM# – industrial emissions only; TAPM0 – buoyancy enhancement excluded; DISP – DISPMOD as per text.

The results for Dampier show good performance by both TAPM and DISPMOD at the important higher percentiles, with the former moderately underestimating and the latter moderately overestimating observed values. TAPM also matches the observations at King Bay well, whereas DISPMOD significantly overestimates concentrations at that site. TAPM avoids a corresponding problem by accounting for the buoyancy enhancement of plumes from Woodside's sources. Buoyancy enhancement refers to the fact that plumes from stacks adjacent to other stacks do not rise in ambient air, but in a mixture of ambient air and emitted gas. The end result is a higher effective plume height than normal as plumes are rising in a buoyant environment. This leads to a large reduction of predicted NO_x concentrations at the nearby King Bay site and a lesser reduction at Dampier. To demonstrate this effect, TAPM was run with buoyancy enhancement excluded giving the results in Figure 6.1 called TAPM0. The TAPM0 and DISPMOD results for King Bay are similar for concentrations above the 99th percentile level, apart from the "hump" in the RHC value for DISPMOD (which is an artefact of the RHC calculation caused by relatively high values, less than MAX, in the top 10 concentrations). DISPMOD will be altered to include buoyancy enhancement. Note that alternative models like AUSPLUME and CALPUFF do not currently include buoyancy enhancement of plumes.

Figure 6.2 shows NO_x statistics at Dampier from alternative configurations of DISPMOD.

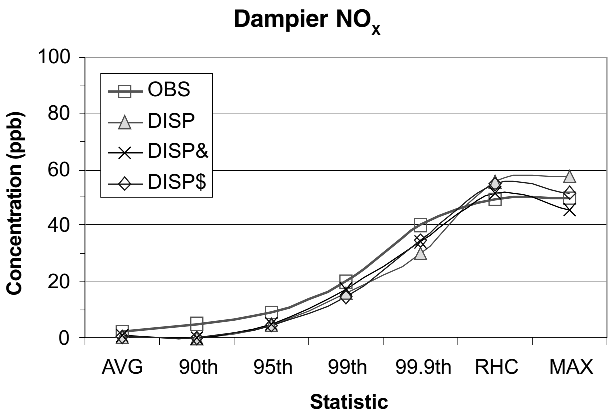


Figure 6.2 Annual mean, maximum, robust highest concentration (RHC) and percentile statistics for modelled (DISPMOD) and observed NO_x at Dampier for 1999. The curves represent different inputs to DISPMOD, as detailed in the text.

The curve labelled DISP is the same as that presented in Figure 6.1 for Dampier, using the meteorological data processed as per section 5.2 and onshore flow lapse rates derived from the generic profile categories described in section 5.1. The curve titled DISP& uses the same meteorological data but uses onshore flow lapse rates generated by TAPM up to 750 metres at a fixed location just offshore from Dampier. This change causes small increases at the 99th and 99.9th percentile levels and a reduction at the MAX level, all being improvements relative to measurements. The third curve, titled DISP$ is based on use of meteorological data generated by TAPM for a location close to the Dampier monitoring station and onshore flow lapse rates derived from TAPM as per DISP&. Comparing this curve to those for DISP and DISP&, it is encouraging to see that there is little difference between the results obtained using observed meteorology and those obtained using meteorological files generated by TAPM. Further work is required to assess the merits of these alternatives, however it is clear that shoreline fumigation of plumes is an important feature affecting air quality in this coastal area, as it is elsewhere in the state.

The variability in atmospheric stability as the plumes travel along the irregular coastline from source to monitors is an especially difficult aspect for conventional models to simulate. DISPMOD is not properly designed to handle the complexity of plume dispersion over water downwind of the source of emissions (e.g. over an embayment or inland estuary) and is therefore likely to suffer reduced accuracy in such situations.

Assuming the King Bay measurements are reliable, TAPM provides an overall better representation of the NO_x measurements at both sites than does DISPMOD in its current form.

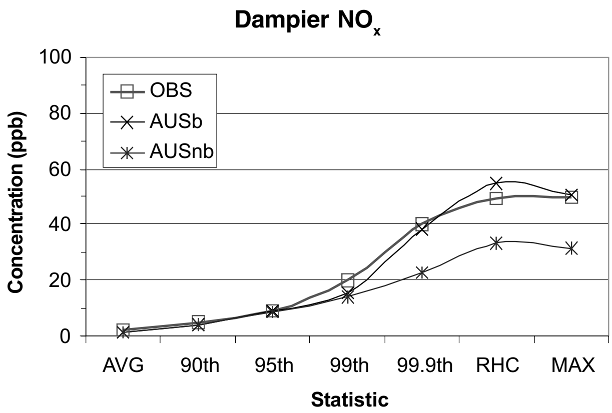


Figure 6.3 Annual mean, maximum, robust highest concentration (RHC) and percentile statistics for modelled (AUSPLUME) and observed NO_x at Dampier for 1999.

Definitions: OBS – measurements; AUSnb – no building effects modelled; AUSb – building effects modelled using the PRIME algorithm.

Results from AUSPLUME are presented in Figure 6.3. Running this model without configuring it to simulate the effect of building wakes at the Woodside plant yields the statistics titled AUSnb, which are little more than half of the measured values at high percentiles. Enabling the PRIME building wake algorithm yields the results titled AUSb, which on face value match the observations well. However an assessment of the concentration events which cause the high percentile values show that these are dominated by very light wind, very stable conditions. This fact, together with the nature of the sources (plumes with high temperature, high volume flow and high exit velocity from reasonable height stacks, e.g. 40 metre stacks adjacent to 22 metre high structures), indicates that the building wake algorithm of AUSPLUME is giving misleading results.

In light of the above, and AUSPLUME's inability to properly simulate dispersion near the coastline, this model should arguably not be used for the Burrup. If it is used, the user must undertake a comprehensive assessment of the results, considering the problems identified above, to determine reliability.

Concentrations of NO_2 and O_3 were predicted by the GRS photochemical mechanism employed in TAPM. Emissions sources defined in the gridded emission inventory (DEP, 2004a) were included. TAPM predictions and measurements of 1-hour average NO_2 at Dampier and King Bay and O_3 at Dampier are shown in Figures 6.4a, 6.4b and 6.4c respectively.

The results for Dampier show that NO_2 is predicted well by TAPM, with good prediction of the average and up to 99.9 percentile concentrations, but with an overestimation of the extreme. When gridded emissions sources are removed (TAPM#), the concentrations at Dampier are lower, and the extreme concentrations (RHC and MAX) for NO_2 are a little closer to the observations, although there is only a minor difference in the 99.9th percentile.

The results at King Bay show that NO_2 is predicted reasonably well by TAPM, with a general overestimation of NO_2 for all concentration levels. When gridded emissions sources are removed (TAPM#), the NO_2 concentrations at King Bay decrease, particularly the average and lower percentiles, and the overall comparisons are very close to the observations. It is possible that the King Bay wharf emissions may be overestimated or not simulated correctly within TAPM.

Excluding buoyancy enhancement of plume rise (TAPM0) causes a significant over-prediction of NO_2 at both Dampier and King Bay.

The TAPM predictions of O_3 at Dampier are very close to the observations for all concentration levels and much less sensitive to buoyancy enhancement than NO_x or NO_2.

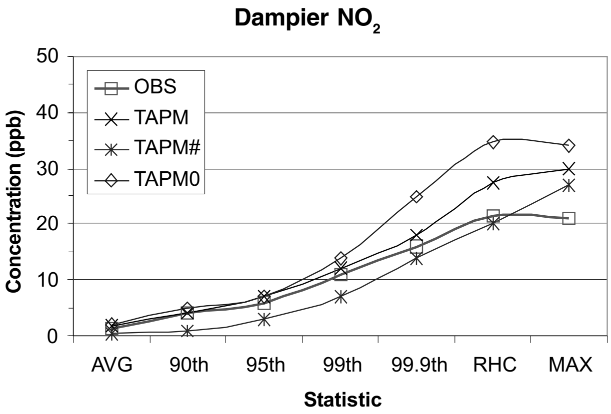


Figure 6.4a Annual mean, maximum, robust highest concentration (RHC) and percentile statistics for modelled (0.25-km grid) and observed NO_2 at Dampier for 1999.

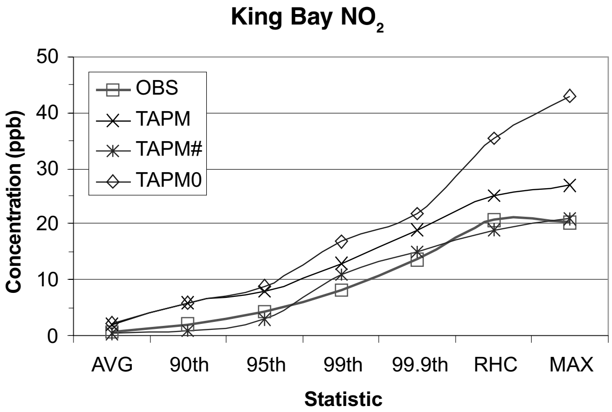


Figure 6.4b Annual mean, maximum, robust highest concentration (RHC) and percentile statistics for modelled (0.25-km grid) and observed NO_2 at King Bay for 1999.

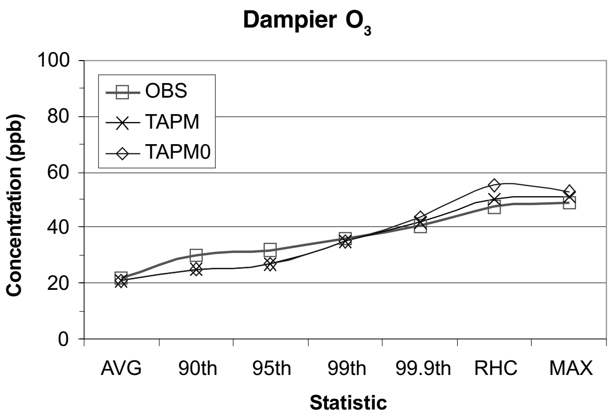


Figure 6.4c Annual mean, maximum, robust highest concentration (RHC) and percentile statistics for modelled (0.25-km grid) and observed O_3 at Dampier for 1999.

Definitions: OBS – measurements; TAPM – TAPM as per text; TAPM# – industrial emissions only; TAPM0 – buoyancy enhancement excluded.

Hurley et al. (2004) present regional maps showing contoured TAPM predictions for NO_2 and O_3 for 1999.

The contour maps for the maximum 1-hour average concentrations of NO_2 and O_3, modelled on a 1.5-km spaced pollution model grid, are reproduced in Figure 6.5.

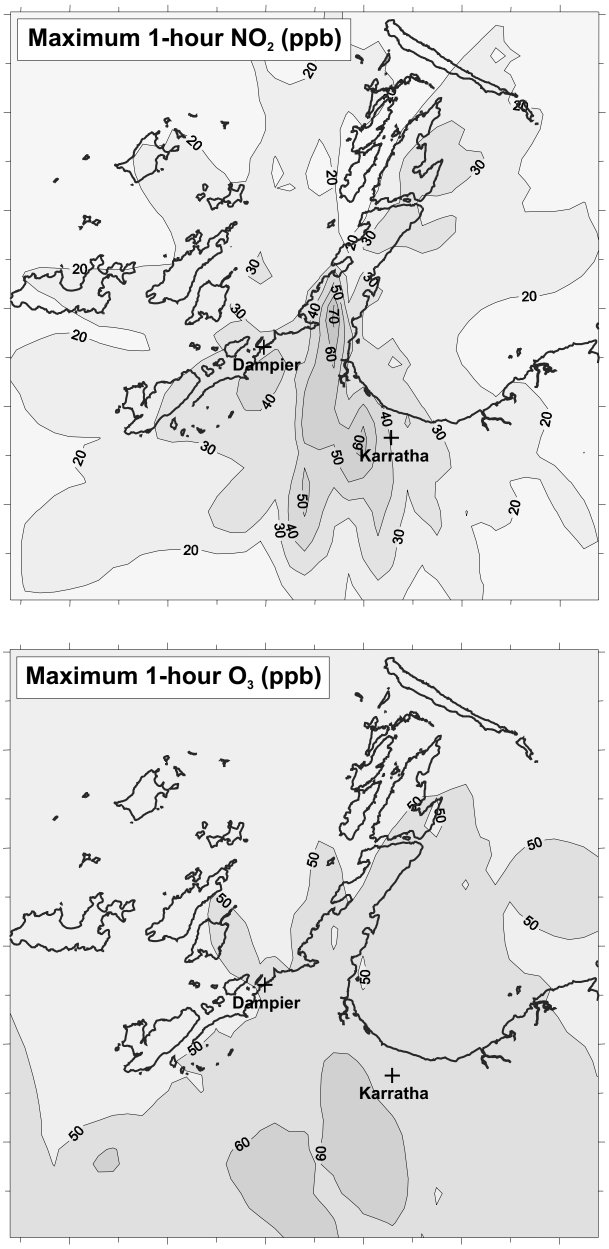


Figure 6.5 Modelled (TAPM) maximum 1-hour average concentrations (ppb) of NO_2 (top) and O_3 (bottom) for 1999.

The maximum concentration for hourly averaged NO_2 is dominated by Woodside onshore gas plant (OGP) plumes, with peak concentrations occurring to the south of the plant. These occur mid-morning during the summer when the growing convective boundary layer mixes OGP plumes to the ground, a process known as fumigation. The predicted maximum 1-hour average contours show a highest concentration of 73 ppb, below the NEPM standard of 120 ppb. Allowing for exceedence on one day per year as described in the NEPM, the next highest predicted concentration is 63 ppb, meeting the NEPM goal. The predicted highest concentration for 1999 is not near residential areas.

Hurley et al. (2004) describe the process of ozone formation offshore and subsequent transport of this ozone onshore in the sea breeze to give elevated concentrations to the south of the emission sources, as seen in Figure 6.5. The predicted highest 1-hour average O_3 concentration of 70 ppb is below the NEPM standard of 100 ppb. Allowing for exceedence on one day per year as described in the NEPM, the next highest predicted concentration is 66 ppb. The predicted maximum 1-hour average O_3 in the Karratha township is close to 60 ppb. Although the contours are not presented, the highest and next highest four-hour average regional concentrations are also below the NEPM standard of 80 ppb. All of the above O_3 predictions exclude the contribution of bushfire smoke (which is episodic and difficult to quantify).

This type of regional modelling should be done for other years (i.e. different meteorological data) to compare results and to determine whether high NO_2 concentrations associated with morning fumigation of plumes is a regular feature and, if so, whether it might occur over residential areas.

7 Conclusions

The Pilbara Air Quality Study has significantly improved the state of knowledge regarding the current air quality and the air pollution meteorology of Pilbara coastal centres.

Despite some problems with the monitoring program, a reliable data base now exists for use in assessing current and future air quality issues. The main missing element is comprehensive, good quality meteorological data from a suitable site in the Burrup Peninsula, as indicated below.

In relation to possible health effects, particulate matter (PM_{10} and $PM_{2.5}$) is the most significant current air quality issue, both at Port Hedland and Dampier. An assessment of particulate levels at Port Hedland and the neighbouring Boodarie industrial estate has shown that, even though regional dust and smoke are significant contributors, most of the PM_{10} in the town of Port Hedland is locally generated. Analysis of PM_{10} data from Dampier showed that the ore handling areas are the main overall source of PM_{10} on an annual basis, although smoke or dust storms may cause the highest short-term concentrations.

Similarly, $PM_{2.5}$ concentrations in Port Hedland are much higher than those at the Bureau of Meteorology station near the airport, which are representative of natural background concentrations.

At the time of writing, BHP Billiton Iron Ore and its consultants are investigating the extent to which standard High Volume Sampler measurements might overestimate the concentration of particulate matter in the Port Hedland context. These investigations may lead to revisions of methods and results, however neither the company nor other informed parties see the measurement uncertainty as reason to delay addressing the readily apparent dust issue.

Current measured levels of nitrogen dioxide and ozone are comfortably below the NEPM standards but show moderately elevated levels associated with the current industry and, in the case of ozone, with regional bushfires. Modelling suggests that levels of nitrogen dioxide and ozone higher than those measured at the Dampier monitoring station may occur close to residential areas. There is a need for effective management of emissions of NO_x and VOC from existing industries and new industries locating in the region, particularly on the Burrup Peninsula which appears likely to become an area of concentrated development.

There has not been an exhaustive review of all emissions to air in this study, however the models and meteorological data provided by this study may be used to assess a wide variety of emissions. The emission of benzene from the Woodside LNG facility has been quantified and modelled by that company and its consultants with the benefit of information provided by this study. Woodside is committed to significantly reducing benzene emissions.

Assessment of computer models for the Burrup Peninsula and adjacent areas has not yielded simple solutions and recommendations. Conventional models like AUSPLUME and DISPMOD are not generally suited to the complex coastline and topography, although DISPMOD has shown a pleasing level of skill in modelling industrial emissions. AUSPLUME has been shown to seriously overestimate the effects of building wakes on strongly buoyant plumes from the Woodside plant. In summary, these models should only be used with careful, expert attention given to the effects of assumptions and errors.

The CSIRO model TAPM has the capability to handle the complexities of the Burrup Peninsula. This model has been successfully checked against measurements at two monitoring stations and may be used to provide reliable statistics of the air quality in the Karratha-Dampier-Burrup Peninsula area. CSIRO is continuously reviewing and improving the scientific basis of the model.

The length of time required to complete modelling simulations with TAPM (several days at the time of writing) makes it potentially unsuitable at present for evaluating multiple scenarios of industrial development. This problem will reduce over time with increased computer speed. There are also likely to be model developments which improve this situation. Model users should consult the DEP to determine the best options before embarking on major modelling projects for developments in the region.

It is apparent that meteorological monitoring will be required in the King Bay-Hearson Cove area to provide model input data in the immediate vicinity of proposed industrial developments. There is also likely to be a need for ambient air quality monitoring to assess the cumulative air quality impact of industries on the Burrup Peninsula.

References

BHP 1996, *Port Hedland Dust Management Programme.* Consultative Environmental Review. BHP Iron Ore Pty Ltd, July 1996

BHP HBI 2000 *Annual Environmental Report.* BHP Direct Reduced Iron Pty Ltd. May 2001

BHPBIO 2002 *Port Hedland Dust Management Program* BHP Billiton Iron Ore, February 2002

DEP 2000 *State of Knowledge – Perth Air Quality Management Plan*. Department of Environmental Protection, Perth, Western Australia, July 2000.

DEP 2002a *Monitoring of ambient air quality and meteorology during the Pilbara Air Quality Study.* Technical Series 113, Department of Environmental Protection, Perth Western Australia, September 2002.

DEP 2004a *Karratha–Dampier and Burrup Peninsula Emissions Inventory 1999.* Department of Environmental Protection, Perth Western Australia.

DEP 2004b *Meteorological data processing for the Pilbara Air Quality Study.* Department of Environmental Protection, Perth Western Australia, (in preparation).

Golder, D.G. 1972 'A comparison of stability parameters.' *Boundary-Layer Meteorol. 3, 47-57.*

Hurley, P. 2002, 'The Air Pollution Model (TAPM) Version 2: Part 1: Technical description and examples', *CSIRO Atmospheric Research Technical Paper No. 55.* Available at <http://www.dar.csiro.au/TAPM>.

Hurley, P., Physick, W. and Cope, M. 2004, 'Summary of TAPM Verification for the Pilbara Region.' CSIRO Atmospheric Research. March 2004. Report to the Department of Environment.

Lorimer, G. 1986, 'The AUSPLUME Gaussian dispersion model'. *Environment Protection Authority of Victoria, publication no. 264*.

NEPC 1998. *National Environment Protection Measure and Revised Impact Statement for Ambient Air Quality.* National Environment Protection Council Service Corporation, June 1998.

NEPC 2001. *Issues Paper: The Need for a $PM_{2.5}$ Standard in Australia.* Prepared for the National Environment Protection Council, May 2001.

Physick, W.L., Rayner, K. and Mountford, P. 2000, 'Dispersion meteorology of the Pilbara region', *Proceedings of the 15th International Clean Air and Environment Conference, Sydney, Australia, November 2000.*

Physick, W.L. 2001. *Meteorology and air quality of the Pilbara region.* CSIRO Atmospheric Research. May 2001. Report to the Department of Environmental Protection.

Physick and Blockley 2001. *An evaluation of air quality models for the Pilbara region*. CSIRO Atmospheric Research and Department of Environmental Protection, June2001. Report to the Department of Environmental Protection.

Physick, W.L., Blockley, A., Farrar, D., Rayner, K. and Mountford, P. 2002, 'Application of three air quality models to the Pilbara region', *Proceedings of the 16th International Clean Air and Environment Conference, Christchurch, New Zealand, August 2002.*

Rayner K.N. and Blockley A. 2000 'Improvements in the coastal dispersion model DISPMOD.' *Proceedings of the 15th International Clean Air and Environment Conference, Sydney, Australia, November 2000.*

Appendix A
Air NEPM standards and goal

Standards and Goal

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

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

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

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

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

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

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

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

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

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

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

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