Monitoring of Ambient Air Quality and Meteorology during the Pilbara Air Quality Study

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1. Introduction

The scope and objectives of the Pilbara Air Quality Study are discussed in DEP (2002). One of the key objectives was to obtain reliable air quality and meteorological data in order to provide a sound basis for the assessment of the air quality impacts of existing industries and proposed industrial developments in and around Pilbara coastal towns. The study region, shown in Figure 1.1, covered the coastal region extending from west of Dampier / Karratha to Port Hedland. The region did not extend to inland centres.

Although there was some high quality information available prior to the study (notably in the Port Hedland area), it was generally specific to a particular industry and air quality issue (dust). The Pilbara Air Quality Study focused mainly on the Karratha / Dampier / Burrup area, where the existing information was most deficient, but information was also gathered for the Cape Lambert and Port Hedland areas.

This report describes the air quality and meteorological monitoring program undertaken, as a part of the Pilbara Air Quality Study, by the Department of Environmental Protection (DEP), Woodside Energy Limited (Woodside), BHP Iron Ore Pty Ltd (BHP), Department of Resources Development and Landcorp (DRD/Landcorp), and the Bureau of Meteorology (BoM).

Figure 1.1 Location of study region.

2. Overview of Monitoring Activities

2.1 Historical Monitoring Activities

Before considering the range of monitoring required in this study, a review of previous monitoring activities was undertaken. Note that the issue of monitoring and management of asbestos will not be considered in this study.

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 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. From 1995 onwards, BHP has also monitored PM_{10} (particulate matter with an equivalent aerodynamic diameter of 10 micrometres or less) at selected sites. Meteorological data have also been monitored.

Hamersley Iron (HI) have run High Volume samplers collecting 24-hr TSP every sixth day at the two stockpiling/ship loading ports at East Intercourse Island and Parker Point, and at two sites within Dampier since 1993. These measurements are 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.

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 Energy Limited and its related companies have, over the years, conducted quite extensive meteorological and source emission monitoring programs, which have provided data for modelling estimates of air quality. This work is described in Woodside (1984), and Woodside (1985).

Bureau of Meteorology weather stations have been present in the Pilbara for many years (e.g. Dampier Salt, established 1969). Stations with manual observations taken several times a day have been progressively replaced with automatic weather stations (AWS), providing time-continuous data in computer format. BoM stations from which data have been obtained for this study will be described in the relevant sections.

2.2 Planning the Monitoring Program

The monitoring program for this study reflected a prioritisation of requirements to improve the understanding of the various air quality issues in the Pilbara.

Fine and coarse particulate matter is clearly the most significant widespread ambient air contaminant (not considering the localised issue of asbestos around Pt Samson and Roebourne). However particulate matter was not a central focus of this study because:

- There has been, and currently is, a significant monitoring program by BHP at Port Hedland and, to a lesser extent, by Hamersley Iron at Dampier;

- To the extent that dust can be managed by Pilbara industries, that management will be via good dust control design and practice at the various facilities, which does not require an understanding of complex meteorological and chemical processes;
- Particulate matter from natural sources (dust and wildfires) is generally very widespread during any particular high concentration event, and can therefore be characterised, for a particular town, by measurement at one site (e.g. one of the industry's monitoring sites) together with information on the high winds or location of wildfires causing the event. Satellite images, available from the internet, have proven to be very useful for analysing wildfire smoke plumes.

The study instead focused on gathering information on air quality issues which may not at the current time be significant (i.e. current concentrations well below standards) but which need to be understood and managed to ensure that problems do not emerge in the future. The focus of greatest effort was to gain an understanding of the complex coastal meteorology which determines the transport and dispersion of primary and secondary pollutants, via continuous measurement, intensive field measurement programs, data analyses and modelling.

With respect to primary pollutants (gases and fine particles emitted directly from industries and other sources), the highest ground level concentrations are determined by the rise, transport and dispersion of the pollutant plume (or plumes) directly downwind of the source. In a coastal environment, the rise, transport and dispersion of plumes are markedly affected by wind shear and the influence of thermal internal boundary layers which form over the land within onshore winds (notably sea breezes). The complex shape of the coastline and the topography of the Burrup / Dampier / Karratha area also influence the wind patterns.

With respect to secondary pollutants (ozone, nitrogen dioxide, secondary aerosols and particles, etc.), it is well known that the highest concentrations of these occur in circumstances where there is a pattern of recirculating winds, namely a morning offshore wind followed by an onshore sea breeze. In these conditions, emissions of oxides of nitrogen and volatile organic compounds are transported offshore where they react under sunlight, forming the secondary pollutants, which are then recirculated over populated areas by the sea breeze.

The Pilbara Air Quality Study monitoring network was established with the objective of supporting the investigation of coastal meteorology and dispersion, while at the same time gathering a "baseline" record of air quality. The network and associated activities are summarised below to provide an overview and rationale of the monitoring program. Individual components of the monitoring network are described in Section 3. Figures 2.1 and 2.2 are maps showing two-letter codes for the monitoring sites referred to below and throughout this report.

Figure 2.1 Monitoring stations in study region (west).

A baseline air quality monitoring station was established in Dampier (site DA in Figure 2.1), in order to measure secondary pollutants recirculated onshore in sea breezes. The station is immediately adjacent the ocean, with no road between it and the ocean. The absence of upwind roads ensured that concentrations of ozone would not be reduced by nitrogen oxide emitted by motor vehicles. This station was also sited appropriately to measure 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 measured at the site.

A second baseline air quality monitoring station for the Dampier/Karratha area, owned and operated by Woodside, was sited at King Bay (site KB in Figure 2.1) for the period November 1998 to October 1999. This site was then moved north of the Karratha township (site KT) for the period November 1999 to October 2000, in order to get a more detailed picture of the distribution of primary and secondary pollutants. This station monitored ozone, nitrogen oxides, sulfur dioxide, wind speed and direction. In the Pt Hedland area, an air quality monitoring and meteorological station, owned by BHP Iron Ore, has been operated on the Boodarie industrial estate (site BD in Figure 2.2) since December 1996 (meteorological measurements since 1992). This station measures concentrations of primary air pollutants. Particles (TSP and PM_{10}) and basic meteorology are also monitored at several other sites around Pt Hedland in connection with the BHP iron ore ship loading facilities.

Figure 2.2 Monitoring stations in study region (east).

A comprehensive meteorological station was sited 12 km west-south-west of Karratha townsite (site KA in Figure 2.1). This station was located remote from towns and from sources of noise to allow the operation of a Sodar (Doppler acoustic sounder), which is an instrument that measures wind speed and direction at intervals up to several hundred metres above ground level. The site was close to the Maitland Industrial Estate, and representative of the meteorology of the region. In addition to those measuring upper air winds, other sensors needed for modelling purposes were installed at Karratha, including total and net solar radiation, and temperature gradient.

Measurement of wind across the region was of prime importance. In addition to meteorology being measured at the three air quality stations and the special meteorological station at Karratha, wind and several other parameters were also obtained from the following locations.

The Bureau of Meteorology automatic weather stations at Karratha Airport (KP), Port Hedland Airport (PA), and Legendre Island (LG) measured wind at 10 meters, plus typically, air temperature, humidity (dew point), and pressure (see list of specific parameters measured in Section 3).

The DEP operated two basic meteorology-only sites in the region, at Wickham (WI), and at Radio Hill Nickel Mine (RN) south of Karratha. 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.

The Department of Resources Development (DRD) established a station on the proposed industrial development area of Maitland Estate (MT) to augment data in the Karratha area.

Woodside intended to install an anemometer near its plant on the Burrup Peninsula, but this unfortunately did not occur soon enough to provide data for the study. Vertical profiles of wind were measured by the acoustic sounder at Karratha Station (KA), as described earlier. In addition, soundings of both wind and temperature were routinely obtained from the Bureau of Meteorology at Port Hedland (PA). The Bureau of Meteorology also assisted the CSIRO and DEP with extra radiosonde releases during two intensive field measurement programs, and conducted additional releases – this work is described in more detail in Section 3.

3. Description of Monitoring Sites and Monitoring Methods

This section describes each monitoring site in turn, including site selection, development and commissioning, photographs, table of parameters and methods, and issues relating to performance and reliability. Refer to Appendix A for a detailed description of calibration methods. The data completeness rate for each parameter is covered in Section 4 and Appendix E of this report.

3.1 Dampier Air Quality Monitoring Station (AQMS)

As summarised in Section 2, the Dampier monitoring site was chosen because it is:

- Immediately adjacent the ocean, with no intervening roads, and well sited for measuring ozone being blown onshore;
- Representative site for measuring direct impact of primary pollutants on Dampier;
- Well sited to measure dust from ship loading facilities.

The site, marked DA on Figure 2.1, (AMG 470050,7716100) is close to the two iron ore ship loading facilities at East Intercourse Island and Parker Point, and has a good open aspect over the ocean, from East Intercourse Island in the west, around to Parker Point, which bears northeast from the station. Figure 3.1 shows a ship loading at the Parker Point jetty.

The Dampier site was adjacent to the training facilities of Hamersley Iron Pty Ltd, in Dampier townsite, and the cooperation of the company in allowing access to the site is appreciated.

Three-phase electrical power was made available at the site, together with a phone line for data telemetry. A second phone line was subsequently installed to assist with the remote monitoring of instrument diagnostic parameters.

Figure 3.1 Dampier AQMS - looking north, with Parker Point jetty in background.

Figure 3.2 Dampier AQMS - view from shore with townsite in background.

The parameters monitored at the Dampier AQMS are listed below in Table 3.1. Monitoring commenced in April 1998 and continued until December 2000.

Short Name	Long Name	Manufacturer	Instrument Model	Operational Parameters
O_3	Ozone	Thermo Environmental Instruments Inc.	Model 49C	Range: 0 to 200 ppb
NO	Nitric oxide	Thermo Environmental Instruments Inc.	Model 42C	Range: 0 to 500 ppb
NO_2	Nitrogen dioxide	Thermo Environmental Instruments Inc.	Model 42C	Range: 0 to 500 ppb
CO	Carbon monoxide	Thermo Environmental Instruments Inc.	Model 48C	Range: 0 to 20 ppm
T10	Particulate (PM_{10})	Rupprecht & Patashnick	TEOM Model 1400	Range: 0 to 400 ug/m^3
SP10	Wind speed	Climatronics	F460	Range: 0.2 to 100 m/s *
DN10	Wind direction	Climatronics	F460	Range: 0 to 360 degrees
SG10	Sigma theta	N/A	Statistical Calc	Range: 0 to 50 degrees
AT10	Air temperature	Met One	062	Range: 0 to 60 degrees C
RH10	Relative humidity	Rotronics	MP100	Range: 0 to 100 %
PRES	Atmospheric pressure	Vaisala	PTB100A	Range: 900 to 1150 hPa
SOLR	Solar radiation	Middleton	EP08	Range: 0 to 1500 W/m^2
RAIN	Rainfall	Rimco	7499	Resolution 0.2 mm

* Refer to Dampier AQMS instrument performance – meteorological measurements

Table 3.1 Parameters measured at Dampier AQMS.

Data was logged for all parameters every 10 minutes, averaged from 1-second scans. The scanning frequency was determined by the requirement to calculate the standard deviation of wind direction, sigma theta, from wind direction values.

The Dampier AQMS site was adequate for the purposes of monitoring air quality (see Table 3.4 – Site Compliance), but was less satisfactory as a meteorological station, as described below.

The openness of the aspect for monitoring purposes is less than ideal in the southeast direction, towards the Dampier townsite (see Figure 3.2). The higher elevations in that

direction produce a sheltering effect on the winds measured at the station (see the statistics of meteorological data in Appendix C). Trees close to the shore on both sides of the station extend the arc of sheltering from northeast clockwise around to southwest. The sheltering effect of trees along the shore was minimised by siting the mast on the ocean side of the compound, but this in turn caused transient shading of the solar radiation instrument.

The site available at Dampier did not allow for a well-positioned solar radiometer (Karratha Station being better sited for this parameter). The mast was placed in the compound as close as possible to the ocean in order to minimise any sheltering effects from nearby trees during onshore wind conditions. This positioning of the mast in the northern part of the compound meant that the solar radiometer did not have an open aspect position available to it. The period from commencement up to 2 October 1998 contains a period around 1500 hours (3 pm) each day when the shadow of the mast passed over the pyranometer. The sensor was moved on 2 October 1998, and mounted on the end of an arm which extended out to the north side of the mast. The new position eliminated the shadows from the mast, however, due to partial shading from the monitoring shed, the intensity of sunlight in the early morning just after sunrise was reduced. Partial shading in the early morning is also due to the skyline of the townsite to the southeast, being above the natural horizon. The very small effect on the data of these two factors has been taken into account when processing the data for modelling purposes (Blockley, in progress).

Dampier AQMS instrument performance

Tapered Element Oscillating Microbalance (TEOM)

The high humidity levels often experienced in the area, coupled with the Dampier station's close proximity to the ocean, resulted in three major failures of the TEOM particle measuring instrument. In all cases the air mass flow sensor situated in the Auxiliary Flow path failed due to condensate collecting in the line. Downtime as a result of these failures occurred from –

- 19/5/1998 to 2/6/1998 – replacement instrument fitted
- 19/12/1998 to 8/1/1999– replacement instrument fitted
- 20/1/1999 to 29/1/1999– instrument turned off and allowed to dry out

Successful modifications to the sampling system were undertaken to avoid any further problems. The modifications were as follows –

- The Auxiliary Flow line was insulated upon its entry into the monitoring station. This prevented the cooling effect of the air conditioners from causing the water vapour in the warm ambient air sample to condense (see Figure 3.3).
- Heater tape was installed around the main sample line above the Sensor Unit column.

- The installation of pneumatic Coalescing Filter/Drier (CFD) assemblies in both the Auxiliary Flow and Main Flow lines. The unit was installed in the Auxiliary Flow line immediately upon the entry of the line into the station. The CFD was installed in the Main Flow line between the Sensor Unit and the Control Unit, and as such did not affect the particle loading of the air sample. The CFDs were drained monthly. The CFD installed in the Auxiliary Flow line collected condensate regularly – it has been documented on Site Check sheets that 40 mL was collected in the device (5/1/2000 and 3/3/2000) over a 1-month period. The CFD installed in the Main Flow line did not yield any condensate. This is to be expected as a result of the air sample being heated to 50^{o}C in the TEOM Sensor Unit column.
- The internal station temperature was also increased from 22^{o}C to approximately 27^{o}C to decrease the temperature difference between the station and the ambient air, thus reducing the chance of condensate formation.

Gas analysers

Similar problems with condensation were encountered with the operation of the TEI gas analysers. Despite the installation of a condensate drain in the PTFE manifold block (see Figure 3.4) there were occasions when water did collect in the 5 µm filter holders on the rear of the analysers. This was consequently drained, the filter holder dried and a new 5 µm filter fitted. No downtime was experienced due to a gas analyser failing through the intake of condensate water.

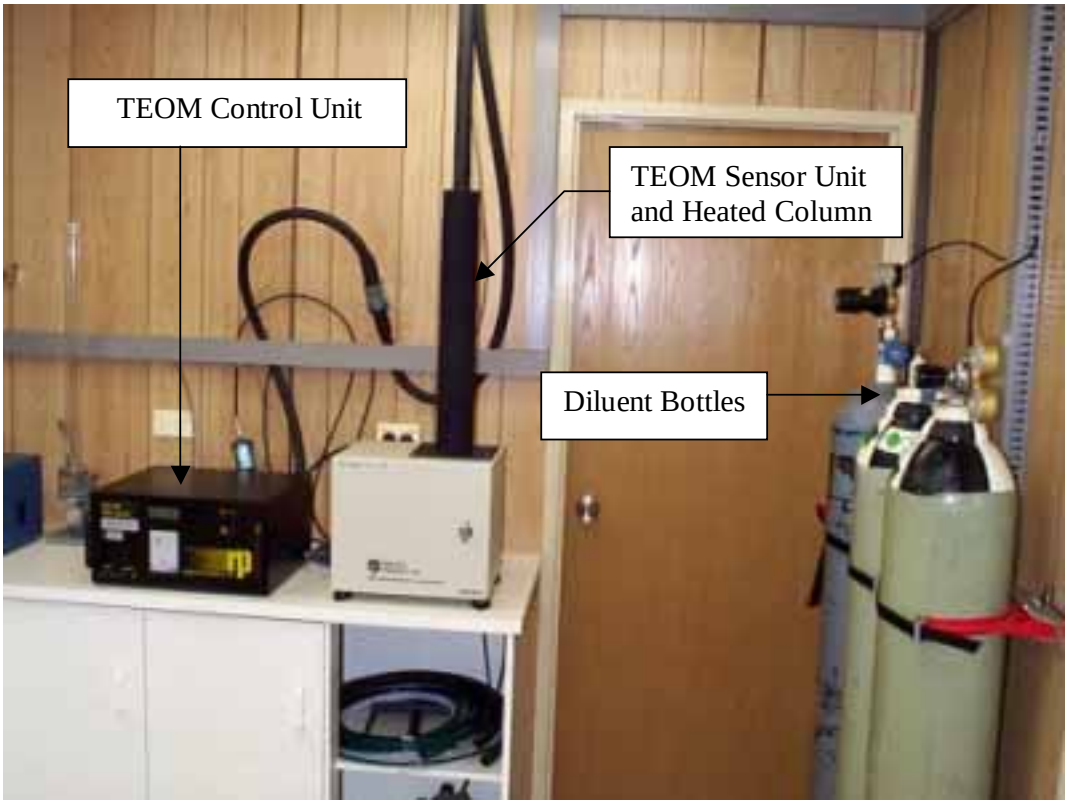

Figure 3.3 Dampier AQMS - TEOM showing insulated flow lines, but prior to the installation of coalescing filter/driers.

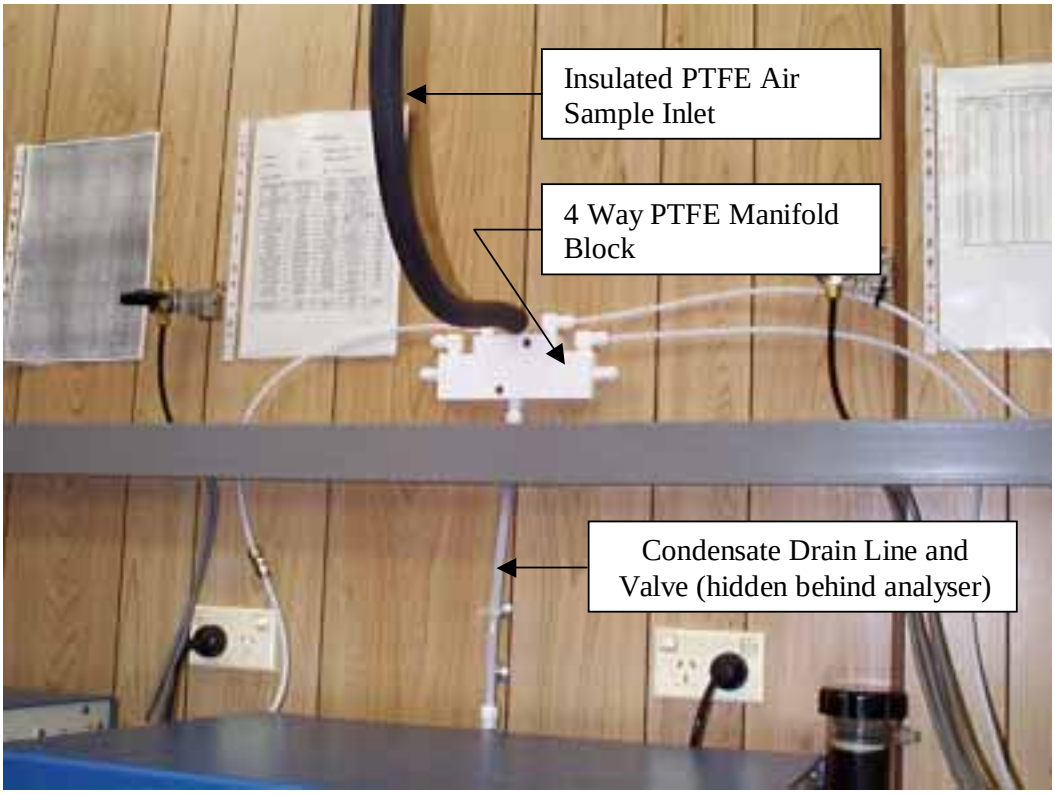

Figure 3.4 Dampier AQMS - 4 Way PTFE Manifold Block, showing condensate drain line.

Meteorological measurements

From commencement of monitoring in February 1998 up to 12 March 1999, wind speed data was invalid for those records when gusting exceeded 10.9 m/s. This was due to a problem with the data logger program using only one byte of memory for totalising the anemometer pulses. Wind data is still stored for periods of high wind but the maximum value is restricted to 10.9 m/s. The program was changed to two bytes of memory after 12 March 1999, lifting the maximum measurable speed beyond the 56 m/s ceiling imposed by sensor non-linearity. The loss of high wind speed information is not important for most air quality issues (strong winds give large dispersion), however it may be important for some purposes, like calculating plume downwash in the wake of buildings and estimating dust lift-off in strong wind conditions. Therefore it is necessary to consider what error might be introduced by the use of the pre-March 1999 data for particular applications. Note that the BoM has reliable data for periods of high winds, so this problem may be reliably addressed via data analysis and substitution.

3.2 King Bay AQMS

A monitoring caravan, owned and operated by Woodside Environmental Ltd, was deployed at King Bay from November 1998 to October 1999 (see Figure 2.1 KB, AMG 473500,7719650). The site was selected to monitor primary and secondary pollutants on the Burrup Peninsula, complementary to the Dampier station. Site development was minimal due to the ease of establishment of the caravan on a car parking area close to the shore of King Bay. Figure 3.5 shows the monitoring van at King Bay with the islands of the Dampier archipelago on the horizon.

Figure 3.5 King Bay AQMS - looking west.

The instruments used at King Bay are tabulated in Table 3.2 and pictured in Figure 3.6.

Short Name	Long Name	Instrument Manufacturer	Model	Operational Parameters
O_3	Ozone	Thermo Environmental Instruments Inc.	Model 49	Range: 0 to 200 ppb
NO	Nitric oxide	Thermo Environmental Instruments Inc.	Model 42	Range: 0 to 500 ppb
NO_2	Nitrogen dioxide	Thermo Environmental Instruments Inc.	Model 42	Range: 0 to 500 ppb
SO_2	Sulphur dioxide	Thermo Environmental Instruments Inc.	Model 45H	Range: 0 to 1000 ppb
SP10	Wind speed	Monitor Sensors	AN2	Range: 0.2 to 40 m/s
DN10	Wind direction	Monitor Sensors	WD2	Range: 0 to 360 degrees

Table 3.2 Parameters measured at King Bay AQMS.

Figure 3.6 King Bay AQMS - gas analysers.

3.3 Karratha Town AQMS

The same caravan that was operated at King Bay was moved in November 1999 to the north side of the Karratha townsite (KT, Figure 2.1, AMG 482500,7707000). The

Water Corporation Pumping Station No.2 on the north side of Balmoral Road provided a suitable fenced compound. Monitoring by Woodside continued at the Karratha townsite until October 2000. The Karratha townsite monitoring location is pictured in Figure 3.7.

Figure 3.7 Karratha Town AQMS - looking northwest.

The data supplied from the Woodside van was received monthly. The data recovery for the King Bay site for the period December 1998 to October 1999 was 86.5% while the data recovery for the Karratha townsite between November 1999 and October 2000 was 88.7%. Several periods showed elevated NO baselines, which may indicate a faulty monitor. These periods were not removed from the data. Data recovery of the air quality parameters was 100% for January, June and July 2000, indicating either that no calibrations were performed during the month or calibration spikes were not removed from the data.

Parameters measured at Woodside's Karratha townsite station are the same as described above for the King Bay station.

3.4 Boodarie AQMS

In the Port Hedland area, Boodarie station (see Figure 2.2 – station BD, AMG 664131,7745645), owned by BHP Iron Ore, was established initially as a meteorological station in October 1992, and then upgraded to include air quality in 1996. The Boodarie monitoring site is pictured in Figure 3.8, and parameters monitored listed in Table 3.3. Associated with the transport and ship loading of BHP iron ore , there are several dust monitoring sites around Pt Hedland, which measure particulates (TSP and PM_{10}) and basic meteorology.

Figure 3.8 Boodarie AQMS.

Short Name	Long Name	Instrument Manufacturer	Instrument Model	Operational Parameters
NO	Nitric oxide	Monitor Labs	9841	0-20 ppm
NO_2	Nitrogen dioxide	Monitor Labs	9841	0-20 ppm
SO_2	Sulphur dioxide	Monitor Labs	9850	0-20 ppm
H_2S	Hydrogen sulphide	Monitor Labs	9891	0-20 ppm
T10	Particulate (PM_{10})	R&P	TEOM 1400A	0-5 g/m^3
T2.5	Particulate ($PM_{2.5}$)	R&P	TEOM 1400A	0-5 g/m^3
SP10	Wind speed at 10 m	RM Young	5305	Range 0 to 40 m/s
SP30	Wind speed at 30 m	RM Young	5305	Range 0 to 40 m/s
DN10	Wind direction 10 m	RM Young	5305	0-355 degs
DN30	Wind direction 30 m	RM Young	5305	0-355 degs
SG10	Sigma at 10 metres	Statistical Calc	N/A	N/A
SG30	Sigma at 10 metres	Statistical Calc	N/A	N/A
AT10	Air temperature 10 m	Thermistor	N/A	N/A
DT10	Delta temperature	Thermistor	N/A	10-1.5 m
RH	Relative humidity	Rotronics	MP100	0 to 100 %
SOLR	Solar radiation	Middleton	EP-08	0-1400 W/m^2
RAIN	Rainfall	Ecotech	Rainmaster 1000	N/A
PRES	Atmospheric pressure	Rupprecht & Patashnick	N/A	N/A

Table 3.3 Parameters measured at Boodarie AQMS.

The Boodarie AT10 air temperature sensor was at a height of 8.5 m above ground prior to 13 Oct 2000, then 10 m above ground level after this date. This sensor was also used for the upper measurement of the DT10 parameter. Care should be taken when using the Boodarie Delta T measurement for modelling purposes, as the two radiation shields are not aspirated.

Compliance of the four air quality monitoring sites with Australian Standard AS2922-1987 Ambient Air – Guide for the Siting of Sampling Units is tabulated in Table 3.4 below.

	Height above ground	Min. distance to support structures	Clear sky angle of 120°	Unrestricted airflow of 270°/360°	20 m from trees	No boilers or incinerators nearby	Minimum distance from road or traffic	Sample line material	Sample line length	Comments
Northwest Region										
Dampier	☑	☑	☑	☑	☒	☑	☑	☑	☑	15 metres to small to medium size trees. Surrounding area dominated by low scrub.
King Bay	☑	☑	☑	☑	☑	☑	☑	☑	☑	Top of a small rise with no obstructions
Karratha	☑	☑	☑	☑	☑	☑	☑	☑	☑	No obstructions
Boodarie	☑	☑	☑	☑	☑	☑	☑	☑	☑	No obstructions

Table 3.4 Site compliance with AS 2922-1987 Ambient Air - Guide for the Siting of Sampling Units.

3.5 Karratha Meteorological Station (MS)

The site for the Karratha meteorological monitoring station was chosen as being representative of the coastal plain in that area. It is situated approximately 2 km inland from the shallow tidal waters which separate Dampier from the mainland (see Figure 2.1 – station KA, AMG 472700,7702950).

Figures 3.9 and 3.10 show Karratha meteorological station looking west and north respectively. Figure 3.11 shows the Doppler acoustic sounder. Figures 3.12 and 3.13 show indoor views of the sounder electronics and general monitoring equipment.

Figure 3.9 Karratha MS - looking west.

Figure 3.10 Karratha MS - looking north.

Figure 3.11 Karratha MS - Doppler acoustic sounder.

Figure 3.12 Karratha MS - acoustic sounder electronics.

Figure 3.13 Karratha MS - data logger and communications equipment.

Electric power requirements for instrumentation at Karratha MS were substantially less than for Dampier AQMS, as there were no air quality analysers in operation. While solar power was initially considered, mains power was provided to the site, allowing for air conditioning of the shed, thereby relieving heat stress on electronic components. The air conditioner was placed on the north-facing side of the shed, minimising the impact of noise on the acoustic sounder, which was on the south side of the shed.

The availability of mains power led to Hamersley Iron setting up a High Volume Air Sampler at the site from January 2000. This was sited, like the air conditioner, on the north side of the site.

Mobile phone communications were used for data telemetry of meteorological data, with a separate connection to the acoustic sounder. Changes in the mobile phone systems in the region forced a switch from analog to digital mobile phones in October 2000 without any noticeable impact on data recovery.

The parameters monitored at Karratha are listed below (Table 3.5). Monitoring commenced at Karratha in February 1998 and continued to December 2000.

Short Name	Long Name	Manufacturer	Model	Operational Parameters
SP10	Wind speed	Climatronics	F460	Range : 0.2 to 100 m/s *
DN10	Wind direction	Climatronics	F460	Range : 0 to 360 degrees
SG10	Sigma	Statistical Calc	N/A	Range : 0 to 50 degrees
AT10	Air temperature (10 m)	Met One	062	Range : -30 to 60 degrees C
AT02	Air temperature (2 m)	Met One	062	Range : -30 to 60 degrees C
RH10	Relative humidity	Rotronics	MP100	Range : 0 to 100 %
SOLR	Solar radiation	Middleton	EP08	Range : 0 to 1500 W/m^2
NR10	Net solar radiation	Middleton	CN1-R	Range : -200 to 1500 W/m^2
RAIN	Rainfall	Rimco	7499	Resolution 0.2mm
DAS	Doppler Acoustic Sounder	Remtech	PA1-LR	Wind speed range 0-25m/s Wind direction range 0-360 degs Height range 50 m to 825 m Height resolution 25 m

Table 3.5 Parameters measured at Karratha MS.

* Max speed 11 m/s initially – see below

Data recovery and quality was reduced by the following instrumental problems during the monitoring period.

Wind speed monitoring from commencement up to 12 March 1999 was invalid for periods when gusting exceeded approximately 11 m/s (see notes relating to Dampier for further comment on this shared problem).

The Doppler acoustic Sodar had two substantial periods when no data was recorded due to instrument problems, being most of May 1998 and the period from February to July 1999. A third period of data loss was for most of January to March 2000 during the cyclone season when the sounder was intentionally shut down for protection.

Air temperature measured at the mast top (AT10) was low by several tenths of a degree commencing approximately mid-October 1999. The problem was not resolved until the sensor was replaced on 27 Mar 2000. The parameter of temperature difference between the heights of 10 and 2 metres is inaccurate for the same period and reason. Analysis work using these data (Blockley, in progress) has made allowances for these inaccuracies.

3.6 Wickham MS

The meteorological monitoring station at Wickham, situated on land leased by Robe River Mining (see Figure 2.1 – station WI, AMG 511060,7715005), was chosen to bridge the gap in meteorological data between the two larger centres of interest for air quality, Dampier/Karratha and Pt Hedland.

The station was sited in an open area approximately 2 km west of the Wickham townsite. The equipment was solar powered, with data telemetry facilitated by a

digital mobile phone. The site is pictured in Figure 3.14, with instruments listed in Table 3.6.

Figure 3.14 Wickham MS - looking northwest.

Short Name	Long Name	Manufacturer	Model	Operational Parameters
SP10	Wind speed	Climatronics	F460	Range: 0.2 to 56 m/s
DN10	Wind direction	Climatronics	F460	Range: 0 to 360 degrees
SG10	Sigma theta	Statistical Calc	N/A	Range: 0 to 50 degrees
AT10	Air temperature	Rotronics	MP100	Range: -30 to 60 degrees C
RH10	Relative humidity	Rotronics	MP100	Range: 0 to 100 %

Table 3.6 Parameters measured at Wickham MS.

Wickham meteorological station suffered from some periods of data loss (see data recovery chart – Appendix E) due to the failure of equipment associated with the solar charged batteries.

3.7 Radio Hill MS

Radio Hill Nickel Mine is situated approximately 28 km due south of Karratha (see Figure 2.1 – station RN, AMG 486600,7679600), adjacent to the Hamersley Iron railway to the Tom Price mine. The site was chosen to identify differences from meteorological parameters measured near the coast, notably the time of arrival of sea breezes. The station was commissioned in August 1999 and operated up to December 2000.

The equipment was originally set up against the perimeter fence of the mine site, monitoring at a height of 4 m. Changes at the mine meant the station had to be relocated in October 2000 to the weighbridge shed, where greater levels of dust from passing trucks meant that the data was less reliable. The site aspect was not very open, looking towards the south (i.e. towards the mine site), but had an open aspect looking between north and west towards the coast.

The equipment was powered from a solar powered battery, with data transferred periodically by exchange of PC memory card. This method of data collection was chosen as the area is just outside the range of mobile phone telemetry.

Table 3.7 lists the instruments operated at Radio Hill station.

Short Name	Long Name	Manufacturer	Model	Operational Parameters
SP04	Wind speed	Climatronics	F460	Range: 0.2 to 56 m/s
DN04	Wind direction	Climatronics	F460	Range: 0 to 360 degrees
SG04	Sigma theta	Statistical Calc	N/A	Range: 0 to 50 degrees
AT04	Air temperature	Rotronics	MP100	Range: -30 to 60 degrees C
RH04	Relative humidity	Rotronics	MP100	Range: 0 to 100 %

Table 3.7 Parameters measured at Radio Hill MS.

Some loss of data was experienced at Radio Hill due to problems with battery charging (see data recovery chart – Appendix E).

3.8 Maitland MS

A meteorological station was established at the future development site of the Maitland Industrial Estate (see Figure 2.1 – station MT, AMG 464300,7700300) by the Department of Resources Development. The station was sited on the flat coastal plain, at a similar distance from the coast as the Karratha meteorological station, but further west along the coast.

The period of operation was from September 1998 to September 1999. A photograph of the station (Figure 3.15) shows the wind sensor and data telemetry antenna at the top of the mast, with temperature and humidity sensors lower down. These sensors are described in Table 3.8.

Figure 3.15 Maitland MS.

Short Name	Long Name	Instrument Manufacturer	Model	Operational Parameters
SP10	Wind speed	Climatronics	WM3	Range: 0.2 to 56 m/s
DN10	Wind direction	Climatronics	WM3	Range: 0 to 360 degrees
SG10	Sigma theta	Statistical Calc	N/A	Range: 0 to 50 degrees
AT02	Air temperature	Rotronics	MP100	Range: -30 to 60 degrees C
RH02	Relative humidity	Rotronics	MP100	Range: 0 to 100 %

Table 3.8 Parameters measured at Maitland MS.

Maitland station experienced problems at times due to birds sitting on the wind sensors. This was minimised by the use of nylon cable ties pointed directly upwards to discourage perching. Some data problems were also experienced in calculating sigma theta values of wind direction whereby low values of sigma theta were truncated to zero. This problem was caused by an error in the logger program.

3.9 Karratha Airport MS

The Bureau of Meteorology maintains an automatic weather station at the Karratha Airport (see Figure 2.1 – station KP, AMG 476342,7709800). Part of the station is pictured in Figure 3.16 and the instruments used are listed in Table 3.9.

Figure 3.16 Karratha Airport MS.

Short Name	Long Name	Inst Manufacturer	Inst Model	Operational Parameters
SP10	Wind speed	Syncrotac	706	Threshold < 1 m/s
DN10	Wind direction	Syncrotac	706	Range: 0 to 360 degrees
AT02	Air temperature	Rosemount	Pt100	N/A
RH02	Relative humidity	Rotronics	MP100	Range: 0 to 100 %
Press	Atmospheric pressure	Vaisala	N/A	Range: 800 – 1050 hPa
Rain	Rainfall	Rimco	N/A	Resolution: 0.2 mm

Table 3.9 Parameters measured at Karratha Airport MS.

3.10 Legendre Island MS

The Bureau of Meteorology has maintained an automatic weather station on Legendre Island, north of the Burrup Peninsula, since February 1992 (see Figure 2.1 – station LG, AMG 483500,7748665). The logging and telemetry equipment is of the Sutron type. Table 3.10 shows the instruments used at this station.

Short Name	Long Name	Inst Manufacturer	Inst Model	Operational Parameters
SP10	Wind speed	Syncrotac	706	Threshold < 1 m/s
DN10	Wind direction	Syncrotac	706	0 to 360 degrees
AT02	Air temperature	Rosemount	Pt100	N/A
Pres	Atmos pressure	Vaisala	PA11A	800 – 1050 hPa

Table 3.10 Parameters measured at Legendre Island MS.

3.11 Port Hedland Airport MS

The Bureau of Meteorology maintains a manned office at Port Hedland, located at the airport (see Figure 2.2 – station PA, AMG 670122,7746723), operating a standard surface synoptic meteorological program plus an upper air radiosonde program (see Section 3.12). Figure 3.17 shows the surface synoptic instrumentation at this station, which is listed in Table 3.11.

Figure 3.17 Pt Hedland Airport MS.

Short Name	Long Name	Inst Manufacturer	Inst Model	Operational Parameters
SP10	Wind speed	Syncrotac	706	Threshold < 1 m/s
DN10	Wind direction	Syncrotac	706	Range: 0 to 360 degrees
AT02	Air temperature	Rosemount	Pt100	N/A
WT02	Wet bulb temp	Rosemount	Pt100	N/A
Press	Atmospheric Pressure	Vaisala	N/A	Range: 800 – 1050 hPa
Rain	Rainfall	Rimco	N/A	Resolution: 0.2 mm

Table 3.11 Parameters measured at Port Hedland Airport MS.

3.12 Radiosonde Releases

Vertical profile meteorological data in the Pilbara region is collected at Pt Hedland airport by the Bureau of Meteorology as part of a continuous daily program. Radiosonde profiles of temperature and humidity, together with wind parameters, are recorded in the early morning at approximately 0715 WST (2315 UST) and again in the evening at 1915 WST. Wind parameters were derived from tracking the balloon by radar, however an upgrade to the Pt Hedland equipment in 1998 introduced satellite global positioning (GPS) as the method of measuring winds. Figure 3.18 shows the Pt Hedland radiosonde release equipment subsequent to the upgrade.

Figure 3.18 Pt Hedland Airport - radiosonde station.

In September and October 1996, a short program of six radiosonde releases was undertaken by Bureau personnel at the Pt Hedland coast, to provide a comparison with profiles based at the airport, which is approximately 8 km inland. The first sonde in the series was released from the Spoilbank, with subsequent releases from Finucane Island. These two locations are both featured on Figure 2.2. The Spoilbank is directly to the east of Finucane Island, just offshore from the main townsite area. The Bureau of Meteorology was able to collect data from these sondes using the airport receiving system, with winds derived from radar.

In addition to the well-established radiosonde station at Pt Hedland, a new radiosonde receiving station was located at the Dampier AQMS in November 1998. The equipment chosen for this was an Atmospheric Instrumentation Research (AIR) GPS system, which utilised the satellite based GPS system for measuring winds. Personnel from Woodside Energy Limited released one sonde in the early afternoon on several days when sea breezes were present. Data were obtained for 18 days up to August 1999.

Further sondes were released from Dampier simultaneous with releases from Pt Hedland airport during a 10-day period from August 14 - 23 1999. In this period, five sondes were released from Dampier, and 20 from Pt Hedland (in addition to the normal 2 per day schedule).

From August 1999 to March 2000, both sites continued to occasionally release sondes in suitable sea breeze conditions. Three sondes were released from Dampier, and 10 sondes from Pt Hedland. It was intended that releases during this period should if possible be simultaneous from the two sites, but this was achieved on just one occasion (Physick et al., 2000).

In March 2000, the sonde equipment from Dampier was transferred to Pt Hedland for an intensive series of releases from both the coast and the airport. From 28 March to 2 April, 27 sondes were released from the coast, and 13 sondes from the airport (in addition to the normal schedule of 2 per day). Most sondes were released between mid-morning and mid-afternoon to cover the various stages of sea breeze development (Physick et al., 2000). Figure 3.19 shows a corner of the Pt Hedland swimming pool compound, from which the receiving equipment of the coastal station was operated. Inside the compound can be seen a temporary meteorological station for sonde reference purposes. A theodolite tripod is visible outside the fence for use as a backup for balloon tracking and computation of upper air winds. On the far right horizon of the same picture is the low profile of the Spoilbank, from which the first of the exploratory sonde releases was made in 1996.

Figure 3.19 Pt Hedland coast.

A second intensive sonde release experiment was carried out during November 2000, in a similar style to the period in March 2000, comprising 26 sondes released at the coast, and 24 sondes from the airport.

4. Data Collection, Processing and Storage

This section describes the methods used to collect air quality and meteorological data from the various sites in the study region. The procedures and equipment used to log, retrieve, and store data from both DEP and non-DEP stations are described.. Further information on the air quality monitors and meteorological equipment used at the DEP sites, together with the calibration procedures used, is detailed in Appendix A.

4.1 Data Collection

Data collection, comprising the logging on site and transmission of data back to the office, is described for the stations of interest in this study.

4.1.1 Data Collection at DEP Stations

The DEP operated four fixed stations in the Dampier / Karratha area, plus a temporary station in Port Hedland associated with the radio sonde balloon studies. Two of these, Dampier (air quality plus basic meteorology) and Karratha (comprehensive meteorology) were established with equipment similar to that used at metropolitan Perth monitoring stations, namely a mains powered site with air-conditioned shed housing the data collection equipment. Data collection from the remaining three sites is discussed later.

Data logging at Dampier and Karratha used a Unidata STARLOG Macro data logger with a memory capacity of 64 kilobytes. Once a second, an on-site data acquisition system scans all the air quality and meteorological channels at the DEP monitoring sites. Internal processing by the logger then generates a ten-minute average for each parameter, which is stored in the logger's memory. Depending on the number of parameters measured at each site, a logger's memory fills within a period ranging from two weeks to two months. Any new data collected after the logger's memory has been filled will overwrite the oldest data in the logger's memory.

The Dampier and Karratha stations were automatically contacted twice daily, normally at 7 am and 3 pm, using phone line connections. Dampier station had a regular, land-line phone connection, while Karratha used a cellular mobile link. New data stored by each logger since the last transmission was downloaded to a computer (Linux based workstation) located at the DEP head office, and automatically entered into the relevant database. A connection to each site could also be initiated manually at any time throughout the day, and the data viewed and/or retrieved.

The remaining three DEP stations at Wickham, Radio Hill, and the Port Hedland radiosonde ground station, used solar power to run Data-Taker DT50 loggers together with the several meteorological sensors. The data telemetry method varied with location. Wickham data was downloaded approximately weekly by computer phone connection to a cellular modem. Radio Hill was outside the coverage of GSM phones and had data collected manually on to a PCMCIA card which slotted directly into the logger. The Port Hedland radiosonde station was operational only for short periods, with operators on hand to download the data direct to a laptop computer.

4.1.2 Data Collection at Non-DEP Stations

The equipment and processes used for data collection at non-DEP stations was largely agency specific.

The Bureau of Meteorology has progressively upgraded sites to a standardised automatic weather station, manufactured by Almos Systems. Equipment and procedure variations are due partly to location and importance of a station. Port Hedland is a regional centre servicing the needs of an airport with high frequency telemetry. By comparison, Legendre Island is a remote station with the older generation of automatic weather station.

Data was collected from the Department of Resources Development station at Maitland was by means of a Unidata logger and mobile phone modem. This was similar to that employed at the DEP site at Karratha except that the DEP system used an on-site computer to handle the telemetry and logger interrogation software. Data collection from Maitland was handled by an environmental consultant on behalf of DRD.

The meteorological station at Boodarie, owned by BHP Iron, was operated by environmental consultants until August 1997, using an EMS16 data logger. Air quality data was collected from December 1996 using an Ecotech logger, and subsequently the two data streams were merged onto the same Ecotech logging system.

The stations at King Bay and Karratha townsite, both of which in turn used the monitoring caravan owned by Woodside Environmental, had data collected by Unidata logger and mobile phone. The logger software used was that provided for the logger by Unidata.

4.2 Data Processing and Storage

The wide variety of ways and formats in which data were received at DEP from the different agencies were managed with a flexible system of data processing.

4.2.1 Processing of Data from DEP Stations

The data collected by telemetry from Dampier and Karratha were in the form of hexadecimal bytes representing the voltage of each channel as measured by the logger. Each line of raw data represented a ten-minute averaged output from instruments at the two sites.

The process of converting the raw hexadecimal file representing voltages, to a file of engineering units was carried out automatically by software written by DEP staff, and running on a central computing facility, which calculates what fraction of the monitor's full-scale output each byte represents by using a site-specific calibration file. This, together with the known full-scale voltage output of the monitor, is used to determine the original output voltage. Using the most current calibration equation available for that piece of equipment, the voltage is converted to the relevant units and placed into the database for that site.

Each morning, time series plots of all ten-minute averaged data for the previous seven days are examined to determine whether any faults or breakdowns have occurred. These plots included both the raw voltage data and the database values, and comprised all parameters measured at the site. Any monitor irregularities such as baseline drift or any power cuts that occurred are recognised and attended to.

Once a month, all the air quality data that has entered each site's database for the previous month is reprocessed to replace any unwanted or incorrect data with error codes. The data removed includes calibrations, power failures, monitor repairs,

monitor baseline drifts, and other spurious occurrences that are not relevant and/or incorrectly reflect the ambient conditions prevailing at the time. The site logbook contains the dates and times of calibrations, monitor repairs, etc. performed by DEP staff. The remainder, such as power failures and instrument failures, are found by checking the graphical plot of the monitor's voltage output. As each monitor runs with an elevated baseline (typically 5%), an output of zero volts indicates a power failure or monitor fault.

When reprocessing the air quality data, any drift in the monitor's output during the period between any two calibrations is assumed linear. A linear interpolation is accordingly performed over time, from one calibration equation to the next, and an individual calibration equation generated from the interpolation for every ten-minute average. The newly calculated ten-minute average value is then re-entered into the database, overwriting the original interim value.

The data processing involved for the three DEP stations using a Data-Taker logger (Wickham, Radio Hill, Port Hedland radiosonde) was somewhat different in that data was stored in the logger in engineering units, updated in the logger as necessary with calibration factors. Data screening for the meteorological data from these stations was simpler than that described above for air quality data, having lower levels of calibration drift. Quality control procedures were carried out by reviewing data once processed into DEP databases, using techniques such as graphically comparing several datasets by overlay. Other data editing derived from knowledge about a station gained from visits by technicians.

4.2.2 Processing Data Collected by other Organisations

The processing of data from the stations not operated by DEP was restricted mainly to conversion of input files into the DEP databases. The frequency of this varied widely with the agency involved. BHP, Woodside, and DRD supplied their data on a regular basis, typically monthly, whereas the majority of data from Bureau of Meteorology sites were obtained by request towards the end of the study. Quality control of these data was carried out by the agencies involved before forwarding to DEP, however feedback was provided to agencies by DEP staff when irregularities were occasionally observed in data.

4.3 Data Recovery Statistics

Data recovery information for all parameters measured at each site is shown in Appendix E.

5. Summary of Air Quality and Meteorological Data

Air quality data statistics are presented in Appendix B, which contains air quality data from the Dampier, King Bay, Karratha town, and Boodarie monitoring sites.

5.1 Carbon Monoxide

No exceedences of the NEPM ozone standard of 9.0 ppm averaged over 8 hours were recorded anywhere in the Pilbara region.

Carbon monoxide was measured at Dampier. Appendix B shows a summary of all carbon monoxide monitoring performed at Dampier. The maximum 8-hour average concentration of carbon monoxide recorded at Dampier was 0.328 ppm which represents less than 4% of the NEPM standard.

5.2 Ozone

No exceedences of the NEPM ozone standard of 0.1 ppm averaged over 1 hour or 0.08 ppm averaged over 4 hours were recorded anywhere in the Pilbara region.

Ozone was measured at three sites, Dampier, King Bay and Karratha townsite. Appendix B shows a summary of all ozone monitoring performed at each site. The highest 1-hour averaged concentration of 0.064 ppm was recorded at Dampier. The highest 4-hour averaged ozone concentration of 0.062 ppm was also recorded in Dampier. These concentrations represent approximately 64% and 78% of the respective NEPM standards.

5.3 Nitrogen Dioxide

No exceedences of the NEPM nitrogen dioxide standard of 0.12 ppm averaged over 1 hour or 0.03 ppm averaged over 1 year were recorded anywhere in the Pilbara region.

Boodarie, Dampier, King Bay and Karratha townsite recorded nitrogen dioxide concentrations. Appendix B shows a summary of all nitrogen dioxide monitoring performed at each site. The maximum 1-hour averaged concentration of 0.062 ppm was recorded at the Karratha townsite. This concentration is 52% of the NEPM standard. Annual averages at all sites were 0.002 ppm or less.

5.4 Sulfur Dioxide

No exceedences of the NEPM sulfur dioxide standard of 0.20 ppm averaged over 1 hour, 0.08 ppm averaged over 1 day or 0.02 ppm averaged over 1 year were recorded anywhere in the Pilbara region.

Sulfur dioxide was measured at three sites, Boodarie, King Bay and the Karratha townsite. Appendix B shows a summary of all sulfur dioxide monitoring performed at each site. The maximum 1-hour averaged concentration of 0.134 ppm was recorded at the Karratha townsite. This concentration is 67% of the NEPM standard. The maximum daily average at all sites was 0.006 ppm and the annual averages at all sites were less than 0.001 ppm.

5.5 Particles as PM_{10}

There were numerous exceedences of the NEPM PM_{10} standard of 50 micrograms per cubic metre averaged over 1 day.

PM_{10} was measured at Boodarie and Dampier. Appendix B shows a summary of all PM_{10} monitoring performed at each site. Both these sites recorded large exceedences of the standard.

	1997	1998	1999	2000
Boodarie	16	10	8	12
Dampier	-	0*	3	18
* Only 57% data recovery for 1998 year				

Table 5.1 Number of days where the PM_{10} concentration exceeded the NEPM standard of 50 micrograms per cubic metre.

The NEPM goal of no more than 5 days per year where the NEPM standard is exceeded was not met over each of the four years that PM_{10} monitoring was conducted at the Boodarie monitoring site, and over one out of the two years monitoring was conducted at the Dampier site.

A detailed analysis of two particle events is given in Appendix D. The first was caused by a large scrub-fire in October 2000 and the second caused by the ship-loading facilities at East Intercourse Island.

5.5 Particles as $PM_{2.5}$

$PM_{2.5}$ was measured at Boodarie and Appendix B shows a summary of all $PM_{2.5}$ monitoring performed at that site. While there is no NEPM standard set for $PM_{2.5}$ particles, there were numerous days when concentrations were high. The highest 24-hour averaged concentration was 41.1 micrograms per cubic metre.

5.6 Summary of Meteorological Data

Wind roses of the two major centres of the study region are presented in Appendix C. Further statistics of meteorological data are provided by Blockley (in progress).

6. Data Accessibility

Data collected by the DEP and presented in this report are stored in computer databases and are available for various purposes including further analysis and modelling.

Data will be available free of charge to Study participants. A charge may be levied for the supply of data to other parties, depending on the intended use of the data.

Other data presented in this report and collected by various industry groups may be made available to interested parties on application to the respective industries.

7. Summary

This report has described the air quality and meteorological monitoring program undertaken, as a part of the Pilbara Air Quality Study, by the Department of Environmental Protection (DEP), Woodside Energy Limited (Woodside), BHP Iron Ore Pty Ltd (BHP), Department of Resources Development and Landcorp (DRD/Landcorp), and the Bureau of Meteorology (BoM).

One of the key objectives of the Pilbara Air Quality Study was to obtain reliable air quality and meteorological data, in order to provide a sound basis for the assessment of the air quality impacts of existing industries and proposed industrial developments in and around Pilbara coastal towns.

Despite running most operational aspects of the monitoring from Perth, the logistical problems associated with the project were overcome and in the main data recovery rates were in excess of 95% each month.

The data collected from the various stations extends over approximately two years, and forms a substantial dataset on which to base future planning decisions. The meteorological data will be of direct use in modelling the dispersion of air pollutants from proposed industrial and other developments, while the air quality data defines the current pollution levels existing prior to any further development in the region.

8. References

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Appendix A – Calibration and Maintenance Procedures

DEP Air Quality

Ozone

An ultraviolet photometric ozone analyser (Thermo Environmental Instruments Inc. Model 49) was set to measure ozone in the 0-0.2 ppm range.

Measurement principle:

Measurement of ozone concentration in air uses the principle of absorption of ultraviolet light by ozone. An ultraviolet photometer can determine the ozone concentration of an ambient air sample passed through an absorption cell by measuring the attenuation of ultraviolet light with a wavelength of 254 x 10^{-9} metres. The concentration of ozone is directly related to the magnitude of the attenuation. First, reference (ozone-free) air is generated by passing sampled air through an ozone removing converter before it is passed through the absorption cell. The intensity of the light reaching the detector through the reference air is measured. Ambient air is then drawn through the cell and the intensity of light at the detector measured again. The intensity of light reaching the detector is greater in the ozone-free air than the ambient air. A comparison of these two signals gives the concentration of ozone in the sample.

Oxides of nitrogen

A chemiluminescent NO-NO_2-NO_x analyser (Thermo Environmental Instruments Inc. Model 42) was set to measure oxides of nitrogen in the 0-0.5 ppm range.

Measurement principle:

The technique for monitoring nitrogen oxides is known as chemiluminescence. Detection of nitrogen oxides is based on the gas-phase reaction between nitric oxide (NO) and ozone (O_3), which emits light with intensity linearly proportional to the concentration of nitric oxide.

$$NO + O_3 \rightarrow NO_2 + O_2 + h\upsilon$$

Light emission results when the electronically excited NO_2 molecules decay to a lower energy state. Nitrogen dioxide (NO_2) must be transformed into nitric oxide (NO) before it can be measured using this technique. A molybdenum converter heated to 325^{o}C converts NO_2 to NO via the reaction:

$$3NO_2 + Mo \rightarrow 3NO + Mo + O_3$$

When the sample flows through the NO_2-to-NO converter, the chemiluminescence measured within the reaction chamber represents the total NO_X (NO_2 + NO) concentration. Bypassing the converter allows the measurement of the NO concentration only. The difference between the two signals is the value for NO_2.

Carbon monoxide

A gas filter correlation (GFC) carbon monoxide analyser (Thermo Environmental Instruments Inc. Model 42) was set to measure carbon monoxide in the 0-10 ppm range.

Measurement principle:

Radiation from an infrared source is passed through a rotating gas filter containing a high concentration of carbon monoxide in one hemisphere and nitrogen gas in the other. The carbon monoxide gas portion of the filter acts on the infrared radiation to produce a reference beam that cannot be further attenuated by any carbon monoxide that may be present in the sample cell through which the beam then passes. The nitrogen side of the filter wheel is transparent to the infrared radiation and therefore produces a measured beam, which can be absorbed by any carbon monoxide present in the sample cell. The chopped detector signal is modulated by the alternation between the two gas filters, with amplitude related to the concentration of carbon monoxide in the sample cell. Other gases do not cause any modulation of the detector signal since they absorb the reference and measured beams equally within the sample cell. The GFC system therefore responds specifically to carbon monoxide.

Particles

A Tapered Element Oscillating Microbalance (TEOM) ambient particulate monitor (Rupprecht & Patashnick Co., Inc. Model 1400AB) with a 10 μm size selective head was used to measure particles less than 10 μm in diameter respectively. The monitor was set to measure in the range 0 to 400 $\mu g/m^3$.

Measurement principle:

The TEOM ambient particulate monitor measures ambient particulate concentrations directly and in near real time using a tapered element oscillating microbalance. A known airflow is drawn through a 10 μm size selective inlet head and maintained over a tapered glass element with a filter cartridge attached. This glass element is vibrated at its natural frequency. As particulate matter gathers on the cartridge, the element's natural frequency decreases. The ambient mass concentration is proportional to the change in frequency.

Monthly Calibrations

DEP equipment

The O_3, NO_X and CO analysers were calibrated using three span points and a zero, once a month.

Calibrations for NO_X and CO analysers were performed on-site using certified span gases and calibrated gas-blending equipment (GBE). Calibration of GBE was performed at the central workshop facility. The span channel of the Unit Instruments UCS-200 GBE (used to calibrate the NO_X and CO monitor) was calibrated at 90%, 70%, 50% and 30% of its full-scale output.

All diluent gas flows were converted to their correct standard temperature (0°C) and pressure (1013.25 hPa) (STP) flow values by multiplying the measured flow by a Flow Correction Factor (FCF) calculated on site.

$FCF = \frac{P_a - P_{H_2O} - P_{alt}}{1013.25(hPa)} \times \frac{273.15(K)}{T_a(K)}$	• $\boldsymbol{P_a}$ *ambient pressure at sea level* • $\boldsymbol{T_a}$ *ambient temperature* • $\boldsymbol{P_{H_2}o}$ *saturated water vapour pressure @* $\boldsymbol{T_a}$ • $\boldsymbol{P_{alt}}$ *altitude correction factor*

The span gas flows used in all gas monitor calibrations were those determined at the GBE calibrations and were assumed to remain constant throughout the period between calibrations. The flow at each selected span point was calculated to reflect its value at STP.

Ozone calibrations were performed on-site using a Thermo Environmental Instruments Inc. Model 49C-PS Ozone Calibrator. Three span points were chosen (150 ppb, 100 ppb and 50 ppb) together with a zero.

The calibration formula was determined using the method of least squares. If the calculated correlation coefficient squared (r^2) was less than 0.9990, the slopes of each individual span point and the zero point were calculated. Any point that showed a significant deviation from the median value of all the individual slopes was re-done.

Figure A1 A DEP staff member performing a monthly calibration at the Dampier air quality monitoring station.

Non-DEP Air Quality

BHP and Woodside provided the DEP with data pertaining to their respective sites and implemented their own calibration and quality assurance procedures.

DEP Meteorological Stations

The quality control program employed for the meteorological monitoring at DEP stations in the Pilbara (Dampier, Karratha, Wickham, Radio Hill) was broken down into three main elements.

1. Weekly checking of data received from the stations.

   The data from DEP sites at Dampier, Karratha, Wickham, and Radio Hill were appraised for general integrity. A comparison between stations using graphical overlays was used to help identify suspect data.

2. Fortnightly site visit for basic checking and cleaning.

   Site visits were used to perform simple visual checks for the correct operation of sensors, and to clean solar radiation sensors. The condition of sensors needing cleaning less often was monitored on these visits.

3. Regular calibration of sensors.

   Sensors were either exchanged or calibrated on-site according to the type of sensor. These procedures are described below under the heading of each parameter.

Description of meteorological sensors, including maintenance and calibration procedures.

Windspeed

Windspeed was measured at each station by a 3 cup anemometer. The standard calibration provided by the manufacturer was taken as being the actual calibration for each site. The confidence placed in this standard calibration stemmed from the maintenance of the aerodynamics of the cups (clean, upright, and not damaged) and the maintenance of bearings with low friction. These two main factors were accomplished by regular checking, cleaning, and replacement of cups and bearings. The only objective measure used in this process was a low torque meter to gauge the friction of the bearings.

Wind Direction

A wind vane was used as the sensor for wind direction, employing a single potentiometer with narrow gap at north. Calibration was performed approximately 6 monthly using a 2 stage procedure. First, the approximately East – West crossarm orientation was measured accurately by compass bearing. Second, the signal measured for the two vane directions parallel to the crossarm were recorded by

clamping the vane using a special bracket. The resulting 2 values were used to derive a linear regression equation.

Air Temperature

The air temperature sensor used at each station was a high resistance thermistor. A standard reference resistor was used in series with the thermistor to produce an output voltage linear with temperature. Calibration of the thermistor was made on-site by immersion in a water bath. The reference thermometer used was in turn compared to the primary temperature standard held in the department: a mercury-in-glass thermometer with current NATA certification. The on-site calibrations were performed using the station data logger and wiring to measure the sensor outputs, as is the case in normal operation.

Relative Humidity

Calibration of spare humidity sensors was performed in the laboratory and then exchanged with the sensor in the field, approximately annually. The calibration in the laboratory was performed by comparison with standard salt solutions with humidities of 35% and 80%. Sensors registering a significant difference would be adjusted and then rechecked.

Solar Radiation

Total solar (or global, or incoming shortwave) radiation was measured by a first class (ISO9060) pyranometer. These sensors were re-calibrated at least every 2 years by a NATA certified laboratory. Sensors were exchanged in the field to facilitate this without loss of data.

Net radiation (short and longwave) was measured by a pyrradiometer. The calibration of these sensors was similar to the pyranometers. The low level output signal of the pyrradiometer was amplified close to the sensor by a stabilised (chopper) amplifier which was calibrated in the laboratory using a high quality multimeter.

Rainfall

Rainfall was measured by sensors using the tipping bucket method. These were checked for calibration at least annually by dripping a measured amount of water (500 ml) into the gauge.

Upper Air

Windspeed and direction values between 100 m and 800 m elevation were monitored using a Doppler acoustic sounder. Data checks were made for consistency between levels and comparison with the station 10m values, but no calibration was made during the experimental period.

Non-DEP Meteorological Stations

The meteorological stations operated by agencies other than DEP had quality control programs as defined by the particular agency. The Bureau of Meteorology (Karratha Airport, Legendre Island, Port Hedland Airport) have a program using their own personnel, both local and interstate. BHP Iron Ore (Boodarie) maintain their equipment by using their own staff plus environmental consultants. External consultants were also used to maintain data quality at Maitland Station (Dept of Resources Development).

Appendix B – Pollution Data Summary

Boodarie NO_2 (1-hr and annual)

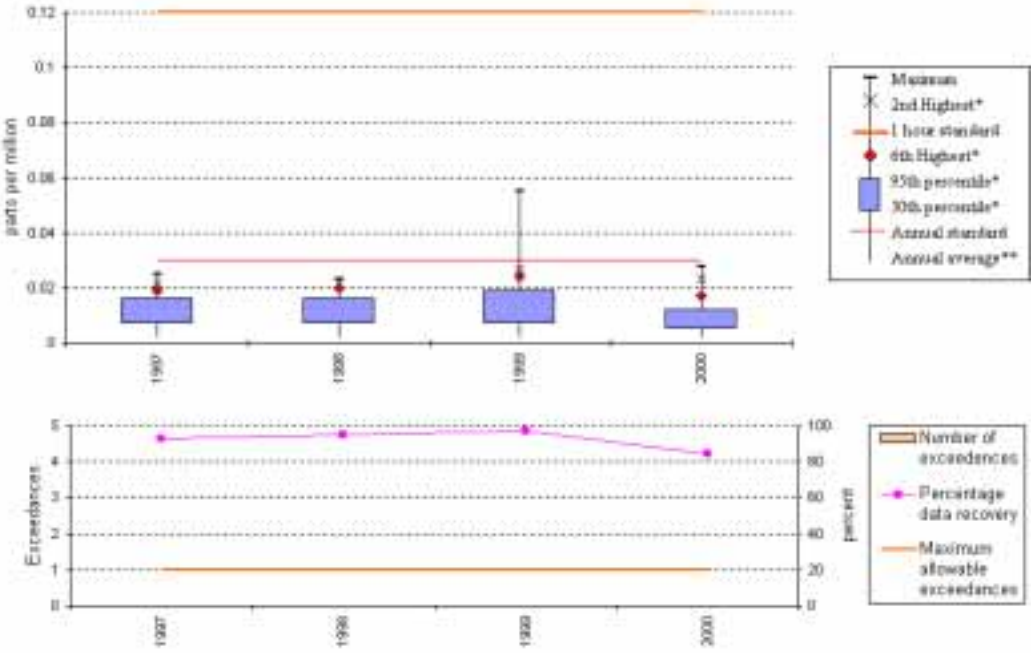
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Nitrogen dioxide**
AQMS Location:	**Boodarie**
AQMS Operated By:	BHP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.12 ppm (1-hour) 0.03 ppm (annual)
Criterion Basis:	NEPM

Results for 1997 - 2000

Dampier NO_2 (1-hr)

Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

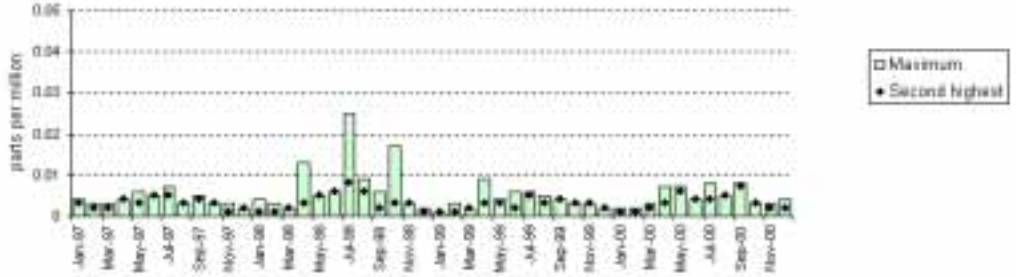
Boodarie SO_2 (1-hr and annual)

Data Measurement Details

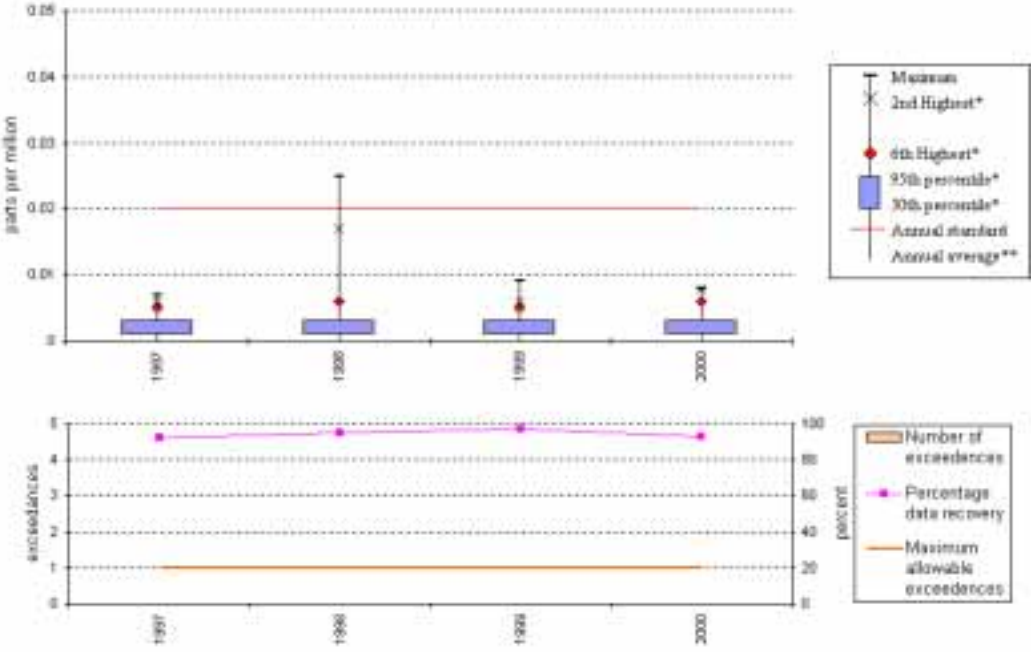
Study Region:	**Pilbara**
Pollutant:	**Sulfur dioxide**
AQMS Location:	**Boodarie**
AQMS Operated By	BHP
Data Sampling Period	10 minute averages
Air Quality Criterion:	0.20 ppm (1-hour) 0.02 ppm (annual)
Criterion Basis:	NEPM

Results for 1997 - 2000

Boodarie SO_2 (1-hr)



Annual Statistics



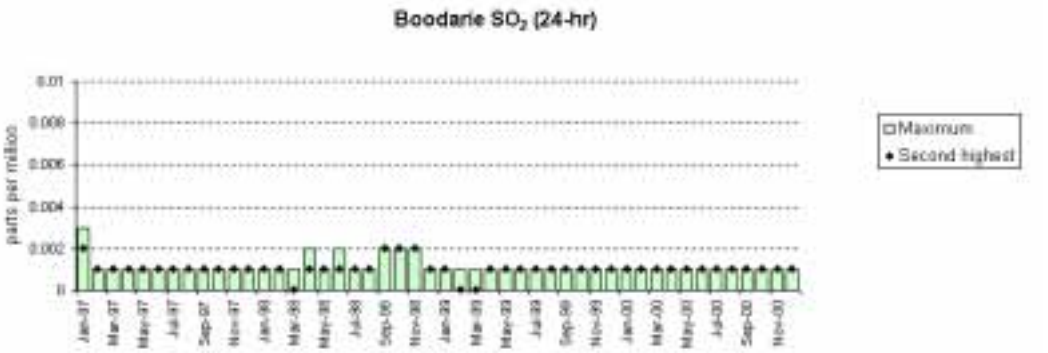
* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

Boodarie SO_2 (24-hr)

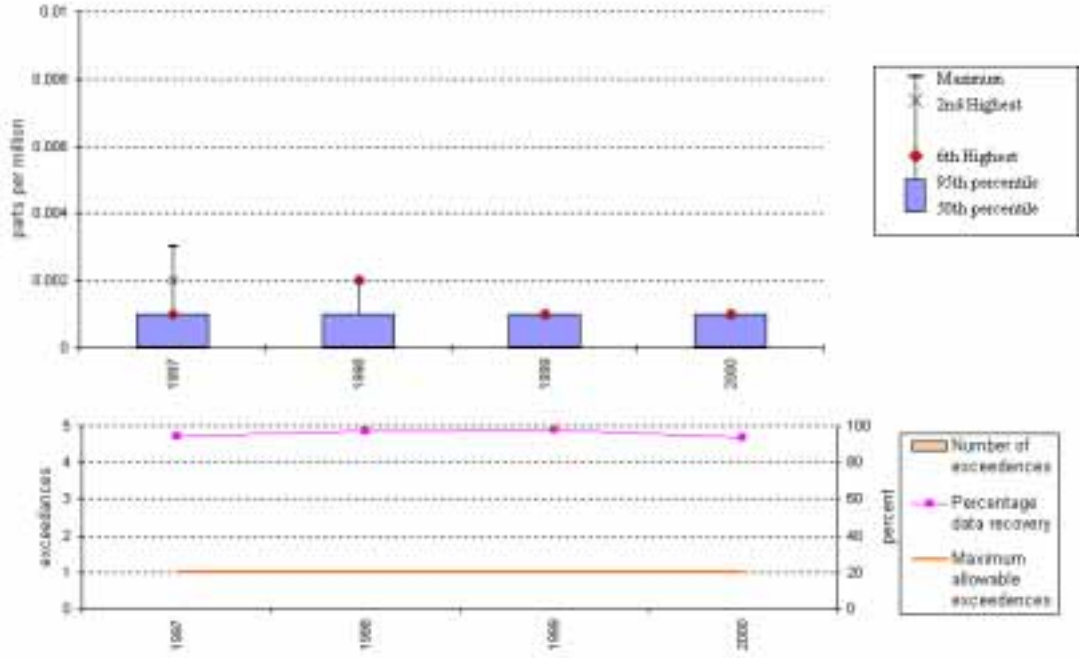
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Sulfur dioxide**
AQMS Location:	**Boodarie**
AQMS Operated By:	BHP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.08 ppm (24-hour)
Criterion Basis:	NEPM

Results for 1997 - 2000



Annual Statistics



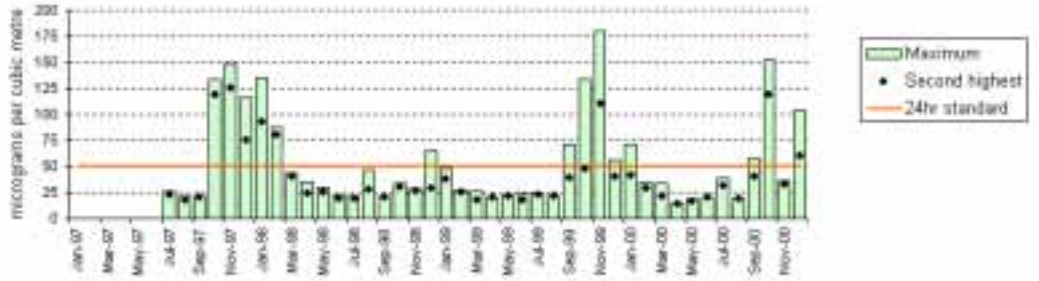
Boodarie PM_{10} (24-hr)

Data Measurement Details

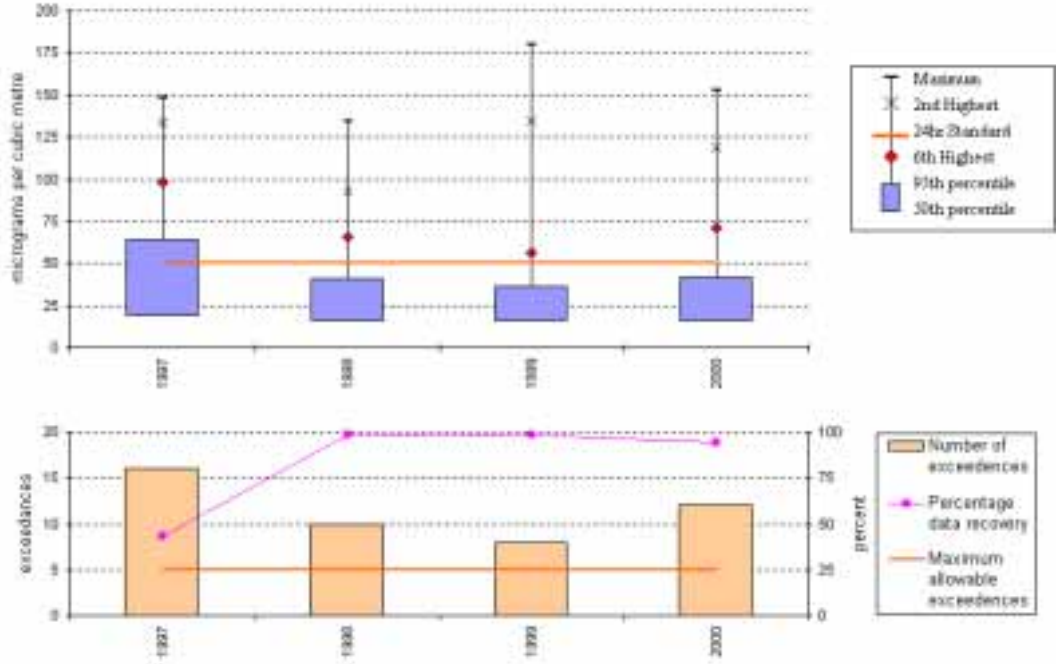
Study Region:	**Pilbara**
Pollutant:	**Particles (PM_{10})**
AQMS Location:	**Boodarie**
AQMS Operated By:	BHP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	50 ug/m^3 (24-hour)
Criterion Basis:	NEPM

Results for 1997 - 2000

Boodarie PM_{10} (24-hr)



Annual Statistics



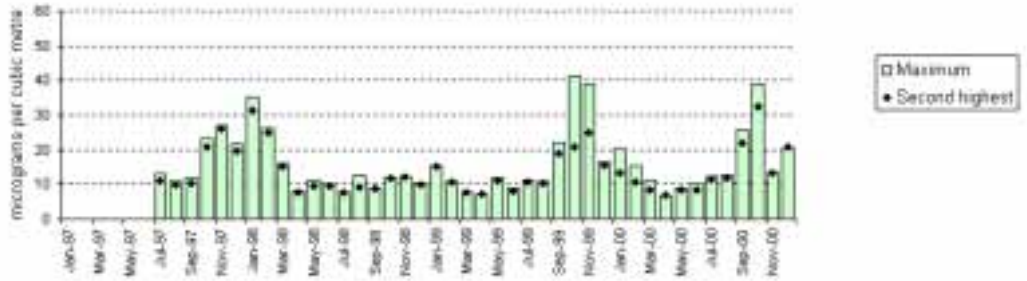
Boodarie $PM_{2.5}$ (24-hr)

Data Measurement Details

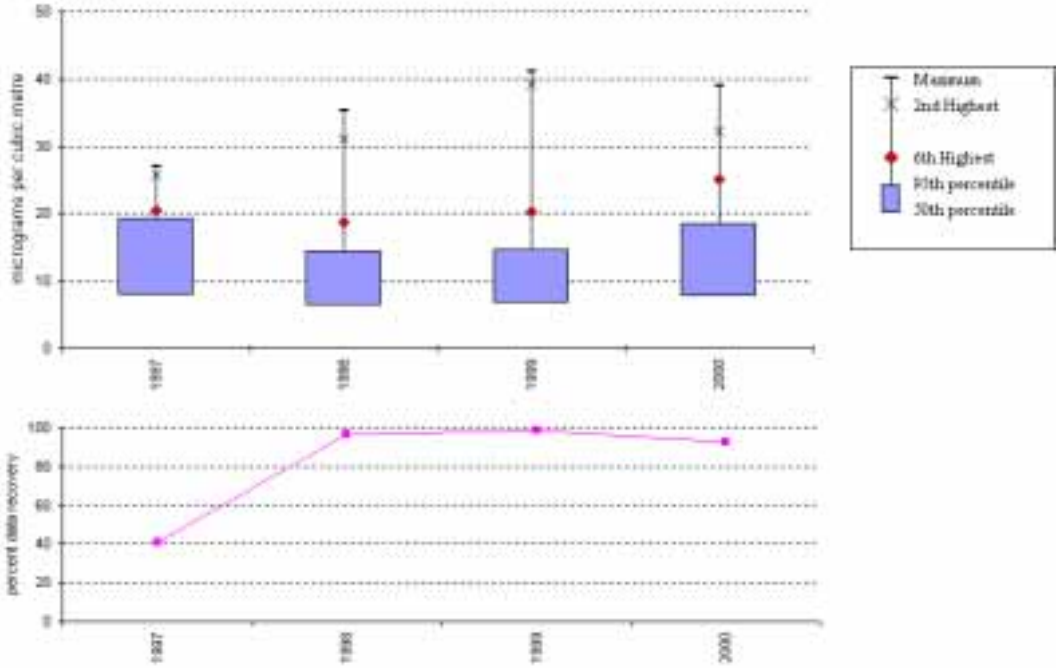
Study Region:	**Pilbara**
Pollutant:	**Particles ($PM_{2.5}$)**
AQMS Location:	**Boodarie**
AQMS Operated By	BHP
Data Sampling Period	10 minute averages
Air Quality Criterion	N/A
Criterion Basis	N/A

Results for 1997 - 2000

Boodarie $PM_{2.5}$ (24-hr)



Annual Statistics



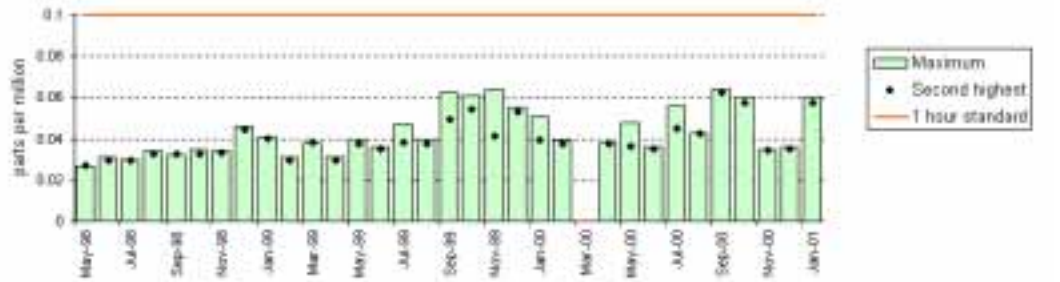
Dampier O_3 (1-hr)

Data Measurement Details

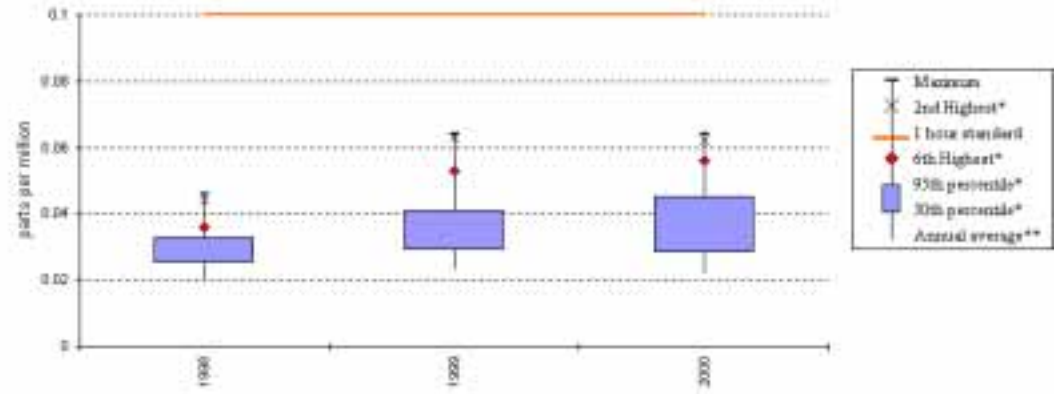
Study Region:	**Pilbara**
Pollutant:	**Ozone**
AQMS Location:	**Dampier**
AQMS Operated By:	DEP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.10 ppm (1-hour)
Criterion Basis:	NEPM

Results for 1998 - 2001

Dampier O_3 (1-hr)



Annual Statistics



*- Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

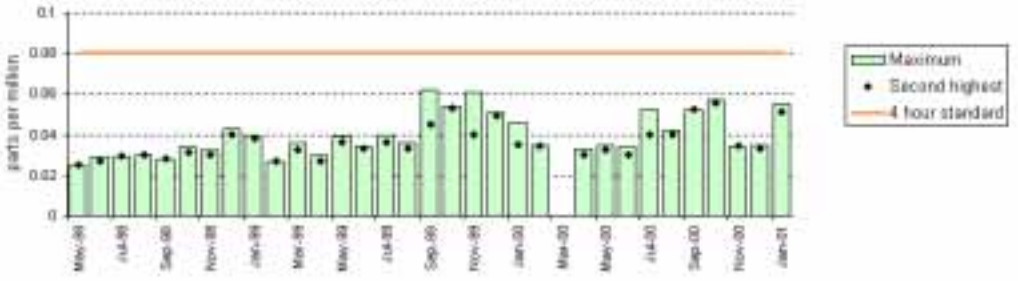
Dampier O_3 (4-hr)

Data Measurement Details

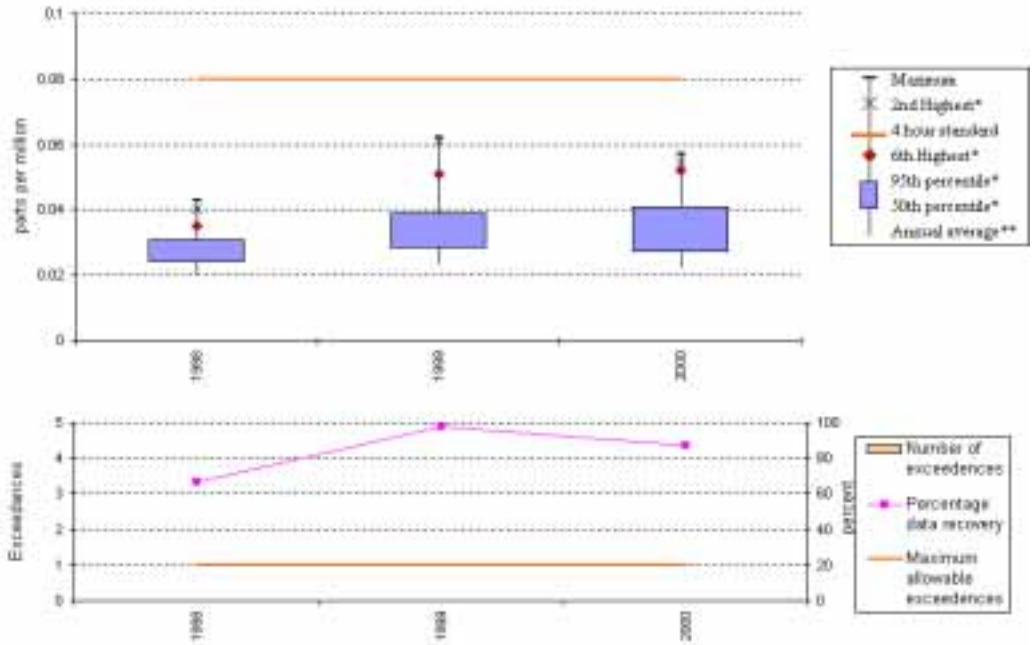
Study Region:	**Pilbara**
Pollutant:	**Ozone**
AQMS Location:	**Dampier**
AQMS Operated By:	DEP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.08 ppm (4-hour)
Criterion Basis:	NEPM

Results for 1998 - 2001

Dampier O_3 (4-hr)



Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

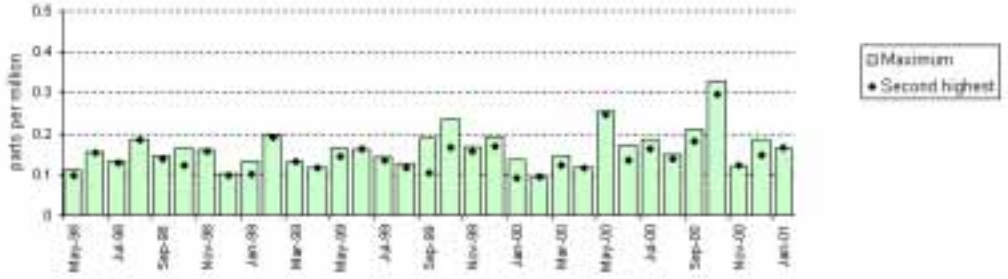
Dampier CO (8-hr)

Data Measurement Details

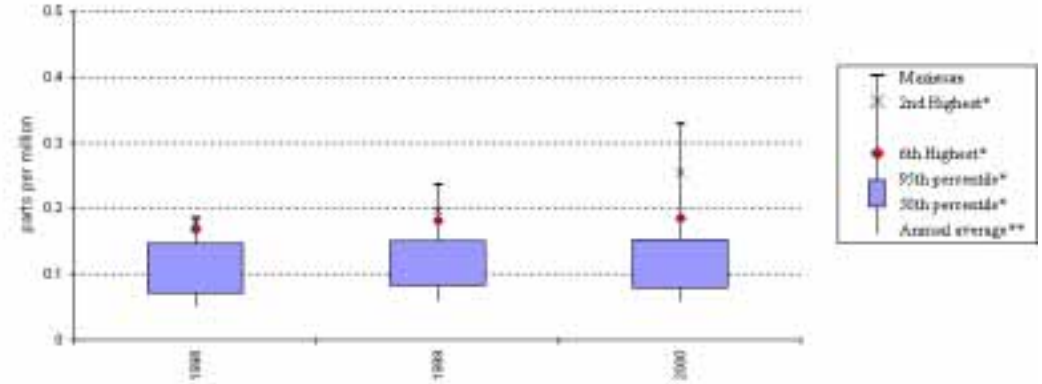
Study Region:	**Pilbara**
Pollutant:	**Carbon monoxide**
AQMS Location:	**Dampier**
AQMS Operated By:	DEP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	9.0 ppm (8-hour)
Criterion Basis:	NEPM

Results for 1998 - 2001

Dampier CO (8-hr)



Annual Statistics



* - Ranked values determined from the daily maxima.
** - Concentration calculated from all recorded data

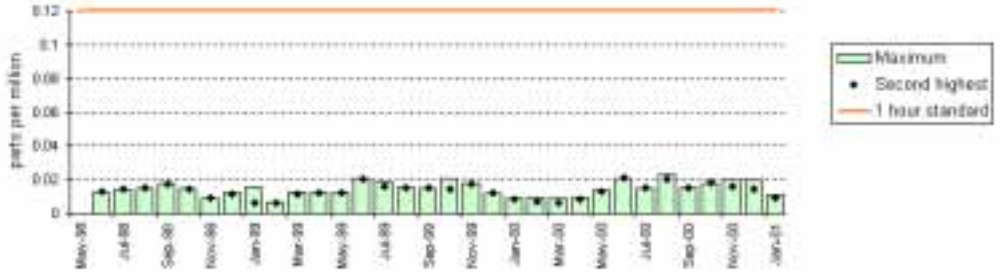
Dampier NO_2 (1-hr and annual)

Data Measurement Details

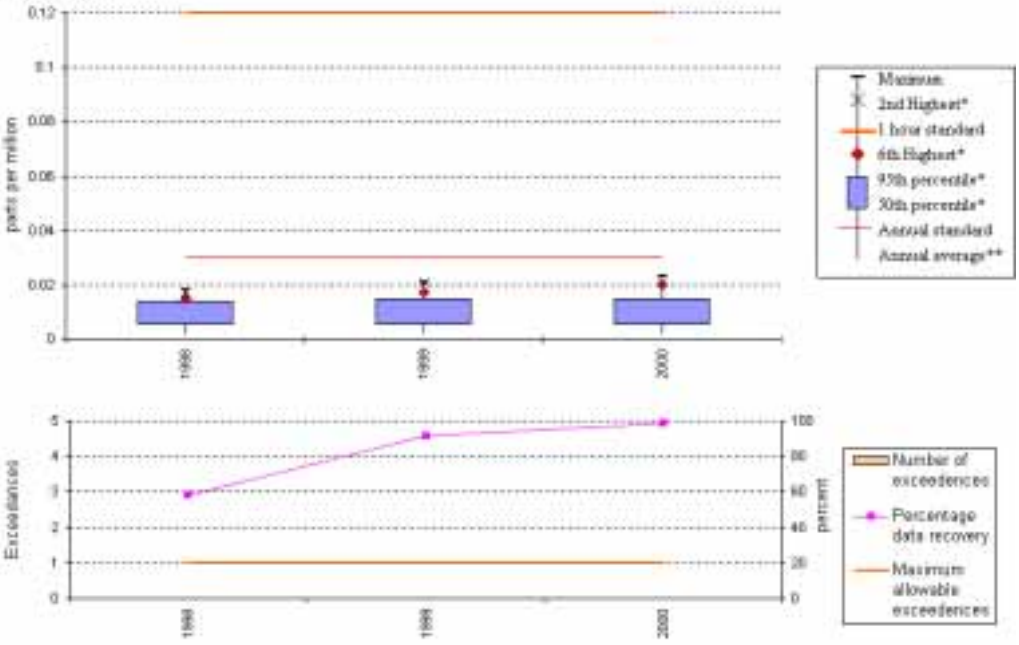
Study Region:	**Pilbara**
Pollutant:	**Nitrogen dioxide**
AQMS Location:	**Dampier**
AQMS Operated By:	DEP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.12 ppm (1-hour) 0.03 ppm (annual)
Criterion Basis:	NEPM

Results for 1998 - 2001

Dampier NO_2 (1-hr)



Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

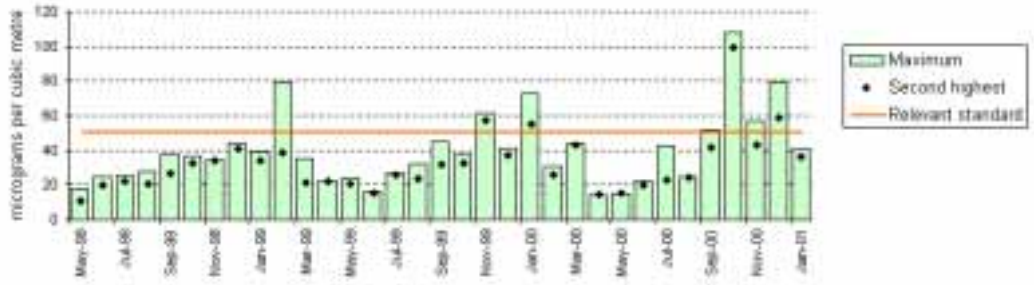
Dampier PM_{10} (24-hr)

Data Measurement Details

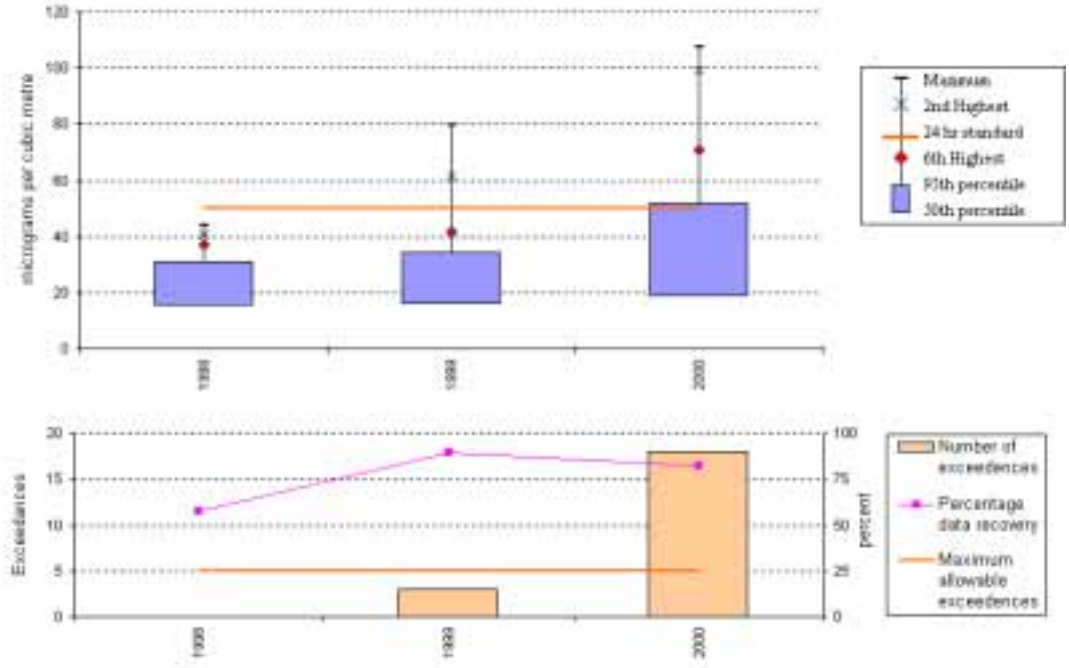
Study Region:	**Pilbara**
Pollutant:	**Particles (PM_{10})**
AQMS Location:	**Dampier**
AQMS Operated By:	DEP
Data Sampling Period:	10 minute averages
Air Quality Criterion:	50 ug/m^3 (24-hour)
Criterion Basis:	NEPM

Results for 1998 - 2001

Dampier PM_{10} (24-hr)



Annual Statistics



Karratha Townsite O_3 (1-hr)

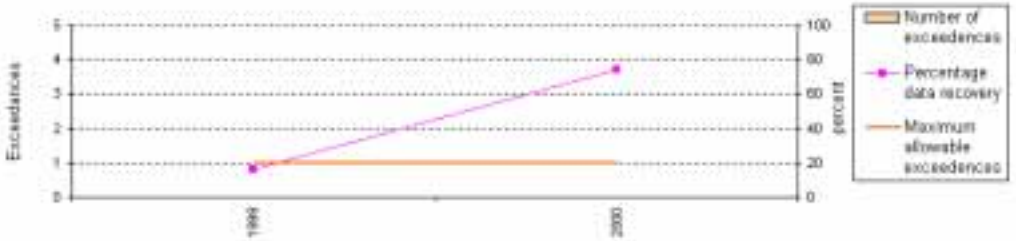
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Ozone**
AQMS Location:	**Karratha Townsite**
AQMS Operated By:	Woodside
Data Sampling Period	10 minute averages
Air Quality Criterion	0.10 ppm (1-hour)
Criterion Basis	NEPM

Results for 1999 - 2000

Karratha Townsite O_3 (1-hr)

Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

Karratha Townsite O_3 (4-hr)

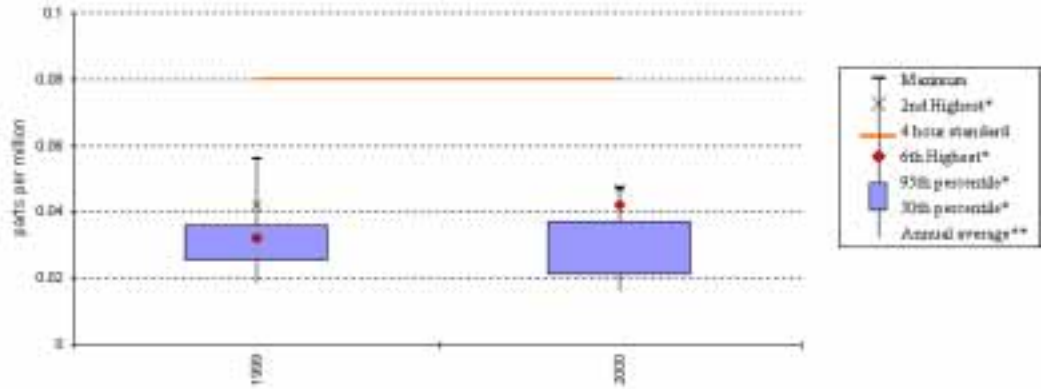
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Ozone**
AQMS Location:	**Karratha Townsite**
AQMS Operated By:	Woodside
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.08 ppm (4-hour)
Criterion Basis:	NEPM

Results for 1999 - 2000

Karratha Townsite O_3 (4-hr)

Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

Karratha Townsite NO_2 (1-hr and annual)

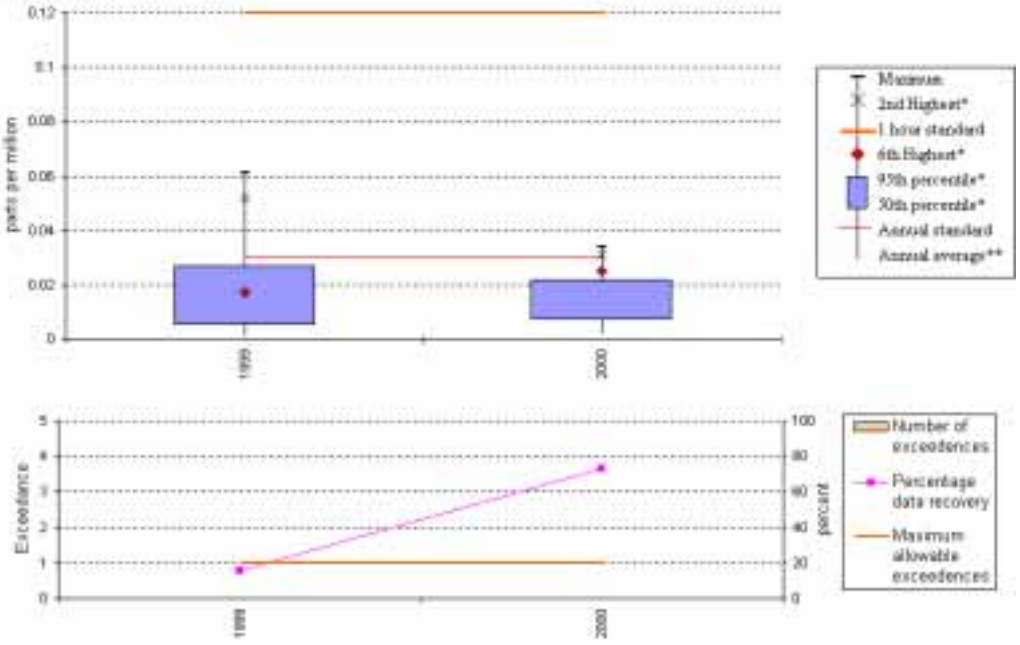
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Nitrogen dioxide**
AQMS Location:	**Karratha Townsite**
AQMS Operated By:	Woodside
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.12 ppm (1-hour) 0.03 ppm (annual)
Criterion Basis:	NEPM

Results for 1999 - 2000

Karratha Townsite NO_2 (1-hr)

Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

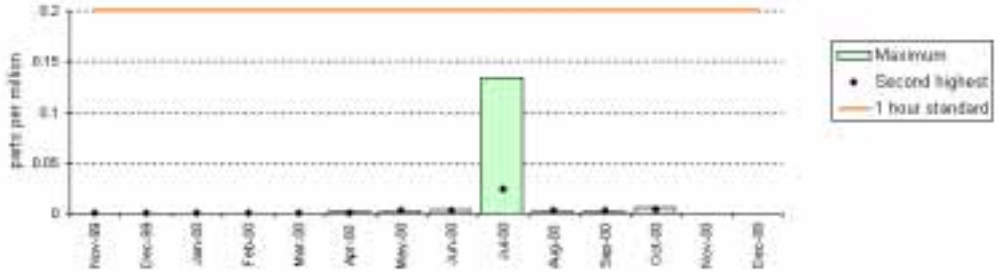
Karratha Townsite SO_2 (1-hr and annual)

Data Measurement Details

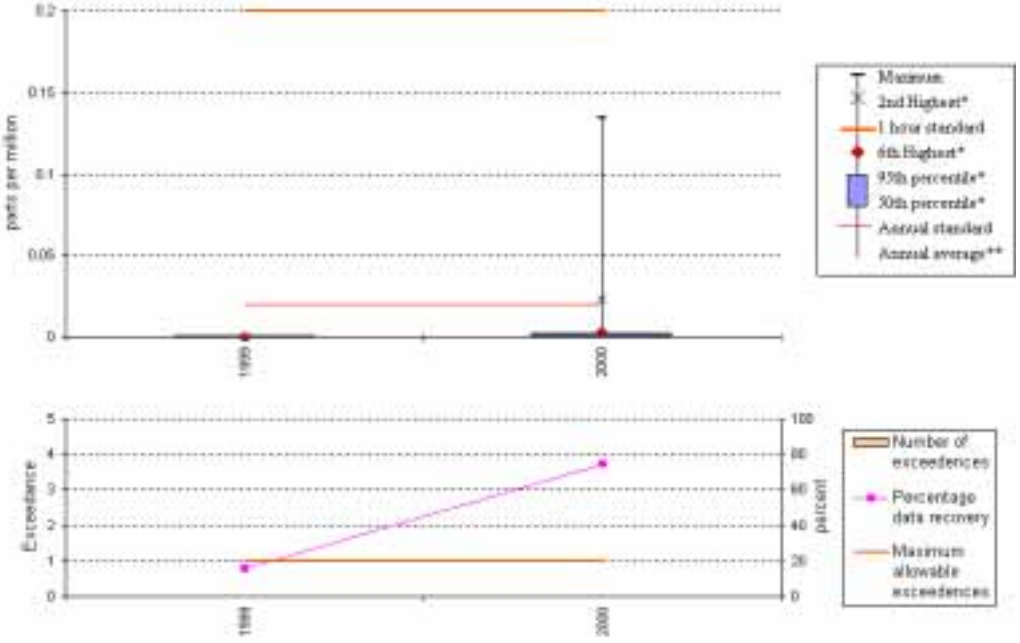
Study Region:	**Pilbara**
Pollutant:	**Sulfur dioxide**
AQMS Location:	**Karratha Townsite**
AQMS Operated By:	Woodside
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.20 ppm (1-hour) 0.02 ppm (annual)
Criterion Basis:	NEPM

Results for 1999 - 2000

Karratha Townsite SO_2 (1-hr)



Annual Statistics



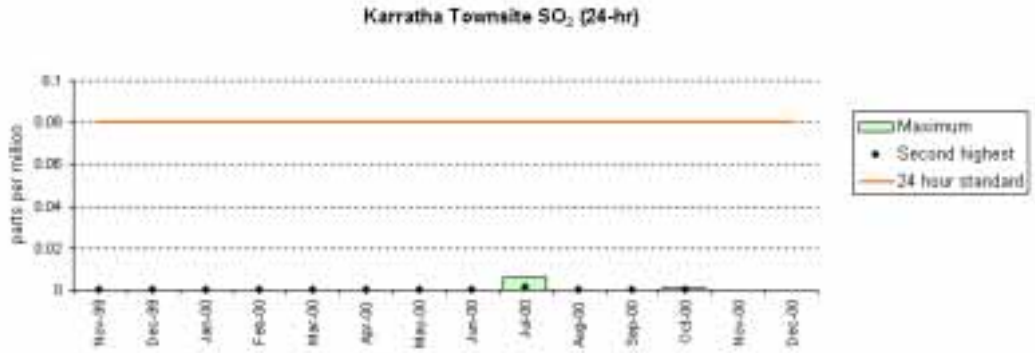
* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

Karratha Townsite SO_2 (24-hr)

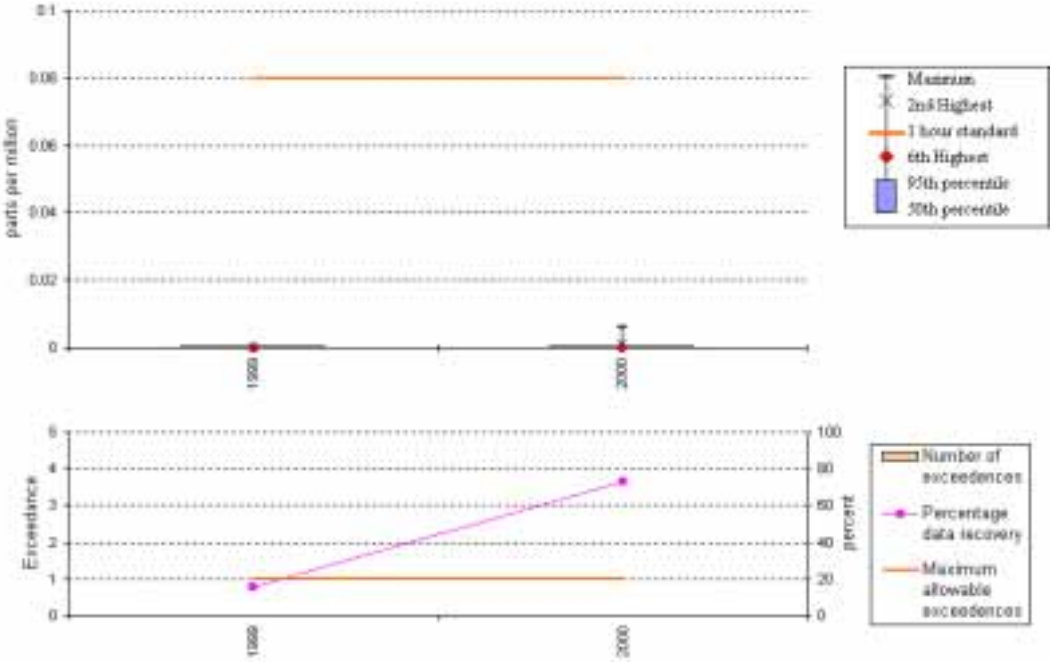
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Sulfur dioxide**
AQMS Location:	**Karratha Townsite**
AQMS Operated By:	Woodside
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.08 ppm (24-hour)
Criterion Basis:	NEPM

Results for 1999 - 2000



Annual Statistics

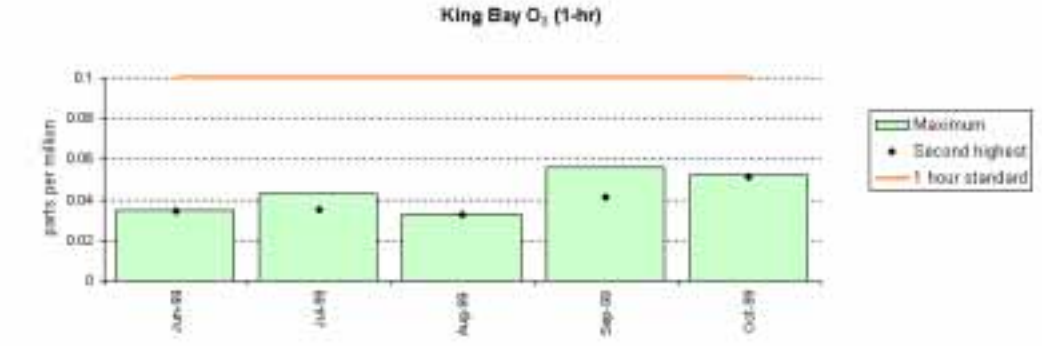


King Bay O_3 (1-hr)

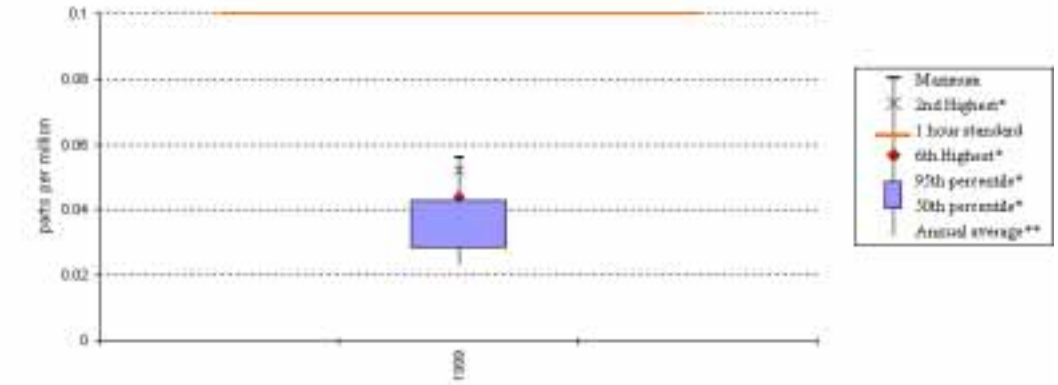
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Ozone**
AQMS Location:	**King Bay**
AQMS Operated By:	Woodside
Data Sampling Period	10 minute averages
Air Quality Criterion	0.10 ppm (1-hour)
Criterion Basis	NEPM

Results for 1999



Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

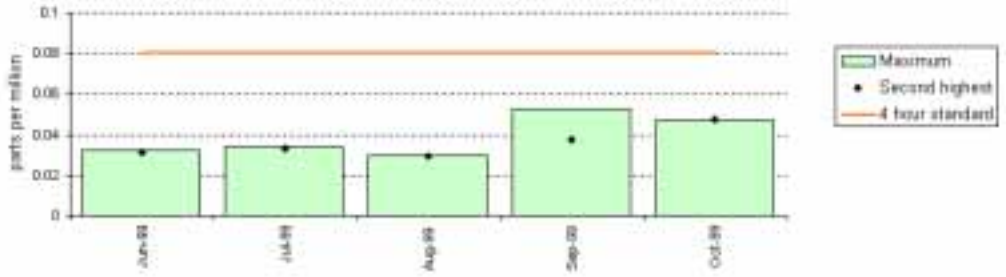
King Bay O_3 (4-hr)

Data Measurement Details

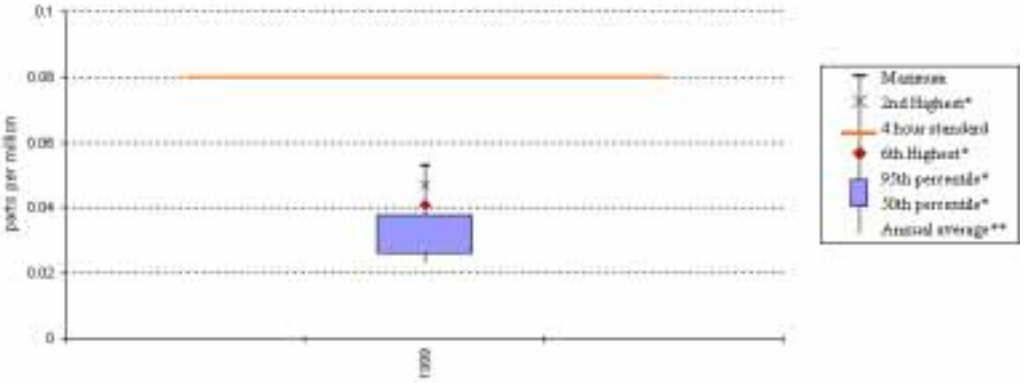
Study Region:	**Pilbara**
Pollutant:	**Ozone**
AQMS Location:	**King Bay**
AQMS Operated By:	Woodside
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.08 ppm (4-hour)
Criterion Basis:	NEPM

Results for 1999

King Bay O_3 (4-hr)



Annual Statistics



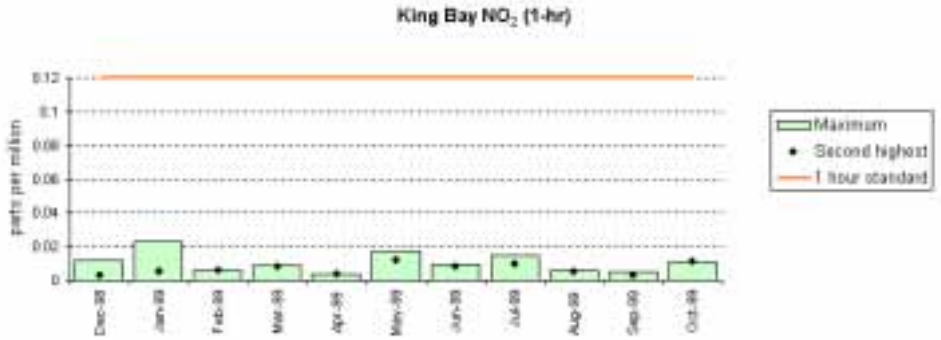
* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

King Bay NO_2 (1-hr and annual)

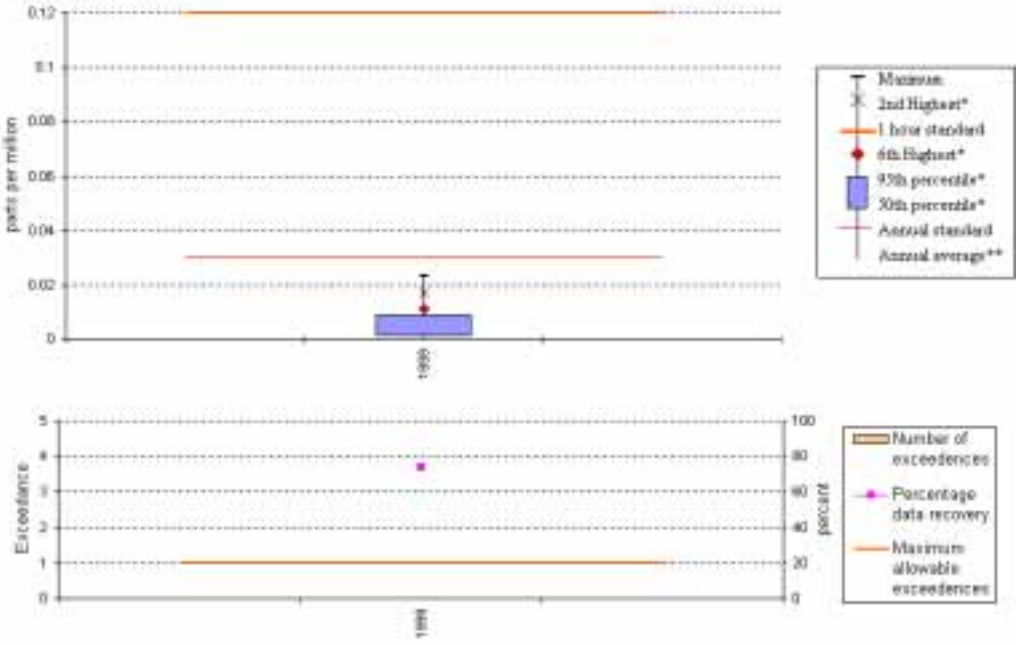
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Nitrogen dioxide**
AQMS Location:	**King Bay**
AQMS Operated By:	Woodside
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.12 ppm (1-hour) 0.03 ppm (annual)
Criterion Basis:	NEPM

Results for 1998 - 1999



Annual Statistics



* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

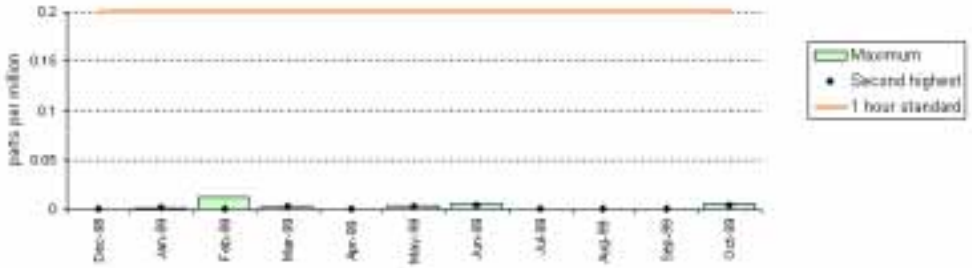
King Bay SO_2 (1-hr and annual)

Data Measurement Details

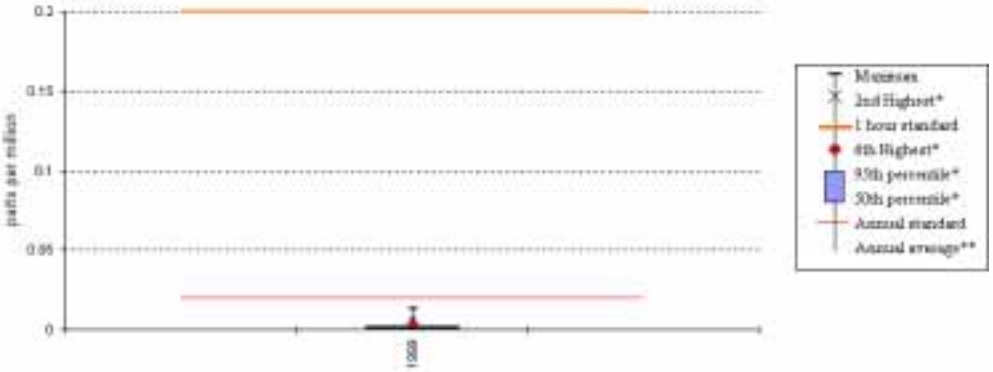
Study Region:	**Pilbara**
Pollutant:	**Sulfur dioxide**
AQMS Location:	**King Bay**
AQMS Operated By:	Woodside
Data Sampling Period:	10 minute averages
Air Quality Criterion:	0.20 ppm (1-hour) 0.02 ppm (annual)
Criterion Basis:	NEPM

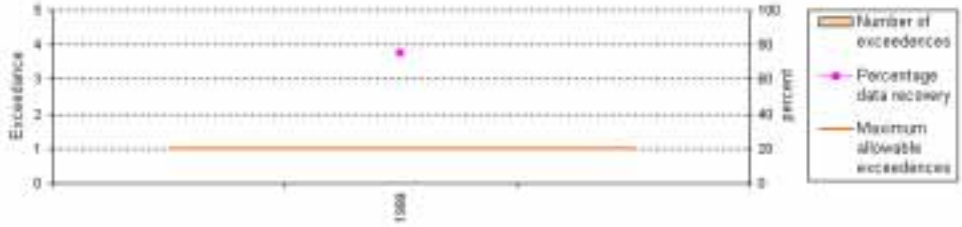
Results for 1998 - 1999

King Bay SO_2 (1-hr)



Annual Statistics





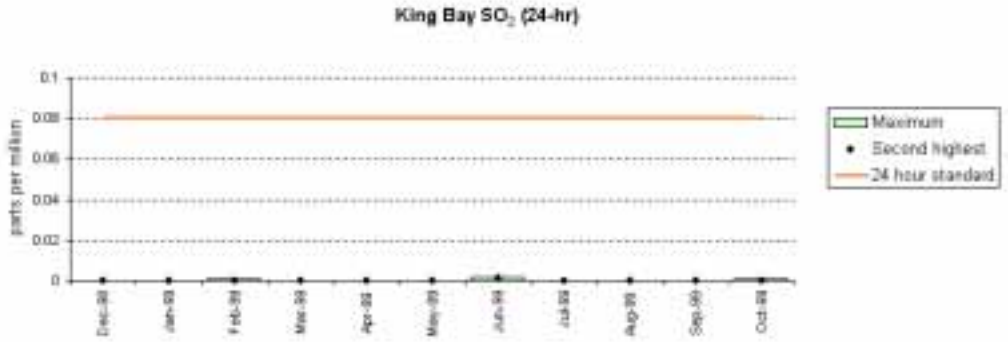
* - Ranked values determined from the daily maxima
** - Concentration calculated from all recorded data

King Bay SO_2 (24-hr)

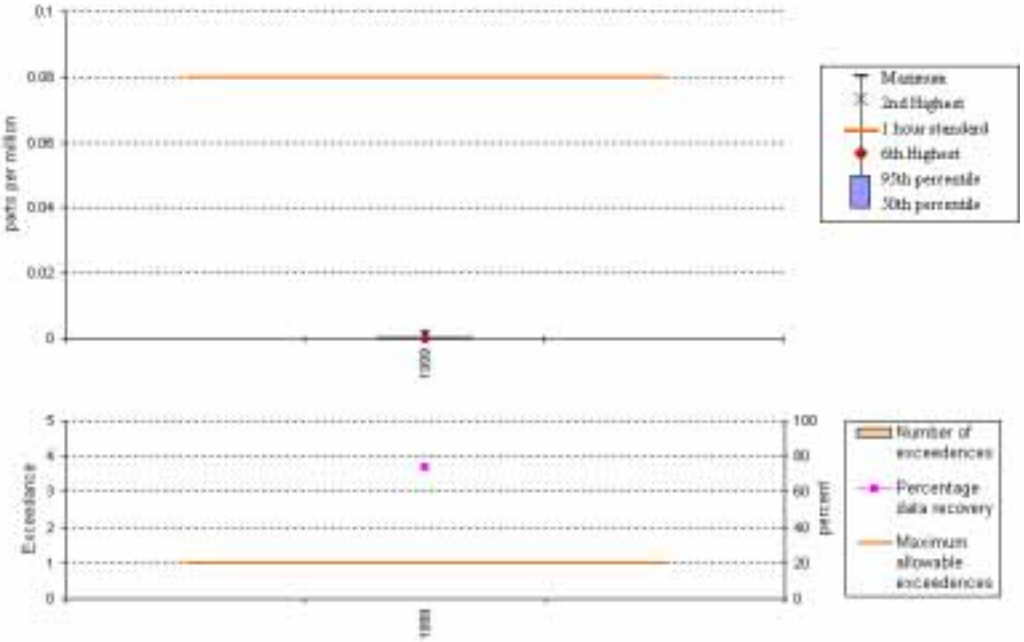
Data Measurement Details

Study Region:	**Pilbara**
Pollutant:	**Sulfur dioxide**
AQMS Location:	**King Bay**
AQMS Operated By:	Woodside
Data Sampling Period	10 minute averages
Air Quality Criterion	0.08 ppm (24-hour)
Criterion Basis	NEPM

Results for 1998 - 1999



Annual Statistics



Appendix C – Meteorological Statistics

Wind roses are presented below for the two principal areas of interest in the study region. The Karratha/Dampier area is represented by the DEP monitoring station near Karratha, and the Port Hedland area by the BHP monitoring station at Boodarie. Data analysed were from the period April 1999 to March 2000. The period was chosen to miss one tropical cyclone in March 1999 (T.C. Vance), but does include T.C. Steve in March 2000.

Additional meteorological statistics are to be found in the section on meteorological modelling (Blockley, in progress).

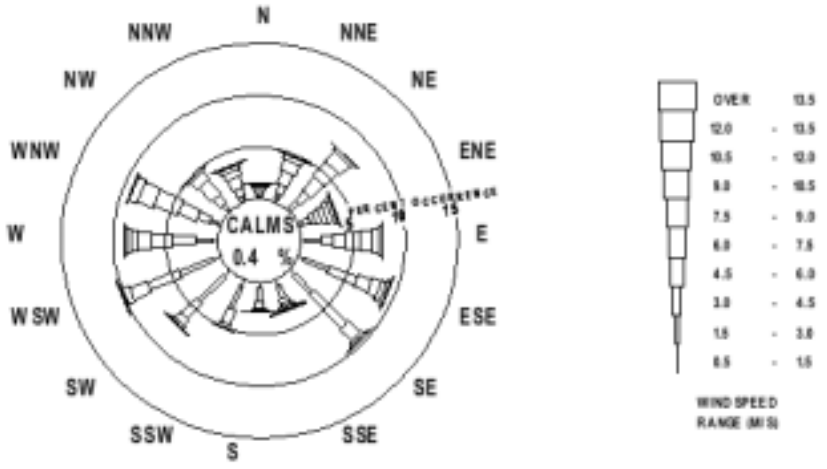


Figure C1 Karratha annual wind rose (Apr 99 – Mar 00)

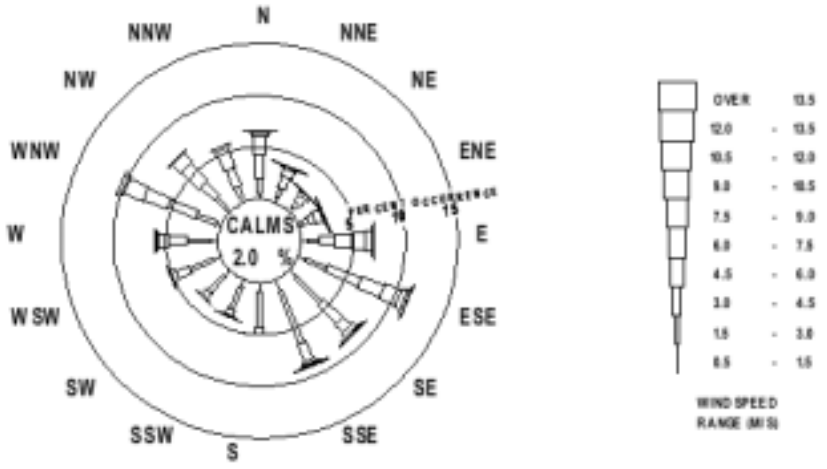
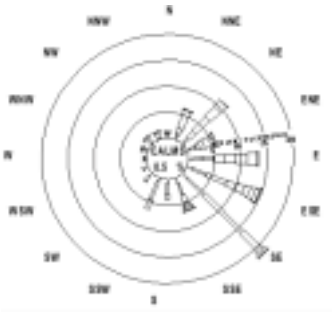
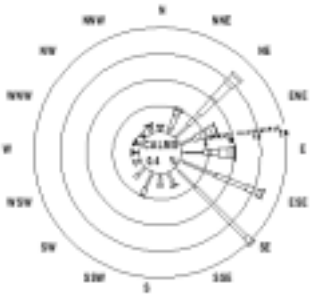
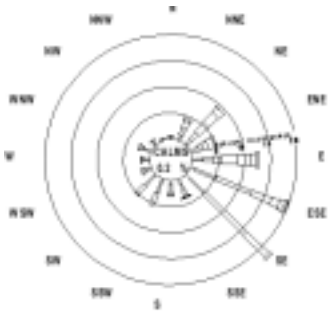
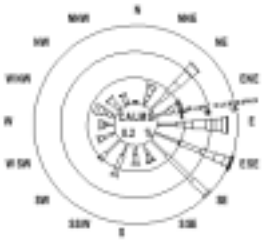
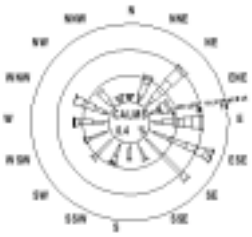
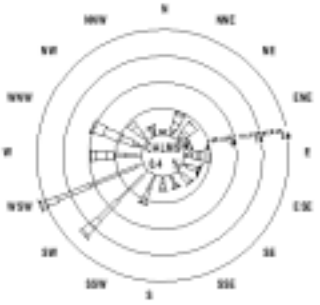
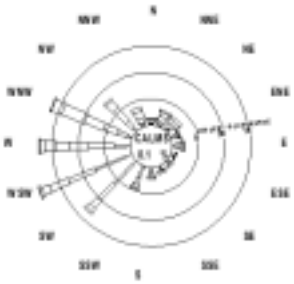
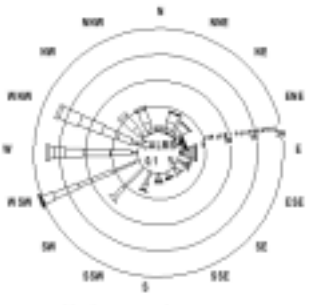
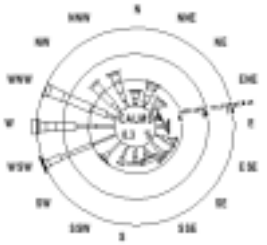


Figure C2 Boodarie annual wind rose (Apr 99 – Mar 00)

		
April 99	May 99	June 99
		
July 99	August 99	September 99
		
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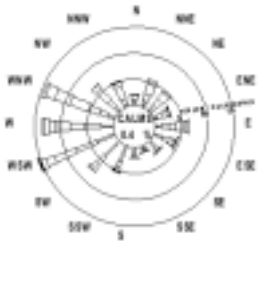
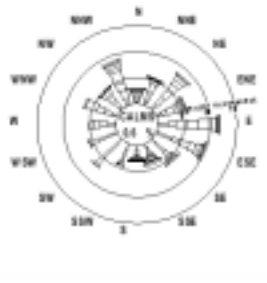
		
January 00	February 00	March 00

Figure C3 Karratha monthly wind roses

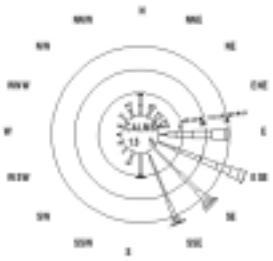
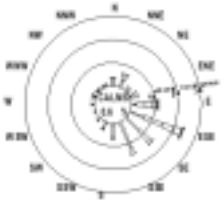
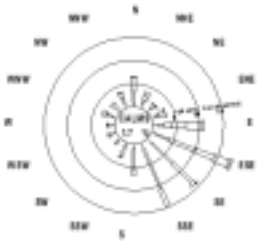
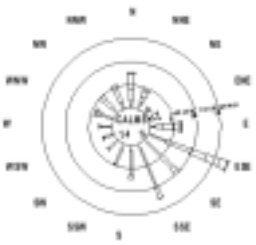
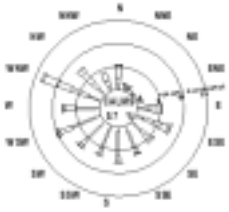
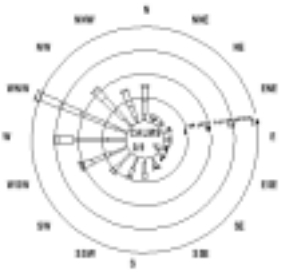
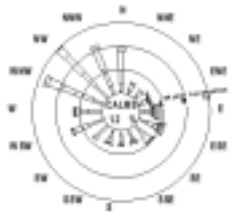
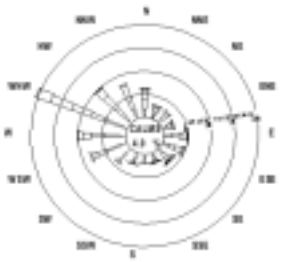
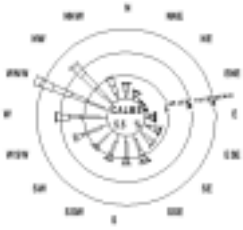
		
April 99	May 99	June 99
		
July 99	August 99	September 99
		
October 99	November 99	December 99
		
January 00	February 00	March 00

Figure C4 Boodarie monthly wind roses

Appendix D – Analysis of High Particle Events

Particulate pollutants consist of wind borne matter such as smoke and dust. These are of concern as they can be inhaled. The particles themselves, or in conjunction with associated chemicals, may cause injury to the respiratory tract. While the inhalation of small particles (less than 10 micrometres) may be associated with increases in the daily prevalence of respiratory symptoms, fine particles (less than 2.5 micrometers) are implicated as the major influence on human health effects associated with PM_{10}. These fine particles may lodge in the alveolar tissue of the lung where oxygenation of the blood occurs, decreasing overall efficiency.

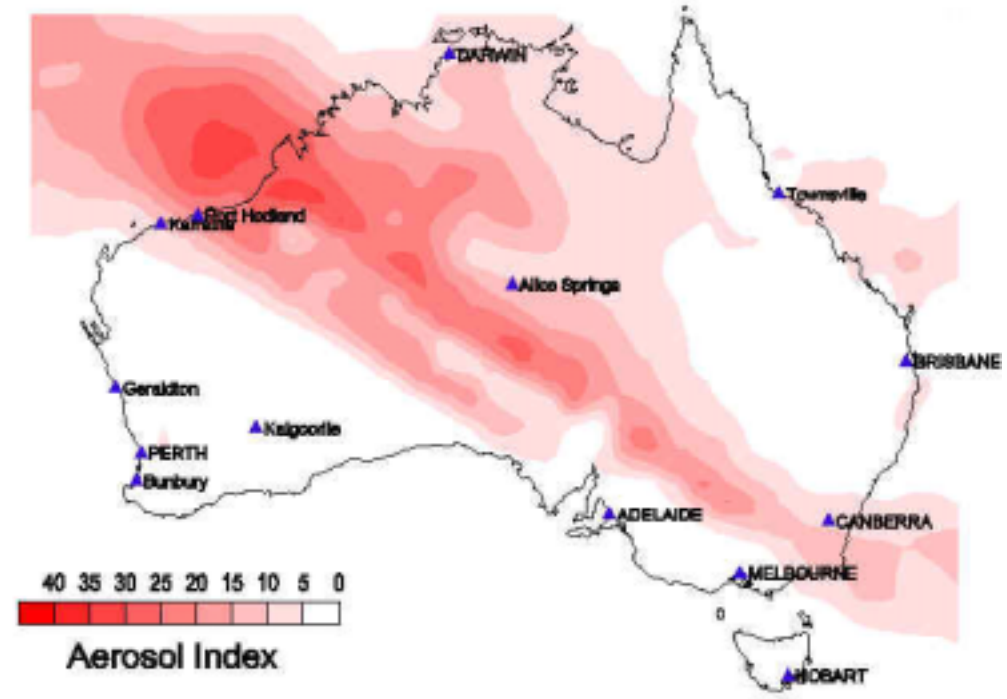
Biomass burning:

During September, October and December 2000, several wildfires in the northwest were started from lightning strikes. One of the major fires in and around the Karijini National Park (150 km east of Newman) caused extensive damage, burning 1.8 million hectares of land, and blanketed the northwest region in smoke that at times extended across Australia. Figures D1(a)-(d) show the extent of the plume mapped during four days in October. The plots associated with each map show the 1-hour averaged ground level concentration of PM_{10} for the relevant day. The 24-hour averaged concentration for each day is also given.

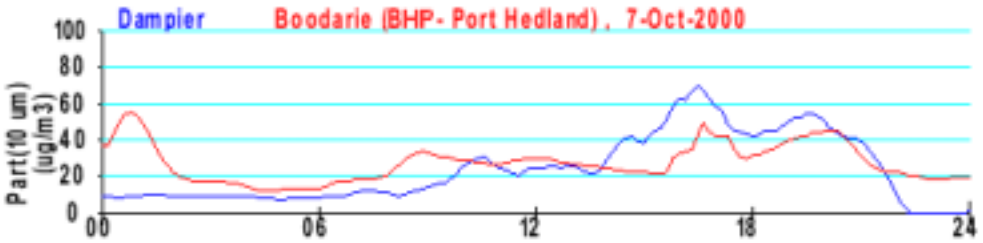
The maximum 24-hour PM_{10} concentrations recorded were 107 ug/m^3 at Dampier and 152 ug/m^3 at Boodarie. The NEPM standard of 50 ug/m^3 was exceeded 18 times at Dampier and 12 times at Boodarie during 2000.

The contours on the following maps are a measure of UV-absorbing tropospheric aerosols from the NASA Total Ozone Mapping Spectrometer (TOMS) on the Earth Probe satellite, launched on 2 July 1996. Using the 331 and 360 nm wavelength channels, the strong molecular scattering by aerosols in the near ultraviolet is used to generate daily global maps of aerosol particles. UV-absorbing aerosols in the boundary layer near the ground (below about 1 km) cannot be readily detected by this method. The maps in Figure D1(a)-(d) are 3-day composites which can only resolve aerosol levels above 300 metres, which explains the occasional discrepancy between the Aerosol Index and the ground based instantaneous TEOM measurements.

07/10/2000



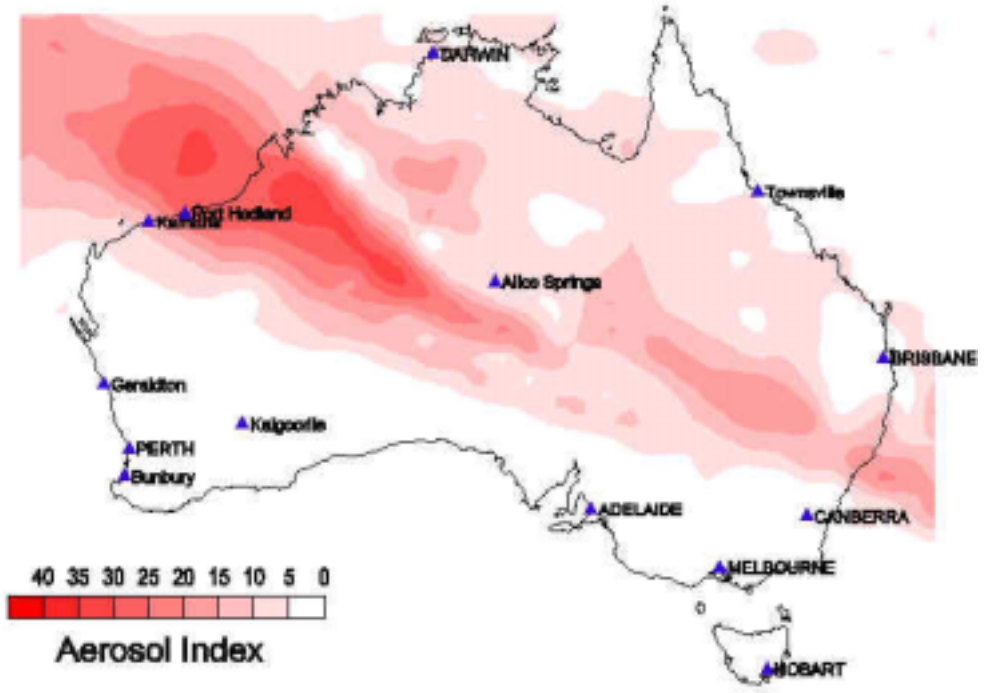
1-hour averaged PM_{10}



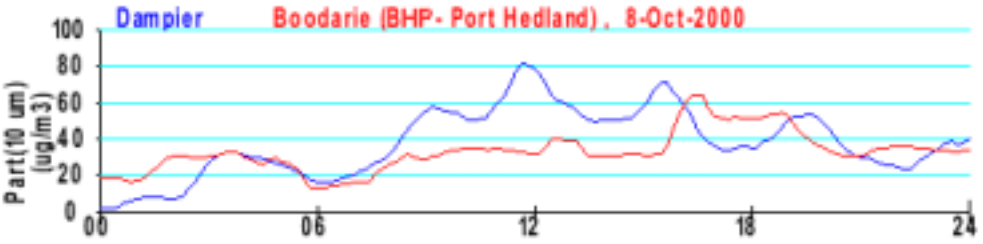
Dampier 24-hour average = 23.5 ug/m^3
Boodarie 24-hour average = 27.0 ug/m^3

Figure D1(a) Satellite composite and ground-based PM_{10} measurements of particle levels originating from a wildfire.

08/10/2000



1-hour averaged PM_{10}

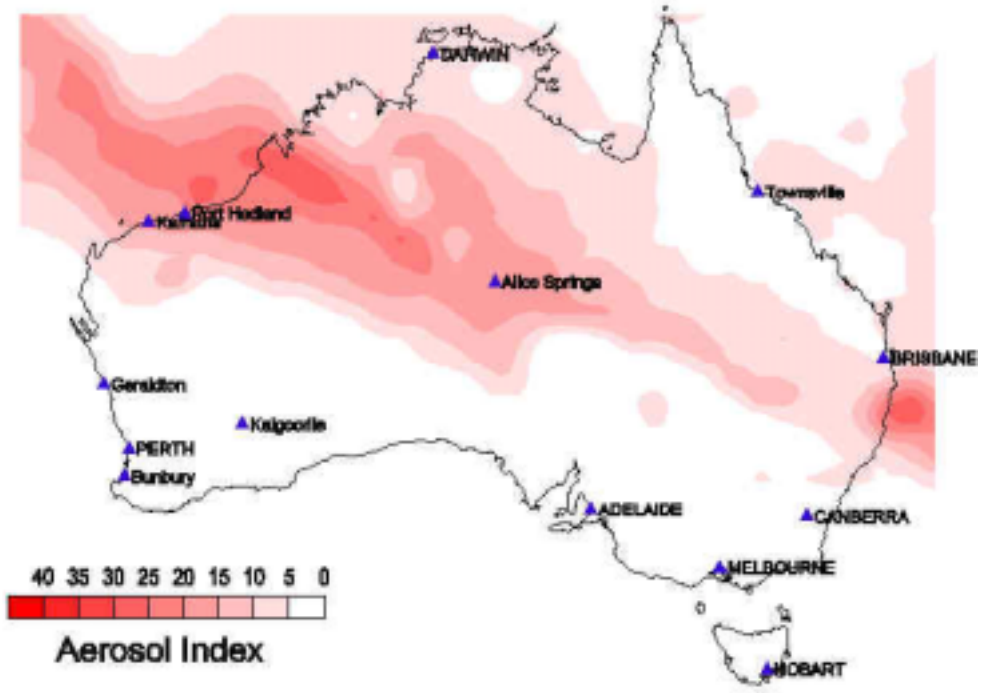


Dampier 24-hour average =38.9 ug/m^3

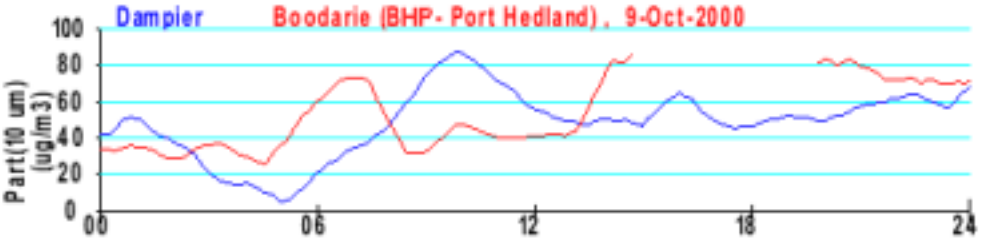
Boodarie 24-hour average =33.4 ug/m^3

Figure D1(b) Satellite composite and ground-based PM_{10} measurements of particle levels originating from a wildfire.

09/10/2000



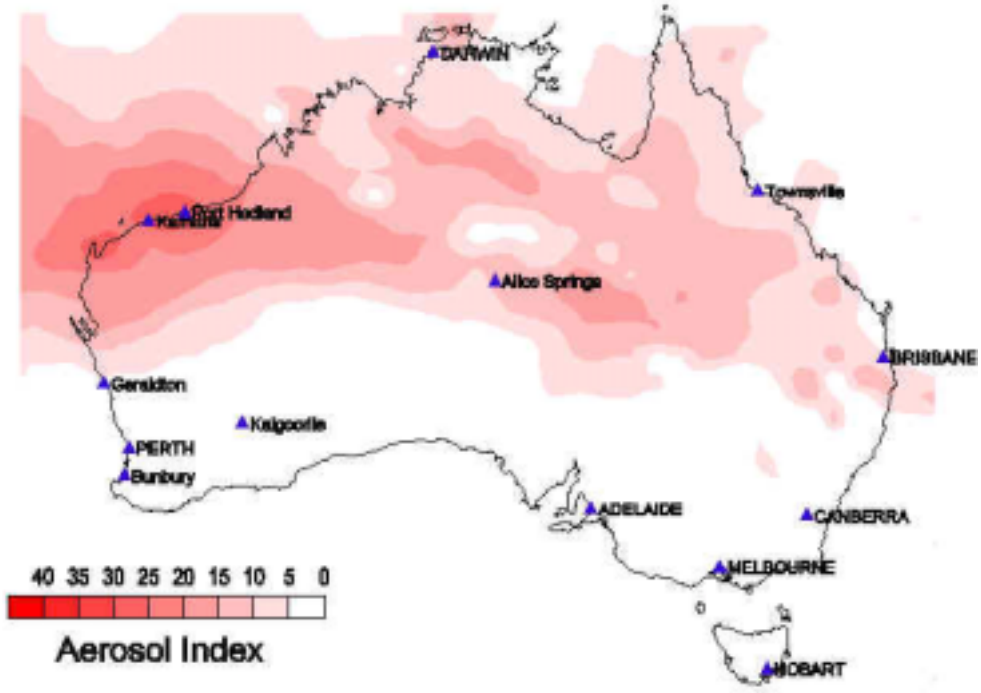
1-hour averaged PM_{10}



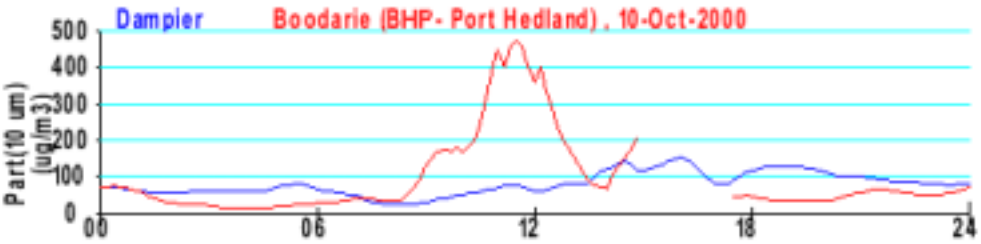
Dampier 24-hour average = 49.0 ug/m^3
Boodarie 24-hour average = 53.0 ug/m^3

Figure D1(c) Satellite composite and ground-based PM_{10} measurements of particle levels originating from a wildfire.

10/10/2000



1-hour averaged PM_{10}



Dampier 24-hour average = 80.8 ug/m^3
Boodarie 24-hour average = 98.3 ug/m^3

Figure D1(d) Satellite composite and ground-based PM_{10} measurements of particle levels originating from a wildfire.

Figure D2 shows a plot of particle levels recorded at Boodarie on 18 October 2000. While this represents only one event during the haze period, its form is typical of all the bushfire-induced haze events experienced throughout the September to December 2000 period.

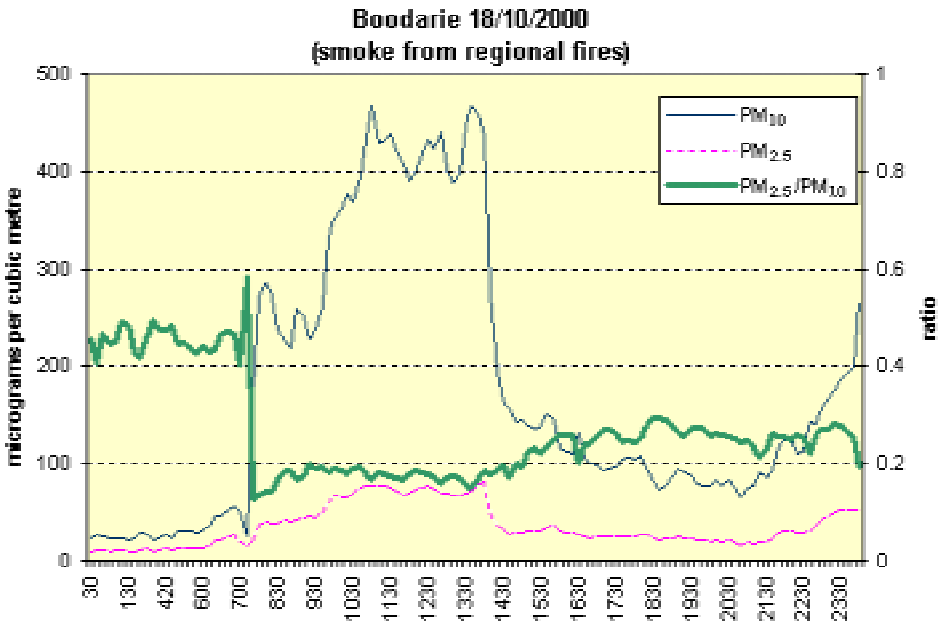


Figure D2 High particle concentration measured at Boodarie caused by a regional fire. The data is shown as 10-minute averages over a 24-hour period.

A feature of Figure D2 and all the fire-induced events recorded at Boodarie during 2000 is the low ratio of $PM_{2.5}$ to PM_{10} during the peak of the particle events. In most cases, the ratio of $PM_{2.5}$ to PM_{10} is less than 0.5 and in some cases (as on 18/10/2000) as low as 0.2.

This low $PM_{2.5}$ to PM_{10} ratio is inconsistent with studies done on particles emitted during biomass burning where the $PM_{2.5}$ fraction was found to represent 80-90% of the total mass while the fraction between 2 and 10 micrometers accounted for less than 10% of the total mass (Ward, 1997; Heil, 1998). Other measurements made of $PM_{2.5}$ to PM_{10} ratios in urban and rural background environments during 1998 to 2000 show a mean $PM_{2.5}$ to PM_{10} ratio of 0.72 to 0.77 (Lasaridis et al., 2001).

In Perth, particle events caused by domestic heating and/or regional fires are characterised by a high $PM_{2.5}$ to PM_{10} ratio of the order of 0.7 to 0.9 and are therefore consistent with these studies. Figure D3 is an example of a typical bushfire-induced haze event recorded at a Perth metropolitan site during 1997.

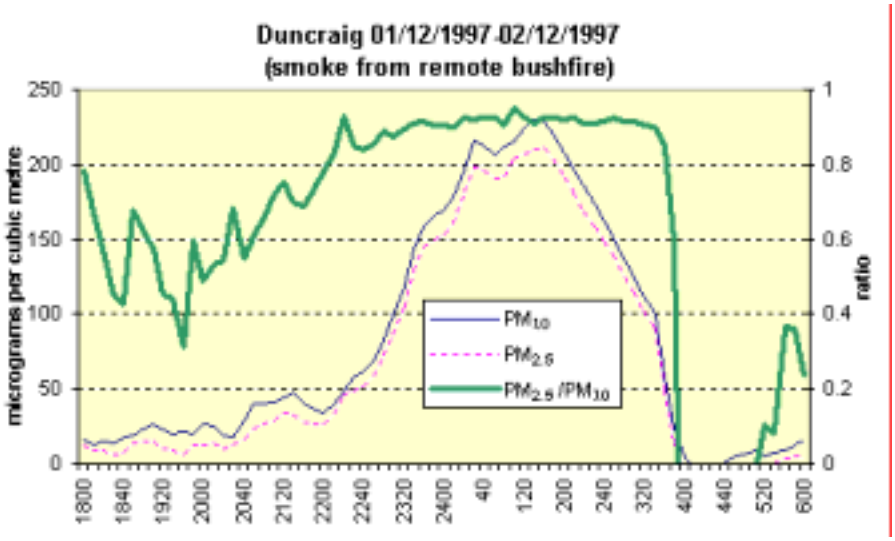


Figure D3 High particle concentrations measured at a Perth metropolitan site from a bushfire source in the lower southwest. The data is shown as 10-minute averages over a 12-hour period between 1800 hours (6 pm) on 01/12/1997 and 0600 hours (6 am) on 02/12/1997.

During the peak concentration period, between 2300 hours (11 pm) on 01/12/1997 to 0300 hours (3 am) on 02/12/1997, the $PM_{2.5}$ to PM_{10} ratio was 0.9.

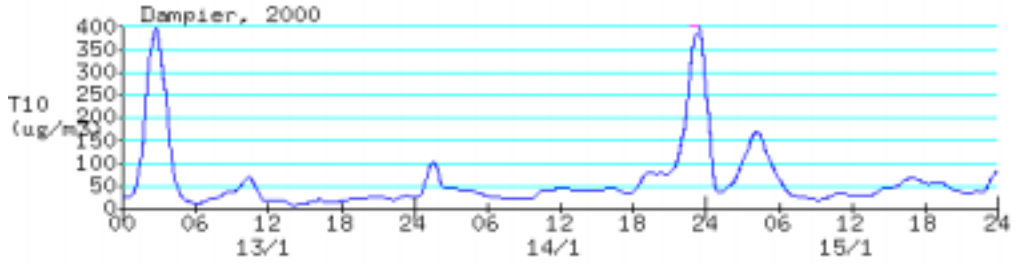
Reasons for the low $PM_{2.5}$ to PM_{10} ratios at Boodarie are unknown; however, many of the high haze periods recorded in the Pilbara during 2000 occurred during moderate to high wind conditions of 6 to 12 ms^{-1}. The low $PM_{2.5}$ to PM_{10} ratios may result from a combination of wind-swept coarse fraction dust particles combining with combustion-induced smoke. In all cases during the peak events, the relative humidity was less than 40% and in most cases below 25%. The annual averaged particle concentrations for Boodarie are listed in Table D1.

Table D1. 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

Ship-loading facilities:

An iron ore loading facility at East Intercourse Island is a potential source of elevated dust levels in the Dampier townsite. In January 2000, the NEPM 24-hour PM_{10} standard was exceeded for three consecutive days (see Figure D4). Figure D5 shows the wind speed and direction during 13/01/2001 to 15/01/2001. The wind direction was such as to indicate the particle matter originated from the East Intercourse Island facility. A back trajectory for the two days is shown in Figures D6 and D7.



24-hour average: 53.7 ug/m^3 (13/01/00), 72.4 ug/m^3 (14/01/00) and 54.7 ug/m^3 (15/01/00).

Figure D4 1-hour averaged ground level concentrations of PM_{10} during the period 13/01/2000 to 15/01/2000. The 24-hour averaged concentration for each day is also given.

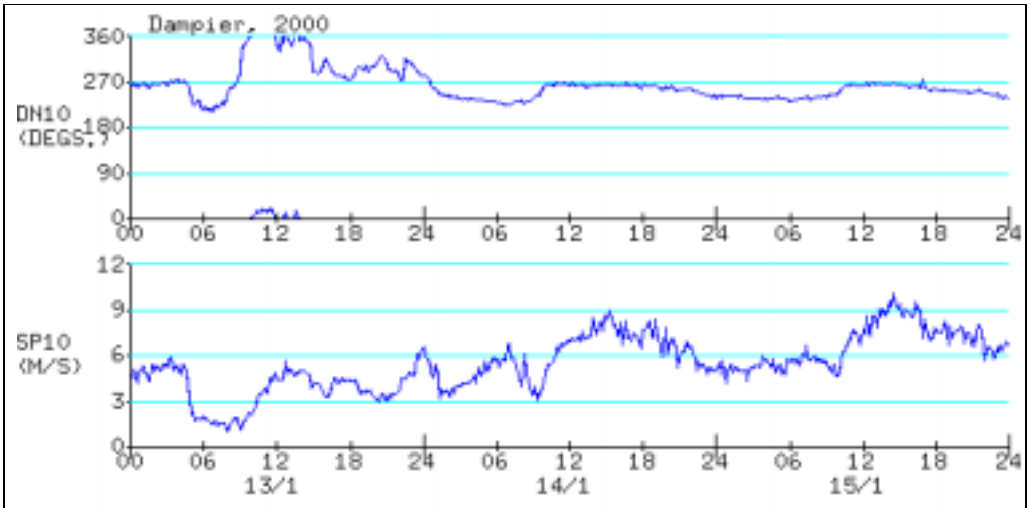


Figure D5 10-minute averaged wind speed and wind direction at 10 metres during the period 13/01/2000 to 15/01/2000.

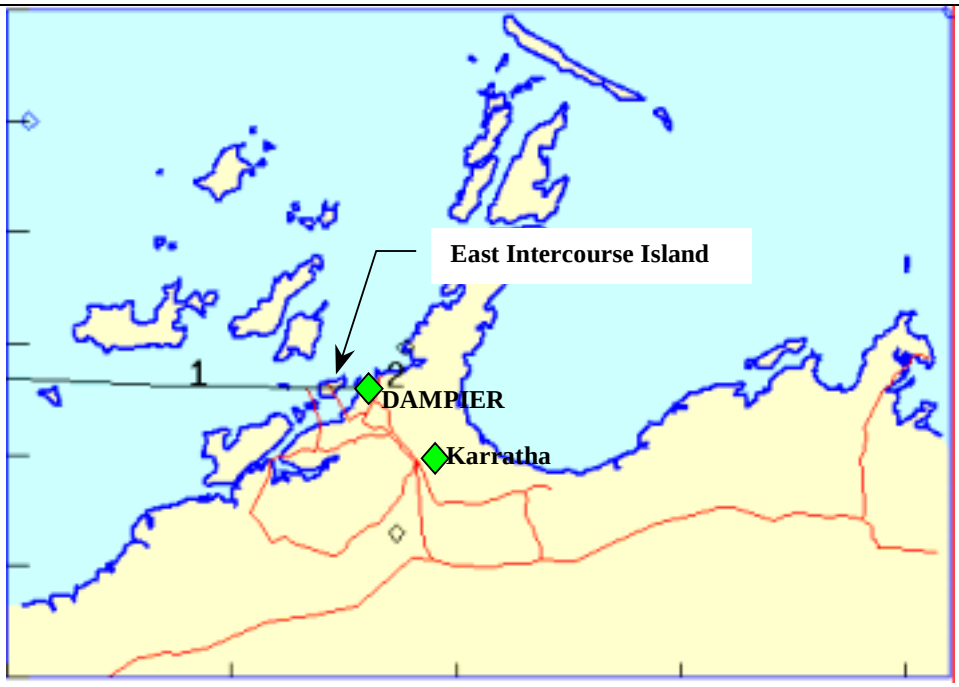


Figure D6 Back trajectory to Dampier over a period of 120 minutes ending at 0200 hours on 13/01/2000.

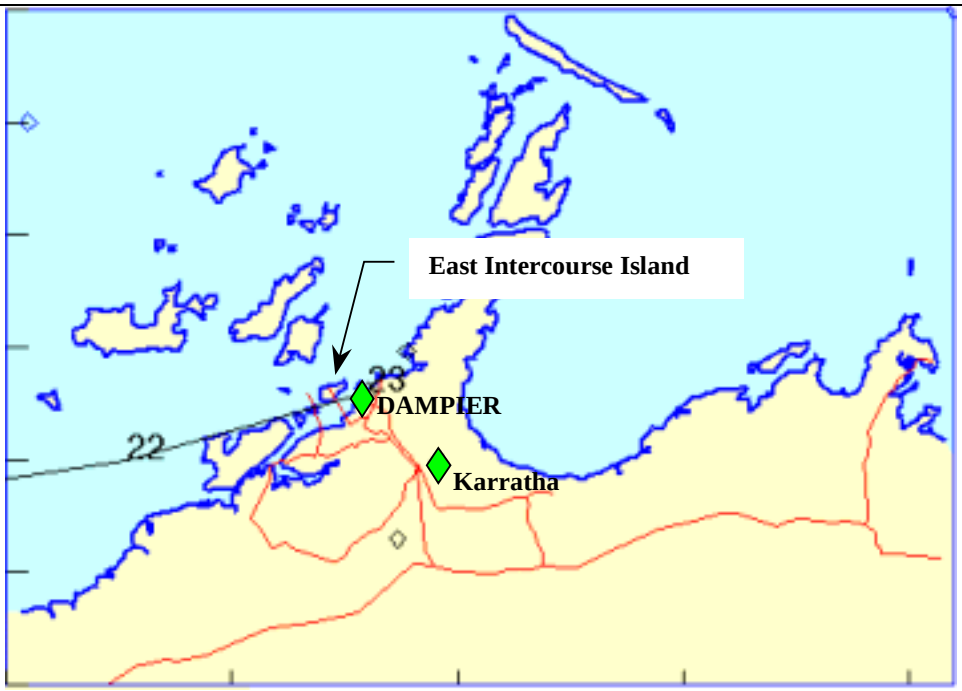


Figure D7 Back trajectory to Dampier over a period of 120 minutes ending at 2300 hours on 14/01/2000.

Generally, the contribution of dust from ore handling facilities to the PM_{10} concentrations measured at the Dampier monitoring station is significant. This can be seen from the "pollution rose" in Figure D8, which is a polar plot of the 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 directly to the iron ore handling facilities at Parker Point and East Intercourse Island respectively.

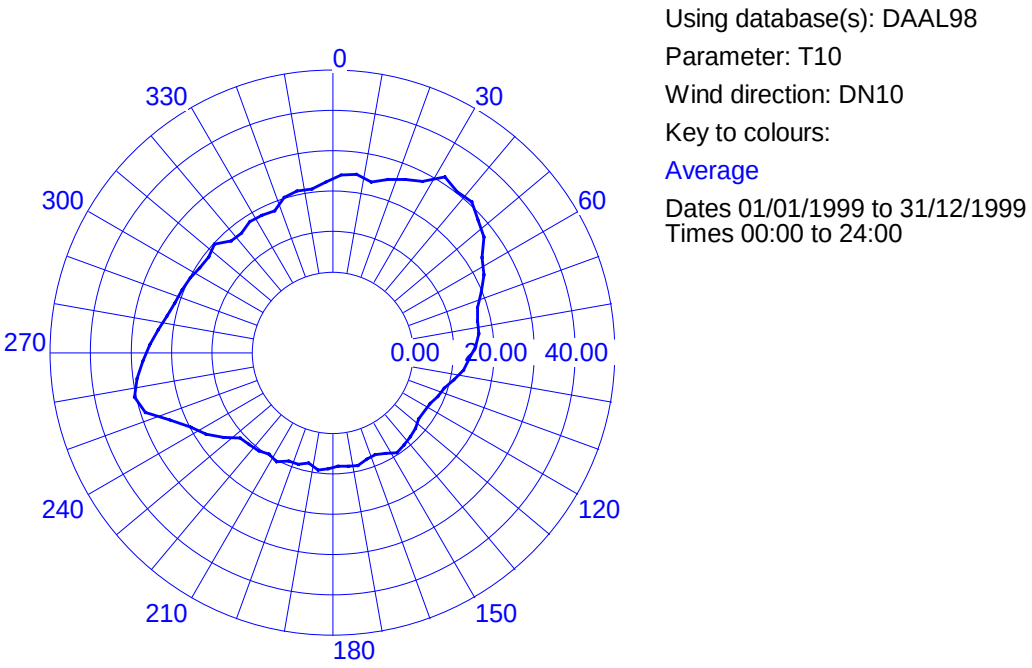
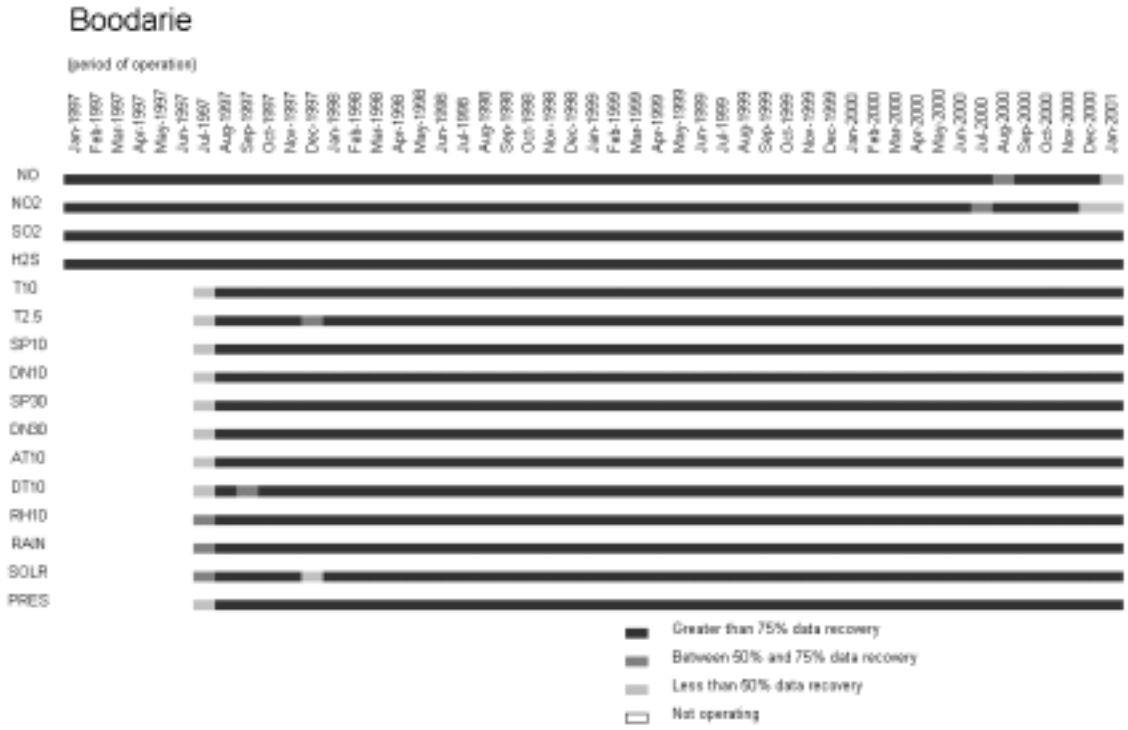
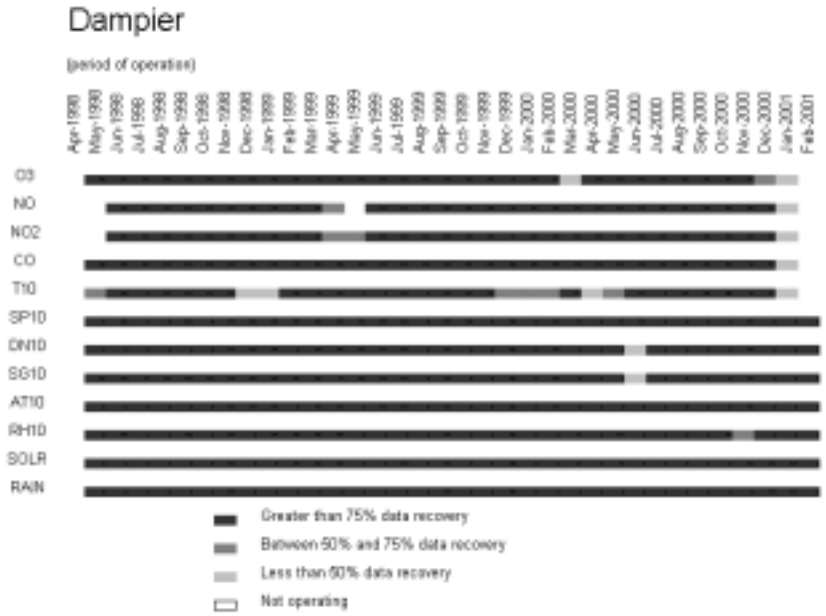
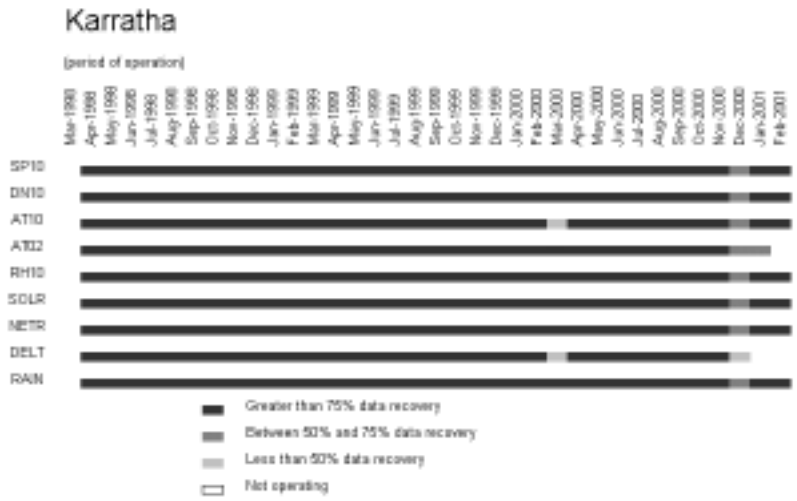


Figure D8. Polar plot, for the Dampier monitoring station, of the average of PM_{10} concentrations measurements in each of 72 five-degree wind direction sectors for the 1999 calendar year.

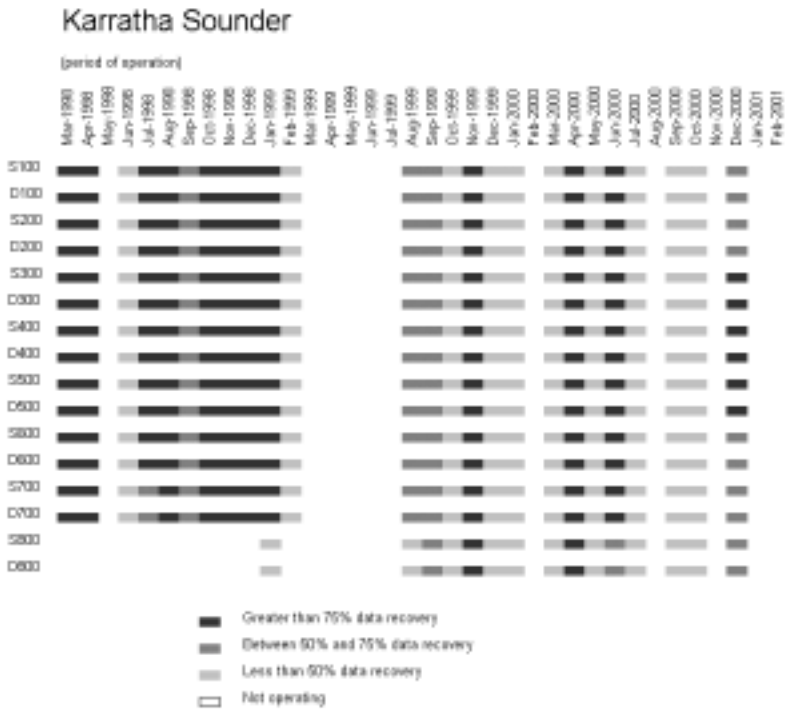
Appendix E – Data Recovery Statistics


Boodarie
(period of operation)
Jan-1997
Feb-1997
Mar-1997
Apr-1997
May-1997
Jun-1997
Jul-1997
Aug-1997
Sep-1997
Oct-1997
Nov-1997
Dec-1997
Jan-1998
Feb-1998
Mar-1998
Apr-1998
May-1998
Jun-1998
Jul-1998
Aug-1998
Sep-1998
Oct-1998
Nov-1998
Dec-1998
Jan-1999
Feb-1999
Mar-1999
Apr-1999
May-1999
Jun-1999
Jul-1999
Aug-1999
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
Jul-2000
Aug-2000
Sep-2000
Oct-2000
Nov-2000
Dec-2000
Jan-2001
NO
NO2
SO2
H2S
T10
T2.5
SP10
DN10
SP30
DN30
AT10
DT10
RH10
RAIN
SOLR
PRES
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating

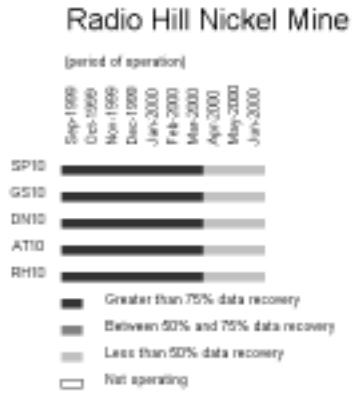

Dampier
(period of operation)
Apr-1998
May-1998
Jun-1998
Jul-1998
Aug-1998
Sep-1998
Oct-1998
Nov-1998
Dec-1998
Jan-1999
Feb-1999
Mar-1999
Apr-1999
May-1999
Jun-1999
Jul-1999
Aug-1999
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
Jul-2000
Aug-2000
Sep-2000
Oct-2000
Nov-2000
Dec-2000
Jan-2001
Feb-2001
O3
NO
NO2
CO
T10
SP10
DN10
SG10
AT10
RH10
SOLR
RAIN
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating

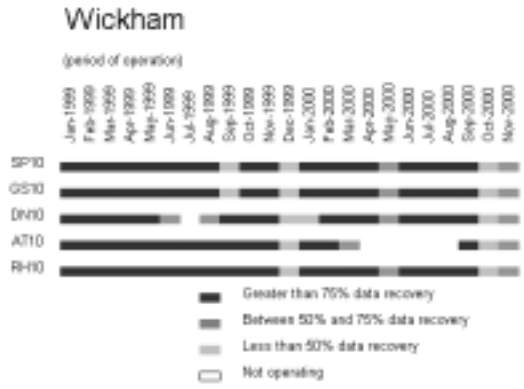

Karratha
(period of operation)
Mar-1998
Apr-1998
May-1998
Jun-1998
Jul-1998
Aug-1998
Sep-1998
Oct-1998
Nov-1998
Dec-1998
Jan-1999
Feb-1999
Mar-1999
Apr-1999
May-1999
Jun-1999
Jul-1999
Aug-1999
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
Jul-2000
Aug-2000
Sep-2000
Oct-2000
Nov-2000
Dec-2000
Jan-2001
Feb-2001
SP10
DN10
AT10
AT02
RH10
SOLR
METR
DELT
RAIN
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating


Karratha Town
(period of operation)
Jan-1999
Feb-1999
Mar-1999
Apr-1999
May-1999
Jun-1999
Jul-1999
Aug-1999
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
Jul-2000
Aug-2000
Sep-2000
Oct-2000
O3
NO
NO2
SO2
SP10
DN10
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating


Karratha Sounder
(period of operation)
Mar-1998
Apr-1998
May-1998
Jun-1998
Jul-1998
Aug-1998
Sep-1998
Oct-1998
Nov-1998
Dec-1998
Jan-1999
Feb-1999
Mar-1999
Apr-1999
May-1999
Jun-1999
Jul-1999
Aug-1999
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
Jul-2000
Aug-2000
Sep-2000
Oct-2000
Nov-2000
Dec-2000
Jan-2001
Feb-2001
S100
D100
S200
D200
S300
D300
S400
D400
S500
D500
S600
D600
S700
D700
S800
D800
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating


King Bay
(period of operation)
Jan-1999
Feb-1999
Mar-1999
Apr-1999
May-1999
Jun-1999
Jul-1999
Aug-1999
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
Jul-2000
Aug-2000
Sep-2000
Oct-2000
CO
NO
NO2
SO2
SP10
DN10
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating


Radio Hill Nickel Mine
(period of operation)
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
SP10
GS10
DN10
AT10
RH10
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating


Wickham
(period of operation)
Jan-1999
Feb-1999
Mar-1999
Apr-1999
May-1999
Jun-1999
Jul-1999
Aug-1999
Sep-1999
Oct-1999
Nov-1999
Dec-1999
Jan-2000
Feb-2000
Mar-2000
Apr-2000
May-2000
Jun-2000
Jul-2000
Aug-2000
Sep-2000
Oct-2000
Nov-2000
SP10
GS10
DN10
AT10
RH10
Greater than 75% data recovery
Between 50% and 75% data recovery
Less than 50% data recovery
Not operating