Burrup Peninsula Air Pollution Study: Final Report

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Final report
WA DOIR Rock Art Committee

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GLOSSARY

Simple definitions of various technical terms are given here to assist the reader. If required, the reader should look to other sources for more formal and technical definitions.

Aerosol	A suspension of fine solid, liquid or mixed-phase particles in air.
BTEX	Gaseous mixture of benzene, toluene, ethylbenzene, o-xylene, m-xylene and p-xylene.
CALM	Conservation and Land Management (WA Government).
CALPUFF	An air pollution dispersion model developed by Earth Tech Inc. (USA). It simulates the transport and diffusion of a plume via the puff approach in which a plume is described as consisting of a series of puffs. CALPUFF typically uses meteorological data generated by the processor CALMET.
CC	Conservation Commission (WA Government).
CMAR	CSIRO Marine and Atmospheric Research http://www.cmar.csiro.au).
CSIRO	Commonwealth Scientific and Industrial Research Organisation (http://www.csiro.au).
Deposition flux	deposition of mass in the form of gas, particle or rainwater to an area of ground over a particular period of time. General units are in mass per area per time.
DOIR	Department of Industry and Resources (WA Government).
GAW station	Global Atmosphere Watch stations are organised through the World meteorological Organisation. Bukit Koto Tabang, Indonesia and Tanah Rata, Malaysia are regional GAW stations.
GC/FID	Gas chromatograph with a flame ionisation detector.
HNO_3	Nitric acid gas.
Limit of detection	The smallest concentration detectable by a measurement system as the concentration of the substance being measured approaches zero.
LNG	Liquified natural gas. It is composed mainly of methane.
LPG	liquefied petroleum gas. It is composed mainly of propane.
mg	Milligram (1 mg = 10^{-3} gram = 0.001 gram). One thousandth of a gram.
Milli-Q water	High purity water having resistivity of 18 $M\Omega \cdot cm$.

NH_3	ammonia gas.
nm	Nanometre (1 nm = 10^{-9} metre = 0.000000001 metre). One billionth of a metre.
NO_2	Nitrogen dioxide.
PM_{10}	Particulate matter in the air, with an aerodynamic diameter of 10 µm (micrometres) or less.
ppt	Parts per trillion (by volume): a unit of concentration of a gas in air. 1 ppt = 1 cubic metre in 1million million cubic metres of air.
ppb	Parts per billion (by volume): a unit for the concentration of a gas in the atmosphere based on the mixing ratio approach. A concentration of 1 ppb is equivalent to a volume of 1 cubic metre of pure undiluted gas in 1 thousand million cubic metres of air. The expression ppb is without dimensions. The ppb unit is useful because its value is unaffected by changes in temperature and pressure, and also because many sampling techniques are based on volume concentrations. Concentrations of gaseous compounds can be converted from mixing ratio units, e.g. ppb units (volumetric), to density units, e.g. µg m^{-3} (mass/volume), using the following formula: $$C(\mu\mathrm{g\,m}^{\;3}) = \frac{273.15 \times M_w \times C}{22.4136 \times (273.15 + T)}$$ where C is the concentration (ppb), Mw is the molecular weight of the gas, and T is the ambient temperature in degrees Celsius.
SKM	Sinclair Knight Merz (an environmental consulting company).
SO_2	Sulfur dioxide gas.
TAPM	The Air Pollution Model. A prognostic meteorological and air pollution dispersion model developed by CSIRO Atmospheric Research (http://www.dar.csiro.au/tapm). The meteorological component of TAPM predicts the local-scale flow, such as sea breezes and terrain-induced circulations, given the larger-scale synoptic meteorology. The air pollution component uses the model-predicted three-dimensional meteorology and turbulence, and consists of a set of species conservation equations and an optional particle trajectory module.
TSP	Total Suspended Particulates– all particles below about 50 µm in diameter suspended in the atmosphere.
µg	Microgram (1 µg = 10^{6} gram = 0.000001 gram). One millionth of a gram

µm	Micrometre (1 µm = 10^{-6} metre = 0.000001 metre). One millionth of a metre.
µg m^{-3}	microgram per cubic metre. 1 µg m^{-3} = one millionth of a gram per cubic metre of air.
µmol l^{-1}	one millionth of a mole per litre.
VWM	Volume weighted mean. A method used to calculate the average concentration of ions in rainwater. This accounts for variability in rainwater sample volumes and allows larger samples to influence the average compared with smaller samples.

1. EXECUTIVE SUMMARY

The Burrup Peninsula is located in the Pilbara area of Western Australia, northeast of Dampier. It is bounded by latitude 20.42 ^{O}S and 20.65 ^{O}S and longitude 116.71 ^{O}S and 116.90 ^{O}S comprising about 110 km^2. This area is home to a large number of aboriginal petroglyphs or etchings which are of enormous cultural significance to Australia, particularly to the local indigenous communities. The etchings are around 10,000 to 20,000 years old, and provide a glimpse into the life of the early inhabitants of the area. In addition, they are still of spiritual importance to indigenous people.

In addition to the rock etchings, the Burrup Peninsula has several large industrial complexes including iron ore, liquefied natural gas production (LNG) and salt production. All are located around Dampier and the southern area of the Peninsula. Since some of the rock etchings are adjacent to industrial areas, especially in the southern Peninsula, there has been some concern that the etchings could be damaged by emissions from industry.

To assess the likelihood that air pollution from the industrial area may damage the petroglyphs an air pollution study was carried out on the Burrup Peninsula by CSIRO Marine and Atmospheric Research from August 2004 until September 2005. The study comprised a total of 10 Sites; two of these were located on the northern Burrup area and one at Mardie Station 81 km southwest of Dampier, and were considered to be representative of the local background concentrations of gases and particles. One Site was located in the town of Karratha, and the other five were located on the lower Burrup Peninsula, near to the industrial areas.

Since the sites were located at sites that had no power and were quite remote they were visited on a monthly basis to change samples and to download data. Most of the measurements presented in this study are taken over periods of about one month so they represent monthly averaged results. The range of measurements included concentrations of sulfur dioxide, nitrogen dioxide, nitric acid and ammonia gases. These were measured at nine sites using passive samplers which were ideal, since they could be deployed for monthly periods at remote sites where power was not available. Total suspended particulate samples were collected at the seven sites located on the Peninsula using Microvol samplers. These sampled at low flow rates and provided monthly integrated samples on Teflon filters which were used to provide gravimetric mass and chemical measurements. Microvol samplers were also installed at two sites to measure PM_{10} concentrations during particular preset wind directions. They were designed to assess the PM_{10} concentrations resulting from the ore loading procedures at Parker Point.

Rainwater samplers were installed at seven sites to collect rainwater during the wet season. The rainwater samples were analysed for a pH and a range of soluble ions so that and this data was provide at five sites, one background and four in the industrial area. Unfortunately two samplers experienced problems during the year so that little data was available from those sites.

During one visit to the sites an aerosol spectrometer was used measure the particle number distribution in a number of particle sizes at the sites. Although these measurements were only carried out for a short period they did give some valuable information on the magnitude of dust deposition at the various sites.

The results of the nitrogen gas measurements show that concentrations are low at all sites. The highest monthly averaged concentration at the Burrup sites was 3.5 ppb recorded at Site 5; Site 5 had the highest annual average concentration of 2.4 ppb. In contrast to this, the background concentration, defined by the Sites on the northern Burrup and at Mardie Station, was about 0.6 ppb. There was an obvious although small gradient in concentration between the background nitrogen dioxide concentrations and those in the industrial sector. Annual average ammonia concentrations ranged from 0.3 ppb to 0.5 ppb at the Burrup and background sites, and the annual average for the background sites was about 0.5 ppb. There was no real difference in ammonia concentrations across the sites, suggesting that for the most part ammonia had a natural source, possibly from vegetation and animals. The site located in Karratha had higher concentrations than any of the other sites, but this was probably due to local influences.

Sulfur dioxide concentrations were also very low and monthly average concentrations ranged from 19 ppt at Site 10 to 367 ppt at Site 4. The annual average background concentration was about 108 ppt compared with annual average of 175 ppt and a maximum annual average concentration of 215 ppt at Site 5. These results suggest that the gradient of sulfur dioxide concentration between background sites and those in the industrial sector is low. Monthly average nitric acid concentrations ranged from 21 ppt at Site 10 to 632 ppt at Site 9. The background nitric acid concentration was about 155 ppt compared with 229 ppt which was the average in the industrial sector, at Sites 4, 5, 6, 7 and 8. Again, there is little evidence of a gradient between background nitric acid concentration and that in the industrial sector.

Annual average TSP concentrations ranged from 21.8 $\mu g\ m^{-3}$ at Site 3 to 51.1 $\mu g\ m^{-3}$ at Site 8. Site 1 and 3 represent the background TSP concentrations and the average of those was about 22 $\mu g\ m^{-3}$ compared with an average of 34 $\mu g\ m^{-3}$ for the sites on the lower Burrup area. The TSP loadings at site 8 were higher than other sites, and probably originated from Parker Point. At various sites the influence of TSP derived from iron ore transport and loading was investigated by measuring the iron and sea-salt fractions of TSP. This showed that compared to other sites, Site 1 was least influenced by iron ore loading and transport and was most influenced by sea-salt. At Site 8, close to Parker Point, the iron fraction of the TSP was the highest, compared with other sites and the sea-salt fraction the lowest, indicating that TSP from ore loading was a significant fraction of the total TSP. High frequency PM_{10} concentrations measured at Site 8 showed significantly higher concentrations when the wind came from the Parker Point or from the local road, again indicating that ore loading at Parker Point increases the PM_{10} concentrations at Site 8.

Dust deposition fluxes were measured for brief periods during field studies to the Burrup Peninsula. Although they cover only short periods they indicate that the background flux was about 10 mg m^{-2} day^{-1} compared with 69 mg m^{-2} day^{-1} measured at Site 8 and an average of 32 mg m^{-2} day^{-1} for the industrial area of the Burrup.

Total acid deposition fluxes were measured at five sites by calculating the wet and dry deposition of all nitrogen and sulfur species in the gas and aqueous phases. This included nitrogen dioxide, sulfur dioxide, nitric acid and ammonia gases and ammonium ion, nitrate ion and sulfate in rainwater. Total acid deposition fluxes varied from a background of 14.3 meq m^{-2} yr^{-1} to 24.3 meq m^{-2} yr^{-1} at Site 6 with an average of 21.1 meq m^{-2} yr^{1} at sites adjacent to the industrial areas. Although the enhancement of acid deposition fluxes from the background to the industrial areas is observable it is small. The absolute fluxes are of the magnitude that would only affect soil or rock that is in the most sensitive class of critical loads. In fact the Burrup area is in a critical load class that can cope with a deposition flux of about 200 meq m^{-2} yr^{-1}, and since this is significantly more than the observed deposition fluxes at the sites they are unlikely to cause any deleterious effects to rock or rock art on the Burrup Peninsula.

2. BURRUP PENINSULA AIR POLLUTION STUDY: FINAL REPORT

2.1 Introduction

The Burrup Peninsula is a thin finger of land to the northeast of Dampier, Western Australia in an area bounded by latitude 20.42 ^{O}S and 20.65 ^{O}S and longitude 116.71 ^{O}S and 116.90 ^{O}S. The main Peninsula area is about 27 km long and about 5 km wide, and includes a collection of over 40 small islands. It is located in the shire of Roebourne, which has a population of 15,281. The population density of the area is about 1 person km^{-2} and the populations of the two adjacent small towns of Karratha and Dampier are about 11,000 and 2,500 respectively.

The Burrup Peninsula has several large industrial complexes including iron ore, liquefied natural gas production (LNG) and salt production. All are located around Dampier and the southern area of the Peninsula. Iron ore is mined at several locations inland from Dampier and transported by rail to Dampier where it is loaded into ships for export to Asia. LNG is produced off shore and transported to the coast via a 132 km pipeline where it is processed. The infrastructure for this includes a complex LNG processing plant, LPG extraction facilities, domestic gas plant, storage tanks and ship loading facilities. In addition, an ammonia plant is currently under construction on the Peninsula and there are plans to construct other industrial plants to produce methanol and dimethyl ether.

In addition to the industrial activity, the Burrup Peninsula is well known for the large collection of aboriginal rock etchings. The etchings, dated to the Pleistocene era, (about 10,000 to 20,000 before present) are clearly of great cultural significance to Australia. It has been estimated that as many as 1,000,000 individual etchings may be located on the Burrup Peninsula. Pictures 1 and 2 show typical examples. For a fuller discussion of the origins of the etchings, the methods used to produce them and a descriptive analysis the reader is referred to a paper by Vinnicombe (2002). Since some of the rock etchings are adjacent to industrial areas, especially in the southern Peninsula, there has been some concern that the etchings could be damaged by emissions from industry.

Picture 1. Typical example of Burrup Peninsula rock art.

Picture 2. Typical example of Burrup Peninsula rock art.

To address these concerns the Western Australian Department of Industry and Resources (DOIR) appointed a committee, the Burrup Rock Art Monitoring Management Committee, to coordinate a study of air pollution measurements on the Peninsula.

The set of objectives established by the Committee were to:

- ***Investigate and report on impacts of proposed industrial developments on the rock art of the Burrup***
- ***Ensure that the studies are undertaken in an open and transparent manner***
- ***Based on these studies, recommend management actions to the management body***

As a consequence of the objectives listed above the following research questions were posed by the Committee:

- ***Is the natural weathering of the rock art of the Burrup Peninsula being accelerated by industrial emissions?***
- ***Is there a significant and measurable problem?***
- ***If there is a significant issue, what management approaches are recommended?***

The DOIR issued two tenders for work to be carried out on the Burrup Peninsula.

- Tender 32DIR0603, Monitoring of Ambient Concentrations of Air Pollutants, including the following:
  - Measure nitrogen dioxide concentrations
  - Measure ammonia gas concentrations (one control and one industrial area location only)
  - Measure BTEX (benzene, toluene, xylene, total volatile organic compounds)
  - Measure sulfur dioxide concentrations (one control and one industrial area location only)

  - Establishment of the sampling system
  - A detailed proposal for a measurement system and QA/QC details, including estimates of accuracy and reliability
  - Conducting analyses and reporting progress of the study following each sampling run.
  - An interim progress report at six months and a final report after 12 months and
  - A commitment to train and use local organisations, Government staff, individuals or volunteers to conduct the sampler replacements in accord with appropriate standards.

- Tender 39DIR0603, Microclimate and Deposition Study, including the following:
  - Temperature
  - Relative humidity
  - Wet deposition – amount and chemical composition
  - Dry deposition – amount and chemical composition
  - Bulk deposition – amount and chemical composition
  - Chemical composition (including pH) of dew on rock surfaces on exposed and protected/shaded
  - faces
  - Chemical composition shall include sodium, chloride, iron, total nitrogen and sulphur.
  - The establishment of the monitoring system
  - A description of sampling and sample collection arrangements
  - A detailed proposal for the measurement system, and QA/QC details, including estimates of
  - accuracy and reliability
  - Conducting analyses and monthly reporting of results and progress.
  - An interim progress report at six months, and a final report for the project and
  - A commitment to train and use local organisations, Government staff, individuals or volunteers
  - to participate in the program in accordance with appropriate standards.

The terms of reference set out in the Tenders were to:

- Research the effect of natural processes and industrial emissions from existing and proposed industrial development on Aboriginal rock art of the Burrup Peninsula

- Ensure that this study is undertaken in an open and transparent manner engaging community input throughout the entire process

- Recommend management measures to the relevant management body, outlining mitigation and remediation measures for the preservation and conservation of the indigenous rock art, whether further industrial development on the Burrup Peninsula proceeds or not.

CSIRO Marine and Atmospheric Research (CMAR) applied for these tenders (32DIR0603 and 39DIR0603) and was subsequently invited to carry out an air pollution study on the Burrup Peninsula

3. SITE SELECTION

The site selection process was carried out during 6th – 9th April 2004, in conjunction with Bill Carr from DOIR, Rob Gillett, CMAR, Geoff Kregor, Conservation and land Management (CALM) and several aboriginal elders including Trevor Solomons, Wilfred Hicks, Tim Douglas, Robert Boona and Michael Boona. During this visit eight sites were selected on the Burrup Peninsula, one of which was used only for

PM_{10} particulate measurements. Of these, sites 1 and site 3 are considered to be local background sites since they are distant from industrial development and anthropogenic influences. In addition two other sites, away from the Burrup Peninsula, were selected. One was in Karratha, to provide a comparison of gas concentrations on the Burrup with those in an adjacent urban area. The other was located at Mardie Station south west of the Burrup, to provide a comparison of gas concentrations in an adjacent area where there is no industrial activity. Table 1 shows the locations of the ten sites. It should be noted that Site 2 existed, but was not used for atmospheric measurements. Picture 3 shows equipment installed at Site 8.

Picture 3. Equipment installed at Site 8.

Table 1. Locations of the ten sampling sites.

Site No.	Site Name	Latitude	Longitude
1	Dolphin Island	20.45233	116.85233
3	North Burrup	20.52611	116.83067
4	Woodside east	20.60167	116.78276
5	Burrup Road	20.62093	116.76928
6	Water Tank	20.61800	116.78516
7	Deep Gorge	20.63692	116.78848
8	King Bay south	20.64416	116.75067
8HI	Hamersley Iron	20.64218	116.74037
9	Karratha	20.73575	116.83662
10	Mardie Station	21.16790	116.12000

Figure 1 shows a map of the sites located on the Burrup Peninsula and the site in Karratha. Site 10, Mardie Station, is not shown on this scale. It is located about 81 km from Dampier at a bearing of about 215°.

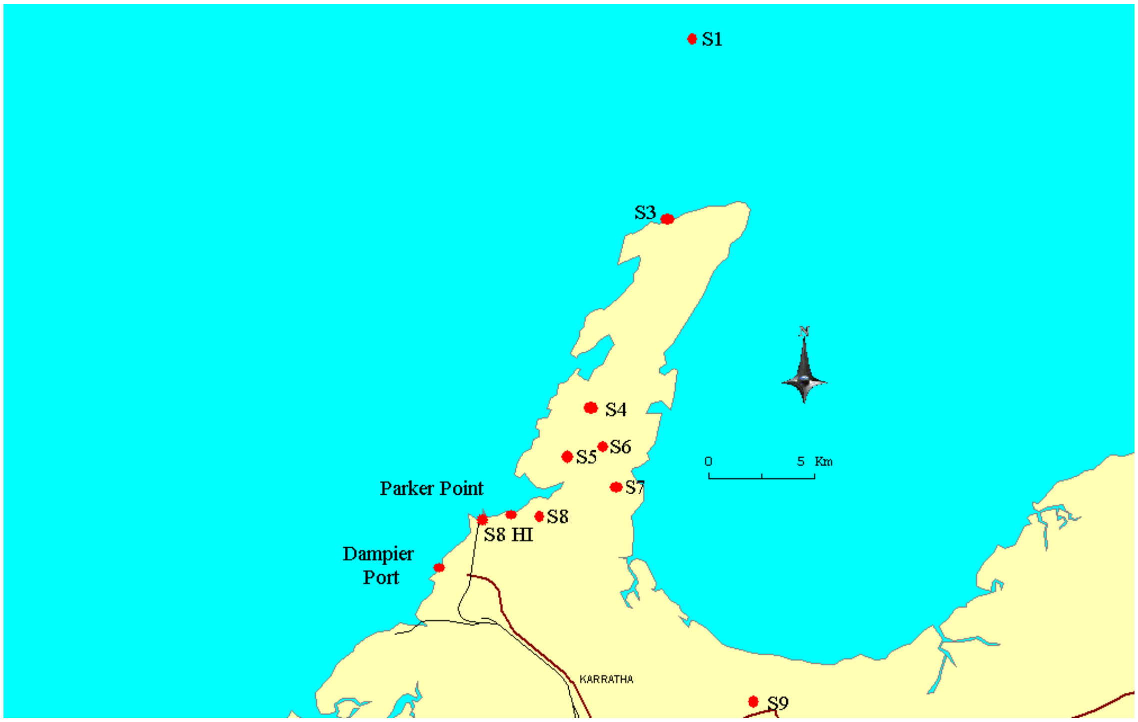


Figure 1. Burrup Peninsula Sampling Sites. Although Site 1 shown on this map Dolphin Island is not. Site 10 is located 81 km southwest.

4. MEASUREMENTS

This study was designed to measure concentrations of gases, particulate concentrations and chemical composition, dust deposition and rainwater amount and composition.

4.1 Passive Gas measurements

Gas concentrations of nitrogen dioxide, sulfur dioxide, nitric acid and ammonia and were measured in duplicate with passive sampling devices, over sampling periods of about one month. Figure 2 shows the construction of the samplers used to measure concentrations of nitrogen dioxide, sulfur dioxide, nitric acid and ammonia gases. Passive gas samplers have several important benefits, which are essential for a study in a remote area such as the Burrup Peninsula. The samplers are light and easy to install and require no power to sample. They can be used to measure concentrations of a number of gases for periods of about one month.

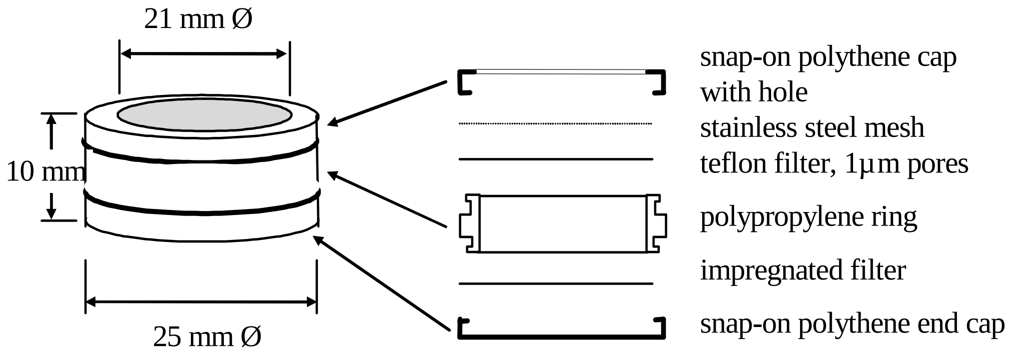


Figure 2. Construction of passive samplers used for measurement of nitrogen dioxide, sulfur dioxide, nitric acid and ammonia gas concentrations.

At each site the passive samplers were housed in a channel underneath an aluminium holder which is mounted on a pole about 1.5 metres above the ground, as shown in Figure 3 and Picture 4. The lid protects the samplers from rain; in addition a sheet of aluminium is mounted about 50 mm above the lid to protect it from direct solar radiation.

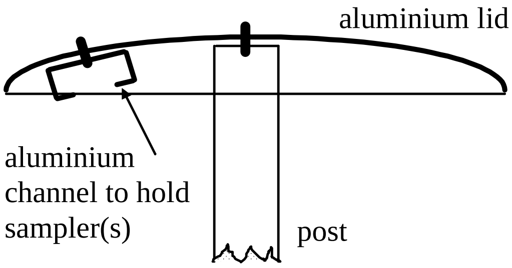


Figure 3. Installation of passive samplers

Picture 4. Installation of passive samplers under lid with aluminium radiation screen.

Passive samplers trap sample gas that diffuses into the cylindrical body of the sampler. This is driven by a concentration gradient of gas in the sampler that decreases from the ambient level down to a very low level at the filter paper interface, where the gas is reacting with the chemical coating. Validation of passive samplers against active sampling has been provided by Ayers et al. (1998).

There is also a resistance to the gas moving down the cylindrical body of the sampler and this constant must be included in the calculation of ambient gas concentrations. It comprises four partial resistances as shown below. The major resistance is due to the geometry of the cylinder and the others to the stainless steel mesh, the Teflon filter and the laminar boundary layer. The detail in equation (1) below shows how the total air resistance is calculated in units of m^{-1}.

$$total\ air\ resistance \quad = \quad \frac{LR}{AR} + \frac{LF}{AF} + \frac{LN}{AN} + \frac{LBL}{AR} \qquad (1)$$

where :

LR = length of the ring

AF = total pore area of aerosol filter

LF = thickness of aerosol filter

LN = thickness of the steel mesh

AR = Area of the ring (20 mm diameter)

AN = area of steel mesh

LBL = laminar boundary layer

Passive samplers include a filter that is impregnated with a chemical that reacts with the gas of interest, where it is trapped on the filter. For sulfur dioxide and nitric acid, which are measured on the same passive sampler, the gases are trapped on Millipore Grade 223 cellulose filters in an acid base reaction using an impregnation of 50 µl of a 1% (w/v) solution of NaOH prepared in methanol. Sulfur dioxide is trapped as sulfate ion and nitric acid as nitrate ion, as reactions (2) and (3) show.

$$2SO_2 + 2OH^- + O_2 \Longrightarrow 2H^+ + 2SO_4^{2-} \qquad (2)$$

$$HNO_3 + OH^- \Longrightarrow NO_3^- + H_2O \qquad (3)$$

At the end of the sampling period filters are removed and extracted in clean polythene bags in Milli-Q grade (18 MΩ·cm) water. The aqueous concentrations of sulfate and nitrate ion are determined by ion chromatography using a Dionex DX500 ion chromatograph equipped with a guard column, a 4 mm x 250 mm AS11 analytical column and an ASRS Ultra II suppressor. The ions are separated using a gradient eluent of NaOH producing chromatogram; an example is shown below in Figure 4. The Figure shows a typical anion chromatogram with peaks for the range of ions that are regularly measured in sulfur passive gas samples, rainwater samples and aerosol extracts. The ions are separated using a gradient chromatogram where 5 millimolar and 100 millimolar NaOH are continually mixed with Milli-Q water to produce a smooth increase in eluent concentration during the chromatogram.

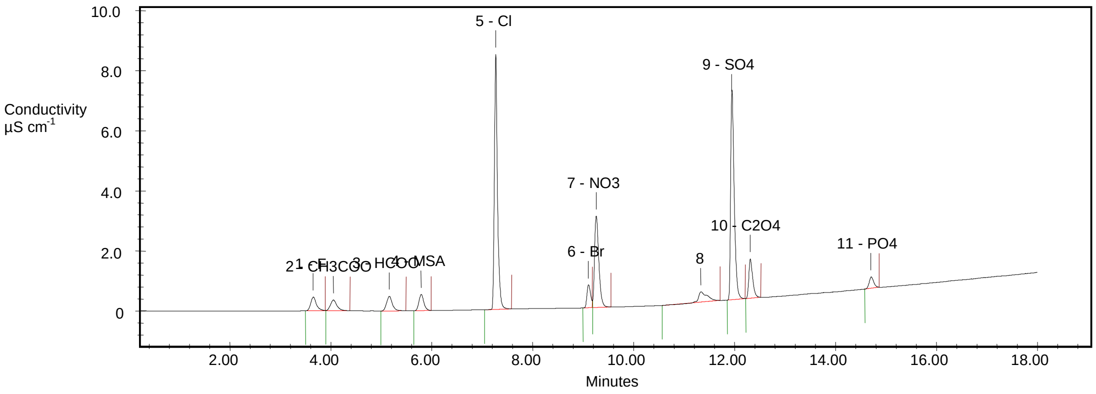


Figure 4. Typical ion chromatograph showing sulfate and nitrate peaks.

The area of the peak is converted to a molar concentration by utilising a calibration line produced from a range of seven standards. Figure 5 shows the relationship between peak area and concentration for a range of seven sulfate standards. Standards are prepared by serial dilution of 1000 µg ml^{-1} NIST traceable reference standards (Ultra Scientific). Table 2 shows the range of standard concentrations used in analysis of sulfur dioxide passive gas extracts, rainwater analysis and analysis of aerosol extracts. Sulfate standards, for example, cover a concentration range from 1 µmol L^{-1} to 64 µmol L^{-1}.

Table 2. Anion standards used in anion chromatography.

Anions				Conc. µmol l^{-1}			
F^-	16	8	4	2	1	0.5	0.25
CH_3COO^-	16	8	4	2	1	0.5	0.25
$HCOO^-$	16	8	4	2	1	0.5	0.25
$CH_3SO_3^-$	16	8	4	2	1	0.5	0.25
Cl^-	128	64	32	16	8	4	2.00
NO_2^-	16	8	4	2	1	0.5	0.25
Br^-	16	8	4	2	1	0.5	0.25
NO_3-	64	32	16	8	4	2	1.00
SO_4^{2-}	64	32	16	8	4	2	1.00
$C_2O_4^{2-}$	16	8	4	2	1	0.5	0.25
PO_4^{3-}	16	8	4	2	1	0.5	0.25

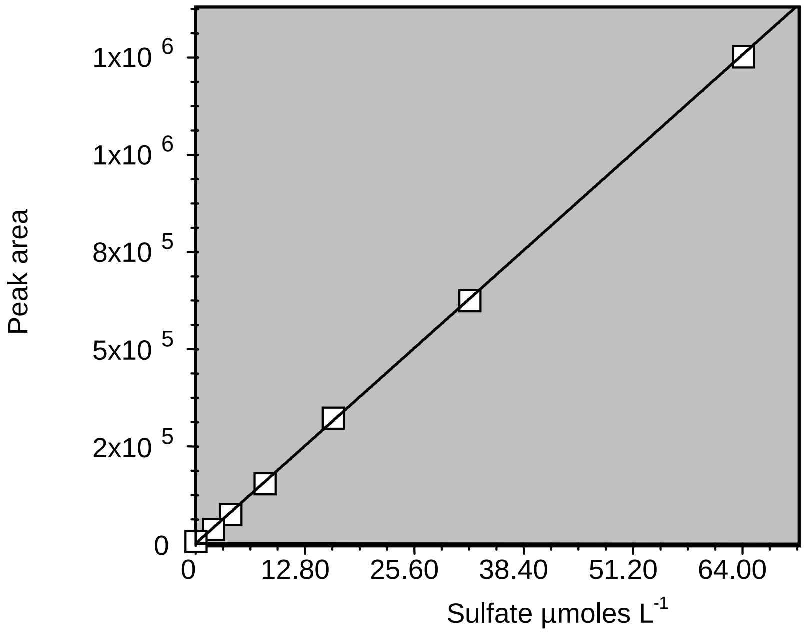


Figure 5. Peak areas plotted against sulfate concentration.

Nitrogen dioxide concentrations are also measured using the passive samplers described in Figure 2. In this case Millipore Grade 223 cellulose filters are impregnated with 50 µl of a solution of 0.44 g NaOH and 3.95 g NaI diluted to 50 ml in a volumetric flask. The reaction to trap $NO_2(g)$ on the filter can be expressed as follows :

$$2NO_2 + 3I^- \Longrightarrow 2NO_2^- + I_3^- \tag{4}$$

After sampling is complete the filters are removed from the sampler and extracted into a known volume of Milli-Q water in clean food grade plastic bags. The nitrite ion concentration is then measured as a diazonium salt, which is produced from a reaction of nitrite ion with sulphanilamide, phosphoric acid and N-1-naphthyl ethylenediamine dihydrochloride (NEDA). The absorbance of the diazonium salt produced in the reaction was measured in a Shimadzu UV-2401PC UV/Vis spectrophotometer at a wavelength of 540 nm. The aqueous nitrite concentrations were determined from nine nitrite standards which are serially diluted from NIST traceable standards and range from 0 µmoles l^{-1} to 100 µmoles l^{-1}. Figure 6 shows a calibration curve of nitrite concentrations as a function of the absorbance of the diazonium salt at 540 nm.

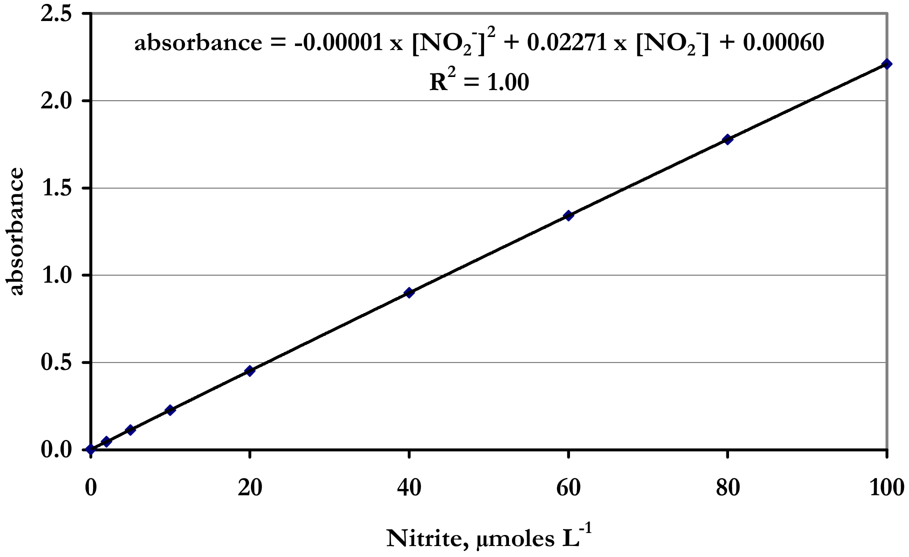
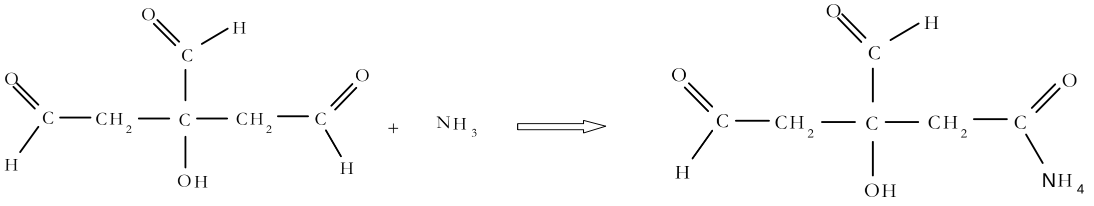


Figure 6. Nitrite concentration as a function of diazonium salt concentration. A quadratic curve is fitted to the data.

Ammonia gas concentrations were also measured with passive samplers using Millipore Grade 223 cellulose filters impregnated with 50 µl of a solution of 2 % w/v citric acid prepared in acetone. Ammonia gas was collected on the filter in an acid base reaction as shown in reaction (5).



(5)

After sampling is complete the impregnated filter is removed from the sampler and extracted in a known volume of Milli-Q water in a food grade plastic bag. The aqueous ammonium concentration is measured using a Dionex DX500 ion chromatograph. The chromatograph is equipped with a CS12A 250 mm x 4 mm analytical column and a CSRS Ultra II suppressor column. The ions are detected with a conductivity detector after they are separated using an isocratic eluent of 20 millimolar methane sulfonic acid. Ammonium standards are prepared by serial dilution of a NIST traceable standard.

Blank samplers were sent from CMAR to the Burrup Peninsula during each sampling period. The blanks were used to determine errors associated with sampler preparation, contamination during sample transport, and from reagents during analysis. The average aqueous blank level was subtracted from the individual samples before concentrations were calculated. Blank samplers were also used to determine the limit of detection for gases measured by the passive samplers. The limit of detection is the lowest concentration that can be detected with a given degree of confidence. This was determined in accordance with ISO 6870 (ISO 1995) which states that a zero sample has a 5% chance of giving a measured concentration above the limit of detection. This is defined in equation (6).

$$LOD = t_{0.95} \; x \; s_{c(0)} \qquad (6)$$

Where:
$t_{0.95}$ = the value of the 1-tailed t distribution for P < 0.95 (95% confidence limits).
$S_{c(0)}$ = the standard deviation of the blanks.

Concentrations of sulfur dioxide, nitric acid, nitrogen dioxide and ammonia were calculated in units of ppb or ppt from equation (7) below.

$$p \;=\; \frac{C_{aq} \; x \; EV \; x \; Res \; x \; R \; x \; Temp \; x \; 10^{6}}{D \; x \; Time} \qquad (7)$$

Where:
C_{aq} = aqueous analyte concentration in moles l^{-1}
EV = extraction volume in cm^3
Res = resistance (m^{-1}) as described in (1)
Temp = average sampling temperature (K)
D = diffusion coefficient of sampled gas in air ($m^2 \; s^{-1}$)
= 1.32×10^{-5} $m^2 \; s^{-1}$ for nitrogen dioxide and HNO_3 at 20 ºC. (Ferm, 1991)
= 1.54×10^{-5} $m^2 \; s^{-1}$ for NO_2 at 21 ºC. (Ferm, 1991)
= 2.54×10^{-5} $m^2 \; s^{-1}$ for NH_3 at 25 ºC (Ferm, 1991)
Time = sample period in seconds
10^6 = conversion to ppt

BTEX gases (benzene, toluene, ethylbenzene and the xylene isomers) were measured using sorbent tubes, and these were used in accordance with International Organisation for Standardisation (ISO 16017-2:2003). Sorbent tubes operate by physically trapping the gas of interest on a sorbent bed due to a concentration gradient which exists between the sorbent bed and the ambient air. During this study gas measurements were carried out over periods of about 30 days at all of the 10 sites. Figure 7 shows the structure of a sorbent tube used for BTEX sampling.

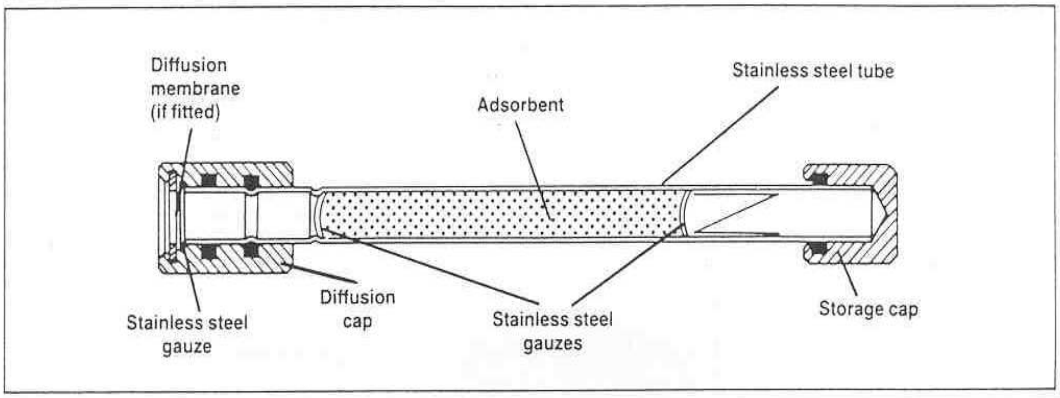


Figure 7. Diagram of a sorbent tube used to measure BTEX gas concentrations.

BTEX sorbent tubes are manufactured from stainless steel tubing 6.35 mm diameter and 88.9 mm long ($^1/_4$″ x $3^1/_2$″) packed with Chromosorb 106 sorbent, and purchased from either Perkin Elmer (USA) or Markes (UK). Tubes were sent to the Burrup Peninsula sealed with Swagelok fittings, wrapped in baked aluminium foil and secured in an uncoated metal tin. The tubes were installed under the aluminium lid after the Swagelok seal is removed from the sampling end and replaced with a diffusion cap. After the tubes were exposed at each site they were sealed with Swagelok fittings, wrapped in clean baked aluminium foil and returned to CMAR in the uncoated sealed metal tin. BTEX species are analysed by gas chromatography with a flame ionisation detector (GC/FID). BTEX gases were desorbed by heating the sorbent tubes under a stream of ultra high purity helium gas at 180°C for 2 minutes, in a Perkin Elmer 400 automated thermal desorber (ATD). The gases were then concentrated on a Tenax cold trap in the ATD at -30°C. The cold trap was then heated to 180°C and the desorbed species are transferred through a heated line to a Perkin Elmer AutoSystem XL gas chromatograph where they were separated by an SGE BP 20 column and detected with a flame ionization detector. Table 3 gives details of the column and temperature program used for the analysis.

Table 3. Gas Chromatography conditions

Item	Description
Column	50 m x 0.32 mm I.D. SGE fused silica capillary column with 1.0 µm BP20 bonded phase
Injector	ATD 400 (mode 2)
Carrier gas	Helium
Oven Temperature	Hold 35°C for 4 minutes programmed at 5°C min^{-1} to 115°C programmed at 45°C min^{-1} to 200°C Hold 200°C for 6 minutes
Detector	Flame Ionization Detector

Peak areas obtained in the GC/FID analysis were converted to mass using a NIST traceable working standard with a mixture of benzene, toluene, ethyl benzene, m-xylene and o-xylene with mixing ratios of 10.1 ppm, 10.1 ppm, 10.1 ppm, 10.1 ppm and 10.0 ppm respectively and an accuracy of ± 2% (Scott Specialty Gases, San Bernadino, CA, USA). Working standards were injected into an 812 µl stainless steel loop heated to 80°C (353K), and then through an empty tube loaded into the ATD which experiences the same desorption conditions as the samples. The mass of each gas injected is calculated from equation 8 below.

$$mass = \frac{v_{loop}\ x\ C_{gas}\ x\ MW_{gas}}{R\ x\ T} \tag{8}$$

Where :

R = gas constant (0.082054 l atm mol^{-1} K^{-1})

T = temperature (353 K)

V_{loop} = loop volume (0.000812 L)

MW_{gas} = molecular weight of gas of interest (g mol^{-1})

C_{gas} = gas concentration (ppmv)

An injection of one loop volume of the working standard gas mixture results in the masses shown in Table 4. Therefore, dividing this mass by the peak area, gives the mass per unit area ratio and multiplication of this ratio by the peak area of each species gives the mass of each species collected by the sorbent tube.

Certified Reference standards (CRS) containing known masses of benzene, toluene and o-xylene were purchased from Markes International Ltd, UK, who prepared the tubes according to ISO Standard 6145 (1981) part 8. The calibration of the results presented here is based on these certified reference standards.

Table 4. Mass of gases for one ATD loop injection

Gas	Mass injected (ng)
Benzene	22.15
Toluene	26.12
Ethyl-benzene	30.12
m-xylene	30.12
o-xylene	29.82

Ambient BTEX concentrations are calculated from the mass collected on each tube, the sampling time and the uptake rate of each gas on Chromosorb 106, as shown in equation (9). The uptake rates, used in equation 9, are taken from ISO 16017-2 (2003) and are for sampling periods of four weeks and are listed in Table 5.

Table 5. Four-weekly uptake rates used to calculate ambient BTEX concentrations

Gas	Adsorbent	Uptake rate ng ppm^{-1} min^{-1}
Benzene	Chromosorb 106	1.28
Toluene	Chromosorb 106	1.82
Ethyl benzene	Chromosorb 106	2.24
p-xylene	Chromosorb 106	1.91
m-xylene	Chromosorb 106	1.91
o-xylene	Chromosorb 106	1.91

$$p = \frac{Wt \ x \ 10^6}{Up \ x \ T} \tag{9}$$

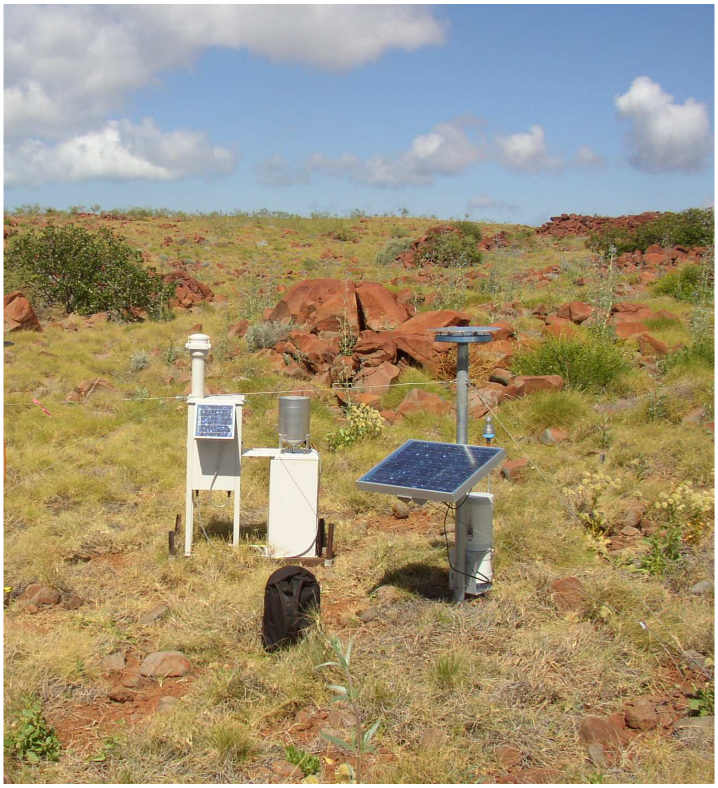
Where:
p = gas mixing ratio (ppt)
Wt = mass of sample adsorbed onto the Chromosorb 106 (ng)
Up = uptake rate of species on Chromosorb 106 (ng ppm-1 min-1)
T = sampling time (minutes)

The precision of sulfur dioxide, nitric acid, nitrogen dioxide and ammonia measurements is expressed in the results as the relative percent difference (RPD), and is determined between the sample pairs at each of the sites. The RPD is the deviation between duplicate pairs of passive samplers calculated as the difference divided by their mean and expressed as a percentage as shown in equation (10).

$$RPD = \frac{abs\left(X_a - X_b\right)}{\left(\frac{X_a + X_b}{2}\right)} \times 100 \qquad (10)$$

4.2 Particulate Sampling

Sampling was carried out for total suspended particulate (TSP) at all sites, except Karratha, Hamersley Iron and Mardie Station, Sites 9, 8HI and 10 respectively. TSP samples were collected on 47 mm diameter Fluoropore PTFE membrane filters (Millipore, USA, FALP 04700) using Microvol 1100 low volume samplers, (Ecotech Pty Ltd, Blackburn, Australia) and the sampling period was about 30 days, the same as for gas sampling. At sites 8 and 8HI PM_{10} samples were collected on 47 mm stretched Teflon filters (Pall K2PJ047, 2.0 µm pore size) using Microvol 1100 samplers fitted with a PM_{10} inlet. The sampling period was the same as for TSP samples. PM_{10} is particulate matter that has an aerodynamic diameter of 10 µm or less. The mass of the filters was measured before and after sampling to produce monthly averaged PM_{10} or TSP concentrations for each sampling period. The mass was measured using NATA certified protocols on a Mettler UMT2 microbalance, which measures to a maximum of 2100 mg with a resolution of 0.0001 mg (0.1 µg). Picture 5 shows a rainwater sampler and a microvolt sampler on location at Site 1.



Picture 5. Rainwater sampler and Microvol sampler at Site 1.

A DustTrak aerosol monitor (TSI model 8250) was installed at site 8 to measure PM_{10} concentrations at sampling frequencies of two minutes. This sampler was modified to use a battery which is charged using a solar panel. Since the signal from the DustTrak can driftt, due to temperature and other changes, it was further modified to allow a zero to be obtained for 10 minutes every four hours. This was done by adding a relay which turned the pump off allowing the sampler chamber to clear by sedimentation and diffusion. The final PM_{10} concentrations were calculated by fitting a line between each zero point and subtracting this zero from the raw concentrations.

4.3 Rainwater Sampling

Model 200 rainwater samplers (Ecotech Pty Ltd, Blackburn, Australia) were installed at all sites except Karratha, Hamersley Iron and Mardie Station, Sites 9, 8HI and 10 respectively. The wet only samplers open after 0.25 mm of rain, and close again if no rain fell within a 30 minute period. Samples were collected in polyethylene bottles that had thymol added to preserve the chemical species in the rain against degradation by bacteria (Gillett and Ayers, 1991; Ayers et al., 1998). Bulk wet-only rainwater samples were collected over the usual sampling period of 30 days. After collection the total rainwater volume of each sample was determined. The samples were returned to CMAR where pH was measured and they were analysed for a range of anions and cations by ion chromatography.

4.4 Meteorological Measurements and Dust Measurements

A range of meteorological measurements were carried out at the sites on the Burrup Peninsula. Temperature and humidity were measured at sites 1, 3, 4, 5, 6, 7 and 8 using Hobo Pro Series sensors at 3 minute intervals. An automatic weather station to measure wind speed and wind direction at 2 minute frequencies was installed at site 8. The DustTrak PM_{10} data can be combined with the wind direction data to determine the influence of wind direction on PM_{10} concentrations.

In addition to TSP measured with Microvol samplers, dust deposition was measured at sites 1, 4, 5, 6, 7 and 8. Measurements of dust deposition fluxes can be made in several ways, although none of them necessarily replicates the real flux. In this case measurements were made using a passive dry Frisbee-type dust deposit gauge (Vallack, 1995; Hall et al., 1994). These consist of a stainless steel Frisbee shaped holder with a foam insert mounted on a pole about 1.5 metres from the ground. The foam pads were sealed in resealable plastic bags and weighed before and after the pads were exposed at the Burrup Peninsula. The mass measurements were carried out on a Sartorius Master Pro LA130S-F balance which has a resolution of 0.0001 g and a maximum mass of 150 g, and is calibrated using NATA certified masses. Measurements were made over 3-monthly periods.

During one field visit to the sites a GRIMM Series 1.100 Aerosol Spectrometer (Technik GmbH & Co. Kg) was used to continuously measure particle number distribution in a number of particle sizes. The GRIMM uses either mains power or a battery and employs a laser scattering technique to measure the number of particles in a series of preset size ranges. In this case the 15 size ranges were used from 0.3 µm to 20 µm. The spectrometer has a large dynamic range and can measure particle numbers from $1 – 2 \times 10^6$ particles l^{-1} and dust masses from 0.1 – 100,000 $\mu g\ m^{-3}$.

4.5 Particle-Induced X-ray Emission

The particulate samples collected at sites 1, 3, 4, 5, 6 and 8 were analysed for a range of 19 elements by particle-induced X-ray emission (PIXE) analysis at the Australian Nuclear Science and Technology Organisation (ANSTO). PIXE is a non destructive ion beam analysis technique that can be used to analyse particle filter samples for a range of 19 elements. The PIXE analysis was carried out after the gravimetric measurements were completed, and before the samples were analysed by ion chromatography.

PIXE analysis was carried out by irradiating an 8 mm diameter section of each filter with a beam of 10 nano amp beam current, 2.6 MeV protons generated by a 3 MV Van de Graaff accelerator. Each filter is irradiated for about 5 min. As charged particles move through the filter and the particulate on the surface they lose energy by exciting electrons in the K and L shells. These electrons can then be ejected, causing electrons in the higher shells to drop down the fill the vacancies, and releasing energy in the form of x-rays in the process. Each element emits x-rays over a short range of energies unique to that element, and this allows each element to be identified. The mass of each element on the filter was measured from the area of each peak shown in Figure 8, since the area is proportional to the absolute concentration of the element on the filter. The ambient concentration of each element is then calculated from the volume of air sampled.

Several previous studies have used PIXE analysis, along with other techniques, to determine particulate composition and sources of particulates in a number of Australian sites. For example, PIXE techniques have been used in studies of particulate in Sydney (Cohen et al., 1993; Cohen et al., 2004) and Brisbane (Chan et al., 2000).

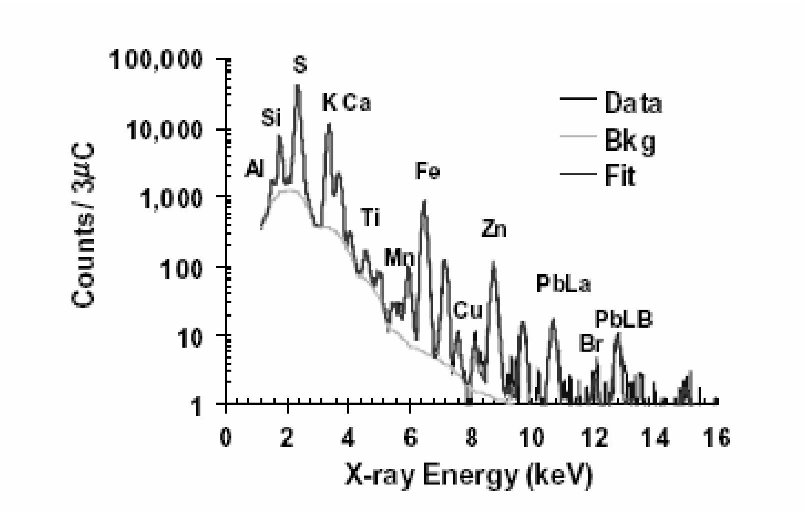


Figure 8. PIXE spectrum of an aerosol sample showing the characteristic X-ray lines and intensities from the trace elements in the aerosol particles Cohen et al., (2004).

5. RESULTS AND DISCUSSION

5.1 Gas measurements

Table 6 presents the results of passive gas measurements of ammonia and nitrogen dioxide carried out at the seven Burrup sites and at the Karratha and Mardie Station sites. The Table lists the individual concentrations of ammonia and nitrogen dioxide at each site for each sampling period, and the average concentrations measured from the beginning of August 2004 until the mid September 2005. Where both pairs are less than the limit of detection the average was set to half the limit of detection. There are several pairs of samplers that have large differences in ammonia concentrations between the duplicate pairs. For example, site 3, site 4 and site 6 have large differences in ammonia concentration during the sampling period beginning on 21/11/04, 20/11/04 and 20/11/04 respectively. One reason for this difference may be due to contamination of the sampler with ammonium salt. Ammonium salts are ubiquitous, especially in a hot environment where they are present in sweat. Although the samplers are handled very carefully ammonia contamination during preparation and or sampling cannot be excluded, for these measurements.

The monthly mean ammonia concentrations are shown in Table 6. Detection limits for ammonia were calculated from the blanks sent with each batch of samplers on a monthly basis, and they ranged from 0.1 ppb to 0.6 ppb. If only one duplicate was above the limit of detection that value is entered as the mean. However, the mean of a duplicate pair was set half the limit of detection when both duplicates were less than the limit of detection. Ammonia concentrations ranged from 0.1 ppb on the Burrup Peninsula and Mardie Station to more than 4 ppb at the Karratha site. Karratha (Site 9) has ammonia concentrations that range from about 2 ppb to 4 ppb with an average of close to 2.6 ppb; this is significantly higher than concentrations at the other sites, and may be due to a local urban source. Average annual ammonia concentrations at the Burrup Peninsula sites range from 0.3 ppb at site 1 to 0.5 ppb at site 6. At site 10, Mardie Station, the annual average ammonia concentration was 0.8 ppb; slightly higher than the Burrup sites. Since sites 1, 3 are situated on the northern end of the Burrup, away from the industrial areas, those, and site 10 could be considered to represent the local background concentration. The average ammonia concentration of the background is then about 0.5 ppb. There appears to be no real differences in concentration at any of these sites, indicating that ammonia is not enhanced above the local background.

Ammonia concentrations are shown in Figure 9 plotted against the sampling mid-date. It shows that except for Site 9, ammonia concentrations on the Burrup are generally quite consistent from site to site. Site 10 has slightly elevated ammonia concentrations during some sampling periods, and this may be due to activities carried out at the Station.

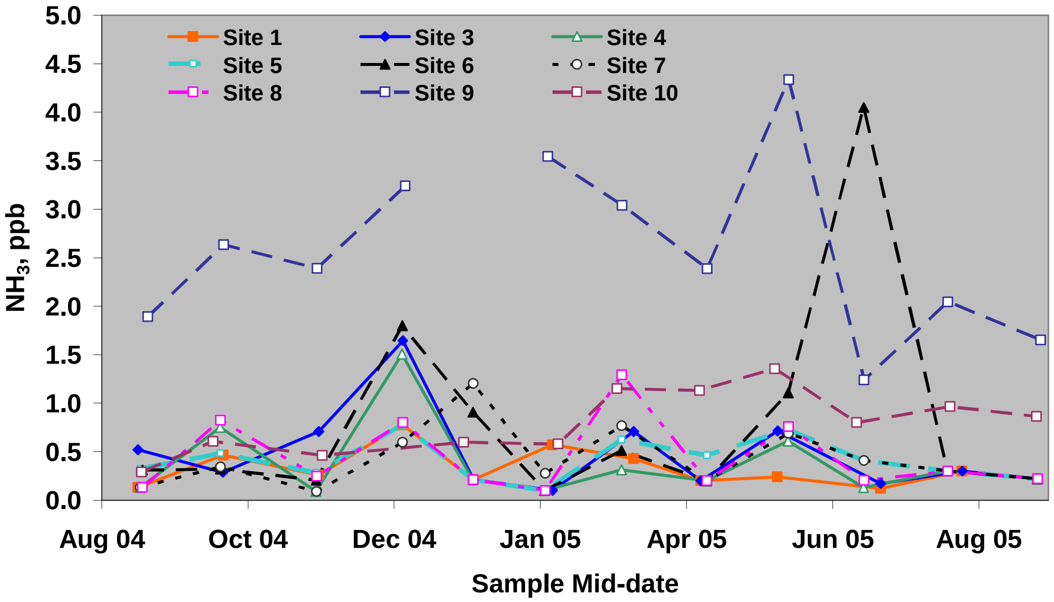


Figure 9. Ammonia concentrations plotted against the mid-date of the sampling period.

The ammonia data presented in Table 6 can be compared to ammonia concentrations of 0.09 ppb measured in maritime air at the Cape Grim Baseline Air Pollution Station by Ayers and Gras, (1983). A series of unpublished passive gas measurements of ammonia during monthly sampling at Kuala Lumpur show that the average concentration is 8.3 ppb with a maximum of 35.2 ppb. Table 6 shows that concentrations on the Burrup are much closer to concentrations measured at Cape Grim than those measured in a polluted urban environment of Kuala Lumpur.

The monthly mean nitrogen dioxide concentrations are also presented in Table 6. Monthly mean concentrations ranged from 0.2 ppb at site 10 during September 2004 to 3.8 ppb at site 9, during May 2004. The nitrogen dioxide concentrations averaged over the 12 sampling periods show that the lowest annual average concentration of 0.5 ppb were measured at Mardie Station, although Sites 1 and 3, at 0.6 ppb and 0.7 ppb, on the Northern end of the Burrup, are also very low. Assuming these sites define a regional back ground the local background concentration for nitrogen dioxide is about 0.6 ppb. The limit of detection for nitrogen dioxide measurements using passive samplers for 30 days is about 0.06 ppb.

Sites 4 to 8 are all located on the lower Burrup, closer to industry and anthropogenic influences and they could be reasonably be expected to show elevated nitrogen dioxide concentrations. The annual average concentrations at these sites range from 1.4 ppb to 2.4 ppb. Taken together, they have nitrogen dioxide concentrations of about 1.9 ppb, and this is only a moderate enhancement over the local background sites on the northern Burrup and Mardie Station.

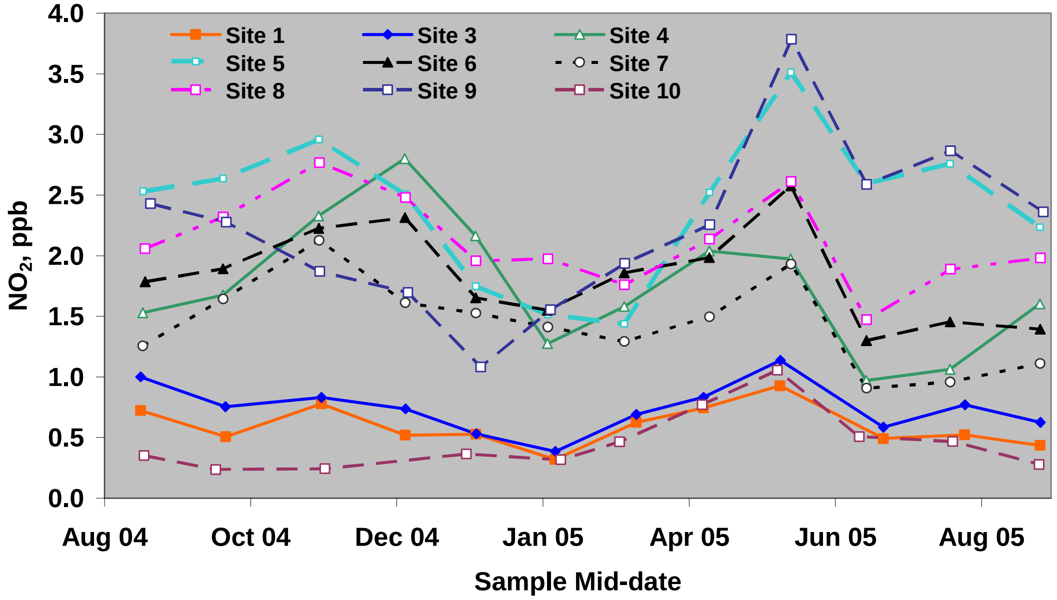


Figure 10. Nitrogen dioxide concentrations plotted against the mid-date of the sampling period.

Nitrogen dioxide concentrations, plotted against the sampling period, are displayed in Figure 10. They show clearly the slight enhancement in concentrations at sites closer to the industrial area of the Burrup relative to those observed at the local background, at Sites 1, 3 and 10.

The nitrogen dioxide concentrations measured on the Burrup Peninsula can be compared with measurements in several other regions. Several studies have produced nitrogen dioxide concentrations at terrestrial "background" sites. In Indonesia, Gillett et al. (2000) measured nitrogen dioxide concentrations of about 1.2 ppb at the Global Atmosphere Watch (GAW) Station at Bukit Koto Tabang, Sumatra. Passive gas measurements were made over approximately monthly periods at a remote site west of Darwin over several years using passive samplers. At this site the annual average nitrogen dioxide concentration was 0.75 ppb (Ayers et al., 2000). Ayers et al. (2002) carried out passive sampling for nitrogen dioxide and measured annual average concentrations of 0.8 ppb at a Malaysian "background" site at Tanah Rata, in the Cameron Highlands, north of Kuala Lumpur. The results from Bukit Koto Tabang, Charles Point and Tanah Rata are comparable to the concentrations at Sites 1, 3 and 10, confirming that a regional background of about 0.5 ppb is quite reasonable, and that a range of 0.5 ppb to 1 ppb could be expected.

In comparison, very high concentrations of nitrogen dioxide have been measured at several large Asian cities. Nitrogen dioxide concentrations of about 29 ppb have been measured in Jakarta (Gillett et al., 2000). In a study in Petaling Jaya, (Kuala Lumpur) Malaysia Ayers et al. (2000) measured annual average nitrogen dioxide concentrations ranging from 27.0 ppb to 30.3 ppb from 1994 to 1998. The results from the Burrup sites show that nitrogen dioxide concentrations are much lower than those experienced in large polluted Asian cities.

Table 6. Concentrations of ammonia and nitrogen dioxide at the nine sampling sites from August 2004 until late March 2005. Concentrations are in ppb. Relative percent differences are calculated using equation (10). Where both samples of the pair are below the limit of detection the average concentration is set at half the limit of detection. If only one sample is above the limit of detection that value is entered as the average concentration. ^{C} signifies contaminated sample.

Date on	Date off	NH_3 (ppb)	NH_3 ppb mean	RPD %	NO_2 (ppb)	NO_2 (ppbv) mean	RPD %
Site 1							
29/07/04 11:50	02/09/04 15:35	<0.2	0.1		0.7	0.7	12.5
29/07/04 11:50	02/09/04 15:35	<0.2			0.8		
02/09/04 15:40	08/10/04 09:35	0.6	0.5	50.5	0.4	0.5	21.6
02/09/04 15:40	08/10/04 09:35	0.4			0.6		
08/10/04 09:45	21/11/04 12:05	<0.2	0.3		0.6	0.8	36.6
08/10/04 09:45	21/11/04 12:05	0.3			0.9		
21/11/04 12:05	17/12/04 12:10	0.9	0.7	22.7	0.5	0.5	2.9
21/11/04 12:05	17/12/04 12:10	0.7			0.5		
17/12/04 12:10	19/01/05 13:02	<0.4	0.2		0.5	0.5	2.6
17/12/04 12:10	19/01/05 13:02	<0.4			0.5		
19/01/05 13:07	21/02/05 12:55	0.6	0.6		0.3	0.3	2.0
19/01/05 13:07	21/02/05 12:55				0.3		
21/02/05 13:12	28/03/05 11:14	0.4	0.4	0.86	0.6	0.6	11.0
21/02/05 13:12	28/03/05 11:14	0.4			0.7		
28/03/05 11:20	18/04/05 09:55	<0.4	0.2		0.8	0.7	4.7
28/03/05 11:20	18/04/05 09:55	<0.4			0.7		
18/04/05 11:17	31/05/05 11:24	<0.5	0.2		1.0	0.9	5.1
18/04/05 11:17	31/05/05 11:24	<0.5			0.9		
31/05/05 11:25	13/07/05 11:50	0.1	0.1		0.5	0.5	9.0
31/05/05 11:25	13/07/05 11:50	<0.1			0.5		
13/07/05 11:45	07/08/05 11:40	<0.6	0.3		0.4	0.5	29.8
13/07/05 11:45	07/08/05 11:40	<0.6			0.6		
07/08/05 11:50	14/09/05 09:53	<0.4	0.2		0.4	0.4	1.4
07/08/05 11:50	14/09/05 09:53	<0.4			0.4		
mean			***0.3***			***0.6***	
Site 3							
29/07/04 16:00	02/09/04 13:10	<0.3	0.5		0.9	1.0	11.4
29/07/04 16:00	02/09/04 13:10	0.5			1.1		
02/09/04 13:20	08/10/04 11:25	0.2	0.3	45.5	0.8	0.8	4.0
02/09/04 13:20	08/10/04 11:25	0.4			0.7		
08/10/04 11:30	21/11/04 15:45	1.1	0.7	124.9	0.9	0.9	
08/10/04 11:30	21/11/04 15:45	0.3					
21/11/04 15:45	17/12/04 14:15	2.5	1.6	98.6	0.8	0.7	7.2
21/11/04 15:45	17/12/04 14:15	0.8			0.7		
17/12/04 14:15	19/01/05 16:40	<0.4	0.2		0.6	0.3	
17/12/04 14:15	19/01/05 16:40	<0.4			0.0		
19/01/05 16:40	21/02/05 10:31	<0.2	0.1		0.4	0.4	9.6
19/01/05 16:40	21/02/05 10:31	<0.2			0.4		
21/02/05 09:53	28/03/05 12:28	0.9	0.7	46.8	0.6	0.7	13.2
21/02/05 09:53	28/03/05 12:28	0.5			0.7		
28/03/05 12:30	18/04/05 14:41	<0.4	0.2		0.8	0.8	0.6
28/03/05 12:30	18/04/05 14:41	<0.4			0.8		
18/04/05 14:41	31/05/05 13:15	0.8	0.7	22.4	1.1	1.1	2.3
18/04/05 14:41	31/05/05 13:15	0.6			1.2		

Table 6 cont

Date on	Date off	NH_3 (ppb)	NH_3 Ppb mean	RPD %	NO_2 (ppb)	NO_2 (ppbv) mean	RPD %
31/05/05 13:20	13/07/05 16:05	0.2	0.2	29.8	0.6	0.6	11.3
31/05/05 13:20	13/07/05 16:05	0.1			0.6		
13/07/05 15:46	07/08/05 15:05	<0.6	0.3		0.8	0.8	1.2
13/07/05 15:46	07/08/05 15:05	<0.6			0.8		
07/08/05 15:10	14/09/05 13:00	<0.4	0.2		0.6	0.6	11.6
07/08/05 15:10	14/09/05 13:00	<0.4			0.7		
Mean			***0.5***			***0.7***	
Site 4							
01/08/04 12:09	01/09/04 09:17	<0.3	0.1		1.6	1.5	3.2
01/08/04 12:09	01/09/04 09:17	<0.3			1.5		
01/09/04 09:25	07/10/04 09:15	<0.3	0.8		1.7	1.7	3.2
01/09/04 09:25	07/10/04 09:15	0.8			1.6		
07/10/04 09:20	20/11/04 08:20	<0.2	0.1		2.3	2.3	1.8
07/10/04 09:20	20/11/04 08:20	<0.2			2.3		
20/11/04 08:20	18/12/04 06:30	2.2	1.5	96.9	2.8	2.8	1.2
20/11/04 08:20	18/12/04 06:30	0.8			2.8		
18/12/04 06:30	18/01/05 10:02	<0.4	0.2		2.2	2.2	0.0
18/12/04 06:30	18/01/05 10:02	<0.4			2.2		
18/01/05 10:07	16/02/05 06:30	<0.2	0.1		1.3	1.3	1.5
18/01/05 10:07	16/02/05 06:30	<0.2			1.3		
16/02/05 06:45	23/03/05 09:53	0.3	0.3	37.8	1.6	1.6	2.7
16/02/05 06:45	23/03/05 09:53	0.4			1.6		
23/03/05 09:53	28/04/05 08:48	<0.4	0.2		2.1	2.0	1.5
23/03/05 09:53	28/04/05 08:48	<0.4			2.0		
28/04/05 08:49	30/05/05 10:40	0.6	0.6	11.7	2.0	2.0	1.8
28/04/05 08:49	30/05/05 10:40	0.6			2.0		
30/05/05 10:40	30/06/05 08:45	0.1	0.1		0.9	1.0	14.5
30/05/05 10:40	30/06/05 08:45	<0.1			1.0		
30/06/05 08:48	08/08/05 08:47	<0.6	0.3		1.0	1.1	2.6
30/06/05 08:48	08/08/05 08:47	<0.6			1.1		
08/08/05 08:47	13/09/05 08:43	<0.4	0.2		1.4	1.6	22.3
08/08/05 08:47	13/09/05 08:43	<0.4			1.8		
Mean			***0.4***			***1.8***	
Site 5							
01/08/04 16:04	01/09/04 13:35	0.4	0.3	23.3	2.4	2.5	11.5
01/08/04 16:04	01/09/04 13:35	0.3			2.7		
01/09/04 13:40	07/10/04 11:15	0.6	0.5	37.2	2.6	2.6	3.6
01/09/04 13:40	07/10/04 11:15	0.4			2.7		
07/10/04 11:20	20/11/04 12:40	0.3	0.3		2.8	3.0	8.5
07/10/04 11:20	20/11/04 12:40	<0.2			3.1		
20/11/04 12:40	18/12/04 07:45	0.9	0.8	30.5	2.6	2.5	3.7
20/11/04 12:40	18/12/04 07:45	0.7			2.5		
18/12/04 07:45	18/01/05 12:38	<0.4	0.2		1.7	1.7	1.4
18/12/04 07:45	18/01/05 12:38	<0.4			1.8		
18/01/05 12:44	16/02/05 08:30	<0.2	0.1		1.5	1.5	0.0
18/01/05 12:44	16/02/05 08:30	<0.2			1.5		
16/02/05 08:15	23/03/05 11:56	0.7	0.6	19.3	1.4	1.4	5.3
16/02/05 08:15	23/03/05 11:56	0.6			1.5		
23/03/05 11:56	28/04/05 10:22	<0.4	0.5		2.5	2.5	1.2
23/03/05 11:56	28/04/05 10:22	0.5			2.5		

Table 6 cont

Date on	Date off	NH_3 (ppb)	NH_3 ppb mean	RPD %	NO_2 (ppb)	NO_2 (ppbv) mean	RPD %
28/04/05 10:22	30/05/05 11:40	<0.5	0.7		3.5	3.5	0.5
28/04/05 10:22	30/05/05 11:40	0.7			3.5		
30/05/05 11:40	30/06/05 09:15	0.4	0.4	18.3	2.6	2.6	1.0
30/05/05 11:40	30/06/05 09:15	0.4			2.6		
30/06/05 09:20	08/08/05 09:35	<0.6	0.3		2.8	2.8	5.9
30/06/05 09:20	08/08/05 09:35	<0.6			2.7		
08/08/05 09:35	13/09/05 10:32	<0.4	0.2		2.1	2.2	7.9
08/08/05 09:35	13/09/05 10:32	<0.4			2.3		
Mean			***0.4***			***2.4***	
Site 6							
03/08/04 12:29	01/09/04 12:00	0.3	0.3		1.9	1.8	8.2
03/08/04 12:29	01/09/04 12:00	<0.3			1.7		
01/09/04 12:10	07/10/04 10:30	0.3	0.3	0.4	2.0	1.9	9.3
01/09/04 12:10	07/10/04 10:30	0.3			1.8		
07/10/04 10:35	20/11/04 10:30	0.2	0.2	27.1	2.2	2.2	2.4
07/10/04 10:35	20/11/04 10:30	0.2			2.3		
20/11/04 10:30	18/12/04 08:45	0.8	1.8	113.8	2.4	2.3	4.5
20/11/04 10:30	18/12/04 08:45	2.8			2.3		
18/12/04 08:45	18/01/05 11:15	0.5	0.9	95.3	1.6	1.7	2.8
18/12/04 08:45	18/01/05 11:15	1.3			1.7		
18/01/05 11:25	16/02/05 07:20	<0.2	0.1		1.7	1.6	16.3
18/01/05 11:25	16/02/05 07:20	<0.2			1.4		
16/02/05 07:30	23/03/05 10:52	0.6	0.5	48.8	1.8	1.9	5.0
16/02/05 07:30	23/03/05 10:52	0.4			1.9		
23/03/05 10:52	28/04/05 09:35	<0.4	0.2		2.1	2.0	6.8
23/03/05 10:52	28/04/05 09:35	<0.4			1.9		
28/04/05 09:36	30/05/05 13:00	1.1	1.1	9.1	2.6	2.6	1.6
28/04/05 09:36	30/05/05 13:00	1.2			2.6		
30/05/05 13:00	30/06/05 10:20	0.3	0.5	69.4	1.3	1.3	1.1
30/05/05 13:00	30/06/05 10:20	0.7			1.3		
30/06/05 10:15	08/08/05 10:21	<0.6	0.3		1.4	1.5	1.7
30/06/05 10:15	08/08/05 10:21	<0.6			1.5		
08/08/05 10:21	13/09/05 14:35	<0.4	0.2		1.6	1.4	27.4
08/08/05 10:21	13/09/05 14:35	<0.4			1.2		
Mean			***0.5***			***1.8***	
Site 7							
01/08/04 15:01	01/09/04 08:24	<0.3	0.1		1.3	1.3	1.5
01/08/04 15:01	01/09/04 08:24	<0.3			1.2		
01/09/04 13:45	07/10/04 13:30	0.4	0.3	53.6	1.6	1.6	4.0
01/09/04 13:45	07/10/04 13:30	0.3			1.7		
07/10/04 13:35	20/11/04 14:35	<0.2	0.1		2.1	2.1	1.4
07/10/04 13:35	20/11/04 14:35	<0.2			2.1		
20/11/04 14:35	18/12/04 09:40	0.5	0.6	16.9	1.7	1.6	6.5
20/11/04 14:35	18/12/04 09:40	0.6			1.6		
18/12/04 09:40	18/01/05 15:10	1.0	1.2	27.6	1.5	1.5	3.6
18/12/04 09:40	18/01/05 15:10	0.3			1.6		
18/01/05 15:16	16/02/05 09:15	0.3	0.3	36.3	1.4	1.4	4.3
18/01/05 15:16	16/02/05 09:15	0.2			1.4		
16/02/05 09:30	23/03/05 13:05	0.6	0.8	41.1	1.3	1.3	0.4
16/02/05 09:30	23/03/05 13:05	0.9			1.3		

Table 6 cont

Date on	Date off	NH_3 (ppb)	NH_3 ppb mean	RPD %	NO_2 (ppb)	NO_2 (ppbv) mean	RPD %
23/03/05 13:12	28/04/05 11:20	<0.4	0.2		1.5	1.5	2.7
23/03/05 13:12	28/04/05 11:20	<0.4			1.5		
28/04/05 11:20	30/05/05 14:10	0.6	0.7	16.9	1.9	1.9	7.6
28/04/05 11:20	30/05/05 14:10	0.7			2.0		
30/05/05 14:10	30/06/05 11:25	0.4	0.4		1.0	0.9	15.4
30/05/05 14:10	30/06/05 11:25	<0.1			0.8		
30/06/05 11:23	08/08/05 11:25	<0.6	0.3		1.0	1.0	0.1
30/06/05 11:23	08/08/05 11:25	<0.6			1.0		
08/08/05 11:25	13/09/05 11:41	<0.4	0.2		1.1	0.6	175.8
08/08/05 11:25	13/09/05 11:41	<0.4			0.1		
Mean			***0.4***			***1.4***	
Site 8							
03/08/04 09:07	01/09/04 11:05	<0.3	0.1		2.1	2.1	4.4
03/08/04 09:07	01/09/04 11:05	<0.3			2.0		
01/09/04 11:15	07/10/04 15:00	0.9	0.8	7.0	2.4	2.3	5.5
01/09/04 11:15	07/10/04 15:00	0.8			2.3		
07/10/04 15:05	20/11/04 16:30	0.2	0.2	11.7	2.8	2.8	3.9
07/10/04 15:05	20/11/04 16:30	0.3			2.7		
20/11/04 16:30	18/12/04 11:30	0.8	0.8	1.8	2.5	2.5	1.0
20/11/04 16:30	18/12/04 11:30	0.8			2.5		
18/12/04 11:30	18/01/05 17:17	<0.4	0.2		2.0	2.0	0.4
18/12/04 11:30	18/01/05 17:17	<0.4			2.0		
18/01/05 17:25	16/02/05 10:40	<0.2	0.1		1.9	2.0	2.9
18/01/05 17:25	16/02/05 10:40	<0.2			2.0		
16/02/05 11:15	23/03/05 14:31	0.6	0.6	224.9	1.7	1.8	6.5
16/02/05 11:15	23/03/05 14:31	2.0[C]			1.8		
23/03/05 14:35	28/04/05 11:50	<0.4	0.2		2.1	2.1	0.3
23/03/05 14:35	28/04/05 11:50	<0.4			2.1		
28/04/05 11:51	30/05/05 16:00	0.8	0.8	10.2	2.7	2.6	3.4
28/04/05 11:51	30/05/05 16:00	0.7			2.6		
30/05/05 16:01	30/06/05 12:30	0.2	0.2	26.4	1.5	1.5	0.4
30/05/05 16:01	30/06/05 12:30	0.2			1.5		
30/06/05 12:35	08/08/05 12:35	<0.6	0.3		1.9	1.9	2.7
30/06/05 12:35	08/08/05 12:35	<0.6			1.9		
08/08/05 12:35	13/09/05 15:50	<0.4	0.2		2.0	2.0	2.2
08/08/05 12:35	13/09/05 15:50	<0.4			2.0		
mean			***0.4***			***2.1***	
Site 9							
05/08/04 15:00	03/09/04 18:00	1.8	1.9	7.8	2.3	2.4	12.9
05/08/04 15:00	03/09/04 18:00	2.0			2.6		
03/09/04 18:00	07/10/04 20:30	2.6	2.6	1.2	2.3	2.3	1.7
03/09/04 18:00	07/10/04 20:30	2.6			2.3		
07/10/04 20:35	20/11/04 18:00	2.4	2.4	0.7	1.8	1.9	3.6
07/10/04 20:35	20/11/04 18:00	2.4			1.9		
20/11/04 18:00	20/12/04 11:30	3.2	3.2	3.3	1.7	1.7	1.0
20/11/04 18:00	20/12/04 11:30	3.3			1.7		
20/12/04 11:30	20/01/05 10:15				1.1	1.1	
20/12/04 11:30	20/01/05 10:15						
20/01/05 10:45	16/02/05 18:00	3.2	3.5	21.8	1.5	1.6	6.4
20/01/05 10:45	16/02/05 18:00	3.9			1.6		

Table 6 cont

Date on	Date off	NH_3 (ppb)	NH_3 ppb mean	RPD %	NO_2 (ppb)	NO_2 (ppbv) mean	RPD %
16/02/05 18:10	23/03/05 15:20	3.2	3.0	8.9	1.8	1.9	18.3
16/02/05 18:10	23/03/05 15:20	2.9			2.1		
23/03/05 15:26	28/04/05 13:42	2.2	2.4	13.7	2.2	2.3	0.9
23/03/05 15:26	28/04/05 13:42	2.6			2.3		
28/04/05 13:45	30/05/05 18:04	4.4	4.3	3.5	3.8	3.8	1.5
28/04/05 13:45	30/05/05 18:04	4.3			3.8		
30/05/05 18:08	30/06/05 13:30	1.5	1.2	42.1	2.6	2.6	0.5
30/05/05 18:08	30/06/05 13:30	1.0			2.6		
30/06/05 13:25	08/08/05 17:30	2.5	2.0	48.7	3.0	2.9	8.8
30/06/05 13:25	08/08/05 17:30	1.5			2.7		
08/08/05 17:45	15/09/05 18:00	1.6	1.7	8.2	2.2	2.4	10.1
08/08/05 17:45	15/09/05 18:00	1.7			2.5		
Mean			***2.6***			***2.2***	
Site10							
02/08/04 15:00	01/09/04 10:50	0.3	0.3		0.4	0.3	18.2
02/08/04 15:00	01/09/04 10:50	<0.3			0.3		
01/09/04 10:50	01/10/04 12:35	0.7	0.6	39.2	0.2	0.2	7.1
01/09/04 10:50	01/10/04 12:35	0.5			0.2		
01/10/04 12:35	01/12/04 10:30	0.5	0.5	16.6	0.2	0.2	7.1
01/10/04 12:35	01/12/04 10:30	0.4			0.3		
01/12/04 12:00	27/01/05 14:00	0.8	0.6	60.5	0.4	0.4	1.2
01/12/04 12:00	27/01/05 14:00	0.4			0.4		
27/01/05 14:00	18/02/05 09:30	0.3	0.6	82.6	0.3	0.3	
27/01/05 14:00	18/02/05 09:30	0.8					
18/02/05 09:30	17/03/05 11:30	1.1	1.1	0.4	0.5	0.5	3.7
18/02/05 09:30	17/03/05 11:30	1.2			0.5		
17/03/05 11:30	28/04/05 08:00	0.9	1.1	48.3	0.8	0.8	2.0
17/03/05 11:30	28/04/05 08:00	1.4			0.8		
28/04/05 08:00	19/05/05 10:00	0.5	1.4	122.6	1.1	1.1	3.0
28/04/05 08:00	19/05/05 10:00	2.2			1.0		
19/05/05 10:15	05/07/05 11:05	0.5	0.8	72.6	0.5	0.5	0.3
19/05/05 10:15	05/07/05 11:05	1.1			0.5		
05/07/05 11:15	05/08/05 13:20	0.8	1.0	42.7	0.4	0.5	12.0
05/07/05 11:15	05/08/05 13:20	1.2			0.5		
05/08/05 13:20	15/09/05 12:00	0.7	0.9	26.4	0.3	0.3	8.4
05/08/05 13:20	15/09/05 12:00	1.0			0.3		
Mean			***0.8***			***0.5***	

Table 7 displays the concentrations of sulphur dioxide and nitric acid measured at the Burrup sites and at Mardie Station over the annual period from August 2004 to mid September 2005. Average monthly concentrations of sulphur dioxide range from 19 ppt during August 2005 at Site 10 to 367 ppt at Site 4 during April 2005. The average annual sulphur dioxide concentrations range from 83 ppt at Site 10 to 215 ppt at Site 5. The concentrations, measured at sites 1, 3 and 10, are assumed to be regional background levels and appear to be in the range of about 83 ppt to 139 ppt, with an annual average of about 108 ppt. The annual average concentration at sites 4 – 8 is only about 175 ppt, with a maximum of 215 ppt, so the enhancement in sulphur dioxide concentrations at these sites is very small. Detection limits for sulphur dioxide and nitric acid, calculated from the standard deviation of blanks, using an ISO (1994) technique, were 28 ppt and 45 ppt respectively over a 30 day sampling period.

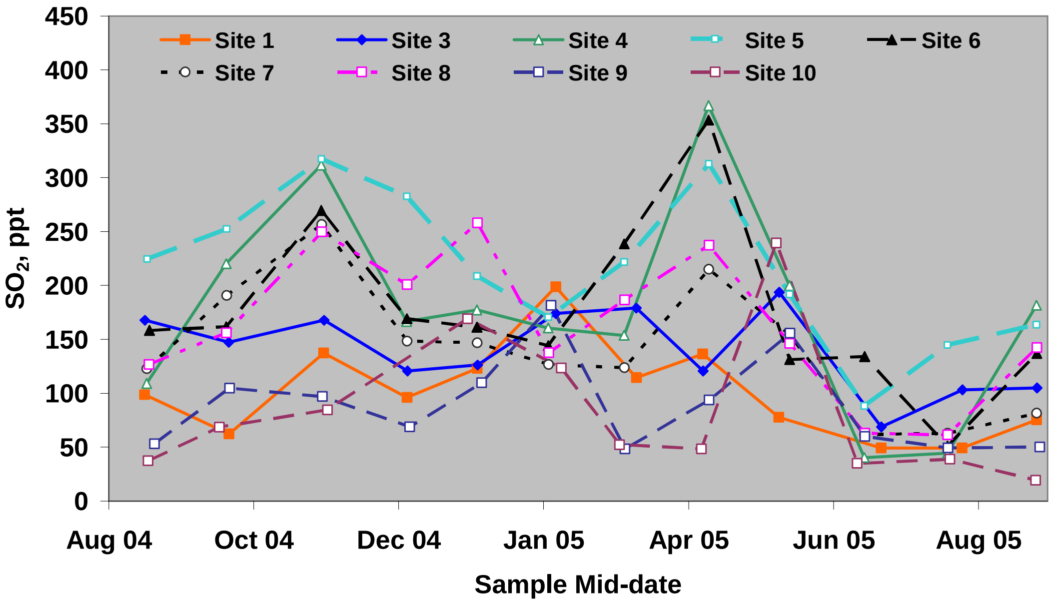


Figure 11. Sulfur dioxide concentrations plotted against the mid-date of the sampling period.

Sulfur dioxide concentrations at each site are plotted against the sampling mid-time in Figure 11. The Figure shows that there is a small elevation in sulphur dioxide concentrations at some sites, such as 4, 5 and 6. Concentrations at the local background sites, 1.3 and 10 tend to have lower concentrations, although Site 9 can also have concentrations near the background at least during some sampling periods.

Several studies have determined sulphur dioxide concentrations in remote terrestrial regions using passive samplers, and in pristine areas using active sampling techniques, and these can be used to compare with the background concentrations on the Burrup Peninsula. In pristine areas very low concentrations of sulphur dioxide have been recorded. For example at the South Pole a 7-day average concentration of less 20 ppt was measured using a chemical ionisation mass spectrometer (Hueya et al., 2004). De bruyn et al. (2002) measured sulphur dioxide concentrations at Baring Head, New Zealand over a period of 15 hours and found a diurnal cycle and average concentration of less than 15 ppt. These studies show that very low sulphur dioxide concentrations are possible in areas that are considered to be pristine and where air is not impacted by anthropogenic pollution.

At Bukit Koto Tabang, GAW station on Sumatra the annual average sulphur dioxide concentrations were 1.3 ppb during 1996 (Gillett et al., 2000). At Charles Point, West of Darwin average sulphur dioxide concentrations were 0.75 ppb between June 1993 and June 1997 (Ayers et al., 2000) and at Tanah Rata, north of Kuala Lumpur, Malaysia the average concentration was 0.5 ppb from August 1990 to January 1992 (Ayers et al., 2002). These “background” concentrations are significantly higher than any of the measurements recorded at any of the Burrup sites.

Sulfur dioxide concentrations have also been recorded in large polluted Asian cities such as Kuala Lumpur, Jakarta and Bogor. In Jakarta annual average concentrations of sulphur dioxide were 7.1 ppb and 4.4 ppb in 1992 and 1996 respectively and in Bogor the annual average concentration was 1.9 ppb in 1996 (Gillett et al., 2000). The concentrations in Petaling Jaya, near Kuala Lumpur averaged 6.3 ppb over a five year period from March 1994 to March 1998 (Ayers et al., 2000). In other sites near Kuala Lumpur concentrations were recorded from August 1996 to January 1997 at Klang, April 1996 to April 1997 at Ulu Langat and August 1996 to June 1997 Johor Baru Malaysia where concentrations were 6.2 ppb, 0.9 ppb and 1.9 ppb respectively. These concentrations are typical of areas that are heavily impacted with anthropogenic pollution and are obviously much higher than those observed on the Burrup Peninsula.

Nitric acid concentrations are also presented in Table 7; these were measured as nitrate ion which is collected with the sulphur dioxide passive sampler. The monthly average concentrations shown in the Table range from 21 ppt at site 10 during August 2004 to 632 ppt at site 9 during May 2005. The assumed background sites of 1, 3 and 10 have nitric acid concentrations of 144 ppt, 162 ppt and 160 ppt respectively, indicating an average annual background concentration of about 155 ppt. At Sites 4 – 8, on the southern Burrup Peninsula, annual average concentrations ranged from 198 ppt at site 4 to 250 ppt at site 8 giving a southern area average of 229 ppt. Although the concentration increase from the background to the southern Burrup sites is noticeable, the enhancement is small, and the concentrations are very low.

Figure 12 shows concentrations of nitric acid at each site plotted against the mid-time of the sampling period. It shows only a small enhancement in nitric acid concentrations at the sites on the lower Burrup compared with those at the local background sites. The concentrations have some temporal trends; most sites had low concentrations during the January/February sampling period and higher concentrations during the May sampling period. A similar temporal trend can also be observed for nitrogen dioxide concentrations, in Figure 10.

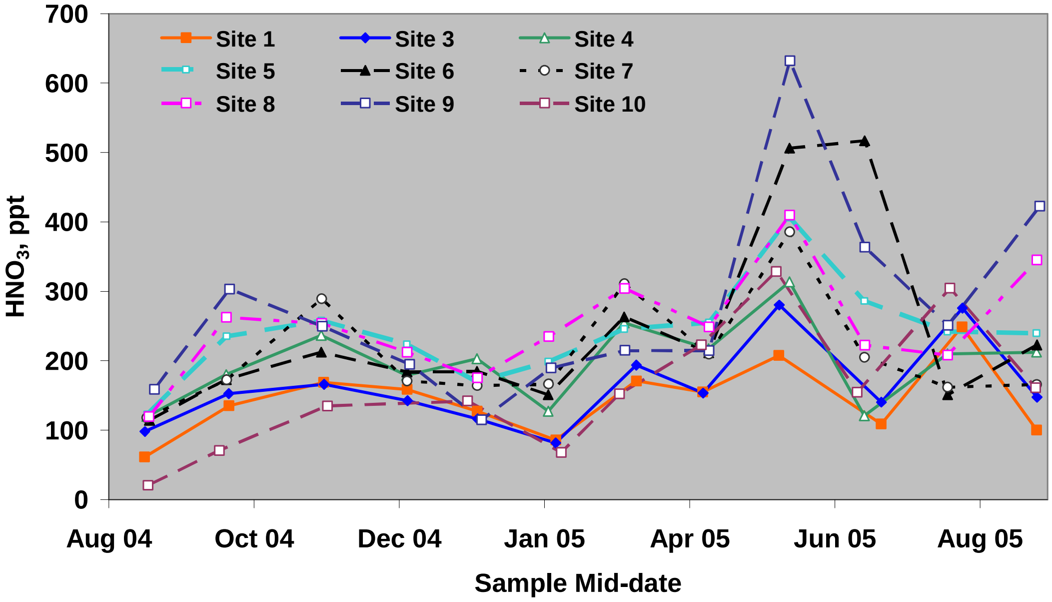


Figure 12. Nitric acid concentrations plotted against the mid-date of the sampling period.

By way of comparison "background" concentrations of 0.34 ppb have been measured at Charles Point from June 1993 to June 1997 (Ayers et al., 2000) and they are in excess of measurements on the Burrup. In heavily polluted areas in Asia concentrations of nitric acid average 1.1 ppb at Petaling Jaya, Malaysia (Ayers et al., 2000) and 2.0 ppb at Klang, Malaysia (Ayers et al., 2002). These concentrations are much higher than those measured on the Burrup Peninsula.

Table 7. Concentrations of sulphur dioxide and nitric acid at the nine sampling sites from August 2004 until late March 2005. Concentrations are in ppt. Where both samples of the pair are below the limit of detection the average concentration is set at half the limit of detection. If only one sample is above the limit of detection that value is entered as the average concentration.

Date on	Date off	SO_2 (ppt)	SO_2 (ppt) mean	RPD %	HNO_3 (ppt)	HNO_3 (ppt) mean	RPD %
Site 1							
29/07/04 11:50	02/09/04 15:35	116	99	35.8	60	61	3.7
29/07/04 11:50	02/09/04 15:35	81			62		
02/09/04 15:40	08/10/04 09:35	59	62	10.9	116	135	28.4
02/09/04 15:40	08/10/04 09:35	66			154		
08/10/04 09:45	21/11/04 12:05	128	137	12.9	167	169	2.2
08/10/04 09:45	21/11/04 12:05	146			171		
21/11/04 12:05	17/12/04 12:10	120	96	51.1	162	159	5.0
21/11/04 12:05	17/12/04 12:10	71			155		
17/12/04 12:10	19/01/05 13:02	90	123	53.7	97	127	47.1
17/12/04 12:10	19/01/05 13:02	156			157		
19/01/05 13:07	21/02/05 12:55	204	199	5.1	81	86	10.2
19/01/05 13:07	21/02/05 12:55	193			90		
21/02/05 13:12	28/03/05 11:14	76	114	67.8	158	171	14.9
21/02/05 13:12	28/03/05 11:14	153			184		
28/03/05 11:20	18/04/05 09:55	115	136	31.4	143	155	15.5
28/03/05 11:20	18/04/05 09:55	158			167		
18/04/05 11:17	31/05/05 11:24	75	78	6.2	214	207	6.0
18/04/05 11:17	31/05/05 11:24	80			201		
31/05/05 11:25	13/07/05 11:50	52	49	10.2	113	109	8.6
31/05/05 11:25	13/07/05 11:50	47			104		
13/07/05 11:45	07/08/05 11:40	60	49	42.2	250	249	0.6
13/07/05 11:45	07/08/05 11:40	39			248		
07/08/05 11:50	14/09/05 09:53	81	75	14.3	97	100	6.7
07/08/05 11:50	14/09/05 09:53	70			103		
mean			***101***			***144***	
Site 3							
29/07/04 16:00	02/09/04 13:10	183	168	17.8	112	98	29.3
29/07/04 16:00	02/09/04 13:10	153			84		
02/09/04 13:20	08/10/04 11:25	145	147	3.0	151	152	1.5
02/09/04 13:20	08/10/04 11:25	150			154		
08/10/04 11:30	21/11/04 15:45	159	168	10.5	162	166	4.5
08/10/04 11:30	21/11/04 15:45	177			170		
21/11/04 15:45	17/12/04 14:15	100	121	34.1	127	142	22.3
21/11/04 15:45	17/12/04 14:15	141			158		
17/12/04 14:15	19/01/05 16:40	126	126	0.0	127	116	18.2
17/12/04 14:15	19/01/05 16:40	126			106		
19/01/05 16:40	21/02/05 10:31	153	174	24.6	84	82	6.2
19/01/05 16:40	21/02/05 10:31	196			79		
21/02/05 09:53	28/03/05 12:28	215	179	40.2	204	194	10.3
21/02/05 09:53	28/03/05 12:28	143			184		
28/03/05 12:30	18/04/05 14:41	128	121	11.3	148	153	6.4
28/03/05 12:30	18/04/05 14:41	114			158		
18/04/05 14:41	31/05/05 13:15	176	194	18.2	270	280	7.5
18/04/05 14:41	31/05/05 13:15	211			291		
31/05/05 13:20	13/07/05 16:05	76	69	21.6	134	140	8.6

Table 7 cont

Date on	Date off	SO_2 (ppt)	SO_2 (ppt) mean	RPD %	HNO_3 (ppt)	HNO_3 (ppt) mean	RPD %
31/05/05 13:20	13/07/05 16:05	61			146		
13/07/05 15:46	07/08/05 15:05	113	103	18.7	290	276	10.5
13/07/05 15:46	07/08/05 15:05	93			261		
07/08/05 15:10	14/09/05 13:00	93	105	22.2	173	147	35.2
07/08/05 15:10	14/09/05 13:00	117			121		
Mean			***139***			***162***	
Site 4							
01/08/04 12:09	01/09/04 09:17	108	109	2.4	107	120	20.6
01/08/04 12:09	01/09/04 09:17	110			132		
01/09/04 09:25	07/10/04 09:15	223	220	2.5	190	180	11.2
01/09/04 09:25	07/10/04 09:15	217			170		
07/10/04 09:20	20/11/04 08:20	335	311	15.3	207	236	24.9
07/10/04 09:20	20/11/04 08:20	288			266		
20/11/04 08:20	18/12/04 06:30	158	167	10.6	184	179	5.8
20/11/04 08:20	18/12/04 06:30	176			174		
18/12/04 06:30	18/01/05 10:02	199	177	24.7	192	203	10.5
18/12/04 06:30	18/01/05 10:02	155			213		
18/01/05 10:07	16/02/05 06:30	135	160	32.1	120	127	11.3
18/01/05 10:07	16/02/05 06:30	186			134		
16/02/05 06:45	23/03/05 09:53	130	154	30.7	220	255	26.9
16/02/05 06:45	23/03/05 09:53	177			289		
23/03/05 09:53	28/04/05 08:48	351	367	8.4	193	217	22.7
23/03/05 09:53	28/04/05 08:48	382			242		
28/04/05 08:49	30/05/05 10:40	216	200	16.5	301	314	8.1
28/04/05 08:49	30/05/05 10:40	183			326		
30/05/05 10:40	30/06/05 08:45	20	40	102.5	127	121	9.6
30/05/05 10:40	30/06/05 08:45	61			115		
30/06/05 08:48	08/08/05 08:47	37	44	32.4	210	210	0.5
30/06/05 08:48	08/08/05 08:47	52			209		
08/08/05 08:47	13/09/05 08:43	198	182	18.4	254	212	38.8
08/08/05 08:47	13/09/05 08:43	165			171		
Mean			***178***			***198***	
Site 5							
01/08/04 16:04	01/09/04 13:35	239	225	13.2	105	123	29.5
01/08/04 16:04	01/09/04 13:35	210			141		
01/09/04 13:40	07/10/04 11:15		252				
01/09/04 13:40	07/10/04 11:15	252			235		
07/10/04 11:20	20/11/04 12:40	311	317	3.8	245	258	10.1
07/10/04 11:20	20/11/04 12:40	323			271		
20/11/04 12:40	18/12/04 07:45	290	283	5.2	272	224	42.9
20/11/04 12:40	18/12/04 07:45	275			176		
18/12/04 07:45	18/01/05 12:38	196	209	12.0	160	169	11.0
18/12/04 07:45	18/01/05 12:38	221			178		
18/01/05 12:44	16/02/05 08:30	182	171	13.4	249	199	50.4
18/01/05 12:44	16/02/05 08:30	159			149		
16/02/05 08:15	23/03/05 11:56	116	222	95.6	238	246	6.2
16/02/05 08:15	23/03/05 11:56	328			253		
23/03/05 11:56	28/04/05 10:22	321	313	5.5	257	255	1.3
23/03/05 11:56	28/04/05 10:22	304			253		
28/04/05 10:22	30/05/05 11:40	194	192	2.6	390	406	7.8

Table 7 cont

Date on	Date off	SO_2 (ppt)	SO_2 (ppt) mean	RPD %	HNO_3 (ppt)	HNO_3 (ppt) mean	RPD %
28/04/05 10:22	30/05/05 11:40	189			422		
30/05/05 11:40	30/06/05 09:15	84	88	8.7	348	286	43.2
30/05/05 11:40	30/06/05 09:15	92			224		
30/06/05 09:20	08/08/05 09:35	158	145	18.4	246	242	3.0
30/06/05 09:20	08/08/05 09:35	131			239		
08/08/05 09:35	13/09/05 10:32	171	163	9.5	265	240	21.3
08/08/05 09:35	13/09/05 10:32	156			214		
Mean			***215***			***240***	
Site 6							
03/08/04 12:29	01/09/04 12:00	175	158	21.8	114	114	0.0
03/08/04 12:29	01/09/04 12:00	141			114		
01/09/04 12:10	07/10/04 10:30	170	162	9.7	183	173	11.0
01/09/04 12:10	07/10/04 10:30	154			164		
07/10/04 10:35	20/11/04 10:30	248	270	16.3	212	212	0.4
07/10/04 10:35	20/11/04 10:30	292			213		
20/11/04 10:30	18/12/04 08:45	161	169	9.6	187	184	3.2
20/11/04 10:30	18/12/04 08:45	177			181		
18/12/04 08:45	18/01/05 11:15		161			185	
18/12/04 08:45	18/01/05 11:15	161			185		
18/01/05 11:25	16/02/05 07:20	125	144	26.8	160	151	12.3
18/01/05 11:25	16/02/05 07:20	164			142		
16/02/05 07:30	23/03/05 10:52	239	239	0.0	256	263	5.4
16/02/05 07:30	23/03/05 10:52	239			270		
23/03/05 13:12	28/04/05 11:20	357	353	2.3	214	212	2.7
23/03/05 13:12	28/04/05 11:20	349			209		
28/04/05 11:20	30/05/05 14:10	115	131	24.1	452	506	21.5
28/04/05 11:20	30/05/05 14:10	147			561		
30/05/05 14:10	30/06/05 11:25	118	134	24.1	461	517	21.5
30/05/05 14:10	30/06/05 11:25	150			572		
30/06/05 11:23	08/08/05 11:25	50	51	2.0	185	151	45.5
30/06/05 11:23	08/08/05 11:25	51			117		
08/08/05 11:25	13/09/05 11:41	145	137	12.1	192	223	27.3
08/08/05 11:25	13/09/05 11:41	129			253		
Mean			***176***			***241***	
Site7							
01/08/04 15:01	01/09/04 08:24	123	123	0.0	91	118	45.4
01/08/04 15:01	01/09/04 08:24	123			144		
01/09/04 13:45	07/10/04 13:30	193	191	2.4	177	172	5.2
01/09/04 13:45	07/10/04 13:30	188			168		
07/10/04 13:35	20/11/04 14:35	253	256	2.5	292	289	1.9
07/10/04 13:35	20/11/04 14:35	260			286		
20/11/04 14:35	18/12/04 09:40	135	148	18.0	166	171	6.1
20/11/04 14:35	18/12/04 09:40	162			176		
18/12/04 09:40	18/01/05 15:10	145	147	2.7	171	164	8.1
18/12/04 09:40	18/01/05 15:10	149			157		
18/01/05 15:16	16/02/05 09:15	157	127	47.6	166	166	
18/01/05 15:16	16/02/05 09:15	97					
16/02/05 09:30	23/03/05 13:05	142	124	29.6	311	311	0.4
16/02/05 09:30	23/03/05 13:05	105			310		
23/03/05 13:12	28/04/05 11:20	206	215	8.0	212	209	2.2

Table 7 cont

Date on	Date off	SO_2 (ppt)	SO_2 (ppt) mean	RPD %	HNO_3 (ppt)	HNO_3 (ppt) mean	RPD %
23/03/05 13:12	28/04/05 11:20	224			207		
28/04/05 11:20	30/05/05 14:10	160	154	7.4	403	386	8.9
28/04/05 11:20	30/05/05 14:10	148			368		
30/05/05 14:10	30/06/05 11:25	73	62	35.6	154	205	49.9
30/05/05 14:10	30/06/05 11:25	51			256		
30/06/05 11:23	08/08/05 11:25	66	63	9.8	182	162	25.3
30/06/05 11:23	08/08/05 11:25	60			141		
08/08/05 11:25	13/09/05 11:41	95	81	32.8	150	166	18.8
08/08/05 11:25	13/09/05 11:41	68			181		
Mean			***141***			***210***	
Site8							
03/08/04 09:07	01/09/04 11:05	107	127	30.4	108	119	18.4
03/08/04 09:07	01/09/04 11:05	146			130		
01/09/04 11:15	07/10/04 15:00	143	156	17.1	260	263	1.7
01/09/04 11:15	07/10/04 15:00	169			265		
07/10/04 15:05	20/11/04 16:30	250	250	0.0	262	254	7.0
07/10/04 15:05	20/11/04 16:30	250			245		
20/11/04 16:30	18/12/04 11:30	206	201	5.2	214	212	2.1
20/11/04 16:30	18/12/04 11:30	196			210		
18/12/04 11:30	18/01/05 17:17	261	258	2.0	173	176	3.0
18/12/04 11:30	18/01/05 17:17	255			178		
18/01/05 17:25	16/02/05 10:40	147	137	13.6	228	235	5.5
18/01/05 17:25	16/02/05 10:40	128			241		
16/02/05 11:15	23/03/05 14:31	134	187	56.9	301	304	2.3
16/02/05 11:15	23/03/05 14:31	240			308		
23/03/05 14:35	28/04/05 11:50	225	237	10.2	253	249	3.2
23/03/05 14:35	28/04/05 11:50	250			244		
28/04/05 11:51	30/05/05 16:00	181	146	47.5	406	410	2.2
28/04/05 11:51	30/05/05 16:00	111			414		
30/05/05 16:01	30/06/05 12:30	49	63	43.1	220	222	2.3
30/05/05 16:01	30/06/05 12:30	77			225		
30/06/05 12:35	08/08/05 12:35	62	61	1.7	155	208	51.3
30/06/05 12:35	08/08/05 12:35	61			261		
08/08/05 12:35	13/09/05 15:50	146	143	5.4	390	345	25.7
08/08/05 12:35	13/09/05 15:50	139			301		
Mean			***164***			***250***	
Site 9							
05/08/04 15:00	03/09/04 18:00	57	53	12.9	158	159	1.7
05/08/04 15:00	03/09/04 18:00	50			160		
03/09/04 18:00	07/10/04 20:30	103	105	3.4	274	303	19.5
03/09/04 18:00	07/10/04 20:30	107			333		
07/10/04 20:35	20/11/04 18:00	100	97	6.7	260	250	7.9
07/10/04 20:35	20/11/04 18:00	94			240		
20/11/04 18:00	20/12/04 11:30	75	69	18.1	197	195	2.8
20/11/04 18:00	20/12/04 11:30	62			192		
20/12/04 11:30	20/01/05 10:15	110	110		115	115	
20/12/04 11:30	20/01/05 10:15						
20/01/05 10:45	16/02/05 18:00	197	182	16.6	190	189	0.8
20/01/05 10:45	16/02/05 18:00	167			189		
16/02/05 18:10	23/03/05 15:20	49	48	2.5	207	215	7.7

Table 7 cont

Date on	Date off	SO_2 (ppt)	SO_2 (ppt) mean	RPD %	HNO_3 (ppt)	HNO_3 (ppt) mean	RPD %
16/02/05 18:10	23/03/05 15:20	48			223		
23/03/05 15:26	28/04/05 13:42	84	94	20.8	199	214	13.9
23/03/05 15:26	28/04/05 13:42	104			229		
28/04/05 13:45	30/05/05 18:04	105	156	64.9	673	632	13.0
28/04/05 13:45	30/05/05 18:04	206			591		
30/05/05 18:08	30/06/05 13:30	77	60	56.3	343	363	11.1
30/05/05 18:08	30/06/05 13:30	43			384		
30/06/05 13:25	08/08/05 17:30	83	49	136.9	252	251	0.8
30/06/05 13:25	08/08/05 17:30	16			250		
08/08/05 17:45	15/09/05 18:00	47	50	14.7	439	422	7.7
08/08/05 17:45	15/09/05 18:00	54			406		
Mean			***89***			***276***	
Site 10							
02/08/04 15:00	01/09/04 10:50	14	37	126.3	25	21	45.6
02/08/04 15:00	01/09/04 10:50	61			16		
01/09/04 10:50	01/10/04 12:35	82	69	39.1	69	71	3.8
01/09/04 10:50	01/10/04 12:35	55			72		
01/10/04 12:35	01/12/04 10:30	87	85	5.6	152	135	25.5
01/10/04 12:35	01/12/04 10:30	82			118		
01/12/04 12:00	27/01/05 14:00	158	169	13.3	150	142	11.7
01/12/04 12:00	27/01/05 14:00	180			134		
27/01/05 14:00	18/02/05 09:30	123	123		68	68	
27/01/05 14:00	18/02/05 09:30						
18/02/05 09:30	17/03/05 11:30	55	52	11.7	168	152	21.1
18/02/05 09:30	17/03/05 11:30	49			136		
17/03/05 11:30	28/04/05 08:00	43	48	24.4	217	223	5.7
17/03/05 11:30	28/04/05 08:00	54			229		
28/04/05 08:00	19/05/05 10:00	236	240	3.2	301	329	17.0
28/04/05 08:00	19/05/05 10:00	243			357		
19/05/05 10:15	05/07/05 11:05	38	35	19.4	164	154	12.1
19/05/05 10:15	05/07/05 11:05	32			145		
05/07/05 11:15	05/08/05 13:20	41	39	13.2	297	305	5.1
05/07/05 11:15	05/08/05 13:20	36			312		
05/08/05 13:20	15/09/05 12:00	17	19	25.4	193	161	40.0
05/08/05 13:20	15/09/05 12:00	22			129		
Mean			***83***			***160***	

Table 8 presents the concentrations of benzene, toluene and ethylbenzene at the sites on the Burrup Peninsula and at Karratha and Mardie Station. At some sites the measurements were below the limit of detection, and in those cases the average was set to half the limit of detection. Limits of detection for benzene, calculated on a monthly basis from the standard deviation of blanks using an ISO (1994) technique, ranged from 1 ppt to 14 ppt over a 30 day sampling period. There were a number of instances where samplers were obviously contaminated. For most of these samplers contamination resulted because the ends of the samplers were not sealed sufficiently to prevent ambient air diffusing to the adsorbent during transport to Melbourne. Contaminated samplers are signified with ^{c}, and these have not been used to calculate averages. Some samplers at Site 9, Karratha may have been contaminated, but they were all included in the averages since it is more difficult to discern contamination in an urban area where petrol is often used. The maximum monthly mean of benzene concentration of 158 ppt was recorded at Site 9, Karratha and the minimum was 4 ppt at Site 10. The annual average benzene concentrations at sites 1, 3 and Mardie Station were about 19 ppt, and with an average of 21 ppt, sites 4 – 8 show no real enhancement above the background concentration.

The data in Table 8 can be compared with concentrations of benzene, toluene and ethylbenzene measured in outer urban areas of Melbourne. In Aspendale, Melbourne concentrations of BTEX gases were measured during 7-day sampling times for a period of 10 months (Lawson et al., 2005). The average concentrations for that period were 300 ppt, 800 ppt and 1100 ppt for benzene, toluene and ethylbenzene respectively; minimum concentrations were 90 ppt, 220 ppt and 30 ppt. Similar concentrations were observed during 7-day sampling periods in March, 2003 in Launceston. Mean concentrations of benzene were 230 ppt with a standard deviation of 120 ppt (Galbally et al., 2003; Galbally et al., 2004).

Table 8. Concentrations of benzene, toluene and ethylbenzene measured at the nine sites from the beginning of August 2004 until the end of January 2005. Concentrations are in ppt. Where both samples of the pair are below the limit of detection the average concentration is set at half the limit of detection. If only one sample is above the limit of detection that value is entered as the average concentration. Results marked with ^{c} are considered to be contaminated and were not used to produce averages.

Date/time On	Date/time Off	Benzene (ppt)	Benzene mean	Toluene (ppt)	Toluene mean	Ethylbenzene (ppt)	Ethylbenzene mean
Site 1							
29/07/04 11:50	02/09/04 15:35	8	8	25	25	10	6
29/07/04 11:50	02/09/04 15:35	7		<2		2	
02/09/04 15:35	08/10/04 09:40	41^{c}	2	226 ^{c}	8	56 ^{c}	3
02/09/04 15:35	08/10/04 09:40	<4		<15		<6	
08/10/04 09:45	21/11/04 12:05	14	14	7	8	<9	4
08/10/04 09:45	21/11/04 12:05	<9		8		<9	
21/11/04 12:05	19/01/05 13:05	18	11	8	7	<11	6
21/11/04 12:05	19/01/05 13:05	4		7		<11	
19/01/05 13:05	21/02/05 12:55	<9	4	5	5	<5	2
19/01/05 13:05	21/02/05 12:55	<9		5		<5	
21/02/05 12:58	28/03/05 11:15	9	9	92	58	<5	2
21/02/05 12:58	28/03/05 11:15	<9		24		<5	
21/03/05 13:12	18/04/05 11:15	19	21	12	13	<6	11
21/03/05 13:12	18/04/05 11:15	23		14		11	
18/04/05 11:18	31/05/05 11:15	26	24	18	17	4	4
18/04/05 11:18	31/05/05 11:15	23		17		4	
31/05/05 11:19	13/07/05 11:45	137	148	<11	27	<7	4
31/05/05 11:19	13/07/05 11:45	158		27		<7	
13/07/05 11:47	07/08/05 11:43	19	22	10	13	<6	3
13/07/05 11:47	07/08/05 11:43	24		16		<6	
17/08/05 11:45	14/09/05 09:53		56 ^{c}	1154 ^{c}	1033 ^{c}	16 ^{c}	20
17/08/05 11:45	14/09/05 09:53	56^{c}		913 ^{c}		25 ^{c}	
Mean			***26***		***18***		***5***
Site 3							
29/07/04 16:00	02/09/04 13:10	20	20	30	25	7	8
29/07/04 16:00	02/09/04 13:10	21		21		9	
02/09/04 13:15	08/10/04 11:30	15	15	85	85	<6	3
02/09/04 13:15	08/10/04 11:30	16		<15		<6	
08/10/04 11:30	21/11/04 15:40	26	23	16	17	<9	4
08/10/04 11:30	21/11/04 15:40	20		18		<9	
21/11/04 15:40	18/01/05 10:02	10	12	16	17	<11	6
21/11/04 15:40	18/01/05 10:02	15		18		<11	
21/01/05 10:28	21/02/05 09:44	<9	15	<10	10	<5	2
21/01/05 10:28	21/02/05 09:44	15		10		<5	
21/02/05 09:48	28/03/05 12:28	<9	13	75	52	<5	5
21/02/05 09:48	28/03/05 12:28	13		29		5	
28/03/05 12:30	18/04/05 14:36	29	29	22	19	<6	3
28/03/05 12:30	18/04/05 14:36	<8		15		<6	
18/04/05 14:40	31/05/05 13:15	9	9	13	14	6	6
18/04/05 14:40	31/05/05 13:15	9		15		5	
31/05/05 13:20	13/07/05 15:46	141	11	19	19	<7	4
31/05/05 13:20	13/07/05 15:46	11		<11		<7	
13/07/05 15:50	07/08/05 15:07	79	14	12	18	<6	3
13/07/05 15:50	07/08/05 15:07	14		24		<6	
07/08/05 15:10	14/09/05 13:00	N/A	12	379 ^{c}	321 ^{c}	4	4
07/08/05 15:10	14/09/05 13:00	12		263 ^{c}		<2	

Table 8 cont

Date/time On	Date/time Off	Benzene (ppt)	Benzene mean	Toluene (ppt)	Toluene mean	Ethylbenzene (ppt)	Ethylbenzene mean
Mean			***16***		***28***		***4***
Site 4							
01/08/04 12:09	01/09/04 09:17	28	26	19	17	20	14
01/08/04 12:09	01/09/04 09:17	23		15		8	
01/09/04 09:32	07/10/04 09:15	23	22	242[c]	361[c]	9	10
01/09/04 09:32	07/10/04 09:15	22		480[c]		11	
07/10/04 09:15	20/11/04 08:20	21	18	30	29	10	9
07/10/04 09:15	20/11/04 08:20	14		29		8	
20/11/04 08:20	18/01/05 10:20	34	34	73	74	<11	6
20/11/04 08:20	18/01/05 10:20	35		76		<11	
18/01/05 10:07	16/02/05 06:40	32	39	79	91	5	5
18/01/05 10:07	16/02/05 06:40	47		104		6	
16/02/05 06:30	23/03/05 09:45	36	33	83	92	12	10
16/02/05 06:30	23/03/05 09:45	29		101		9	
23/03/05 09:50	28/04/05 08:44	37	25	63	65	12	11
23/03/05 09:50	28/04/05 08:44	13		67		11	
28/04/05 08:45	30/05/05 10:36	16	19	29	26	7	9
28/04/05 08:45	30/05/05 10:36	22		24		11	
30/05/05 10:39	30/06/05 08:48	46	46	<11	6	<7	4
30/05/05 10:39	30/06/05 08:48	<12		<11		<7	
30/06/05 08:50	08/08/05 09:30	387[c]	27	14	18	<6	6
30/06/05 08:50	08/08/05 09:30	27		22		6	
08/08/05 08:47	15/09/05 08:43	9	7	252[c]	189[c]	3	3
08/08/05 08:47	15/09/05 08:43	4		126[c]		3	
Mean			***27***		***47***		***8***
Site 5							
01/08/04 16:04	01/09/04 12:00	21	19	36	33	17	15
01/08/04 16:04	01/09/04 12:00	18		30		13	
01/09/04 12:00	07/10/04 11:15	41	30	5252[c]	2640	40	26
01/09/04 12:00	07/10/04 11:15	20		28		13	
07/10/04 11:21	20/11/04 12:20	19	14	23	23	19	17
07/10/04 11:21	20/11/04 12:20	10		22		15	
20/11/04 12:40	18/01/05 00:00	12	16	28	28	11	12
20/11/04 12:40	18/01/05 00:00	21		29		13	
18/01/05 12:44	16/02/05 08:07	12	16	28	31	8	10
18/01/05 12:44	16/02/05 08:07	20		33		12	
16/02/05 08:10	23/03/05 11:55	<9	23	39	37	18	19
16/02/05 08:10	23/03/05 11:55	23		35		21	
23/03/05 11:50	28/04/05 10:18	28	22	35	36	21	18
23/03/05 11:50	28/04/05 10:18	15		38		15	
28/04/05 10:17	30/05/05 10:43	6	12	47	43	13	14
28/04/05 10:17	30/05/05 10:43	18		38		15	
30/05/05 11:45	30/06/05 09:20	28	28	31	32	7	7
30/05/05 11:45	30/06/05 09:20	N/A		34		7	
30/06/05 09:22	08/08/05 10:25	36	30	52	45	17	15
30/06/05 09:22	08/08/05 10:25	30		39		14	
08/08/05 09:30	13/09/05 10:32	240[c]	240[c]	2280[c]	2381[c]	344[c]	349[c]
08/08/05 09:30	13/09/05 10:32	N/A		2483[c]		354[c]	
Mean			***21***		***34***		***14***

Table 8 cont

Date/time On	Date/time Off	Benzene (ppt)	Benzene mean	Toluene (ppt)	Toluene mean	Ethylbenzene (ppt)	Ethylbenzene mean
Site 6							
03/08/04 12:09	01/09/04 11:15	24	26	22	23	10	10
03/08/04 12:09	01/09/04 11:15	27		24		11	
01/09/04 11:15	07/10/04 10:30	16	19	11	13	11	12
01/09/04 11:15	07/10/04 10:30	23		14		13	
07/10/04 10:35	20/11/04 12:20	19	10	22	11	11	11
07/10/04 10:35	20/11/04 12:20	<9		<13		<9	
20/11/04 10:40	18/01/05 11:20	10	17	28	32	<11	15
20/11/04 10:40	18/01/05 11:20	24		36		15	
18/01/05 11:25	16/02/05 07:20	9	16	19	24	4	6
18/01/05 11:25	16/02/05 07:20	22		30		8	
16/02/05 07:25	23/03/05 10:52	13	23	35	41	10	11
16/02/05 07:25	23/03/05 10:52	23		41		11	
23/03/05 10:52	28/04/05 09:36	24	20	42	44	13	12
23/03/05 10:52	28/04/05 09:36	15		47		12	
28/04/05 09:33	30/05/05 12:50	19	18	20	22	7	6
28/04/05 09:33	30/05/05 12:50	18		25		5	
30/05/05 12:56	30/06/05 10:15	17	17	<11	6	<7	4
30/05/05 12:56	30/06/05 10:15	39		<11		<7	
30/06/05 10:15	08/08/05 10:25	15	17	16	19	<6	3
30/06/05 10:15	08/08/05 10:25	17		19		<6	
08/08/05 10:25	13/09/05 14:35	42	26	231[c]	192[c]	6	5
08/08/05 10:25	13/09/05 14:35	11		154[c]		4	
Mean			***19***		***24***		***9***
Site 7							
01/08/04 15:01	01/09/04 13:34	21	22	20	18	7	8
01/08/04 15:01	01/09/04 13:34	22		17		8	
01/09/04 13:34	07/10/04 13:35	70[c]	47	10882[c]	25	76[c]	10
01/09/04 13:34	07/10/04 13:35	23		25		10	
07/10/04 13:25	20/11/04 14:45	16	16	<13	17	<9	8
07/10/04 13:25	20/11/04 14:45	16		17		8	
20/11/04 15:00	18/01/05 15:12	22	18	30	30	<11	6
20/11/04 15:00	18/01/05 15:12	14		31		<11	
18/01/05 15:16	16/02/05 09:04	31	25	25	26	<5	8
18/01/05 15:16	16/02/05 09:04	18		27		8	
16/02/05 09:38	23/03/05 13:05	10	22	41	41	10	9
16/02/05 09:38	23/03/05 13:05	22		460[c]		9	
23/03/05 13:12	28/04/05 11:05	18	18	27	28	8	11
23/03/05 13:12	28/04/05 11:05	19		30		13	
28/04/05 11:20	30/05/05 14:10	16	17	17	18	5	6
28/04/05 11:20	30/05/05 14:10	18		19		6	
30/05/05 14:45	30/06/05 11:23	12	12	<11	6	<7	4
30/05/05 14:45	30/06/05 11:23	29		<11		<7	
30/06/05 11:25	08/08/05 11:27	13	15	15	21	<6	3
30/06/05 11:25	08/08/05 11:27	15		21		<6	
08/08/05 11:25	13/09/05 11:41	9	7	302[c]	280[c]	3	3
08/08/05 11:25	13/09/05 11:41	5		258[c]		3	
Mean			***18***		***23***		***7***
Site 8							
03/08/04 09:07	01/09/04 15:43	31	28	33	30	14	12
03/08/04 09:07	01/09/04 15:43	26		27		10	

Table 8 cont

Date/time On	Date/time Off	Benzene (ppt)	Benzene mean	Toluene (ppt)	Toluene mean	Ethylbenzene (ppt)	Ethylbenzene mean
01/09/04 15:43	07/10/04 15:00	24		23		17	
01/09/04 15:43	07/10/04 15:00	37	30	5904	23	40	29
07/10/04 15:10	20/11/04 16:20	19	19	25	25	13	13
07/10/04 15:10	20/11/04 16:20	19		25		13	
20/11/04 16:30	18/01/05 17:17	14	13	26	26	10	9
20/11/04 16:30	18/01/05 17:17	13		25		9	
18/01/05 17:25	16/02/05 10:20	<9	4	24	23	8	7
18/01/05 17:25	16/02/05 10:20	<9		22		7	
16/02/05 11:10	23/03/05 14:34	12	12	201	34	9	10
16/02/05 11:10	23/03/05 14:34	<9		34		11	
23/03/05 14:35	28/04/05 11:50	19	19	33	32	10	9
23/03/05 14:35	28/04/05 11:50	18		31		9	
28/04/05 12:34	30/05/05 16:00	59632[c]	8	13366[c]	21	90[c]	6
28/04/05 12:34	30/05/05 16:00	8		21		6	
30/05/05 16:01	30/06/05 12:35	20	35	<11	22	<7	4
30/05/05 16:01	30/06/05 12:35	51		22		<7	
30/06/05 13:25	08/08/05 17:33	13	20	18	22	<6	3
30/06/05 13:25	08/08/05 17:33	27		25		<6	
08/08/05 12:36	13/09/05 15:50	9	11	254	206	4	3
08/08/05 12:36	13/09/05 15:50	12		159		3	
Mean			***18***		***26***		***9***
Site 9							
05/08/04 15:00	03/09/04 18:00	29	29	32	32	7	7
05/08/04 15:00	03/09/04 18:00	<1		1		<2	
03/09/04 15:30	07/10/04 20:30	40	39	264	244	59	59
03/09/04 15:30	07/10/04 20:30	39		225		47	
07/10/04 20:40	20/11/04 18:00	32	32	174	174	34	34
07/10/04 20:40	20/11/04 18:00	<9		<13		<9	
20/11/04 18:00	20/01/05 10:26	53	46	305	268	61	52
20/11/04 18:00	20/01/05 10:26	38		230		43	
20/01/05 10:45	16/02/05 18:00	39	42	203	212	37	42
20/01/05 10:45	16/02/05 18:00	46		221		46	
16/02/05 18:00	23/03/05 15:22	49	59	477	675	47	47
16/02/05 18:00	23/03/05 15:22	69		873		52	
23/03/05 15:26	28/04/05 13:45	83	81	808	816	71	73
23/03/05 15:26	28/04/05 13:45	79		823		75	
28/04/05 13:45	30/05/05 18:04	157	158	2062	2080	266	270
28/04/05 13:45	30/05/05 18:04	158		2099		275	
30/05/05 18:06	30/06/05 13:25	66	118	589	585	57	58
30/05/05 18:06	30/06/05 13:25	170		581		60	
30/06/05 13:25	08/08/05 17:33	68	65	544	533	51	51
30/06/05 13:25	08/08/05 17:33	63		522		49	
08/08/05 17:45	15/09/05 18:00	149	127	2491	2552	308	330
08/08/05 17:45	15/09/05 18:00	105		2612		352	
Mean			***72***		***743***		***93***
Site 10							
02/08/04 15:00	01/09/04 10:45	20	20	24	24	5	5
02/08/04 15:00	01/09/04 10:45	67[c]		547[c]		35[c]	
01/09/04 10:50	01/10/04 12:35	18	21	1344[c]	1106[c]	7	10
01/09/04 10:50	01/10/04 12:35	24		868[c]		13	

Table 8 cont

Date/time On	Date/time Off	Benzene (ppt)	Benzene mean	Toluene (ppt)	Toluene mean	Ethylbenzene (ppt)	Ethylbenzene mean
01/10/04 12:35	01/12/04 10:30	<9	9	<13	6	<9	4
01/10/04 12:35	01/12/04 10:30	9		<13		<9	
01/12/04 12:00	27/01/05 14:00	5	7	4	3	<11	6
01/12/04 12:00	27/01/05 14:00	9		3		<11	
18/02/05 09:30	17/03/05 11:30	<9	4	16	14	6	6
18/02/05 09:30	17/03/05 11:30	<9		11		7	
17/03/05 11:30	28/04/05 08:00	20	20	116[c]	118[c]	8	7
17/03/05 11:30	28/04/05 08:00	19		121[c]		7	
28/04/05 08:00	19/05/05 10:00	21	19	16	17	9	8
28/04/05 08:00	19/05/05 10:00	17		18		7	
19/05/05 10:15	05/07/05 11:05	4	7	5	7	<1	1
19/05/05 10:15	05/07/05 11:05	9		9		1	
05/07/05 11:15	05/08/05 13:20	<12	12	19	19	<7	16
05/07/05 11:15	05/08/05 13:20	12		174[c]		16	
05/08/05 11:15	15/09/05 12:00	<7	4	12	12	<6	7
05/08/05 11:15	15/09/05 12:00	<7		883[c]		7	
Mean			***12***		***13***	***7***	***5***

Figure 13 shows the temporal variation of benzene at each of the sites. It shows that Site 9, Karratha generally has the highest benzene concentrations, presumably due to the increased emissions of benzene from motor vehicles. There is little enhancement of benzene at the lower Burrup sites copmpared to concentrations measured at the local background, at sites 1, 3 and 10.

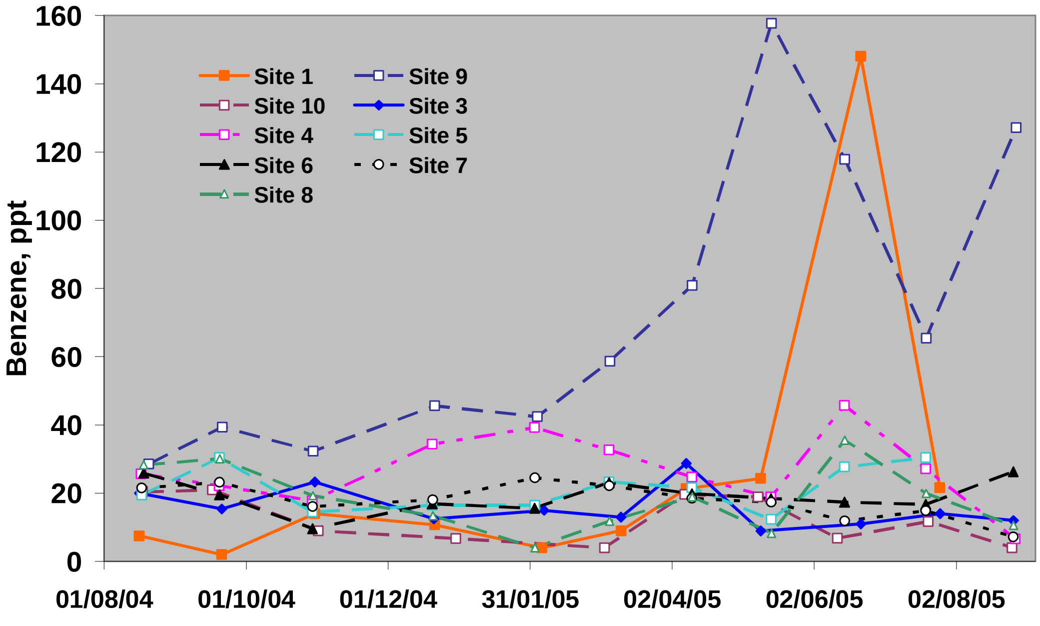


Figure 13. Benzene concentrations at each site plotted against the sample mid-date.

Table 9. Concentrations of p-xylene, m-xylene and o-xylene measured at the nine sites from the beginning of August 2004 until the September 2005. Concentrations are in ppt. Where both samples of the pair are below the limit of detection the average concentration is set at half the limit of detection. If only one sample is above the limit of detection that value is entered as the average concentration. Samples which are believed to have been contaminated during transport are marked with a ^{c}. These samples have not been used to produce averages.

Date/time On	Date/time Off	p+m-Xylene (ppt)	p+m-Xylene mean	o-Xylene (ppt)	o-Xylene mean
Site 1					
29/07/04 11:50	02/09/04 15:35	18	18	<2	1
29/07/04 11:50	02/09/04 15:35	<2		<2	
02/09/04 15:35	08/10/04 09:40	242^{c}	1	92^{c}	2
02/09/04 15:35	08/10/04 09:40	<1		<3	
08/10/04 09:45	21/11/04 12:05	7	8	<3	5
08/10/04 09:45	21/11/04 12:05	10		5	
21/11/04 12:05	19/01/05 13:05	8	7	<3	3
21/11/04 12:05	19/01/05 13:05	7		3	
19/01/05 13:05	21/02/05 12:55	7	6	3	3
19/01/05 13:05	21/02/05 12:55	5		3	
21/02/05 12:58	28/03/05 11:15	12	9	20	15
21/02/05 12:58	28/03/05 11:15	7		10	
21/03/05 13:12	18/04/05 11:15	<2	7	4	4
21/03/05 13:12	18/04/05 11:15	7		<3	
18/04/05 11:18	31/05/05 11:15	11	11	9	7
18/04/05 11:18	31/05/05 11:15	11		5	
31/05/05 11:19	13/07/05 11:45	2	2	<3	2
31/05/05 11:19	13/07/05 11:45	3		<3	
13/07/05 11:47	07/08/05 11:43	<3	2	<1	1
13/07/05 11:47	07/08/05 11:43	<3		<1	
17/08/05 11:45	14/09/05 09:53	66^{c}	73^{c}	31^{c}	48^{c}
17/08/05 11:45	14/09/05 09:53	79^{c}		64^{c}	
Mean			***7***		***4***
Site 3					
29/07/04 16:00	02/09/04 13:10	18	17	14	13
29/07/04 16:00	02/09/04 13:10	15		13	
02/09/04 13:15	08/10/04 11:30	<3	8	<3	6
02/09/04 13:15	08/10/04 11:30	8		6	
08/10/04 11:30	21/11/04 15:40	16	15	<3	4
08/10/04 11:30	21/11/04 15:40	14		4	
21/11/04 15:40	18/01/05 10:02	17	14	8	6
21/11/04 15:40	18/01/05 10:02	12		4	
21/01/05 10:28	21/02/05 09:44	8	9	5	5
21/01/05 10:28	21/02/05 09:44	9		<3	
21/02/05 09:48	28/03/05 12:28	9	9	9	8
21/02/05 09:48	28/03/05 12:28	9		8	
28/03/05 12:30	18/04/05 14:36	<6	7	<3	7
28/03/05 12:30	18/04/05 14:36	7		7	
18/04/05 14:40	31/05/05 13:15	13	13	<4	6
18/04/05 14:40	31/05/05 13:15	13		6	
31/05/05 13:20	13/07/05 15:46	<3	2	<3	2
31/05/05 13:20	13/07/05 15:46	<3		<3	
13/07/05 15:50	07/08/05 15:07	16	13	1	1
13/07/05 15:50	07/08/05 15:07	10		2	

Table 9 cont

Date/time On	Date/time Off	p+m-Xylene (ppt)	p+m-Xylene mean	o-Xylene (ppt)	o-Xylene mean
07/08/05 15:10	14/09/05 13:00	21	21	<1	1
07/08/05 15:10	14/09/05 13:00	<7		<1	
Mean			***12***		***6***
Site 4					
01/08/04 12:09	01/09/04 09:17	16	18	4	4
01/08/04 12:09	01/09/04 09:17	20		4	
01/09/04 09:32	07/10/04 09:15	42	44	13	19
01/09/04 09:32	07/10/04 09:15	46		24	
07/10/04 09:15	20/11/04 08:20	38	37	12	12
07/10/04 09:15	20/11/04 08:20	37		12	
20/11/04 08:20	18/01/05 10:20	55	55	17	16
20/11/04 08:20	18/01/05 10:20	54		14	
18/01/05 10:07	16/02/05 06:40	39	43	19	15
18/01/05 10:07	16/02/05 06:40	46		11	
16/02/05 06:30	23/03/05 09:45	43	47	15	17
16/02/05 06:30	23/03/05 09:45	50		19	
23/03/05 09:50	28/04/05 08:44	43	43	11	10
23/03/05 09:50	28/04/05 08:44	43		8	
28/04/05 08:45	30/05/05 10:36	22	23	11	10
28/04/05 08:45	30/05/05 10:36	24		8	
30/05/05 10:39	30/06/05 08:48	<3	6	<3	2
30/05/05 10:39	30/06/05 08:48	6		<3	
30/06/05 08:50	08/08/05 09:30	16	14	7	6
30/06/05 08:50	08/08/05 09:30	12		6	
08/08/05 08:47	15/09/05 08:43	11	13	16	9
08/08/05 08:47	15/09/05 08:43	14		2	
Mean			***31***		***11***
Site 5					
01/08/04 16:04	01/09/04 12:00	61	61	23	22
01/08/04 16:04	01/09/04 12:00	60		21	
01/09/04 12:00	07/10/04 11:15	105	70	42	29
01/09/04 12:00	07/10/04 11:15	35		16	
07/10/04 11:21	20/11/04 12:20	75	73	24	24
07/10/04 11:21	20/11/04 12:20	72		25	
20/11/04 12:40	18/01/05 00:00	52	52	17	18
20/11/04 12:40	18/01/05 00:00	53		19	
18/01/05 12:44	16/02/05 08:07	52	51	17	17
18/01/05 12:44	16/02/05 08:07	51		16	
16/02/05 08:10	23/03/05 11:55	95	80	37	31
16/02/05 08:10	23/03/05 11:55	65		25	
23/03/05 11:50	28/04/05 10:18	84	68	28	28
23/03/05 11:50	28/04/05 10:18	51		<3	
28/04/05 10:17	30/05/05 10:43	61	59	26	23
28/04/05 10:17	30/05/05 10:43	57		20	
30/05/05 11:45	30/06/05 09:20	25	25	8	8
30/05/05 11:45	30/06/05 09:20	24		<3	
30/06/05 09:22	08/08/05 10:25	69	63	23	24
30/06/05 09:22	08/08/05 10:25	57		24	
08/08/05 09:30	13/09/05 10:32	434[c]	438[c]	168[c]	103[c]
08/08/05 09:30	13/09/05 10:32	442[c]		37[c]	
Mean			***57***		***21***

Table 9 cont

Date/time On	Date/time Off	p+m-Xylene (ppt)	p+m-Xylene mean	o-Xylene (ppt)	o-Xylene mean
Site 6					
03/08/04 12:09	01/09/04 11:15	32	32	12	10
03/08/04 12:09	01/09/04 11:15	31		8	
01/09/04 11:15	07/10/04 10:30	36	37	24	19
01/09/04 11:15	07/10/04 10:30	37		14	
07/10/04 10:35	20/11/04 12:20	48	48	15	15
07/10/04 10:35	20/11/04 12:20	<4		<3	
20/11/04 10:40	18/01/05 11:20	33	43	14	17
20/11/04 10:40	18/01/05 11:20	53		19	
18/01/05 11:25	16/02/05 07:20	33	33	19	16
18/01/05 11:25	16/02/05 07:20	34		13	
16/02/05 07:25	23/03/05 10:52	35	33	15	14
16/02/05 07:25	23/03/05 10:52	31		13	
23/03/05 10:52	28/04/05 09:36	21	28	12	12
23/03/05 10:52	28/04/05 09:36	35		12	
28/04/05 09:33	30/05/05 12:50	31	29	14	15
28/04/05 09:33	30/05/05 12:50	27		16	
30/05/05 12:56	30/06/05 10:15	9	8	<3	2
30/05/05 12:56	30/06/05 10:15	7		<3	
30/06/05 10:15	08/08/05 10:25	10	10	3	3
30/06/05 10:15	08/08/05 10:25	10		3	
08/08/05 10:25	13/09/05 14:35	24	17	3	5
08/08/05 10:25	13/09/05 14:35	10		6	
Mean			***29***		***12***
Site 7					
01/08/04 15:01	01/09/04 13:34	18	18	4	6
01/08/04 15:01	01/09/04 13:34	19		8	
01/09/04 13:34	07/10/04 13:35	195[c]	25	84[c]	9
01/09/04 13:34	07/10/04 13:35	25		9	
07/10/04 13:25	20/11/04 14:45	<4	24	<3	9
07/10/04 13:25	20/11/04 14:45	24		9	
20/11/04 15:00	18/01/05 15:12	27	28	9	10
20/11/04 15:00	18/01/05 15:12	29		12	
18/01/05 15:16	16/02/05 09:04	34	35	10	9
18/01/05 15:16	16/02/05 09:04	35		9	
16/02/05 09:38	23/03/05 13:05	27	27	15	14
16/02/05 09:38	23/03/05 13:05	27		13	
23/03/05 13:12	28/04/05 11:05	33	27	20	12
23/03/05 13:12	28/04/05 11:05	21		5	
28/04/05 11:20	30/05/05 14:10	18	16	8	11
28/04/05 11:20	30/05/05 14:10	14		15	
30/05/05 14:45	30/06/05 11:23	5	4	<3	2
30/05/05 14:45	30/06/05 11:23	4		<3	
30/06/05 11:25	08/08/05 11:27	10	10	2	2
30/06/05 11:25	08/08/05 11:27	10		2	
08/08/05 11:25	13/09/05 11:41	18	16	5	3
08/08/05 11:25	13/09/05 11:41	14		1	
Mean			***21***		***8***
Site 8					
03/08/04 09:07	01/09/04 15:43	30	29	7	7
03/08/04 09:07	01/09/04 15:43	28		6	

Table 9 cont

Date/time On	Date/time Off	p+m-Xylene (ppt)	p+m-Xylene mean	o-Xylene (ppt)	o-Xylene mean
01/09/04 15:43	07/10/04 15:00	88	71	44	32
01/09/04 15:43	07/10/04 15:00	55		20	
07/10/04 15:10	20/11/04 16:20	41	41	18	17
07/10/04 15:10	20/11/04 16:20	41		16	
20/11/04 16:30	18/01/05 17:17	37	35	14	13
20/11/04 16:30	18/01/05 17:17	34		12	
18/01/05 17:25	16/02/05 10:20	39	38	17	16
18/01/05 17:25	16/02/05 10:20	37		14	
16/02/05 11:10	23/03/05 14:34	20	25	14	16
16/02/05 11:10	23/03/05 14:34	29		17	
23/03/05 14:35	28/04/05 11:50	31	31	12	11
23/03/05 14:35	28/04/05 11:50	31		10	
28/04/05 12:34	30/05/05 16:00	208	26	248	17
28/04/05 12:34	30/05/05 16:00	26		17	
30/05/05 16:01	30/06/05 12:35	10	9	<3	2
30/05/05 16:01	30/06/05 12:35	7		<3	
30/06/05 13:25	08/08/05 17:33	14	13	3	3
30/06/05 13:25	08/08/05 17:33	11		4	
08/08/05 12:36	13/09/05 15:50	34	22	9	8
08/08/05 12:36	13/09/05 15:50	10		7	
Mean			***29***		***12***
Site 9					
05/08/04 15:00	03/09/04 18:00	20	20	8	8
05/08/04 15:00	03/09/04 18:00	<2		<2	
03/09/04 15:30	07/10/04 20:30	296	271	109	104
03/09/04 15:30	07/10/04 20:30	246		98	
07/10/04 20:40	20/11/04 18:00	164	164	63	63
07/10/04 20:40	20/11/04 18:00	<4		4	
20/11/04 18:00	20/01/05 10:26	299	261	112	96
20/11/04 18:00	20/01/05 10:26	222		79	
20/01/05 10:45	16/02/05 18:00	174	182	61	65
20/01/05 10:45	16/02/05 18:00	190		68	
16/02/05 18:00	23/03/05 15:22	212	221	94	98
16/02/05 18:00	23/03/05 15:22	230		102	
23/03/05 15:26	28/04/05 13:45	312	316	120	120
23/03/05 15:26	28/04/05 13:45	320		120	
28/04/05 13:45	30/05/05 18:04	1241	1262	483	492
28/04/05 13:45	30/05/05 18:04	1283		502	
30/05/05 18:06	30/06/05 13:25	273	256	95	94
30/05/05 18:06	30/06/05 13:25	238		94	
30/06/05 13:25	08/08/05 17:33	204	199	73	72
30/06/05 13:25	08/08/05 17:33	195		71	
08/08/05 17:45	15/09/05 18:00	473	464	190	191
08/08/05 17:45	15/09/05 18:00	455		191	
Mean			***329***		***128***
Site 10					
02/08/04 15:00	01/09/04 10:45	5	5	4	4
02/08/04 15:00	01/09/04 10:45	83		159	
01/09/04 10:50	01/10/04 12:35	23	19	15	9
01/09/04 10:50	01/10/04 12:35	15		9	
01/10/04 12:35	01/12/04 10:30	5	5	4	3

Table 9 cont

Date/time On	Date/time Off	p+m-Xylene (ppt)	p+m-Xylene mean	o-Xylene (ppt)	o-Xylene mean
01/10/04 12:35	01/12/04 10:30	5		3	
01/12/04 12:00	27/01/05 14:00	6	6	7	7
01/12/04 12:00	27/01/05 14:00	<5		<3	
18/02/05 09:30	17/03/05 11:30	4	4	10	7
18/02/05 09:30	17/03/05 11:30	<3		4	
17/03/05 11:30	28/04/05 08:00	17	17	10	9
17/03/05 11:30	28/04/05 08:00	16		8	
28/04/05 08:00	19/05/05 10:00	13	12	10	11
28/04/05 08:00	19/05/05 10:00	11		13	
19/05/05 10:15	05/07/05 11:05	<1	2	<4	2
19/05/05 10:15	05/07/05 11:05	2		<4	
05/07/05 11:15	05/08/05 13:20	5	5	<3	3
05/07/05 11:15	05/08/05 13:20	14		3	
05/08/05 11:15	15/09/05 12:00	<3	2	<1	3
05/08/05 11:15	15/09/05 12:00	17		3	
Mean			***8***		***6***

Table 9 lists the concentrations of the three xylene isomers measured at the sampling sites. Monthyl average p+m xylene concentrations range from 20 ppt to 1262 ppt at site 9 (Karratha). The average annual concentration of xylenes over the 12 sampling periods for Sites 1 and 3 all is about 7 ppt compared to about 23 ppt for sites 4 – 8. As expected, there is only a small enhancement of xylene at Sites 4 – 8 over the local background concentrations. The average at site 9 is higher than any other site probably due to the influence of motor vehicles.

5.2 Particulate Measurements

5.2.1 TSP Measurements

Concentrations of TSP measured at sites 1 – 8 and PM_{10}, measured at sites 8 and 8 HI with conditional sampling are presented in Table 10. The average for sites 1 and 3, considered to represent background levels, is about 22 $\mu g\ m^{-3}$ over the period from August 2004 until mid September 2005. The maximum monthly averaged TSP concentrations are 136 $\mu g\ m^{-3}$ at Site 7, during January/February 2005 and 135 $\mu g\ m^{-3}$ at Site 8, during January/February 2005, and the average for sites 4 – 8 is about 34 $\mu g\ m^{-3}$. This shows that TSP concentrations, probably due to anthropogenic activities, are enhanced on the lower Burrup Peninsula, at sites 4 – 8. This is particularly true at Site 8, which had an annual average TSP concentration of 51.1 $\mu g\ m^{-3}$.

Conditional sampling to measure PM_{10} was carried out at Site 8HI, about 0.5 km to 1 km east of the Hamersley Iron loading facilities at Parker Point, and at Site 8 which is located about 3 km east of Parker Point; see Figure 1 for site locations. Site 8HI was located in order to sample PM_{10} originating from Parker Point, and the sampler operated when the wind direction was between 225º and 315º. At Site 8 the conditional sampler operated when the wind direction was between 180º and 360º, also to collect PM_{10} from Parker Point. Table 8 shows that at 116.6 $\mu g\ m^{-3}$ and 19.8 $\mu g\ m^{-3}$ at 8HI and Site 8 respectively, there is a large difference in PM_{10} mass concentration between the two sites. Filters from these sites have been analysed for a range of elements and soluble ionic species to seek a fingerprint for particulate originating from the Parker Point iron ore loading facilities.

Table 10. Concentrations of TSP at sites 1 – 8 and PM_{10} conditionally sampled at sites 8 and 8HI from the end of August 2004 until September 2005. Concentrations are in µg m^{-3}.

Date/time on	Date/time Off	TSP µg m^{-3}	Date/time on	Date/time Off	TSP µg m^{-3}	PM_{10} µg m^{-3}
Site 1			Site 3			
29/07/04 11:55	02/09/04 15:34	11.6	29/07/04 16:00	02/09/04 13:10	11.0	
02/09/04 15:34	08/10/04 09:50	14.0	02/09/04 13:10	08/10/04 11:30	19.2	
08/10/04 09:45	21/11/04 11:25	24.3	08/10/04 11:20	21/11/04 15:35	11.6	
21/11/04 11:55	17/12/04 12:00	32.4	21/11/04 15:35	17/12/04 14:00	31.5	
17/12/04 12:39	19/01/05 12:40	35.0	17/12/04 14:20	19/01/05 16:12	43.7	
19/01/05 13:10	21/02/05 13:05	36.6	19/01/05 16:45	21/02/05 09:44	41.7	
21/02/05 13:06	28/03/05 10:27	25.1	21/02/05 09:48	28/03/05 12:13	25.0	
28/03/05 11:09	18/04/05 09:09	13.6	28/03/05 12:25	18/04/05 14:31	15.7	
18/04/05 09:44	31/05/05 10:36	25.0	18/04/05 14:32	31/05/05 12:38	9.7	
31/05/05 10:58	13/07/05 11:30	33.6	31/05/05 13:14	not used		
13/07/05 11:41	07/08/05 11:32	8.8	13/07/05 15:33	07/08/05 14:41	8.62	
07/08/05 11:32	14/09/05 08:05	11.4	not working			
Mean		***22.6***	***Mean***		***21.8***	
Site 4			Site 5			
01/08/04 12:00	01/09/04 08:49	15.3	01/08/04 16:00	01/09/04 11:38	17.1	
01/09/04 08:49	07/10/04 08:51	12.1	01/09/04 12:00	07/10/04 11:20	12.4	
07/10/04 09:04	20/11/04 08:30	42.6	07/10/04 11:00	20/11/04 12:15	32.0	
20/11/04 09:20	18/12/04 06:20	60.3	20/11/04 12:40	18/12/04 07:30	33.4	
18/12/04 06:30	18/01/05 09:40	60.6	18/12/04 07:40	18/01/05 12:36	48.6	
18/01/05 09:50	16/02/05 06:25	55.2	18/01/05 12:37	16/02/05 07:57	36.4	
16/02/05 06:45	23/03/05 09:23	47.6	16/02/05 08:20	23/03/05 11:29	30.7	
23/03/05 10:16	28/04/05 08:30	28.5	23/03/05 11:29	28/04/05 09:57	17.8	
28/04/05 08:30	30/05/05 10:11	22.6	28/04/05 10:10	30/05/05 11:17	15.5	
30/05/05 10:31	30/06/05 08:30	17.6	30/05/05 11:40	30/06/05 09:08	16.2	
30/06/05 08:40	08/08/05 08:25	15.6	30/06/05 09:15	08/08/05 09:11	12.6	
08/08/05 08:40	13/09/05 08:40	33.2	08/08/05 09:15	13/09/05 10:31	17.0	
Mean		***34.3***	***Mean***		***24.1***	
Site 6			Site 7			
03/08/04 13:02	01/09/04 10:35	16.4	01/08/04 14:57	01/09/04 13:25	19.2	
01/09/04 10:35	07/10/04 10:46	21.3	01/09/04 13:34	07/10/04 13:00	21.8	
07/10/04 10:06	20/11/04 10:30	18.7	07/10/04 13:00	20/11/04 14:30	46.6	
20/11/04 11:20	18/12/04 08:30	38.4	20/11/04 14:30	18/12/04 09:30	58.4	
18/12/04 08:45	18/01/05 11:15	47.1	18/12/04 09:50	18/01/05 15:00	42.4	
18/01/05 11:30	16/02/05 07:15	50.0	18/01/05 15:14	16/02/05 09:00	136.0	
16/02/05 07:25	23/03/05 10:32	31.6	16/02/05 09:15	23/03/05 12:42	34.7	
23/03/05 11:32	28/04/05 09:11	18.1	23/03/05 12:50	28/04/05 10:52	21.3	
28/04/05 09:20	30/05/05 12:34	13.3	28/04/05 10:57	30/05/05 13:49	15.0	
30/05/05 12:51	30/06/05 10:03	14.1	30/05/05 13:59	30/06/05 11:15	15.1	
30/06/05 10:10	08/08/05 10:03	11.5	30/06/05 11:20	08/08/05 11:08	11.4	
08/08/05 10:10	13/09/05 14:26	15.9	08/08/05 11:15	13/09/05 11:38	16.8	
Mean		***24.7***	***Mean***		***36.6***	

Site 10 cont

Date/time on	Date/time Off	TSP $\mu g\ m^{-3}$	Date/time on	Date/time Off	TSP $\mu g\ m^{-3}$	PM$_{10}$ $\mu g\ m^{-3}$
Site 8			Site 8 Conditional			
03/08/04 09:19	01/09/04 15:55	22.9	04/08/04 15:20	01/09/04 15:59		10.3
01/09/04 16:00	07/10/04 14:35	28.2	01/09/04 16:05	07/10/04 15:25		13.2
07/10/04 15:00	20/11/04 15:30	52.7	07/10/04 15:15	20/11/04 16:10		21.4
20/11/04 15:30	18/12/04 11:10	53.4	20/11/04 16:10	18/12/04 11:30		31.0
18/12/04 11:30	18/01/05 16:15	61.7	18/12/04 11:20	18/01/05 16:24		42.9
18/01/05 17:31	16/02/05 10:11	94.6	18/01/05 17:37	16/02/05 10:15		32.0
16/02/05 10:25	23/03/05 13:53	29.3	16/02/05 10:28	23/03/05 14:05		24.1
23/03/05 13:58	28/04/05 11:52	135.2	23/03/05 14:05	28/04/05 11:50		13.0
28/04/05 11:54	30/05/05 15:55	65.9	28/04/05 12:10	30/05/05 15:30		16.1
30/05/05 15:57	30/06/05 12:00	23.3	30/05/05 15:45	30/06/05 12:05		10.6
30/06/05 12:01	08/08/05 12:25	16.1	30/06/05 12:20	08/08/05 12:09		8.8
08/08/05 12:30	13/09/05 15:39	30.5	08/08/05 12:20	13/09/05 15:39		13.6
Mean		***51.1***	***Mean***			***19.8***
			Site 8 HI	Conditional		
			04/08/04 11:15	02/09/04 09:00		86.4
			02/09/04 09:00	08/10/04 15:05		64.8
			08/10/04 15:05	30/11/04 08:40		96.6
			30/11/04 13:00	20/12/04 08:30		79.0
			20/12/04 08:40	20/01/05 08:32		53.0
			20/01/05 08:46	23/02/05 08:30		560.9
			23/02/05 08:40	31/03/05 07:26		49.3
			31/03/05 07:30	02/05/05 08:49		81.1
			02/05/05 09:00	09/06/05 08:36		81.4
			09/06/05 10:17	01/07/05 08:50		49.7
			01/07/05 09:00	09/08/05 08:38		82.0
			09/08/05 08:45	16/09/05 00:00		115.2
			Mean			***116.6***

After gravimetric mass was determined on each particulate sample a sub-set was chosen for PIXE analysis. These were sent to ANSTO where they were analysed as described previously in a non-destructive manner. After PIXE analysis was complete they were extracted and analysed by ion chromatography to determine the concentrations of the soluble cations and anions.

The detailed results of the PIXE analysis are given in the Appendix in Table A1. Table 11 presents the results of the gravimetric mass concentrations, the estimated chemical mass (ECM) concentration, the iron concentration, the sea-salt fraction of the total mass and the iron to sea-salt ratio. The ECM was reconstructed by adding the elements, as their ores, measured by PIXE plus SO_4^{2-}, NO_3^-, NH_4^+ Mg^{2+}, HOOC-COOH, HCOOH and CH_3COOH, as suggested by Brook et al. (1997).

$$\text{ECM} = SO_4^{2-} + NO_3^- + NH_4^+ + 1.79V + 1.24Zn + Pb + Br + Cl + Na + \text{soil} + \text{remainder} \qquad (11)$$

Where:

$$\text{Soil} = 3.48Si + 1.63Ca + 1.58Fe + 1.94Ti + 1.41K \qquad (12)$$

$$\text{Remainder} = \text{HOOC-COOH} + \text{HCOOH} + CH_3COOH + Mg^{2+} \qquad (13)$$

Values of ECM are given in Table 11, and are compared with gravimetric mass in Figure 14. Figure 14 shows a straight line fitted to the gravimetric data and the ECM values with a reduced major axis regression. The slope of the line is 0.73, indicating that most of the gravimetric mass is accounted for by the ECM; the remainder is probably due contributions of combustion derived organic and elemental carbon, which were not measured in this study and residual water associated with the gravimetric mass measurement.

Site 8HI was located close to the ore loading facilities at Parker Point and the Microvol sampler was programmed to begin sampling only when the wind direction was from the ore loading area. In this case iron is used as an indicator of soil dust which originates from ore the loading processes or transport of the ore to the loading facilities. The data show that the iron content of the particulate material at Site 8Hi varies from 17 % to 56 %, with an average of 31.5 %. The fraction of sea-salt at each site was estimated from composition of seawater provided by Millero (1974), using Mg^{2+} as an indicator of sea-salt. The results given in Table 11 show that Site 8Hi had an average sea-salt fraction of 9.5 %, the lowest fraction of sea-salt at any of the sites. The particulate samples at this site were composed largely of particulate associated from the ore loading operations.

Table 11 also shows the concentration of iron varies substantially from Site 1, the background site, to Site 8. For example, on average iron contributed 3.5 % and sea-salt 37.6 % of the TSP particulate loading at Site 1. This compares with contributions of 23.4 % and 19.6 % for iron and sea-salt respectively at Site 8. The TSP samples at Sites 5 and 7 had average iron contents of 11.7 % – 11.1 % and sea-salt loadings of about 26 %, which are intermediate between Site 1 and Site 8. This suggests that the increase in TSP observed between Site 1 and Site 8 may be due to dust which originates from the ore loading and transport processes. This point is emphasized by the increasing iron to sea-salt ratios proceeding from Site 1 to Site 8 given in Table 11.

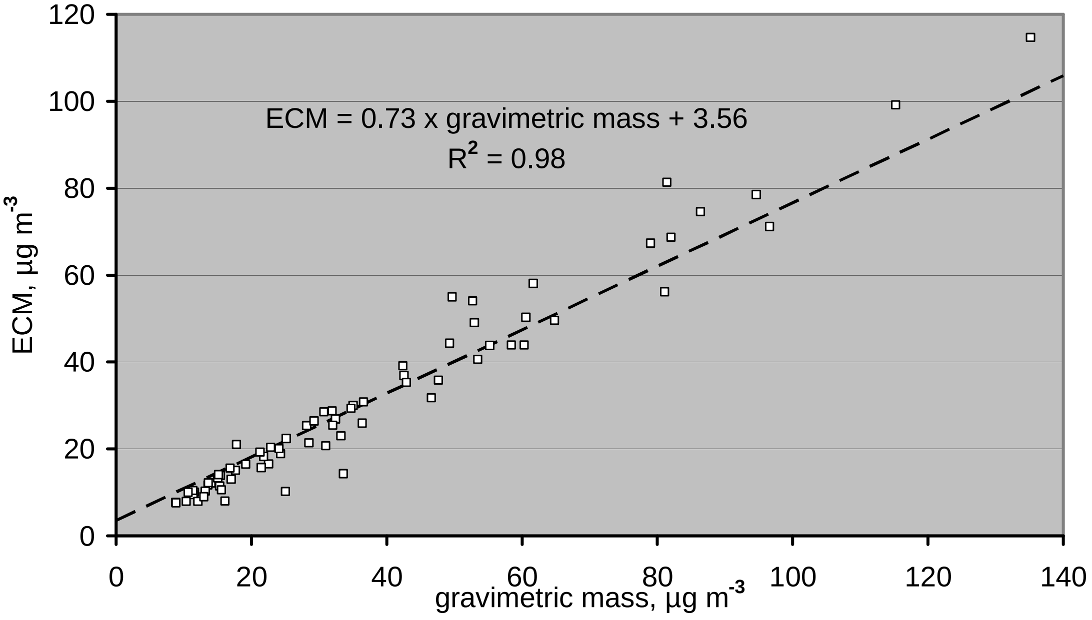


Figure 14. ECM as a function of gravimetric mass for all sites.

Table 11. Concentrations of gravimetric mass, ECM and iron, fraction of ECM to gravimetric mass (%) and the fraction of iron and sea-salt in TSP and PM_{10} samples collected at various sites.

Site	Date on	Date off	Grav Mass µg m^{-3}	ECM µg m^{-3}	% Total mass	Fe µg m^{-3}	% Fe	% Sea salt	Fe : Sea-salt
1	29/07/04	02/09/04	11.6	10.1	87.2	0.649	6.65	36.1	0.18
1	02/09/04	08/10/04	14.0	12.2	86.9	0.519	4.39	47.2	0.09
1	08/10/04	21/11/04	24.3	18.9	77.8	0.736	3.60	42.9	0.08
1	21/11/04	17/12/04	32.4	26.9	82.9	0.545	2.00	43.3	0.05
1	17/12/04	19/01/05	35.0	30.0	85.6	0.635	2.15	48.1	0.04
1	19/01/05	21/02/05	36.6	30.8	84.2	0.380	1.23	54.4	0.02
1	21/02/05	28/03/05	25.1	22.4	89.1	0.853	4.03	33.6	0.12
1	28/03/05	18/04/05	13.6	11.7	86.2	0.452	3.95	34.9	0.11
1	18/04/05	31/05/05	25.0	10.2	40.7	0.397	1.88	16.5	0.11
1	31/05/05	13/07/05	33.6	14.3	42.6	0.493	1.74	14.3	0.12
1	13/07/05	07/08/05	8.8	7.7	87.4	0.422	5.69	34.2	0.17
1	07/08/05	14/09/05	11.4	9.5	83.2	0.406	4.22	45.2	0.09
			22.6	***17.1***	***77.8***	***0.542***	***3.46***	***37.6***	***0.10***
4	01/08/04	01/09/04	15.3	11.5	75.1	0.945	6.17	25.3	0.24
4	01/09/04	07/10/04	12.1	8.0	66.0	0.826	6.84	24.3	0.28
4	07/10/04	20/11/04	42.6	36.9	86.7	4.319	10.15	16.3	0.62
4	20/11/04	18/12/04	60.3	43.9	72.8	2.366	3.92	19.7	0.20
4	18/12/04	18/01/05	60.6	50.3	83.0	2.766	4.57	24.3	0.19
4	18/01/05	16/02/05	55.2	43.8	79.4	2.234	4.05	30.6	0.13
4	16/02/05	23/03/05	47.6	35.9	75.2	2.920	6.13	24.2	0.25
4	23/03/05	28/04/05	28.5	21.4	75.1	1.867	6.55	19.1	0.34
4	28/04/05	30/05/05	22.6	16.5	73.3	1.264	5.61	14.8	0.38
4	30/05/05	30/06/05	17.6	15.1	85.4	0.896	5.08	34.7	0.15
4	30/06/05	08/08/05	15.6	10.6	67.8	0.975	6.26	15.6	0.40
4	08/08/05	13/09/05	33.2	23.0	69.2	1.743	5.24	15.1	0.35
			34.3	***26.4***	***75.8***	***1.927***	***5.88***	***22.0***	***0.29***
5	07/10/04	20/11/04	32.0	25.4	79.5	4.080	12.74	27.9	0.46
5	18/01/05	16/02/05	36.4	25.9	71.2	1.707	4.69	38.1	0.12
5	16/02/05	23/03/05	30.7	28.5	92.9	2.967	9.66	25.1	0.39
5	23/03/05	28/04/05	17.8	21.0	118.3	2.559	14.39	20.6	0.70
5	28/04/05	30/05/05	15.5	13.9	89.7	1.968	12.73	18.5	0.69
5	08/08/05	13/09/05	17.0	13.0	76.6	2.710	15.94	26.8	0.59
			24.9	***21.3***	***88.0***	***2.665***	***11.69***	***26.2***	***0.49***
7	01/08/04	01/09/04	19.2	16.5	86.1	2.696	14.07	20.7	0.68
7	01/09/04	07/10/04	21.8	18.3	83.9	3.094	14.20	24.5	0.58
7	07/10/04	20/11/04	46.6	31.8	68.1	5.118	10.98	20.5	0.53
7	20/11/04	18/12/04	58.4	43.9	75.2	5.864	10.04	19.8	0.51
7	18/12/04	18/01/05	42.4	39.2	92.4	4.047	9.55	29.8	0.32
7	18/01/05	16/02/05	136.0	120.9	88.9	12.602	9.27	33.3	0.28
7	16/02/05	23/03/05	34.7	29.3	84.6	3.164	9.12	23.9	0.38
7	23/03/05	28/04/05	21.3	19.3	90.7	2.788	13.12	19.3	0.68
7	28/04/05	30/05/05	15.0	13.3	88.8	1.809	12.04	23.5	0.51
7	30/05/05	30/06/05	15.1	14.1	93.1	1.155	7.62	41.1	0.19
7	30/06/05	08/08/05	11.4	10.4	91.9	0.976	8.59	26.3	0.33
7	08/08/05	13/09/05	16.8	15.6	92.7	2.495	14.82	29.1	0.51
			36.6	***31.1***	***86.4***	***3.817***	***11.12***	***26.0***	***0.46***

Table 11 cont

Site	Date on	Date off	Grav Mass $\mu g\ m^{-3}$	ECM $\mu g\ m^{-3}$	% Total mass	Fe $\mu g\ m^{-3}$	% Fe	% Sea salt	Fe : Sea-salt
8	03/08/04	01/09/04	22.9	20.4	89.3	6.107	26.72	15.2	1.76
8	01/09/04	07/10/04	28.2	25.4	90.2	7.565	26.86	19.6	1.37
8	07/10/04	20/11/04	52.7	54.1	102.6	19.292	36.62	16.6	2.21
8	20/11/04	18/12/04	53.4	40.6	76.0	7.920	14.82	20.7	0.72
8	18/12/04	18/01/05	61.7	58.1	94.2	13.210	21.42	25.0	0.86
8	18/01/05	16/02/05	94.6	78.5	83.0	19.678	20.80	20.3	1.02
8	16/02/05	23/03/05	29.3	26.4	90.3	5.275	18.02	21.7	0.83
8	23/03/05	28/04/05	135.2	114.7	84.8	29.294	21.67	17.6	1.23
			59.7	***52.3***	***88.8***	***13.543***	***23.37***	***19.6***	***1.25***
8 Cond	04/08/04	01/09/04	10.3	7.9	76.3	0.726	7.02	15.6	0.45
8 Cond	01/09/04	07/10/04	13.2	10.3	78.1	1.186	9.00	20.1	0.45
8 Cond	07/10/04	20/11/04	21.4	15.7	73.1	2.883	13.44	10.4	1.29
8 Cond	20/11/04	18/12/04	31.0	20.8	67.0	1.638	5.29	13.1	0.40
8 Cond	18/12/04	18/01/05	42.9	35.3	82.3	4.166	9.71	16.5	0.59
8 Cond	18/01/05	16/02/05	32.0	28.8	90.0	1.586	4.96	21.4	0.23
8 Cond	16/02/05	23/03/05	24.1	20.0	83.2	1.614	6.70	18.9	0.35
8 Cond	23/03/05	28/04/05	13.0	9.0	69.5	1.398	10.78	9.7	1.11
8 Cond	28/04/05	30/05/05	16.1	8.0	49.7	0.690	4.29	13.3	0.32
8 Cond	30/05/05	30/06/05	10.6	10.1	94.5	0.569	5.34	33.6	0.16
8 Cond	30/06/05	08/08/05	8.8	7.6	85.9	0.836	9.46	17.3	0.55
8 Cond	08/08/05	13/09/05	13.6	12.2	89.7	1.978	14.51	17.7	0.82
			19.8	***15.5***	***78.3***	***1.606***	***8.38***	***17.3***	***0.6***
8Hi	04/08/04	02/09/04	86.4	74.6	86.3	29.857	34.57	5.0	6.95
8Hi	02/09/04	08/10/04	64.8	49.6	76.5	16.905	26.09	10.0	2.61
8Hi	08/10/04	30/11/04	96.6	71.2	73.7	24.653	25.53	10.6	2.40
8Hi	30/11/04	20/12/04	79.0	67.3	85.3	19.797	25.07	14.4	1.74
8Hi	20/12/04	20/01/05	53.0	49.0	92.6	12.067	22.78	24.0	0.95
8Hi	20/01/05	23/02/05	560.9	395.4	70.5	94.333	16.82	16.7	1.01
8Hi	23/02/05	31/03/05	49.3	44.3	89.9	12.535	25.43	13.4	1.90
8Hi	31/03/05	02/05/05	81.1	56.2	69.3	17.493	21.57	6.9	3.12
8Hi	02/05/05	09/06/05	81.4	81.3	99.9	34.902	42.87	3.2	13.46
8Hi	09/06/05	01/07/05	49.7	55.0	110.7	27.673	55.74	2.1	26.47
8Hi	01/07/05	09/08/05	82.0	68.7	83.7	34.789	42.41	1.3	32.80
8Hi	09/08/05	16/09/05	115.2	99.1	86.0	45.562	39.53	6.5	6.09
			116.6	***92.6***	***85.4***	***30.880***	***31.53***	***9.5***	***8.3***

5.2.2 DustTrak Measurements

Figures 15, 16, 17 and 18 show PM_{10} concentrations measured using the DustTrak instrument at site 8 during four periods throughout the study plotted as a function of wind direction. Figures 15 and 17 were plotted using wind directions measured at Site 8 collected at a frequency of 2 minutes, while Figures 16 and 18 employed 30 minute averaged wind direction data from Karratha Airport. The Figures show that background PM_{10} concentration at site 8 appears to be about 10 $\mu g\ m^{-3}$, based on the concentration envelope observed in wind directions about 150º and about 15º. Site 8 is only about 2 – 3 km east of the iron ore loading facilities at Parker Point and it is evident from the Figures, that the activities at Parker Point have a large influence on PM_{10} concentrations at Site 8. The plot shows a large increase in PM_{10} over background concentrations in wind directions ranging from about 220º to 280º and this is directly downwind of Parker Point. The other influence on PM_{10} concentrations at site 8 is vehicle traffic travelling along Burrup Road. This can be seen as increased PM_{10} concentrations, particularly in wind directions from about 43º to 105º.

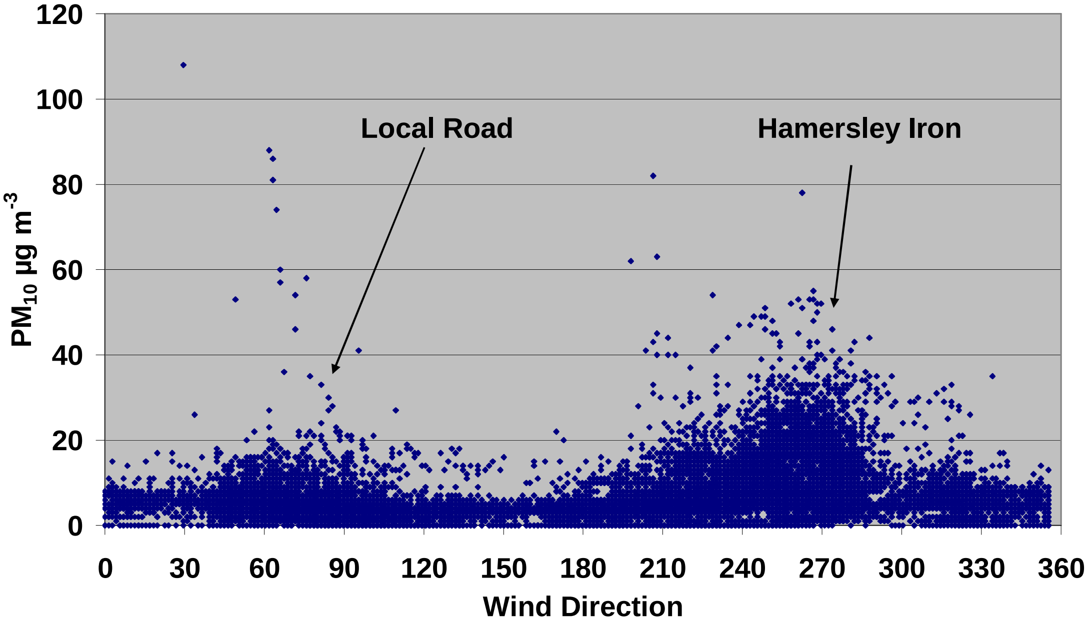


Figure 15. PM$_{10}$ concentrations measured by DustTrak at site 8 from4th August 2004 until 1st September 2004, and plotted against wind direction measured at Site 8 at a frequency of two minutes.

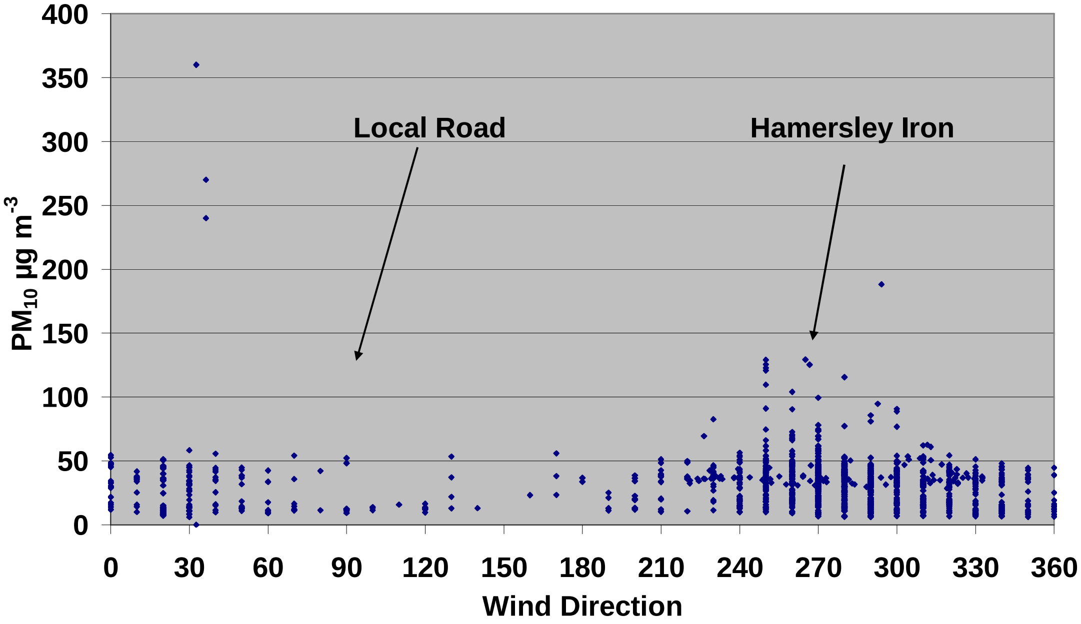


Figure 16. PM$_{10}$ concentration measured at Site 8 measured with DustTrak from 18th January 2005 until 16th February 2005, and plotted against wind direction measured at Karratha Airport at a frequency of thirty minutes.

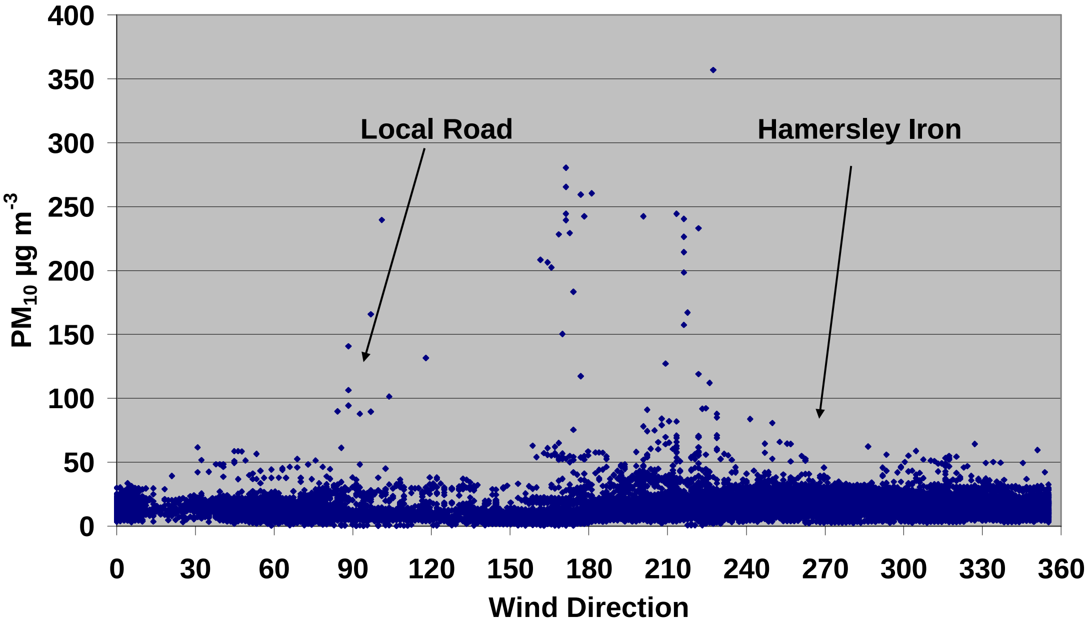


Figure 17. PM_{10} concentration measured at Site 8 measured with DustTrak from 23rd February 2005 until 23rd March 2005, and plotted against wind direction measured at Site 8 at a frequency of two minutes.

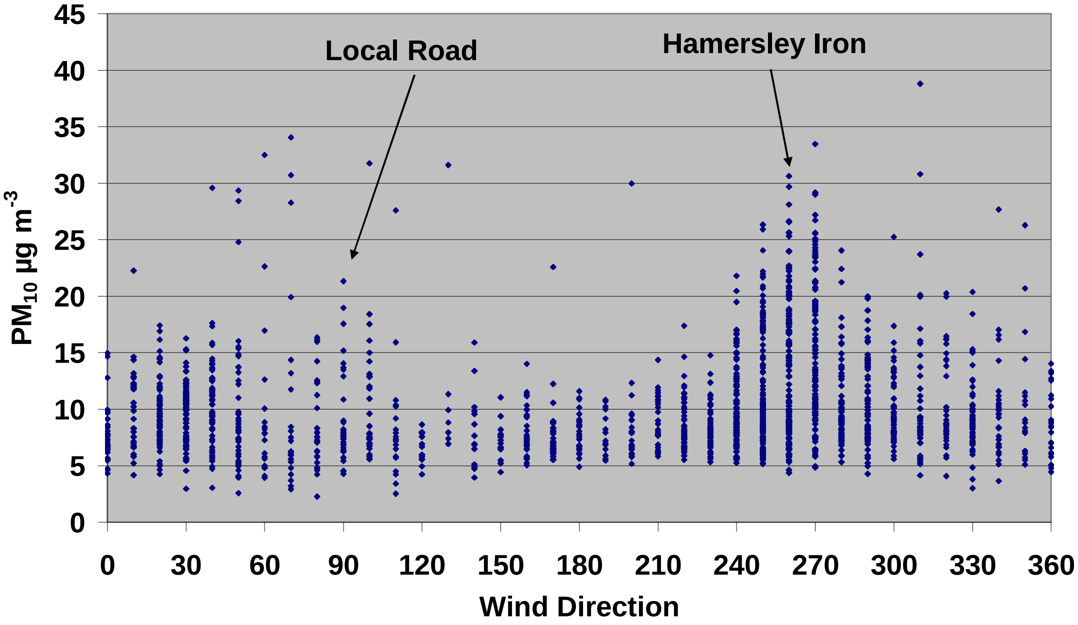


Figure 18. PM_{10} concentration measured at Site 8 measured with DustTrak from 23rd March 2005 until 28th April 2005, and plotted against wind direction measured at Karratha Airport at a frequency of thirty minutes.

5.3 Dust Deposition

5.3.1 Dust Deposition using passive dry Frisbee-type dust deposit gauges

In the Six Monthly Report an initial evaluation of dust deposition flux measurements was included. Since that report 3-monthly samples were collected at Sites 1, 4, 5, 6, 7 and 8 for periods 3 and 4. The results of these samples have been inconsistent at all sites during those periods. It was found that the dust mass on the foam pads was often less than that found on the blank foam pads, which were sent to the Burrup Peninsula, and treated in the same manner, except they were not exposed. Moreover, repeated weighing of the foam pads showed an unacceptably large range of dust mass on individual foam pads. Despite repeated weighings these inconsistencies could not be overcome. For these reasons the results of all the dust depositions cannot be reported in this final report. The only available estimates dust deposition fluxes are those from an aerosol spectrometer discussed in the next section.

5.3.2 Dust Deposition using GRIMM Aerosol Spectrometer.

During a visit to the sites in September 2005 a GRIMM aerosol spectrometer was used to measure the number size distribution of particles at each site. The GRIMM instrument is battery powered and weighs only 2.5 kg, so it presented an opportunity to measure particle size distribution. Although measurements were taken for only for a short period at each site, it nevertheless provides valuable size distribution data which can be converted to particle concentration, and then to dust deposition.

Size distributions were measured over a size range from 0.3 µm – 20 µm in 15 steps at each site over periods of 1 minute. The data were stored on a removable data logger card and then transferred to a notebook computer. The size distributions showed that no particles measured were greater than 10 µm diameter, but this could be due to losses in the inlet or to counting statistics (the sample flow rate is relatively low; about 2 l min^{-1}) . The distributions were then converted to mass concentrations by assuming the particles were spherical and had a density of 2.1 kg l^{-1}. The density was chosen to represent a soil having an iron ore content of about 23 %. This gives a short record of particle concentrations at the sites. The particle distributions were then converted to deposition in mg m^{-2} day^{-1} using particle deposition velocities as a function of particle diameter, as suggested by Nho-Kim et al. (2004).

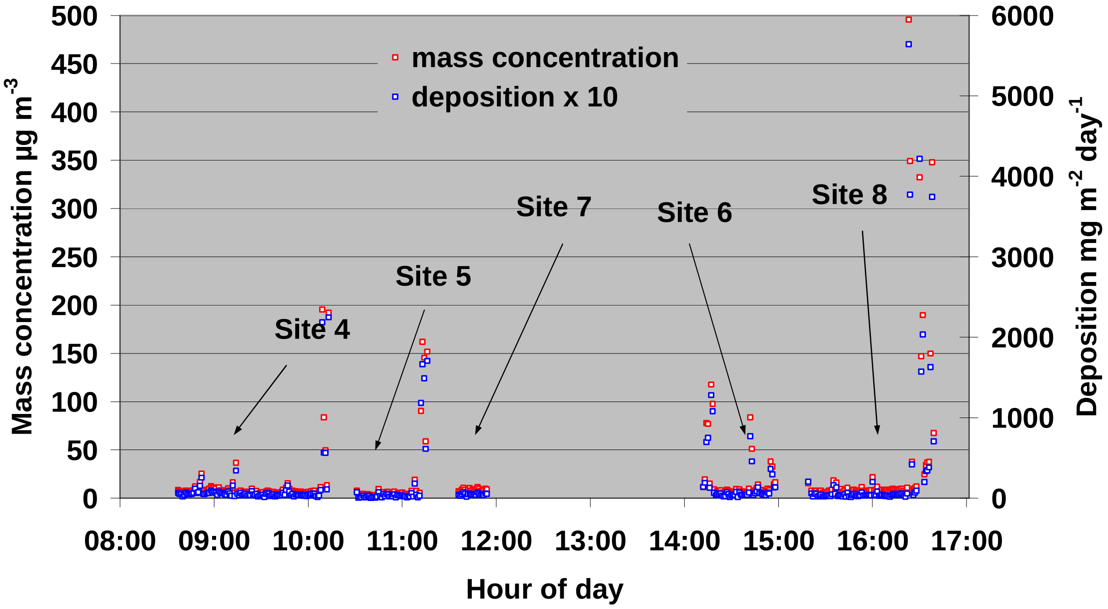


Figure 19. Mass concentration and dust deposition measured with GRIMM aerosol spectrometer at sites 4, 5, 6, 7 and 8 during a short period on 13th September 2005. The deposition fluxes have been multiplied by 10 for display purposes.

The results of the mass concentrations and dust deposition measurements are shown in Figure 19 for sites on the lower Burrup, and in Figure 20 for sites 1 and 3 on northern Burrup area. They appear consistent with PM$_{10}$ results measured with the DustTrak at Site 8, for example. The average TSP concentration measured at Site 8 with the GRIMM was about 40 µg m^{-3}, which is in the range of the DustTrak results shown in Figures 15 – 18. The average TSP loading for sites 1 and 3 was about 9 µg m^{-3} compared with about 40 µg m^{-3} at Site 8, and about 30 µg m^{-3} at sites 4, 5, 6 and 7. These results are of the same order as the averages presented in Table 10, and indicate that higher TSP concentrations exist at the lower Burrup sites compared to the “background” at sites 1 and 3.

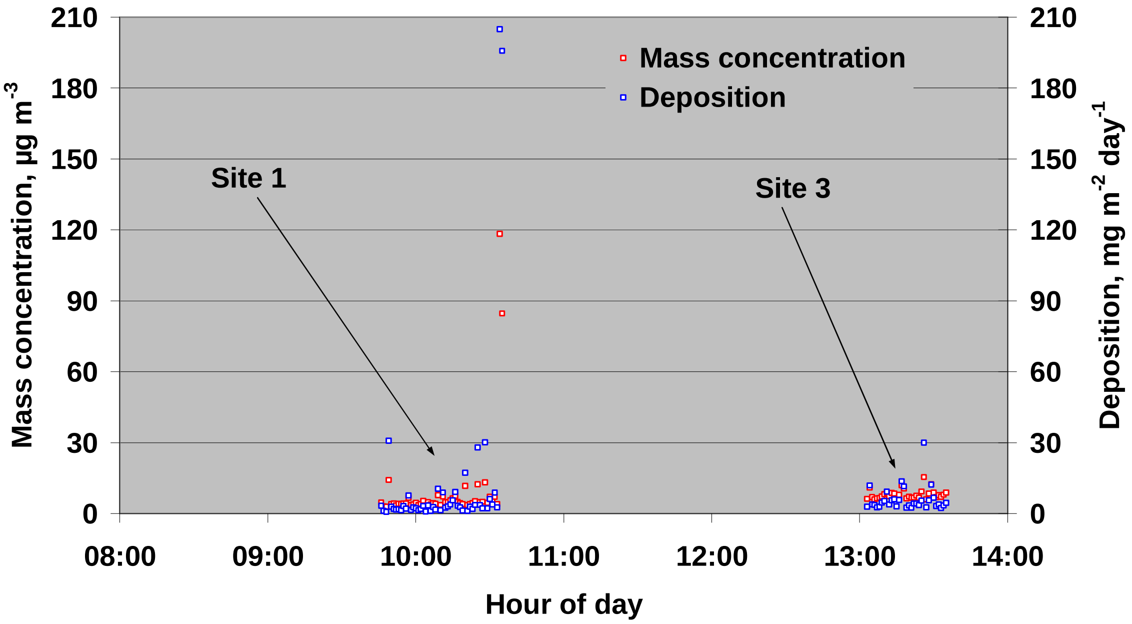


Figure 20. Mass concentration and dust deposition measured with GRIMM aerosol spectrometer at sites 1 and 3 during a short period on 14th September 2005.

The results of the dust deposition calculations for Sites 4, 5, 6, 7 and 8 are presented in Figure 19 and for Sites 1 and 3 in Figure 20. These data show that dust deposition values average about 10 mg m^{-2} day^{-1} at Sites 1 and 3 compared to about 68 mg m^{-2} day^{-1} at Site 8 and 32 mg m^{-2} day^{-1} for sites 4, 5, 6 7, and 8. These depositions indicate that over this short sample period the more industrial area of the Burrup experienced higher dust deposition than the background sites. But, it should be noted that the absolute values of the dust deposition at any of the Burrup sites is quite low. In comparison, Vallack, (1995), using the frisbee type foam pad samplers to measure dust deposition fluxes at two villages in north Yorkshire. One was located near a power station for 17 months in an area known to have relatively high dust fluxes and a maximum of about 120 mg m^{-2} day^{-1} was measured with an average of about 63 mg m^{-2} day^{-1}. The second site was in a rural area known to have lower deposition fluxes and the flux was 23 mg m^{-2} day^{-1}, using a dry frisbee without an insert. The dust fluxes measured at the lower Burrup sites are generally lower than, those measured at the high deposition site in north Yorkshire, except at site 8 which is closest to the ore loading facilities at Parker Point.

5.4 Meteorological Measurements

Figure 21 displays wind directions observed at site 8 from August 2004 and December 2004. No data were collected at site 8 during January 2005 so the rose for that period was compiled using data from Karratha Airport. The Figure shows that during August wind directions were from about 200º to about 250º, with a smaller component from about 70º. From September wind directions generally veered more to the north until November, when they were from about 250º to 290º.

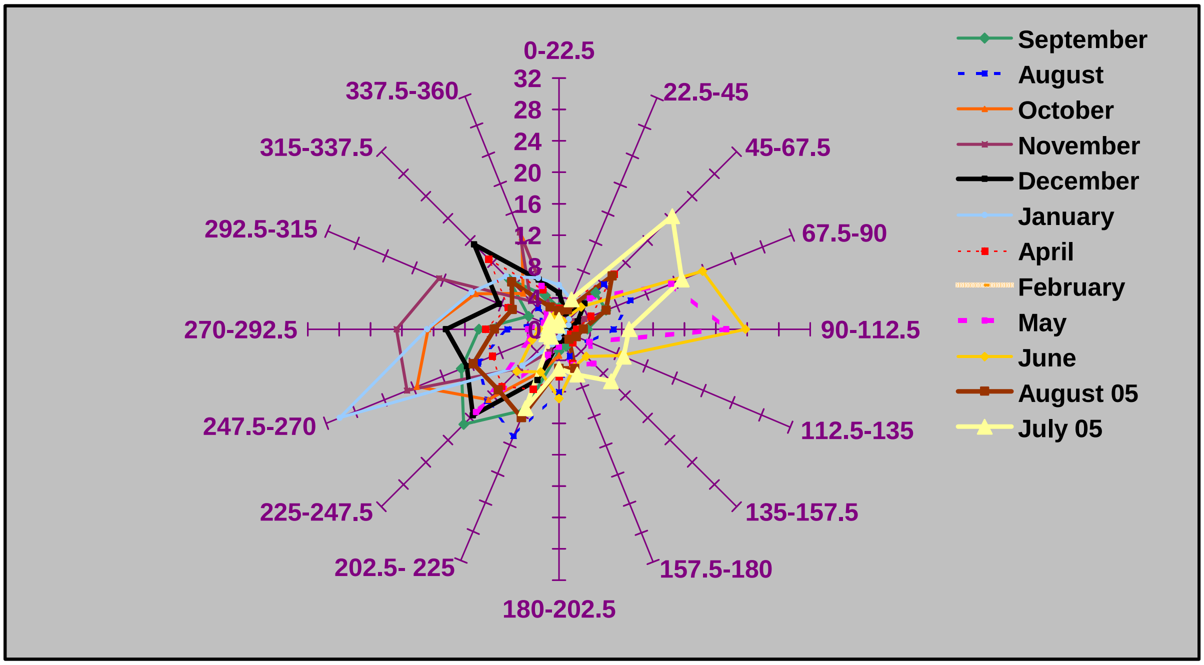


Figure 21. Wind roses recorded at site 8 from August 2004 to August 2005. The data for January 2005 is compiled from data recorded at Karratha airport.

Table 12 shows average, maximum and minimum temperature measurements at sites 1, 3, 4, 5, 6, 7 and 8 from August 2004 until March 2005. Temperatures measured at the sites were used to calculate concentrations of gaseous species measured in the study. The temperatures will assist in interpretation if seasonal cycles are found in any of the gas, particulate matter or dust measurements. The average temperatures show only small variations from site to site and the variation is generally only a fraction of a degree Celsius.

Table 12. Average, maximum and minimum temperature (^{o}C), and relative humidity (%) measurements at sites 1, 3, 4, 5, 6, 7 and 8. MF indicates an equipment malfunction.

Date on	Date off	Temp mean	Temp max	Temp min	Humidity mean	Humidity max	Humidity min
Site 1							
02/09/04 15:46	08/10/04 09:16	23.6	35.2	17.4	61.4	97.5	10.9
08/10/04 09:22	21/11/04 11:34	28.7	40.3	21.2	53.9	94.9	9.5
21/11/04 11:34	17/12/04 12:01	29.4	37.6	23.9	63.6	92.2	17.8
17/12/04 12:12	19/01/05 12:51	30.6	40.3	24.8	68.7	93.7	6.9
19/01/05 12:52	21/02/05 12:52	30.5	36.7	26.3	72.2	92.6	4.5
23/02/05 09:57	28/03/05 10:36	31.7	40.9	25.2	30.1	85.3	0
28/03/05 10:46	18/04/05 09:31	30.3	38.2	23.5	MF	MF	MF
18/04/05 09:36	31/05/05 10:48	27.6	38.4	20.5	MF	MF	MF
31/05/05 11:28	13/07/05 11:37	21.2	27.0	15.3	MF	MF	MF
13/07/05 11:35	07/08/05 11:29	22.0	28.8	16.2	MF	MF	MF
07/08/05 11:23	14/09/05 09:59	21.8	27.9	16.0	MF	MF	MF
Site 3							
02/09/04 13:07	08/10/04 11:34	23.8	35.3	17.3	59.8	98.2	12.7
08/10/04 11:36	21/11/04 15:40	28.8	40.2	21.7	54.6	94.1	10.9
21/11/04 15:40	17/12/04 14:01	29.6	40.0	24.2	62.8	88.8	15.4
19/01/05 16:19	21/02/05 09:52	30.6	37.7	27.0	74.6	91.8	29.9
21/02/05 09:58	28/03/05 12:13	31.9	41.0	27.3	61.7	90.1	16.2
28/03/05 12:15	18/04/05 14:18	30.5	39.2	23.5	54.9	87.6	10.5
18/04/05 14:26	31/05/05 12:50	27.6	38.4	20.8	MF	MF	MF
31/05/05 13:30	13/07/05 13:40	21.2	27.0	15.3	MF	MF	MF
13/07/05 16:02	07/08/05 14:41	22.1	28.3	16.8	MF	MF	MF
07/08/05 14:55	14/09/05 13:19	22.1	33.2	16.0	MF	MF	MF
Site 4							
01/08/04 11:22	01/09/04 08:22	21.5	29.0	15.4	44.2	91.4	8.8
01/09/04 08:28	07/10/04 08:43	23.6	32.4	16.0	55.6	98.3	6.2
07/10/04 08:50	20/11/04 08:38	29.1	41.6	20.9	48.6	94.6	10.9
20/11/04 08:42	18/12/04 06:36	29.8	40.0	23.3	58.5	89.8	11.3
18/12/04 06:38	18/01/05 09:29	31.1	41.8	24.3	63.7	91.0	13.1
18/01/05 09:32	16/02/05 06:29	30.7	38.2	26.9	72.7	92.3	20.4
16/02/05 06:55	23/03/05 09:49	32.1	42.9	27.8	62.0	89.8	16.2
23/03/05 09:37	28/04/05 08:03	30.7	40.0	23.2	55.3	91.0	9.5
28/04/05 08:10	30/05/05 10:07	27.1	36.6	20.9	62.0	99.3	9.5
30/05/05 10:12	30/06/05 08:21	21.4	28.2	15.8	57.1	99.0	20.8
30/06/05 08:25	08/08/05 08:28	21.8	29.2	15.0	48.9	100.0	11.6
08/08/05 08:34	13/09/05 08:52	22.0	28.7	15.2	58.7	98.0	13.5
Site 5							
01/08/04 15:44	01/09/04 11:38	21.0	28.3	14.7	13.3	35.1	1.34
01/09/04 11:41	07/10/04 10:59	23.3	35.7	15.5	57.6	98.5	6.2
20/11/04 12:27	18/12/04 07:42	29.4	41.3	23.1	60.7	89.6	11.6
18/12/04 07:45	18/01/05 12:15	30.9	43.2	24.1	65.1	92.1	13.1
18/01/05 12:23	16/02/05 08:08	30.5	37.1	26.8	74.0	92.9	24.8
16/02/05 08:30	22/03/05 11:33	32.0	43.1	27.5	63.4	91.7	16.2
23/03/05 11:40	28/04/05 10:04	30.4	40.1	22.9	57.2	94.1	10.9
28/04/05 10:05	30/05/05 11:20	26.3	34.3	20.0	65.0	100.5	11.2
30/05/05 11:32	30/06/05 09:11	20.9	27.6	14.9	59.5	99.2	19.1
30/06/05 09:16	08/08/05 09:16	21.2	28.3	15.0	51.7	101.2	13.5
08/08/05 09:21	13/09/05 10:42	21.6	28.5	15.0	61.2	99.9	15.8

Table 12 cont

Date on	Date off	Temp mean	Temp max	Temp min	Humidity mean	Humidity max	Humidity min
Site 6							
03/08/04 12:51	01/09/04 10:21	21.2	28.4	13.8	45.1	91.7	9.5
01/09/04 10:25	07/10/04 10:04	23.7	34.6	15.7	54.9	98.1	6.5
07/10/04 10:14	29/10/04 10:17	29.5	41.8	20.7	45.8	92.9	8.8
20/11/04 10:33	18/12/04 08:45	30.0	41.3	23.0	56.6	88.3	9.5
18/12/04 08:50	18/01/05 11:08	31.4	43.0	24.2	61.2	90.4	12.0
18/01/05 11:13	16/02/05 07:19	31.0	38.9	26.7	70.7	91.3	20.8
16/02/05 07:35	23/03/05 10:47	32.3	43.8	27.3	60.1	90.0	14.2
23/03/05 10:41	28/04/05 09:17	30.8	40.2	23.0	53.3	92.1	7.5
28/04/05 09:20	30/05/05 12:38	26.5	34.6	19.7	67.3	103.8	11.2
30/05/05 12:43	30/06/05 10:04	20.9	27.8	13.8	72.5	103.8	17.8
30/06/05 10:11	08/08/05 10:05	21.2	28.5	14.9	54.7	103.8	11.2
08/08/05 10:12	13/09/05 14:33	21.7	29.5	14.6	68.3	103.8	8.5
23/03/05 10:41	28/04/05 09:17	30.8	40.2	23.0	53.3	92.1	7.5
Site 7							
01/08/04 14:18	01/09/04 13:21	21.6	29.0	14.6	43.1	94.1	10.5
01/09/04 13:28	07/10/04 13:10	23.8	36.9	15.5	54.1	99.5	6.5
07/10/04 13:16	20/11/04 14:16	29.7	41.4	21.2	44.3	93.7	8.1
18/12/04 10:15	18/01/05 15:09	31.5	42.5	24.2	60.8	92.9	12.3
18/01/05 15:07	16/02/05 09:13	31.0	39.9	26.5	71.0	92.1	23
16/02/05 09:25	23/03/05 12:55	32.5	42.3	26.8	59.9	92.5	15
23/03/05 12:59	28/04/05 10:59	31.4	42.4	23.7	51.5	90.9	7.5
28/04/05 10:59	30/05/05 13:56	26.5	35.4	20.1	63.0	98.2	10.5
30/05/05 14:04	30/06/05 11:13	21.1	27.4	14.6	57.7	96.7	17.8
30/06/05 11:15	08/08/05 11:12	21.5	28.2	15.0	49.1	98.2	12.7
08/08/05 11:15	13/09/05 11:45	21.8	29.0	13.7	57.1	97.8	12.3
Site 8							
04/08/04 13:28	01/09/04 15:40	21.1	29.7	13.6	45.6	93.9	8.2
01/09/04 15:45	07/10/04 14:36	23.4	36.4	15.0	56.7	99.7	5.3
07/10/04 14:42	20/11/04 15:45	28.9	41.4	19.3	48.6	94.7	10.6
20/11/04 15:46	18/12/04 10:40	29.5	40.6	22.7	59.7	90.7	10.6
18/12/04 10:50	18/01/05 16:35	31.0	43.1	23.8	64.7	92.3	10.9
18/01/05 16:38	16/02/05 10:20	30.7	38.4	26.5	73.9	92.3	23.1
16/02/05 10:38	23/03/05 14:02	32.1	44.3	26.3	62.7	91.9	13.5
23/03/05 13:58	28/04/05 11:52	30.5	40.0	23.2	57.2	94.3	9.2
28/04/05 11:56	30/05/05 15:17	26.4	34.8	19.1	64.4	99.4	9.5
30/05/05 15:23	30/06/05 11:59	21.0	27.8	14.7	57.6	99.0	12.7
30/06/05 12:04	08/08/05 11:58	21.3	29.5	14.2	49.8	100.4	9.5
08/08/05 12:01	13/09/05 15:22	21.5	30.1	13.7	59.6	99.7	10.2

5.5 Rainwater Composition

Tables 13a and 13b present concentrations of cations, anions, rainfall amount and pH measured in rainwater collected at Sites 3, 5, 6, 7 and 8. The results in the Tables show that the rainwater composition is dominated by sodium and chloride ions. This is because most of the sites are in close proximity to the ocean. The focus of this study will be on the non sea-salt sulfate and nitrate concentrations and deposition in rainwater since they are indicative of the total concentration (neutralised and unneutralised) of sulfuric acid and nitric acid in rainwater. Sulfate in rainwater has a sea-salt source as well as a non sea-salt source. The non sea-salt fraction of the sulfate in rainwater was estimated by assuming chloride had a predominately marine source. Ionic ratios provided by Millero, (1974) were then used to calculate the non sea-salt fraction of sulfate in the rainwater samples.

The volume-weighted mean concentrations are given in bold italics in Tables 13a and 13b. These results show a slight increase in non sea-salt sulfate concentrations, from a local background of 4.8 µeq l^{-1} at Site 3, to 15.6 µeq l^{-1} at site 7. These results can be contrasted with previous studies, using similar sampling and analytical procedures, carried out in Malaysia and Indonesia. Non sea-salt concentrations were measured at several sites covering a range of pollution regimes in Indonesia (Gillett et al., 2000). At the heavily polluted sites in Jakarta and Bogor non sea-salt concentrations were 29 µeq l^{-1} – 38 µeq l^{-1}, whereas it was about 13 µeq l^{-1} at the relatively unpolluted GAW station at Bukit Koto Tabang, in west Sumatra. At Petaling Jaya, near Kuala Lumpur annual VWM non sea-salt sulfate concentrations in rainwater ranged from approximately 40 µeq l^{-1} – 70 µeq l^{-1} over 5 annual periods, (Ayers et al., 2000) and from about 30 µeq l^{-1} – 60 µeq l^{-1} at other polluted Malaysian sites (Ayers et al., 2002). Even at the relatively unpolluted Malaysian site in the Cameron Highlands, north of Kuala Lumpur, non sea-salt concentration VWM was 11.4 µeq l^{-1}. The non sea-salt sulfate concentrations at unpolluted sites in Malaysia and Indonesia exceeded those measured at the local back ground site on the Burrup Peninsula, and were similar to the concentrations at the lower sites on the Burrup.

Table 13a. Measurements of rainfall amount, pH, concentrations of cations, cation sum and anion sum. Ionic concentrations are µeq l^{-1}. VWM is the volume weighted mean concentrations at each site. The VWM anions are in bold.

Sample	Sample (mm)	pH	H^+	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	∑Cat	∑An
Site 3										
18/04/05 – 06/05/05	14.2	4.586	25.9	71.0	6.6	4.6	13.4	18.1	139.7	139.8
06/05/05 – 24/05/05	79.0	5.172	6.7	16.2	1.4	0.6	1.4	0.9	27.3	26.1
31/05/05 – 13/07/05	71.0	4.733	18.5	39.0	7.0	1.2	6.6	3.7	76.1	74.0
VWM			***14.6***	***33.8***	***4.7***	***1.4***	***5.4***	***4.4***		
Site 5										
14/11/04 – 06/03/05	0.8	4.341	45.6	169.4	94.5	25.4	39.6	89.2	463.7	457.5
16/03/05 – 23/03/05	5.8	5.345	4.5	214.1	7.8	6.6	40.4	56.2	329.6	338.4
24/03/05 – 28/04/05	3.4	5.215	6.1	85.5	16.7	5.2	13.8	25.1	152.3	157.3
28/04/05 – 16/05/05	18.2	4.818	15.2	49.9	5.4	1.6	9.5	5.8	87.4	81.0
16/05/05 – 30/05/05	85.4	4.988	10.3	19.3	1.5	0.7	2.3	1.0	35.1	31.7
30/06/05 – 08/08/05	71.0	4.944	11.4	39.4	5.9	1.1	6.0	3.7	67.5	64.1
VWM			***11.2***	***38.5***	***4.8***	***1.4***	***6.1***	***5.3***		
Site 6										
16/03/05 – 23/03/05	5.8			944.9	537.5	107.5	291.1	571.3		
23/03/05 – 28/04/05	3.4	4.698	20.0	123.5	7.4	6.2	24.8	30.5	212.4	222.1
28/04/05 – 16/05/05	14.1	4.736	18.4	46.1	9.9	1.9	9.7	6.7	92.8	84.9
16/05/05 – 30/05/05	60.0	4.830	14.8	30.8	4.4	1.2	4.8	1.8	57.8	54.7
30/06/05 – 08/08/05	71.0	4.762	17.3	31.0	1.4	0.8	4.6	2.9	58.0	46.6
VWM			***15.7***	***63.0***	***20.7***	***4.5***	***12.5***	***21.2***		
Site 7										
16/03/05 – 23/03/05	5.8			1095.3	208.5	91.4	248.7	693.4		
24/03/05 – 28/04/05	3.4	4.732	18.5	92.1	6.5	4.9	17.1	21.4	160.6	165.2
16/05/05 – 30/05/05	76.5	5.059	8.7	29.7	2.6	1.2	4.1	1.4	47.6	48.0
30/06/05 – 08/08/05	71.0	4.835	14.6	43.4	3.2	2.0	6.7	2.4	72.4	68.1
VWM			***11.2***	***74.2***	***10.1***	***4.8***	***14.0***	***26.5***		
Site 8										
16/03/05 – 23/03/05	5.8	7.541	0.03	721.8	27.7	34.3	216.4	759.2	1759.5	1234.8
24/03/05 – 28/04/05	3.4	5.851	1.4	345.4	26.3	21.8	105.9	352.1	853.0	550.3
28/04/05 – 16/05/05	15.0	4.794	16.1	127.9	4.5	15.4	22.9	51.3	238.0	204.0
16/05/05 – 13/05/05	61.8	4.949	11.2	36.3	2.3	1.8	6.9	8.4	66.9	55.0
05/06/05 – 17/06/05	21.4			239.2	30.0	22.4	78.8	221.3		
VWM			***9.4***	***118.5***	***8.7***	***8.8***	***32.0***	***89.4***		

Nitrate concentrations on the Burrup Peninsula ranged from 4.2 µeq l^{-1} at Site 3 to 11.5 µeq l^{-1} and 10.8 µeq l^{-1} at Sites 6 and 7 respectively. These results show a geographical gradient in concentration from the local background site to the lower Burrup sites, and this is probably due a similar geographical gradient in nitrogen dioxide concentrations from the local background to the lower Burrup sites. In contrast to these results, the unpolluted sites in Tanah rata and Bukit Koto Tabang have nitrate concentrations of around 4.7 µeq l^{-1} and 0.8 µeq l^{-1} respectively, (Ayers et al., 1996; Gillett et. al., 2000) which is similar to the concentrations at Site 3. However the more polluted sites in Asia have substantially higher nitrate concentrations than any of the Burrup sites. Concentrations at various sites in Malaysia range from approximately 15 µeq l^{-1} – 30 µeq l^{-1} and from 13 µeq l^{-1} – about 38 µeq l^{-1} in Jakarta (Ayers et al., 1996; Gillett et. al., 2000).

Table 13b. Measurements of anion concentrations in rainwater samples. All concentrations are µeq l^{-1}. $*SO_4^{2-}$ indicates non sea-salt sulfate. Volume weighted mean concentrations are given in bold italics.

Cl^-	NO_2^-	NO_3^-	SO_4^{2-}	$*SO_4^{2-}$	$C_2O_4^{2-}$	PO_4^{3-}	F^-	CH_3COO^-	$HCOO^-$	$CH_3SO_3^-$	HCO_3^-
Site 3											
75.6	0.03	11.5	14.2	6.4	2.2	9.8	1.07	4.4	21.7	0.14	0.2
18.6	0.08	1.2	3.3	1.4	0.1	1.5	0.06	0.4	0.3		0.8
43.2	0.04	4.9	12.0	7.5	0.5	2.9	0.36	2.5	7.8	0.04	0.3
37.3	***0.06***	***4.2***	***8.7***	***4.8***	***0.6***	***3.2***	***0.33***	***4.0***	***7.3***	***0.04***	***0.5***
Site 5											
174.6	0.16	73.4	62.4	44.4	22.3	10.5		19.0	95.2		0.1
235.6	0.20	12.9	59.4	35.0	5.3	7.6	0.79	4.2	12.1	0.16	1.1
78.3	0.22	7.9	17.5	9.4	6.8	28.5	3.19	5.4	11.8	0.12	0.8
55.6	0.02	8.8	9.7	3.9	0.3	5.2	0.35	0.7	0.4		0.3
21.9	0.04	1.5	4.8	2.5	0.02	2.5	0.04	0.3	0.3		0.5
42.4	0.01	5.4	7.7	3.3	0.6	2.5	0.10	1.5	3.7	0.02	0.4
42.0	***0.04***	***4.7***	***8.7***	***4.4***	***0.7***	***3.4***	***0.17***	***1.1***	***2.9***	***0.01***	***0.5***
Site 6											
1026.7	2.30	240.0	323.6	217.4	55.6	18.8				6.49	
131.9	0.10	14.2	27.3	13.7	3.3	22.8	1.2	4.6	17.5	0.05	0.2
52.6	0.02	10.4	13.5	8.0	0.02	6.0	0.7	0.5	0.7	0.77	0.3
34.2	0.03	2.7	6.8	3.3	0.6	2.3	0.2	2.2	5.7		0.3
35.0	0.03	3.5	5.5	1.9		2.0	0.05	0.02	0.2		0.3
69.4	***0.10***	***11.5***	***17.3***	***10.2***	***2.1***	***3.5***	***0.21***	***1.1***	***3.1***	***0.28***	***0.3***
Site 7											
1289.3		165.1	466.0	332.7	56.3	18.9				6.28	
96.6	0.08	10.0	16.9	6.9	2.9	17.2	1.6	5.0	16.3	0.05	0.3
35.0	0.06	2.4	7.0	3.4	0.04	2.3	0.04	0.4	0.3		0.6
47.9	0.03	8.4	9.7	4.8	0.04	1.5	0.08	0.12	0.09	0.03	0.4
85.7	***0.05***	***10.8***	***24.5***	***15.6***	***2.1***	***2.8***	***0.09***	***0.3***	***0.5***	***0.23***	***0.5***
Site 8											
785.7	1.80	73.9	79.2	0.0	52.0	4.6	14.3	33.7	27.7	0.79	177.2
385.8	6.60	4.2	75.8	35.9	44.1	26.3	8.9	9.2	1.4		3.6
136.3	0.94	7.5	18.9	4.8	4.0	0.9		12.6	23.2	0.36	0.3
40.7	0.54	0.01	11.0	6.8	0.1	1.0	0.6	1.0	0.7		0.4
320.0	12.31	18.5	47.9	13.9	7.0	36.5	38.8			1.88	
139.1	***2.68***	***7.3***	***22.4***	***8.1***	***5.1***	***7.4***	***7.40***	***4.1***	***4.8***	***0.38***	***8.1***

5.6 Deposition of Nitrogen and Sulfur

An aim of this study was to measure the total deposition of acidity to the ground. The strong mineral acidity, resulting from industry is in the form of sulfuric and nitric acids, both as free and neutralised acids. These are formed as the products of the oxidation of nitrogen dioxide and sulfur dioxide, some of which is emitted from industrial sources. Reactions 14 to 18 show the basic steps in the atmospheric oxidation of nitrogen to produce nitric acid and ammonium nitrate, the major neutralised form of nitric acid. Sulfuric acid can also be formed as a result of chemical reactions in the atmosphere. The major oxidation steps are shown in reactions 19 to 23. Reactions 17 and 18 and 22 and 23 show the free acid and neutralised forms of nitric acid and sulfuric acid respectively. The reactions also show the role of ammonia in the formation of the neutralised species.

$$N_2 + O_2 \Longrightarrow 2NO \tag{14}$$

$$NO + HO_2^{\bullet} \text{ (or } RO_2\bullet) \Longrightarrow NO_2 + OH \tag{15}$$

$$NO + O_3 \Longrightarrow NO_2 + O_2 \tag{16}$$

$$NO_2 + OH \Longrightarrow HNO_3 \tag{17}$$

$$NH_3 + HNO_3 \Longrightarrow NH_4NO_3 \tag{18}$$

$$S + O_2 \Longrightarrow SO_2 \tag{19}$$

$$SO_2 + O_3 \Longrightarrow SO_3 + O_2 \tag{20}$$

$$SO_2 + H_2O_2 \Longrightarrow SO_3 + H_2O \tag{21}$$

$$SO_3 + H_2O \Longrightarrow H_2SO_4 \tag{22}$$

$$2NH_3 + H_2SO_4 \Longrightarrow (NH4)_2SO_4 \tag{23}$$

Wet deposition fluxes in meq m^{-2} of nitrogen and sulfur were calculated from the rainfall amount in mm and the concentrations of nitrate, sulfate and ammonium in the rainwater samples collected at each site. The results of these deposition fluxes are shown in Table 14. The totals shown in the Table are the annual fluxes at each site. Since the amount of rain that fell at each site was similar, the range in wet deposition fluxes is similar to that observed in the rainfall composition.

Table 14. Wet deposition fluxes of nitrogen and sulfur. $*SO_4^{2-}$ is the non sea-salt fraction of the sulfate.

Sample	NO_3^- meq m^{-2}	$*SO_4^{2-}$ meq m^{-2}	NH_4^+ meq m^{-2}
Site 3			
18/04/05 – 06/05/05	0.2	0.1	0.1
06/05/05 – 24/05/05	0.1	0.2	0.1
31/05/05 – 13/07/05	0.3	0.6	0.5
total	***0.6***	***0.9***	***0.7***
Site 5			
14/11/04 – 06/03/05	0.1	0.1	0.1
16/03/05 – 23/03/05	0.1	0.2	0.1
24/03/05 – 28/04/05	0.0	0.1	0.1
28/04/05 – 16/05/05	0.1	0.1	0.1
16/05/05 – 30/05/05	0.1	0.3	0.1
30/06/05 – 08/08/05	0.4	0.3	0.4
total	***0.8***	***1.0***	***0.9***
Site 6			
16/03/05 – 23/03/05	1.4	1.2	3.1
23/03/05 – 28/04/05	0.1	0.1	0.0
28/04/05 – 16/05/05	0.1	0.1	0.1
16/05/05 – 30/05/05	0.2	0.2	0.3
30/06/05 – 08/08/05	0.2	0.2	0.1
total	***2.0***	***1.8***	***3.6***
Site 7			
16/03/05 – 23/03/05	1.0	1.9	1.2
24/03/05 – 28/04/05	0.0	0.1	0.1
16/05/05 – 30/05/05	0.2	0.4	0.2
30/06/05 – 08/08/05	0.6	0.4	0.2
total	***1.8***	***2.8***	***1.7***
Site 8			
16/03/05 – 23/03/05	0.4	0.1	0.2
24/03/05 – 28/04/05	0.0	0.1	0.1
28/04/05 – 16/05/05	0.1	0.1	0.1
16/05/05 – 13/05/05	0.0	0.4	0.1
05/06/05 – 17/06/05	0.4	0.1	0.6
total	***1.0***	***0.9***	***1.1***

Table 15 displays the dry deposition fluxes of ammonia, nitrogen dioxide, sulfur dioxide and nitric acid estimated at each site. Dry deposition fluxes were estimated from the product of the gas concentration, the sampling period and the dry deposition velocity. Deposition velocities for nitrogen dioxide, sulfur dioxide and nitric acid are taken from Manins, (1994). This used an inferential technique to estimate deposition velocities for Malaysian conditions.

The deposition flux, F*d*, to the surface of a gas such as sulfur dioxide may be described in terms of a dry deposition velocity, V*d*:

$$Fd = C \times Vd = \frac{C}{r_t} = \frac{C}{\left(r_a + r_b + r_c\right)} \qquad (24)$$

Where:
C is the near-surface concentration of the relevant trace gas.
V*d* is inversely proportional to the sum of three resistance terms

$$Vd = \left(ra + rb + rc\right)^{-1} \qquad (25)$$

These terms characterise the critical factors controlling surface-atmosphere exchange (Hicks et al., 1987).
Where:
ra is aerodynamic resistance,
rb is surface boundary layer resistance, and
rc is surface or canopy resistance (Hicks et al., 1987; Baldocchi et al., 1987).

The annual average values were 0.0090 m sec^{-1}, 0.0028 m sec^{-1} and 0.0021 m sec^{-1} for nitric acid, sulfur dioxide and nitrogen dioxide respectively. The dry deposition flux for ammonia was taken from Puxbaum and Gregorgi, (1998). Inferred deposition velocities from such studies as Meyers et. al. (1991) show annual average deposition velocities can vary by about 10%. Since deposition flux is the product of deposition velocity and gas mixing ratio this variability flows through to the deposition flux so that it has at least a 10% uncertainty.

The dry deposition results, shown in Table 15, are calculated from the 12 approximately monthly average concentrations of the gases measured at each site. The annual deposition in meq m^{-2} yr^{-1} is the addition of the monthly values for each gas, and the total dry deposition is given in the last column of Table 15. The total deposition values vary from about 8.8 meq m^{-2} yr^{-1} at Site 1 to 40.4 meq m^{-2} yr^{-1} at Site 9, in Karratha. The large value at Site 9 is due largely to the high deposition of ammonia, which most likely has a local source. The local background dry deposition flux is about 12 meq m^{-2} yr^{-1}, as defined by the average of Sites 1, 3 and 10. There is an obvious, although small increase in the dry deposition flux over the background at the lower Burrup sites which range from 14.2 meq m^{-2} yr^{-1} to 17.7 meq m^{-2} yr^{-1}.

Table 15. Dry deposition fluxes of nitrogen and sulfur. Totals are given in bold italics.

Date on	Date off	NH_3 meq m^{-2}	NO_2 meq m^{-2}	SO_2 meq m^{-2}	HNO_3 meq m^{-2}	total meq m^{-2}
Site 1						
29/07/04 11:50	02/09/04 15:35	0.2	0.2	0.1	0.1	0.5
02/09/04 15:40	08/10/04 09:35	0.6	0.1	0.0	0.2	0.9
08/10/04 09:45	21/11/04 12:05	0.4	0.3	0.1	0.2	1.0
21/11/04 12:05	17/12/04 12:10	0.7	0.1	0.0	0.1	0.9
17/12/04 12:10	19/01/05 13:02	0.2	0.1	0.1	0.1	0.6
19/01/05 13:07	21/02/05 12:55	0.6	0.1	0.1	0.1	0.9
21/02/05 13:12	28/03/05 11:14	0.5	0.2	0.1	0.2	0.9
28/03/05 11:20	18/04/05 09:55	0.1	0.1	0.1	0.1	0.4
18/04/05 11:17	31/05/05 11:24	0.3	0.3	0.1	0.3	1.0
31/05/05 11:25	13/07/05 11:50	0.2	0.2	0.0	0.1	0.5
13/07/05 11:45	07/08/05 11:40	0.3	0.1	0.0	0.2	0.6
07/08/05 11:50	14/09/05 09:53	0.3	0.1	0.1	0.1	0.6
Total		***4.3***	***1.8***	***0.8***	***1.9***	***8.8***
Site 3						
29/07/04 16:00	02/09/04 13:10	0.6	0.3	0.1	0.1	1.1
02/09/04 13:20	08/10/04 11:25	0.3	0.2	0.1	0.2	0.8
08/10/04 11:30	21/11/04 15:45	1.0	0.3	0.1	0.2	1.7
21/11/04 15:45	17/12/04 14:15	1.4	0.1	0.1	0.1	1.7
17/12/04 14:15	19/01/05 16:40	0.2	0.1	0.1	0.1	0.6
19/01/05 16:40	21/02/05 10:31	0.1	0.1	0.1	0.1	0.4
21/02/05 09:53	28/03/05 12:28	0.8	0.2	0.1	0.2	1.3
28/03/05 12:30	18/04/05 14:41	0.1	0.1	0.0	0.1	0.4
18/04/05 14:41	31/05/05 13:15	1.0	0.4	0.2	0.4	1.9
31/05/05 13:20	13/07/05 16:05	0.3	0.2	0.1	0.2	0.7
13/07/05 15:46	07/08/05 15:05	0.3	0.1	0.1	0.2	0.7
07/08/05 15:10	14/09/05 13:00	0.3	0.2	0.1	0.2	0.7
Total		***6.5***	***2.3***	***1.1***	***2.1***	***12.1***
Site 4						
01/08/04 12:09	01/09/04 09:17	0.1	0.4	0.1	0.1	0.7
01/09/04 09:25	07/10/04 09:15	0.9	0.4	0.2	0.2	1.7
07/10/04 09:20	20/11/04 08:20	0.1	0.7	0.3	0.3	1.5
20/11/04 08:20	18/12/04 06:30	1.4	0.6	0.1	0.2	2.2
18/12/04 06:30	18/01/05 10:02	0.2	0.5	0.1	0.2	1.0
18/01/05 10:07	16/02/05 06:30	0.1	0.3	0.1	0.1	0.6
16/02/05 06:45	23/03/05 09:53	0.4	0.4	0.1	0.3	1.1
23/03/05 09:53	28/04/05 08:48	0.2	0.5	0.3	0.2	1.3
28/04/05 08:49	30/05/05 10:40	0.7	0.5	0.1	0.3	1.6
30/05/05 10:40	30/06/05 08:45	0.1	0.2	0.0	0.1	0.5
30/06/05 08:48	08/08/05 08:47	0.4	0.3	0.0	0.3	1.0
08/08/05 08:47	13/09/05 08:43	0.3	0.4	0.1	0.2	1.1
Total		***4.9***	***5.3***	***1.5***	***2.6***	***14.2***
Site 5						
01/08/04 16:04	01/09/04 13:35	0.3	0.6	0.1	0.1	1.2
01/09/04 13:40	07/10/04 11:15	0.6	0.7	0.2	0.3	1.7
07/10/04 11:20	20/11/04 12:40	0.4	1.0	0.3	0.4	2.0
20/11/04 12:40	18/12/04 07:45	0.7	0.5	0.2	0.2	1.6
18/12/04 07:45	18/01/05 12:38	0.2	0.4	0.1	0.2	0.9

Table 15 Cont

Date on	Date off	NH_3 meq m^{-2}	NO_2 meq m^{-2}	SO_2 meq m^{-2}	HNO_3 meq m^{-2}	total meq m^{-2}
18/01/05 12:44	16/02/05 08:30	0.1	0.3	0.1	0.2	0.7
16/02/05 08:15	23/03/05 11:56	0.7	0.4	0.2	0.3	1.5
23/03/05 11:56	28/04/05 10:22	0.5	0.7	0.2	0.3	1.7
28/04/05 10:22	30/05/05 11:40	0.8	0.8	0.1	0.4	2.1
30/05/05 11:40	30/06/05 19:15	0.4	0.6	0.1	0.3	1.4
30/06/05 09:20	08/08/05 09:35	0.4	0.8	0.1	0.3	1.6
08/08/05 09:35	13/09/05 10:32	0.3	0.6	0.1	0.3	1.3
Total		***5.5***	***7.3***	***1.7***	***3.1***	***17.7***
Site 6						
03/08/04 12:29	01/09/04 12:00	0.3	0.4	0.1	0.1	0.9
01/09/04 12:10	07/10/04 10:30	0.4	0.5	0.1	0.2	1.2
07/10/04 10:35	20/11/04 10:30	0.3	0.7	0.2	0.3	1.5
20/11/04 10:30	18/12/04 08:45	1.7	0.5	0.1	0.2	2.4
18/12/04 08:45	18/01/05 11:15	0.9	0.4	0.1	0.2	1.6
18/01/05 11:25	16/02/05 07:20	0.1	0.3	0.1	0.1	0.6
16/02/05 07:30	23/03/05 10:52	0.6	0.5	0.2	0.3	1.5
23/03/05 10:52	28/04/05 09:35	0.2	0.5	0.2	0.2	1.2
28/04/05 09:36	30/05/05 13:00	1.2	0.6	0.1	0.5	2.4
30/05/05 13:00	30/06/05 10:20	0.5	0.3	0.1	0.5	1.4
30/06/05 10:15	08/08/05 10:21	0.4	0.4	0.0	0.2	1.1
08/08/05 10:21	13/09/05 14:35	0.3	0.4	0.1	0.3	1.0
Total		***6.9***	***5.5***	***1.4***	***3.1***	***16.9***
Site 7						
01/08/04 15:01	01/09/04 08:24	0.1	0.3	0.1	0.1	0.6
01/09/04 13:45	07/10/04 13:30	0.4	0.4	0.1	0.2	1.2
07/10/04 13:35	20/11/04 14:35	0.1	0.7	0.2	0.4	1.4
20/11/04 14:35	18/12/04 09:40	0.5	0.3	0.1	0.1	1.1
18/12/04 09:40	18/01/05 15:10	1.2	0.3	0.1	0.2	1.8
18/01/05 15:16	16/02/05 09:15	0.3	0.3	0.1	0.1	0.7
16/02/05 09:30	23/03/05 13:05	0.9	0.3	0.1	0.3	1.6
23/03/05 13:12	28/04/05 11:20	0.2	0.4	0.1	0.2	1.0
28/04/05 11:20	30/05/05 14:10	0.7	0.5	0.1	0.4	1.7
30/05/05 14:10	30/06/05 11:25	0.4	0.2	0.0	0.2	0.9
30/06/05 11:23	08/08/05 11:25	0.4	0.3	0.0	0.2	0.9
08/08/05 11:25	13/09/05 11:41	0.3	0.2	0.1	0.2	0.7
Total		***5.7***	***4.2***	***1.1***	***2.6***	***13.7***

Table 15 Cont

Date on	Date off	NH_3 meq m^{-2}	NO_2 meq m^{-2}	SO_2 meq m^{-2}	HNO_3 meq m^{-2}	total meq m^{-2}
Site 8						
03/08/04 09:07	01/09/04 11:05	0.1	0.4	0.1	0.1	0.8
01/09/04 11:15	07/10/04 15:00	1.0	0.6	0.1	0.3	2.0
07/10/04 15:05	20/11/04 16:30	0.4	0.9	0.2	0.4	1.8
20/11/04 16:30	18/12/04 11:30	0.7	0.5	0.1	0.2	1.5
18/12/04 11:30	18/01/05 17:17	0.2	0.4	0.2	0.2	1.0
18/01/05 17:25	16/02/05 10:40	0.1	0.4	0.1	0.2	0.8
16/02/05 11:15	23/03/05 14:31	1.5	0.4	0.1	0.3	2.4
23/03/05 14:35	28/04/05 11:50	0.2	0.6	0.2	0.3	1.2
28/04/05 11:51	30/05/05 16:00	0.8	0.6	0.1	0.4	1.9
30/05/05 16:01	30/06/05 12:30	0.2	0.3	0.0	0.2	0.8
30/06/05 12:35	08/08/05 12:35	0.4	0.6	0.0	0.3	1.3
08/08/05 12:35	13/09/05 15:50	0.3	0.5	0.1	0.4	1.3
Total		***6.0***	***6.4***	***1.3***	***3.2***	***16.9***
Site 9						
05/08/04 15:00	03/09/04 18:00	1.9	0.5	0.0	0.0	2.5
03/09/04 18:00	07/10/04 20:30	3.0	0.6	0.1	0.1	3.8
07/10/04 20:35	20/11/04 18:00	3.5	0.6	0.1	0.1	4.3
20/11/04 18:00	20/12/04 11:30	3.2	0.4	0.0	0.1	3.6
20/12/04 11:30	20/01/05 10:15		0.3	0.1	0.0	0.4
20/01/05 10:45	16/02/05 18:00	3.2	0.3	0.1	0.1	3.6
16/02/05 18:10	23/03/05 15:20	3.5	0.5	0.0	0.1	4.1
23/03/05 15:26	28/04/05 13:42	2.8	0.6	0.1	0.1	3.6
28/04/05 13:45	30/05/05 18:04	4.7	0.9	0.1	0.2	5.9
30/05/05 18:08	30/06/05 13:30	1.3	0.6	0.0	0.1	2.0
30/06/05 13:25	08/08/05 17:30	2.7	0.8	0.0	0.1	3.7
08/08/05 17:45	15/09/05 18:00	2.1	0.7	0.0	0.2	3.0
Total		***31.9***	***6.7***	***0.7***	***1.1***	***40.4***
Site10						
02/08/04 15:00	01/09/04 10:50	0.3	0.1	0.0	0.0	0.4
01/09/04 10:50	01/10/04 12:35	0.6	0.1	0.0	0.1	0.8
01/10/04 12:35	01/12/04 10:30	0.9	0.1	0.1	0.3	1.4
01/12/04 12:00	27/01/05 14:00	1.1	0.2	0.2	0.3	1.7
27/01/05 14:00	18/02/05 09:30	0.4	0.1	0.1	0.0	0.6
18/02/05 09:30	17/03/05 11:30	1.0	0.1	0.0	0.1	1.3
17/03/05 11:30	28/04/05 08:00	1.6	0.2	0.0	0.3	2.1
28/04/05 08:00	19/05/05 10:00	1.0	0.2	0.1	0.2	1.4
19/05/05 10:15	05/07/05 11:05	1.3	0.2	0.0	0.2	1.7
05/07/05 11:15	05/08/05 13:20	1.0	0.1	0.0	0.3	1.5
05/08/05 13:20	15/09/05 12:00	1.2	0.1	0.0	0.2	1.5
Total		***10.4***	***1.3***	***0.6***	***2.0***	***14.4***

Table 16 displays results for the total of the wet and dry annual deposition flux of nitrogen and sulfur estimated at the various sites, and the proportion of dry deposition. Total wet and dry deposition fluxes are given for sites 3, 5, 6, 7 and 8 since rainwater samples were not collected at Sites 1, 4, 9 or 10. The total annual deposition flux of nitrogen and sulfur varied from 14.3 meq m^{-2} yr^{-1} at Site 3 to 24.3 meq m^{-2} yr^{-1} at Site 6; this represents an increase over the background at Site 3, to the lower Burrup sites which average about 21.1 meq m^{-2} yr^{-1}. The proportion of dry deposition is high at each site, in the range of about 69 % – 85 %, due to the low rainfall amounts compared with a constant deposition of gas to the surface.

Table 16. Notional annual deposition flux of nitrogen and sulfur.

Site	NH_4^+ meq m^{-2}	NO_3^- meq m^{-2}	$*SO_4^{2-}$ meq m^{-2}	NH_3 meq m^{-2}	NO_2 meq m^{-2}	SO_2 meq m^{-2}	HNO_3 meq m^{-2}	Tot Dry meq m^{-2}	Total meq m^{-2}	% Dry
1				4.3	1.8	0.8	1.9	8.8		
3	0.7	0.6	0.9	6.5	2.3	1.1	2.1	12.1	14.3	84.4
4				4.9	5.3	1.5	2.6	14.2		
5	0.9	0.8	1.0	5.5	7.3	1.7	3.1	17.7	20.4	86.7
6	3.6	2.0	1.8	6.9	5.5	1.4	3.1	16.9	24.3	69.3
7	1.7	1.8	2.8	5.7	4.2	1.1	2.6	13.7	19.9	68.8
8	1.1	1.0	0.9	6.0	6.4	1.3	3.2	16.9	19.8	85.3
9	–	–	–	31.9	6.7	0.7	1.1	40.4		
10	–	–	–	10.4	1.3	0.6	2.0	14.4		

The annual nitrogen plus sulfur deposition fluxes measured at the Burrup sites can be compared to previous studies carried out in polluted and unpolluted sites in Malaysia and Indonesia, and a remote site in Australia. At the relatively unpolluted Indonesian GAW station site at Bukit Koto Tabang, the wet plus dry deposition flux of nitrogen plus sulfur was 23.4 meq m^{-2} yr^{-1}, (Gillett et al., 2000) and 53 meq m^{-2} yr^{-1} at a relatively undisturbed site in the Cameron Highlands, north of Kuala Lumpur. In Australia, rainwater composition and gas concentrations were measured at Charles Point, about 13 kilometres west of Darwin, across Port Darwin and the annual wet and dry deposition flux of nitrogen plus sulfur was about 20 meq m^{-2} yr^{-1} at this site (Ayers et. al., 2000).

The critical load concept can be used to compare with deposition fluxes to determine if adverse effects could result to rock or aboriginal rock art. For a fuller discussion of this see Ayers et al. (2000). The critical load has been defined as “a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified elements of the environment do not occur according to our current knowledge” (Nilsson and Grennfelt, 1988). In a global assessment of ecosystem sensitivity to acidic deposition Cinderby et al. (1998) have determined a critical load or deposition flux of 25 meq m^{-2} yr^{-1} for the most sensitive areas of the world. This means that depositions of about 25 meq m^{-2} yr^{-1} would only have a detrimental effect on the most sensitive ecosystems. The depositions presented in Table 16 indicate that some sites are subject to depositions of about 25 meq m^{-2} yr^{-1}. Given that the overall precision of passive gas measurements in this study was about ± 20% Site 6, for example, would have a deposition flux ranging from about 19.5 meq m^{-2} yr^{-1} to 29.2 meq m^{-2} yr^{-1}, which is only just above that for areas which are very sensistive to acid deposition. In fact the assessment by Cinderby et al. (1988) lists 5 sensitivity classes consisting of 25 meq m^{-2} yr^{-1}, 50 meq m^{-2} yr^{-1}, 100 meq meq m^{-2} yr^{-1}, 150 meq meq m^{-2} yr^{-1}, 200 meq m^{-2} yr^{-1} and >200 meq meq m^{-2} yr^{-1}, and places the Burrup area in the least sensitive class. This means that the critical load for the Burrup area is at least 200 meq m^{-2} yr^{-1}, and since this is significantly more than the observed deposition fluxes at the sites they are unlikely to cause any deleterious effects to rock or rockart on the Burrup Peninsula.

The deposition fluxes estimated for any of the Burrup sites are very low when compared to heavily polluted areas in Malaysia and Indonesia. In the heavily polluted urban site at Petaling Jaya, near Kuala Lumpur the total deposition flux of nitrogen and sulfur ranged from 279 meq m^{-2} yr^{-1} to 483 meq m^{-2} yr^{-1}, over 5 consecutive years from 1990 to 1998 (Ayers et al., 2000). At other polluted sites in Malaysia total wet and dry deposition fluxes ranged from 122 meq m^{-2} yr^{-1} to 345 meq m^{-2} yr^{-1} (Ayers et al., 2000). In a study by Gillett et al. (2000) at Jakarta and Bogor total deposition fluxes of nitrogen and sulfur were about 240 meq m^{-2} yr^{-1} were estimated during 1992 and 1996.

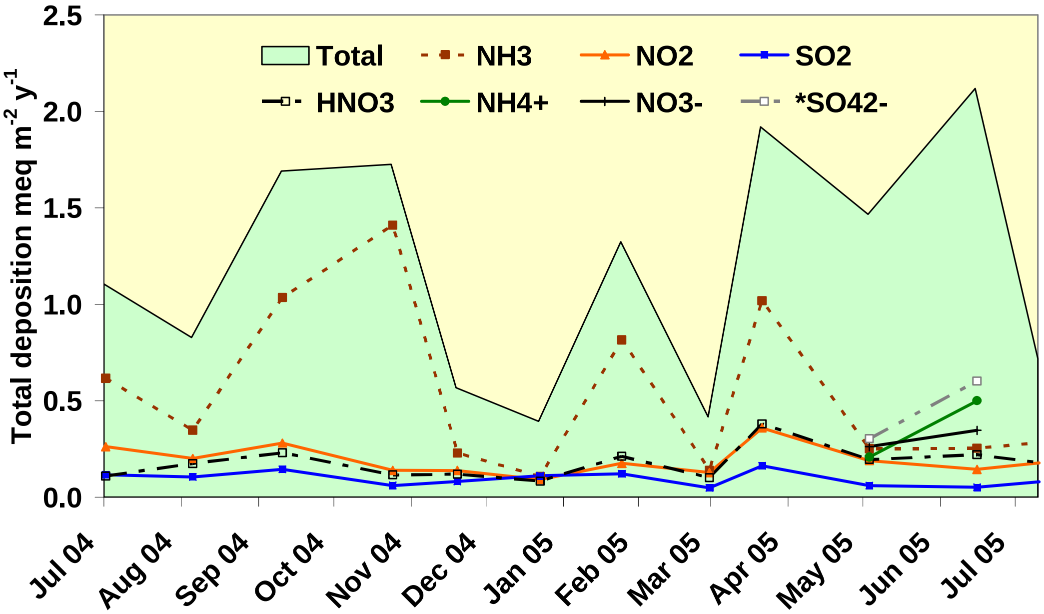


Figure 22. Total annual deposition of nitrogen and sulfur at site 3.

Figures 22 and 23 show the contributions the various sources of nitrogen and sulfur make to the total wet and dry deposition flux of nitrogen and sulfur estimated for Site 3 and Site 6. Figure 22 shows that for most months deposition of ammonia is the largest contributor to the total annual sulfur and nitrogen deposition flux at Site 3; on an annual basis it contributes about 45% of the total deposition. This is because the other gases have a lower deposition flux at the background sites, and because ammonia appears to be derived from natural sources, since the concentrations vary little from site to site. The contribution of ammonia deposition flux is reduced during the periods when rain fell due to the supplementary contributions to the total deposition flux in the form of non sea-salt sulfate, ammonium and nitrate derived from rain. Over the whole year dry deposition at site 3 is about 84 % of the total deposition and nitrogen deposition accounts for about 86 % of the total compared with only about 13 % for sulfur.

The monthly deposition fluxes of sulfur and nitrogen at Site 6, and their individual contributions to them are shown in Figure 23. At this site nitrogen deposition, from ammonia gas, makes a large fraction of the total deposition during a few of the months. During other periods nitrogen deposition from nitrogen dioxide is a significant proportion of the total deposition flux. During the period around the 16th February 2005 wet deposition of ammonium, nitrate and sulfate make large contributions to the total flux during that month. Dry deposition over the whole year is about 69 % and nitrogen deposition is about 87 % compared with only about 13 % deposition of sulfur.

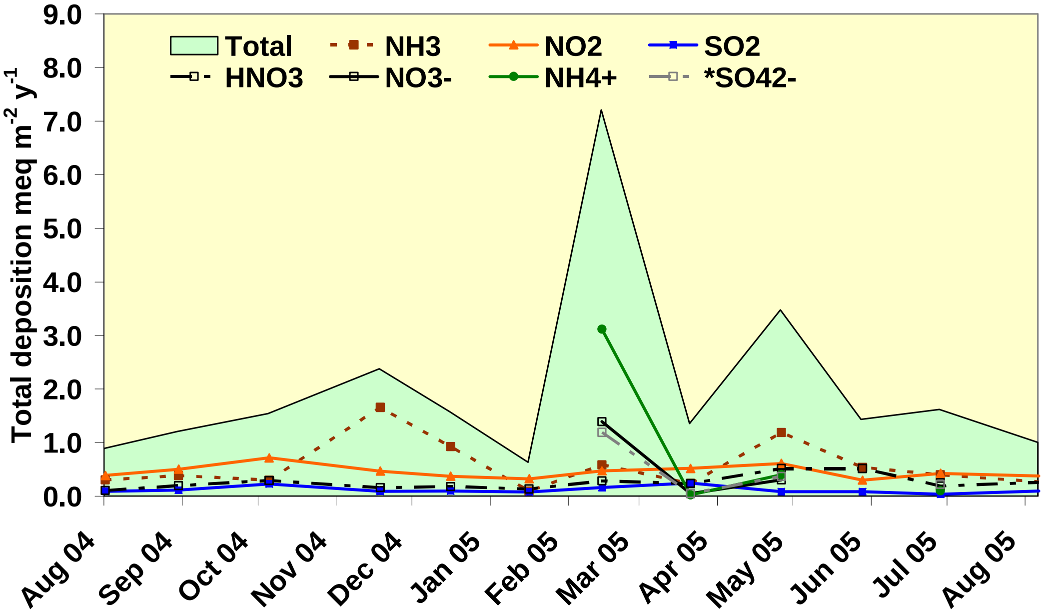


Figure 23. Total annual deposition of nitrogen and sulfur at site 6.

5.7 Comparison with modelling studies.

The annual average concentration of nitrogen dioxide, sulfur dioxide and ammonia, and their deposition are provided in this study, and they can be used to compare with the results of a modelling study (SKM, 2003). SKM, (2003) modelled annual average nitrogen dioxide concentrations around the Burrup Peninsula area using two model approaches: TAPM and CALPUFF. In both cases the modelling was done for the industry which was located on the Burrup Peninsula in 2003.

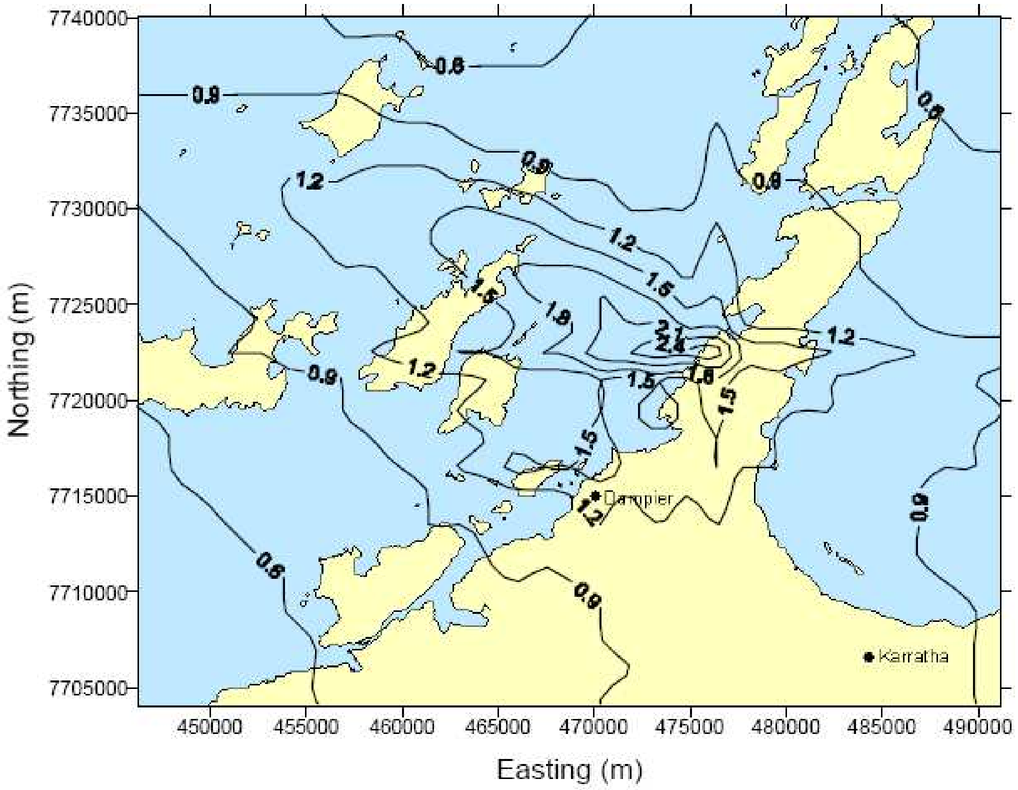


Figure 24. TAPM predicted annual nitrogen dioxide concentrations (ppb) for existing industry (SKM, 2003).

Figure 24 shows the results nitrogen dioxide concentrations predicted by TAPM modelling for the Burrup Peninsula, and the surrounding region. The TAPM model results suggest higher nitrogen dioxide concentrations compared with the results of the CALPUFF modelling shown in Figure 25. The results of nitrogen dioxide concentrations produced in TAPM and CALPUFF modelling are summarised in Table 17, and compared with annual average concentrations at the sites used in the current study.

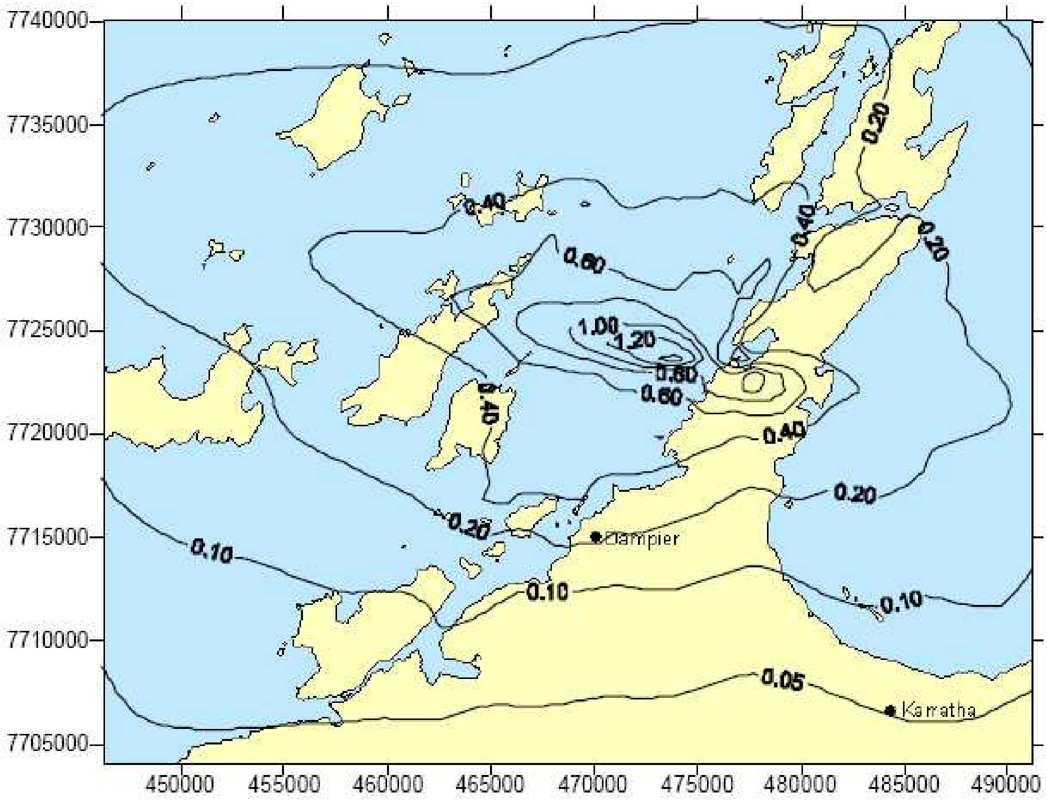


Figure 25. CALPUFF predicted annual nitrogen dioxide concentrations (ppb) for existing industry, (SKM, 2003).

Of the two modelling approaches, TAPM appears to compare much better with the measured values generated during this study. The modelled CALPUFF results appear to be underestimated at all sites, when compared to the measurements. The TAPM results however, are quite close to the measured concentrations at Sites 1, 3 and 4, and a little lower than the measured results at the other sites. At Site 9, Karratha the TAPM modelled result is about 1 ppb and appears to underestimate the nitrogen dioxide concentration of 2.22 measured at this site.

Table 17 Annual average nitrogen dioxide concentrations at Burrup sites produced by TAPM and CALPUFF modelling, and measured nitrogen dioxide concentrations at the sites.

Site	Measured ppb	TAPM ppb	CALPUFF ppb
1	0.59	0.7	0.20
3	0.74	0.8	0.20
4	1.75	1.8	1.00
5	2.41	1.4	0.35
6	1.83	1.4	0.30
7	1.44	1.4	0.25
8	2.12	1.4	0.30
9	2.22	1.0	0.05

The deposition fluxes of nitrogen dioxide produced from TAPM modelling are presented in Figure 26, in kg ha^{-1} yr^{-1}. Table 18 shows these results compared with the estimated nitrogen deposition fluxes generated in this measurement program. The TAPM modelled results are converted from kg ha^{-1} yr^{-1} to meq m^{-2} yr^{-1} in order to make the comparison. The data in the Table show that the TAPM results are substantially less than those estimated by measurements. This is in part due to the lower nitrogen dioxide concentrations TAPM predicts at some sites; Site 9, for example. The other reason is probably due to the deposition velocity used in TAPM compared to the values used in this study. When the concentration ratio between TAPM and this study is considered, the ratio of the deposition flux produced in this study appears to be about 3.3 times that from TAPM. This suggests that the deposition rate used in this study is about 3.3 times that in TAPM. Deposition fluxes of nitrogen dioxide estimated from CALPUFF are not considered here since they were much lower than the TAPM predictions.

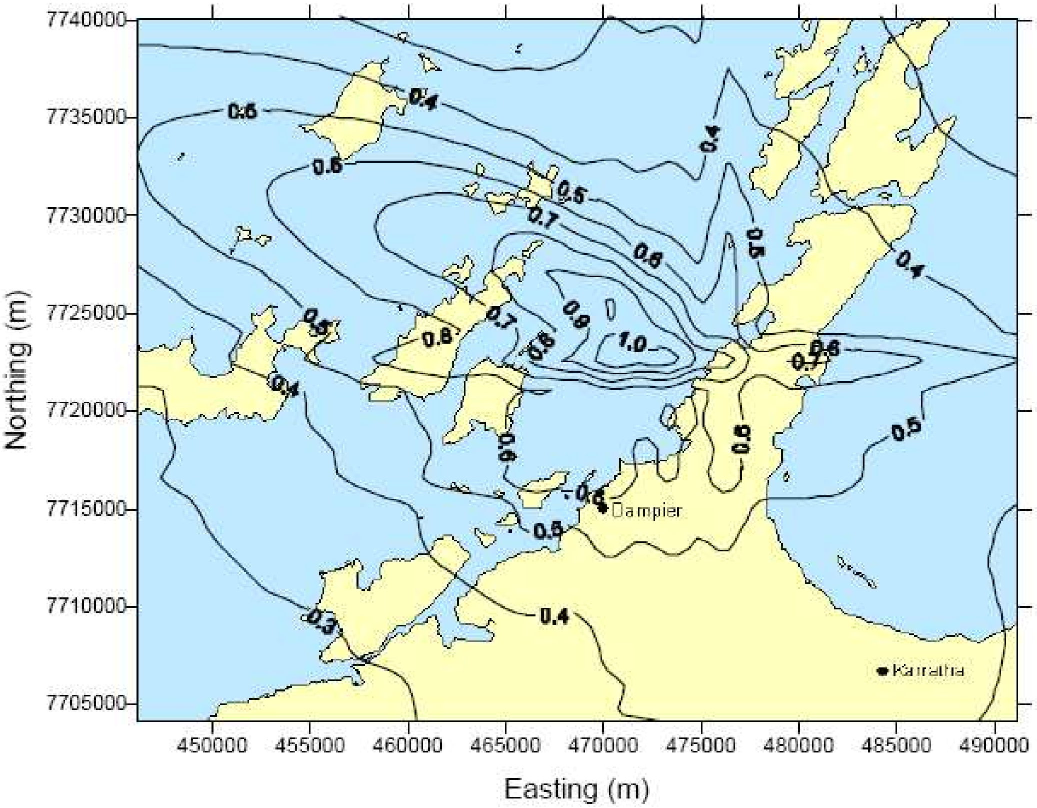


Figure 26. TAPM predicted annual nitrogen dioxide deposition (kg ha^{-1} yr^{-1}) for existing industry, (SKM, 2003).

Table 18. Annual average deposition flux of nitrogen dioxide estimated from measurements at the Burrup Peninsula sites compared with TAPM model results.

Site	Measured meq m^{-2} yr^{-1}	TAPM meq m^{-2} yr^{-1}
1	1.82	0.54
3	2.29	0.91
4	5.25	1.06
5	7.34	1.30
6	5.49	1.28
7	4.20	1.30
8	6.39	1.30
9	6.73	0.93

In the report by SKM (2003) TAPM and CALPUFF models were used to predict the annual average sulfur dioxide concentrations for the industrial conditions existing at that time. Figures 27 and 28 are taken from SKM (2003), and show the sulfur dioxide concentrations predicted by TAPM and CALPUFF respectively. The minimum sulfur dioxide concentration predicted by TAPM is 100 ppt and the maximum is about 600 ppt in contours just north and east of Dampier. CALPUFF modelling shown in Figure 28 gives more detailed results; the minimum contour is 20 ppt and the maximum is about 800 ppt near East Intercourse Island, immediately east of Dampier.

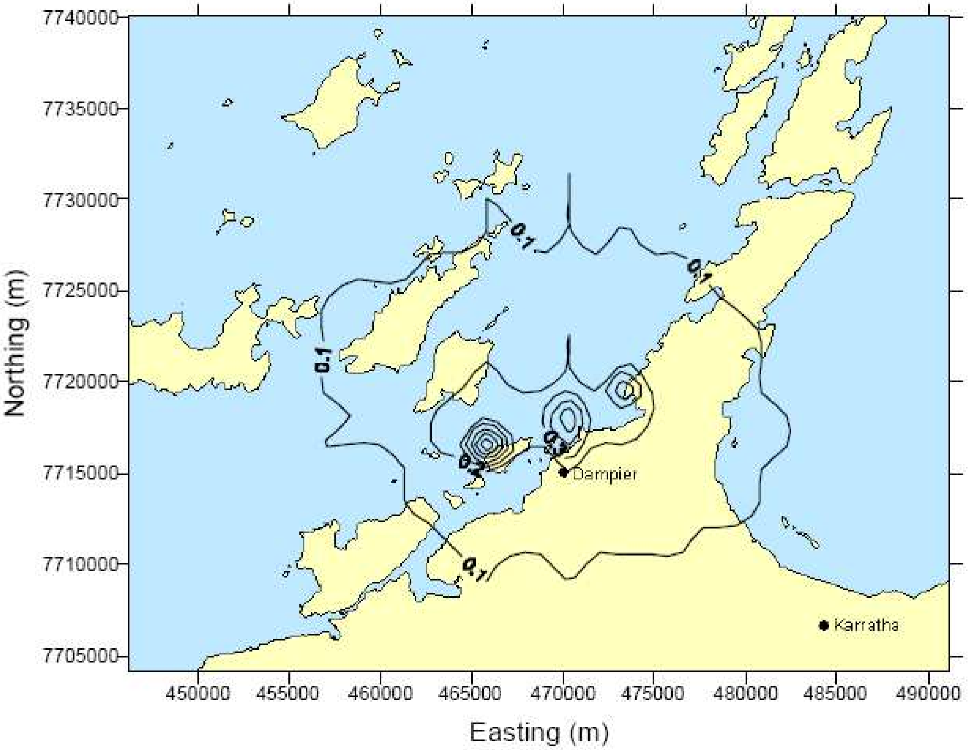


Figure 27. TAPM predicted annual sulfur dioxide concentrations (ppb) for existing industry (SKM, 2003).

A summary of the annual average concentrations of sulfur dioxide estimated by TAPM and CALPUFF modelling and measured in the current study is given in Table 19. The Table shows that the measured sulfur dioxide concentrations are quite close to the concentrations predicted by both TAPM and CALPUFF. The concentrations measured in this study generally seem to be a little higher than the modelled results, especially for TAPM, which gives lower values than CALPUFF, except at Site 8 which has measured concentrations slightly lower than the models predict.

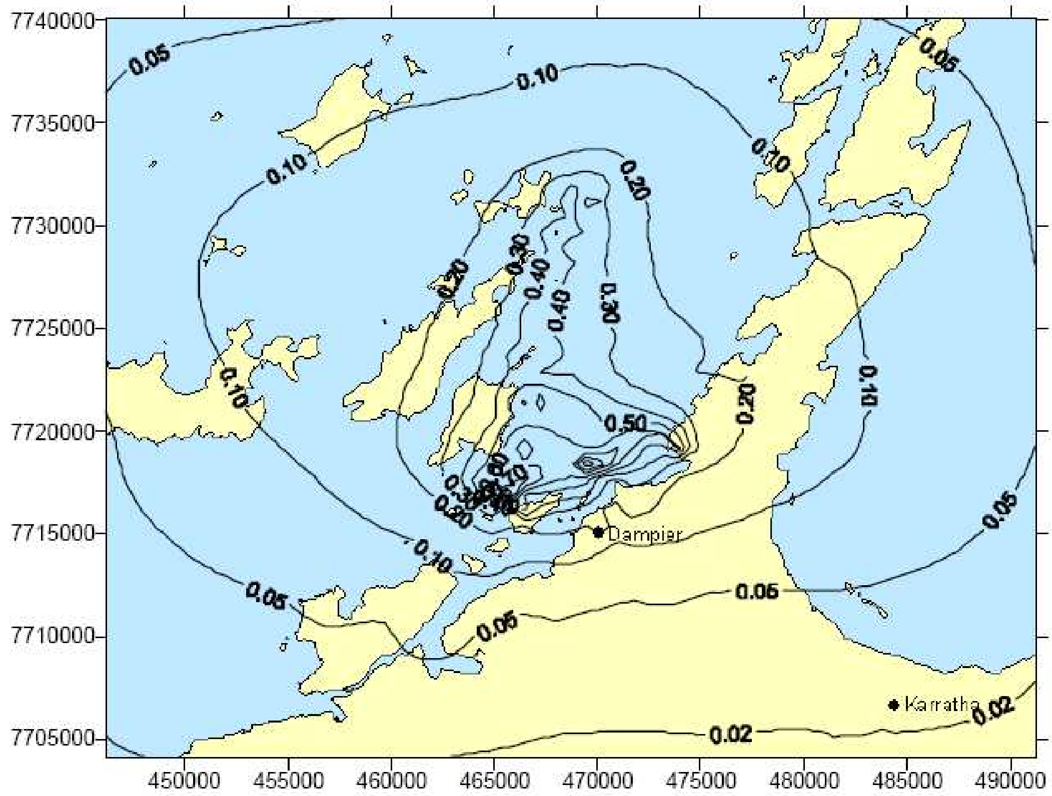


Figure 28. CALPUFF predicted annual sulfur dioxide concentrations (ppb) for existing industry (SKM, 2003).

Table 19 Annual average sulfur dioxide concentrations at Burrup sites produced by TAPM and CALPUFF modelling, and measured sulfur dioxide concentrations at the sites.

Site	Measured ppt	TAPM ppt	CALPUFF ppt
1	101	<100	50
3	139	<100	90
4	178	130	200
5	215	190	220
6	241	120	170
7	141	150	130
8	164	220	250
9	89	<100	28

The deposition fluxes have also been predicted using TAPM and CALPUFF models and the results of these are taken from SKM, (2003), and are displayed in Figures 29 and 30. A summary of these results, converted to meq m^{-2} yr^{-1}, are given in Table 20, along with the results measured at each site. The Table shows that the TAPM and CALPUFF results range from <0.16 meq m^{-2} yr^{-1} at Site 9 to 0.78 meq m^{-2} yr^{-1} at Site 8. However, the deposition fluxes estimated from the gas concentration measured in this study, and the deposition velocity are significantly greater than the fluxes suggested by the models. The measured fluxes are usually a factor of about 3 – 5 times more than the model predictions, and this may be due to the deposition velocities used in the conversion of the gas concentration to a deposition flux.

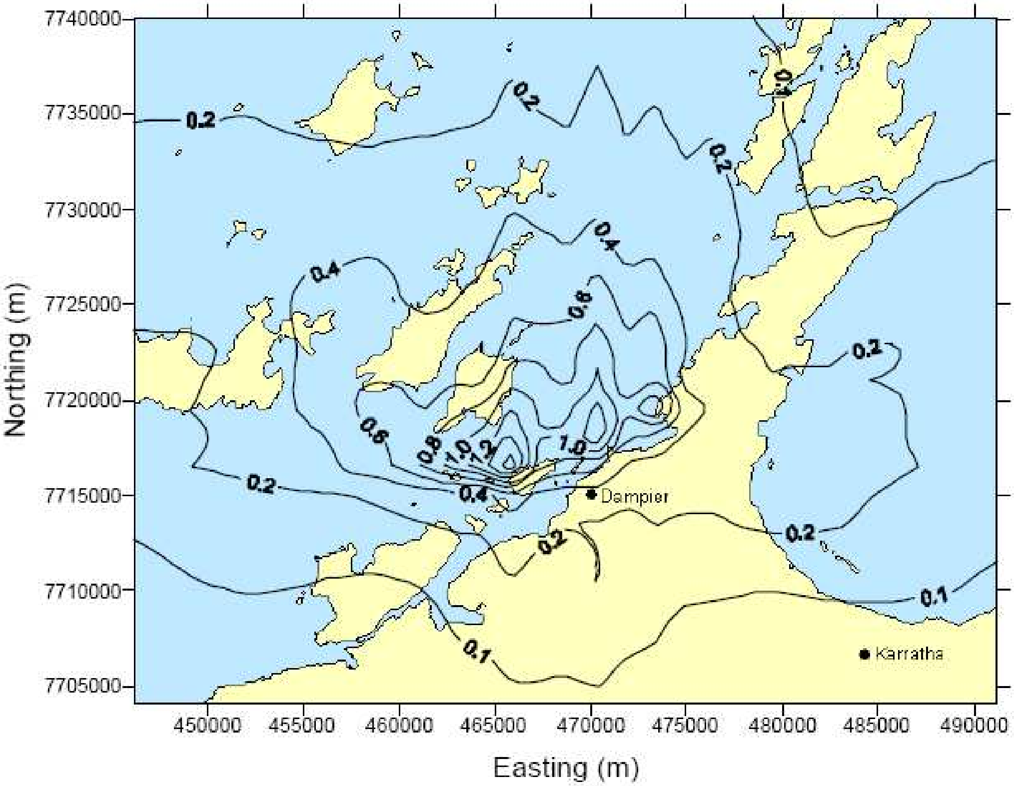


Figure 29. TAPM predicted annual sulfur dioxide deposition (kg ha^{-1} yr^{-1}) for existing industry (SKM, 2003).

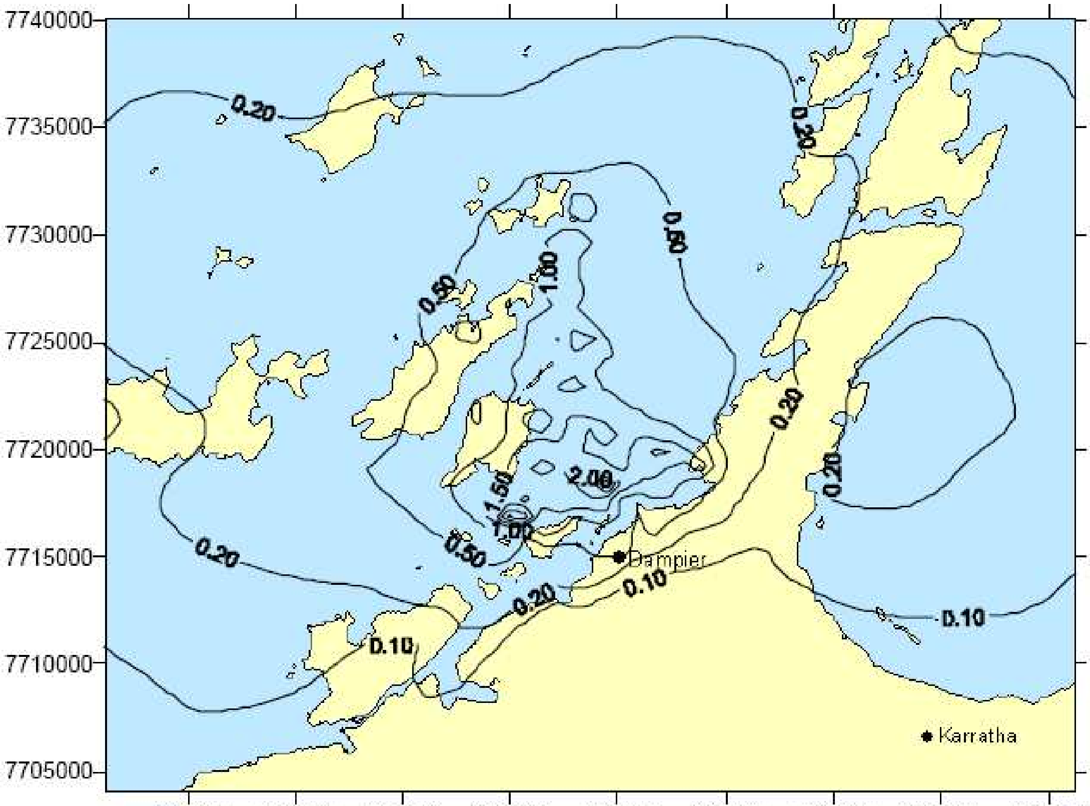


Figure 30. CALPUFF predicted annual sulfur dioxide deposition (kg ha^{-1} yr^{-1}) for existing industry (SKM, 2003).

Table 20. Annual average deposition flux of sulfur dioxide estimated from measurements at the Burrup Peninsula sites compared with TAPM model results.

Site	Measured meq m^{-2} yr^{-1}	TAPM meq m^{-2} yr^{-1}	CALPUFF meq m^{-2} yr^{-1}
1	0.81	0.16	0.22
3	1.14	0.16	0.30
4	1.46	0.42	0.45
5	1.74	0.62	0.55
6	1.42	0.55	0.31
7	1.15	0.55	0.31
8	1.32	0.62	0.78
9	0.70	0.13	<0.16

6. SUMMARY AND CONCLUSIONS

This document reports results from a 12 month study of air pollution and rainwater composition on the Burrup Peninsula from the beginning of August 2004 until September 2005. A total of nine sites were used in the study, 7 of these, Sites 1, 3, 4, 5, 6, 7, and 8, were on the Burrup Peninsula, one was located in Karratha, and the other at Mardie Station 81 Km from Karratha on a bearing of 215º. The study incorporated measurements of concentrations of gases including sulfur dioxide, nitrogen dioxide, nitric acid, ammonia and BTEX gases. TSP samples were collected at seven sites, and conditional sampling for PM_{10} was carried out at Site 8 and near the ore loading facilities at Parker Point. Sampling was conducted over monthly periods and TSP concentration and chemical composition were measured on the samples. Measurements of ionic composition and pH were made on rainwater samples collected at 5 sites 3, 5, 6, 7 and 8, over monthly sampling periods. An aerosol spectrometer was used to measure the size distribution of TSP at each of the sites over a limited period. Size distributions from the measurements were converted to mass concentration and deposition flux to estimate the magnitude of dust deposition at the sites on the Burrup.

The gas concentrations presented show that in all cases, concentrations are very low compared to polluted urban areas. Local background concentrations, deduced from sites 1, 3 and 10 were ammonia 0.5 ppb, nitrogen dioxide 0.6 ppb, sulfur dioxide 108 ppt and nitric acid 155 ppt. Ammonia concentrations showed little spatial variation in concentration indicating that most ambient ammonia has a natural source. There was some small enhancement of nitrogen dioxide, sulfur dioxide and nitric acid concentrations over those at sites which are assumed to represent the local back ground. Even so, the concentrations of ammonia, nitrogen dioxide, sulfur dioxide and nitric acid are very low compared with measurements made at other remote locations. BTEX concentrations were also very low at all sites and for all sampling periods. The benzene concentration at the background sites 1, 3 and 10 was about 19 ppt and the average at the other sites about 21 ppt. Benzene, and other BTEX gas concentrations showed little enhancement over the background levels suggesting that their concentration has a large natural component.

For particulate mass (TSP) concentrations, sites 1 and 3, which were taken to represent the local background level, had an annual average concentration of about 18 $\mu g\ m^{-3}$. In contrast to this the annual average concentrations on the lower Burrup was about 31 $\mu g\ m^{-3}$. TSP on the lower Burrup, where most of the industrial and anthropogenic activities occur, is moderately enhanced over the local background concentration. Samples colleted near Parker Point and at other sites were analysed for a range of elements including iron. TSP at Sites 4, 5, 7 and 8 had a higher fraction of iron and less sea-salt than the background TSP at Site 1. This suggests that the observed increase in TSP at these sites could be due to dust from the ore loading and transportation processes. This suggestion is reinforced by enhanced PM_{10} concentrations during a number of periods at Site 8 when the air was passing over the ore loading facilities at Parker Point.

An aerosol spectrometer was used for a short period to produce particle mass-size distribution data and dust deposition fluxes at each of the sites. The average mass concentrations of 30 $\mu g\ m^{-3}$ calculated from the aerosol spectrometer data at Site 8 are consistent with those measured with the DustTrak instrument. The dust deposition flux at Sites 1 and 3 averaged about 10 mg m^{-2} day^{-1} compared to about 68 mg m^{-2} day^{-1} at site 8 and about 30 mg m^{-2} day^{-1} at sites 4, 5, 6, and 7. They indicate a higher dust deposition flux in the more industrialised area of the Burrup, especially at Site 8 which is closest to the ore loading facilities.

The total deposition flux of nitrogen and sulfur was determined at sites 3, 5, 6, 7 and 8. This included dry deposition in the form of ammonia, nitrogen dioxide, sulfur dioxide and nitric acid gases, and in the form of nitrate, ammonia and non sea-salt sulfate in rainwater. The measurements are similar to previous measurements recorded at another remote location in Australia, and lower than relatively unpolluted sites in Malaysia, and at the Indonesian GAW station. The deposition fluxes at each site were very low and lower than the critical load for even the most sensitive areas to nitrogen and sulfur deposition. Previous ecological studies have suggested that the Burrup Peninsula area is quite insensitive to acid deposition, and a corollary is that the deposition flux of nitrogen and sulfur is only a small fraction of the critical load. The deposition fluxes observed are not of the magnitude which is expected to cause any deterioration of the rock on the Burrup Peninsula.

A comparison of the concentrations of nitrogen dioxide and sulfur dioxide concentrations observed in this study was made with results of modelled concentrations predicted using TAPM and CALPUFF. Nitrogen dioxide concentrations at Sites 1, 3 and 4 compared favourably with TAPM predictions, but tended to be a little higher at the other sites especially at Site 9 Karratha, where the measured concentration was about double that predicted by TAPM. The concentrations measured in this study were much higher than those predicted by CALPUFF. CALPUFF predicts higher sulfur dioxide concentrations than TAPM and are more consistent with the concentrations measured in this study.

Both TAPM and CALPUFF provide deposition fluxes of nitrogen and sulfur and comparisons with the measured fluxes shows that the models always predict less than that suggested by the measured values provided by the current study. The average annual nitrogen dioxide deposition fluxes predicted by TAPM are lower than the measured values by a factor of between about 2 and 5, and may be due to a combination of a lower TAPM predicted concentration and the deposition velocity used in the current study. The predicted deposition fluxes of sulfur dioxide from TAPM and CALPUFF models are similar to each other, but less than those measured in the current study. Measured deposition fluxes are higher than the models by a factor of around 2 to 5, and this may be due to the deposition velocities used in the models, and in the current study.

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9. APPENDIX

Table A1. Elemental concentrations of TSP and PM$_{10}$ samples at various sites measured by PIXE analysis.

Site	Date on	Date off	Na μg m^{-3}	Al μg m^{-3}	Si μg m^{-3}	P μg m^{-3}	S μg m^{-3}	Cl μg m^{-3}	K μg m^{-3}	Ca μg m^{-3}
1	29/07/04	02/09/04	2.822	0.107	0.520	0.000	0.235	2.151	0.094	0.202
1	02/09/04	08/10/04	3.405	0.133	0.556	0.000	0.354	2.321	0.131	0.203
1	08/10/04	21/11/04	5.020	0.238	0.945	0.000	0.644	2.848	0.284	0.341
1	21/11/04	17/12/04	8.232	0.364	1.331	0.000	0.857	5.752	0.315	0.495
1	17/12/04	19/01/05	8.574	0.313	1.329	0.000	0.972	5.856	0.272	0.690
1	19/01/05	21/02/05	9.597	0.267	0.977	0.000	0.908	6.842	0.237	0.556
1	21/02/05	28/03/05	5.784	0.451	1.637	0.000	0.681	3.337	0.239	0.358
1	28/03/05	18/04/05	3.092	0.153	0.686	0.000	0.455	1.920	0.109	0.149
1	18/04/05	31/05/05	1.919	0.340	0.549	0.025	0.301	1.886	0.279	0.149
1	31/05/05	13/07/05	0.000	0.208	0.643	0.001	0.153	1.133	0.063	0.098
1	13/07/05	07/08/05	2.411	0.080	0.332	0.000	0.273	1.494	0.061	0.097
1	07/08/05	14/09/05	3.005	0.145	0.351	0.000	0.278	2.145	0.083	0.125
4	01/08/04	01/09/04	2.138	0.247	0.828	0.000	0.223	1.912	0.116	0.709
4	01/09/04	07/10/04	0.636	0.130	0.559	0.000	0.118	0.842	0.071	0.619
4	07/10/04	20/11/04	3.240	0.900	3.415	0.000	0.699	4.279	0.495	3.610
4	20/11/04	18/12/04	8.251	1.175	3.916	0.000	0.835	5.532	0.560	3.427
4	18/12/04	18/01/05	9.681	1.078	4.006	0.000	0.976	6.477	0.500	4.645
4	18/01/05	16/02/05	8.495	0.819	2.917	0.000	0.938	6.326	0.416	3.734
4	16/02/05	23/03/05	5.632	0.863	3.125	0.000	0.617	3.605	0.364	2.150
4	23/03/05	28/04/05	2.306	0.566	1.987	0.000	0.426	1.841	0.216	2.004
4	28/04/05	30/05/05	1.705	0.420	1.550	0.000	0.384	1.710	0.230	1.623
4	30/05/05	30/06/05	4.373	0.191	0.791	0.000	0.355	3.475	0.149	0.297
4	30/06/05	08/08/05	1.223	0.248	0.917	0.000	0.273	1.310	0.099	0.638
4	08/08/05	13/09/05	2.949	0.628	2.112	0.000	0.310	2.210	0.245	2.845
5	07/10/04	20/11/04	4.411	0.387	1.526	0.000	0.676	3.015	0.327	0.508
5	18/01/05	16/02/05	7.665	0.407	1.485	0.000	0.753	5.277	0.228	0.523
5	16/02/05	23/03/05	4.192	0.661	2.363	0.000	0.481	2.155	0.271	0.533
5	23/03/05	28/04/05	2.022	0.351	1.280	0.000	0.345	0.915	0.143	0.349
5	28/04/05	30/05/05	1.186	0.284	1.026	0.000	0.329	0.850	0.179	0.280
5	08/08/05	13/09/05	2.383	0.200	0.738	0.000	0.281	1.705	0.112	0.278
7	01/08/04	01/09/04	2.411	0.332	1.277	0.000	0.212	1.986	0.148	0.456
7	01/09/04	07/10/04	2.363	0.337	1.200	0.000	0.268	1.673	0.150	0.543
7	07/10/04	20/11/04	4.526	0.563	1.913	0.000	0.597	2.967	0.329	0.802
7	20/11/04	18/12/04	6.524	1.017	3.318	0.000	0.849	4.812	0.438	1.269
7	18/12/04	18/01/05	6.927	0.701	2.707	0.000	0.740	5.088	0.327	1.188
7	18/01/05	16/02/05	22.390	2.045	7.481	0.000	2.172	16.370	0.951	3.087
7	16/02/05	23/03/05	3.920	0.772	2.685	0.000	0.455	2.310	0.289	0.679
7	23/03/05	28/04/05	2.156	0.549	1.687	0.000	0.341	1.247	0.174	0.691
7	28/04/05	30/05/05	2.208	0.285	0.869	0.000	0.333	1.257	0.155	0.320
7	30/05/05	30/06/05	3.904	0.152	0.567	0.000	0.272	2.905	0.107	0.205
7	30/06/05	08/08/05	2.070	0.180	0.685	0.000	0.251	1.338	0.090	0.278
7	08/08/05	13/09/05	2.751	0.235	0.790	0.000	0.271	1.902	0.110	0.411
8	03/08/04	01/09/04	1.783	0.351	1.251	0.000	0.208	1.772	0.127	0.501
8	01/09/04	07/10/04	2.702	0.370	1.286	0.000	0.292	1.748	0.151	0.522
8	07/10/04	20/11/04	4.557	0.694	2.308	0.000	0.541	3.046	0.302	1.167
8	20/11/04	18/12/04	6.306	0.771	2.341	0.000	0.844	4.738	0.373	1.059

Table A1 cont

Site	Date on	Date off	Na µg m^{-3}	Al µg m^{-3}	Si µg m^{-3}	P µg m^{-3}	S µg m^{-3}	Cl µg m^{-3}	K µg m^{-3}	Ca µg m^{-3}
8	18/12/04	18/01/05	8.129	0.848	3.250	0.000	1.058	6.813	0.392	1.291
8	18/01/05	16/02/05	9.630	1.297	4.481	0.000	0.967	6.671	0.508	1.964
8	16/02/05	23/03/05	3.281	0.621	2.114	0.000	0.411	2.082	0.226	0.550
8	23/03/05	28/04/05	12.630	2.041	7.251	0.000	1.732	7.730	0.745	2.192
8 Cond	04/08/04	01/09/04	1.282	0.219	0.747	0.002	0.162	1.408	0.084	0.291
8 Cond	01/09/04	07/10/04	1.146	0.256	0.913	0.001	0.280	1.740	0.126	0.304
8 Cond	07/10/04	20/11/04	0.000	0.475	1.634	0.006	0.568	1.757	0.383	0.485
8 Cond	20/11/04	18/12/04	0.000	0.823	2.781	0.001	0.664	2.940	0.516	0.452
8 Cond	18/12/04	18/01/05	4.063	1.357	3.862	0.000	0.748	4.496	0.400	0.905
8 Cond	18/01/05	16/02/05	5.949	0.932	2.705	0.000	0.762	6.874	0.327	0.763
8 Cond	16/02/05	23/03/05	2.364	0.766	2.381	0.000	0.577	2.687	0.250	0.416
8 Cond	23/03/05	28/04/05	0.000	0.462	1.039	0.000	0.304	0.761	0.111	0.237
8 Cond	28/04/05	30/05/05	1.345	0.205	0.616	0.000	0.353	1.109	0.142	0.188
8 Cond	30/05/05	30/06/05	3.120	0.181	0.556	0.000	0.274	2.464	0.106	0.232
8 Cond	30/06/05	08/08/05	1.428	0.264	0.596	0.001	0.233	0.856	0.070	0.260
8 Cond	08/08/05	13/09/05	2.066	0.303	0.898	0.001	0.249	1.780	0.110	0.399
8Hi	04/08/04	02/09/04	3.367	1.497	4.282	0.000	0.355	2.714	0.370	1.706
8Hi	02/09/04	08/10/04	3.573	0.923	2.547	0.000	0.419	2.402	0.301	1.783
8Hi	08/10/04	30/11/04	5.749	1.074	2.857	0.000	0.522	3.264	0.405	2.838
8Hi	30/11/04	20/12/04	7.193	1.214	3.034	0.000	0.754	5.317	0.376	3.668
8Hi	20/12/04	20/01/05	8.472	0.731	1.804	0.000	1.019	6.148	0.294	1.297
8Hi	20/01/05	23/02/05	58.009	5.862	17.449	0.000	5.822	38.542	2.543	19.839
8Hi	23/02/05	31/03/05	4.881	0.955	2.577	0.000	0.663	2.844	0.289	1.446
8Hi	31/03/05	02/05/05	3.465	1.365	4.087	0.000	0.516	1.727	0.409	1.651
8Hi	02/05/05	09/06/05	2.051	1.802	4.535	0.009	0.422	1.337	0.373	1.407
8Hi	09/06/05	01/07/05	0.000	1.160	1.987	0.021	0.197	2.053	0.077	0.267
8Hi	01/07/05	09/08/05	0.000	1.723	2.529	0.063	0.299	1.202	0.096	0.616
8Hi	09/08/05	16/09/05	4.152	1.200	2.673	0.000	0.487	2.849	0.233	2.668

Table A2. Elemental concentrations of TSP and PM_{10} samples at various sites measured by PIXE analysis.

Site	Date on	Date off	Ti µg m^{-3}	V µg m^{-3}	Cr µg m^{-3}	Mn µg m^{-3}	Fe µg m^{-3}	Co µg m^{-3}	Ni µg m^{-3}	Cu µg m^{-3}
1	29/07/04	02/09/04	0.017	0.002	0.000	0.007	0.771	0.004	0.000	0.000
1	02/09/04	08/10/04	0.016	0.002	0.002	0.008	0.616	0.007	0.001	0.002
1	08/10/04	21/11/04	0.025	0.004	0.000	0.013	0.874	0.012	0.000	0.004
1	21/11/04	17/12/04	0.039	0.000	0.000	0.010	0.647	0.008	0.004	0.013
1	17/12/04	19/01/05	0.041	0.000	0.000	0.014	0.754	0.007	0.002	0.004
1	19/01/05	21/02/05	0.032	0.000	0.000	0.011	0.451	0.000	0.000	0.001
1	21/02/05	28/03/05	0.053	0.002	0.004	0.018	1.012	0.008	0.003	0.010
1	28/03/05	18/04/05	0.017	0.004	0.000	0.006	0.537	0.002	0.001	0.004
1	18/04/05	31/05/05	0.017	0.000	0.003	0.007	0.471	0.005	0.004	0.001
1	31/05/05	13/07/05	0.012	0.004	0.009	0.014	0.585	0.001	0.003	0.025
1	13/07/05	07/08/05	0.010	0.002	0.001	0.006	0.501	0.003	0.000	0.000
1	07/08/05	14/09/05	0.011	0.003	0.000	0.007	0.482	0.003	0.000	0.001
4	01/08/04	01/09/04	0.027	0.000	0.002	0.012	0.945	0.009	0.001	0.005
4	01/09/04	07/10/04	0.019	0.000	0.006	0.010	0.826	0.007	0.001	0.002
4	07/10/04	20/11/04	0.122	0.010	0.000	0.070	4.319	0.043	0.003	0.012
4	20/11/04	18/12/04	0.154	0.000	0.002	0.044	2.366	0.037	0.005	0.007
4	18/12/04	18/01/05	0.155	0.000	0.000	0.043	2.766	0.028	0.000	0.001
4	18/01/05	16/02/05	0.121	0.008	0.000	0.045	2.234	0.025	0.000	0.007
4	16/02/05	23/03/05	0.119	0.002	0.002	0.040	2.920	0.032	0.001	0.005
4	23/03/05	28/04/05	0.074	0.003	0.000	0.021	1.867	0.018	0.000	0.003
4	28/04/05	30/05/05	0.055	0.001	0.004	0.020	1.264	0.013	0.000	0.007
4	30/05/05	30/06/05	0.019	0.001	0.003	0.016	0.896	0.010	0.003	0.004
4	30/06/05	08/08/05	0.034	0.001	0.001	0.012	0.975	0.008	0.001	0.001
4	08/08/05	13/09/05	0.084	0.000	0.001	0.023	1.743	0.016	0.000	0.001
5	07/10/04	20/11/04	0.044	0.004	0.001	0.029	4.080	0.023	0.000	0.005
5	18/01/05	16/02/05	0.047	0.002	0.000	0.022	1.707	0.025	0.000	0.005
5	16/02/05	23/03/05	0.084	0.003	0.003	0.030	2.967	0.025	0.003	0.011
5	23/03/05	28/04/05	0.044	0.002	0.002	0.025	2.559	0.023	0.003	0.019
5	28/04/05	30/05/05	0.031	0.001	0.001	0.018	1.968	0.014	0.000	0.006
5	08/08/05	13/09/05	0.027	0.003	0.003	0.022	2.710	0.023	0.002	0.010
7	01/08/04	01/09/04	0.042	0.001	0.002	0.021	2.696	0.014	0.001	0.005
7	01/09/04	07/10/04	0.038	0.003	0.000	0.024	3.094	0.022	0.001	0.007
7	07/10/04	20/11/04	0.066	0.002	0.003	0.041	5.118	0.042	0.000	0.012
7	20/11/04	18/12/04	0.110	0.005	0.012	0.053	5.864	0.054	0.011	0.028
7	18/12/04	18/01/05	0.100	0.004	0.004	0.036	4.047	0.045	0.002	0.011
7	18/01/05	16/02/05	0.281	0.008	0.000	0.099	12.602	0.111	0.005	0.046
7	16/02/05	23/03/05	0.104	0.003	0.003	0.036	3.164	0.028	0.001	0.012
7	23/03/05	28/04/05	0.068	0.003	0.004	0.023	2.788	0.024	0.000	0.010
7	28/04/05	30/05/05	0.028	0.001	0.002	0.016	1.809	0.010	0.000	0.000
7	30/05/05	30/06/05	0.020	0.000	0.000	0.010	1.155	0.007	0.000	0.008
7	30/06/05	08/08/05	0.023	0.001	0.002	0.010	0.976	0.005	0.001	0.003
7	08/08/05	13/09/05	0.026	0.003	0.003	0.020	2.495	0.021	0.003	0.005
8	03/08/04	01/09/04	0.049	0.006	0.000	0.041	6.107	0.041	0.000	0.009
8	01/09/04	07/10/04	0.051	0.003	0.001	0.045	7.565	0.063	0.002	0.015
8	07/10/04	20/11/04	0.110	0.009	0.007	0.087	19.292	0.177	0.009	0.049
8	20/11/04	18/12/04	0.073	0.010	0.011	0.057	7.920	0.054	0.000	0.013
8	18/12/04	18/01/05	0.124	0.003	0.005	0.082	13.210	0.109	0.003	0.015
8	18/01/05	16/02/05	0.179	0.012	0.003	0.132	19.678	0.194	0.020	0.056
8	16/02/05	23/03/05	0.070	0.004	0.005	0.035	5.275	0.046	0.000	0.009
8	23/03/05	28/04/05	0.217	0.000	0.042	0.173	29.294	0.251	0.001	0.068

Table A2 cont

Site	Date on	Date off	Ti µg m^{-3}	V µg m^{-3}	Cr µg m^{-3}	Mn µg m^{-3}	Fe µg m^{-3}	Co µg m^{-3}	Ni µg m^{-3}	Cu µg m^{-3}
8 Cond	04/08/04	01/09/04	0.019	0.000	0.002	0.009	0.726	0.006	0.001	0.002
8 Cond	01/09/04	07/10/04	0.027	0.003	0.046	0.017	1.186	0.000	0.006	0.001
8 Cond	07/10/04	20/11/04	0.041	0.000	0.002	0.025	2.883	0.016	0.000	0.008
8 Cond	20/11/04	18/12/04	0.081	0.003	0.022	0.023	1.638	0.029	0.010	0.011
8 Cond	18/12/04	18/01/05	0.109	0.000	0.108	0.044	4.166	0.025	0.061	0.021
8 Cond	18/01/05	16/02/05	0.070	0.000	0.004	0.018	1.586	0.019	0.000	0.012
8 Cond	16/02/05	23/03/05	0.075	0.001	0.002	0.022	1.614	0.010	0.002	0.009
8 Cond	23/03/05	28/04/05	0.028	0.001	0.089	0.013	1.398	0.008	0.048	0.011
8 Cond	28/04/05	30/05/05	0.020	0.000	0.000	0.009	0.690	0.000	0.000	0.002
8 Cond	30/05/05	30/06/05	0.018	0.001	0.000	0.008	0.569	0.005	0.001	0.004
8 Cond	30/06/05	08/08/05	0.020	0.001	0.049	0.008	0.836	0.004	0.025	0.004
8 Cond	08/08/05	13/09/05	0.028	0.001	0.009	0.018	1.978	0.009	0.000	0.004
8Hi	04/08/04	02/09/04	0.167	0.005	0.007	0.164	29.857	0.234	0.013	0.055
8Hi	02/09/04	08/10/04	0.102	0.004	0.007	0.119	16.905	0.131	0.010	0.042
8Hi	08/10/04	30/11/04	0.140	0.005	0.008	0.146	24.653	0.293	0.058	0.169
8Hi	30/11/04	20/12/04	0.127	0.002	0.012	0.133	19.797	0.135	0.007	0.033
8Hi	20/12/04	20/01/05	0.079	0.012	0.003	0.091	12.067	0.083	0.000	0.019
8Hi	20/01/05	23/02/05	0.825	0.036	0.000	0.708	94.333	0.806	0.009	0.209
8Hi	23/02/05	31/03/05	0.104	0.003	0.007	0.103	12.535	0.078	0.001	0.021
8Hi	31/03/05	02/05/05	0.179	0.004	0.016	0.149	17.493	0.112	0.000	0.016
8Hi	02/05/05	09/06/05	0.205	0.002	0.021	0.232	34.902	0.161	0.000	0.216
8Hi	09/06/05	01/07/05	0.105	0.000	0.018	0.201	27.673	0.116	0.000	0.271
8Hi	01/07/05	09/08/05	0.107	0.010	0.010	0.364	34.789	0.041	0.000	0.019
8Hi	09/08/05	16/09/05	0.157	0.005	0.020	0.299	45.562	0.292	0.000	0.053

Table A3. Elemental concentrations of TSP and PM$_{10}$ samples at various sites measured by PIXE analysis, total elemental mass, gravimetric mass and fraction of iron in gravimetric mass.

Site	Date on	Date off	Zn µg m^{-3}	Br µg m^{-3}	Pb µg m^{-3}	Total elemental µg m^{-3}	Gravimetric Mass µg m^{-3}	% Total mass	% Fe
1	29/07/04	02/09/04	0.004	0.005	0.000	10.10	11.59	87.16	6.65
1	02/09/04	08/10/04	0.004	0.007	0.000	12.20	14.04	86.90	4.39
1	08/10/04	21/11/04	0.009	0.021	0.010	18.90	24.30	77.77	3.60
1	21/11/04	17/12/04	0.013	0.024	0.014	26.90	32.44	82.93	2.00
1	17/12/04	19/01/05	0.005	0.011	0.014	30.00	35.03	85.63	2.15
1	19/01/05	21/02/05	0.005	0.015	0.008	30.80	36.57	84.22	1.23
1	21/02/05	28/03/05	0.007	0.008	0.017	22.40	25.14	89.10	4.03
1	28/03/05	18/04/05	0.003	0.008	0.020	11.70	13.57	86.23	3.95
1	18/04/05	31/05/05	0.009	0.007	0.002	10.20	25.04	40.73	1.88
1	31/05/05	13/07/05	0.013	0.013	0.012	14.30	33.60	42.56	1.74
1	13/07/05	07/08/05	0.000	0.008	0.002	7.70	8.81	87.42	5.69
1	07/08/05	14/09/05	0.002	0.004	0.001	9.50	11.41	83.23	4.22
4	01/08/04	01/09/04	0.004	0.004	0.000	11.50	15.31	75.07	6.17
4	01/09/04	07/10/04	0.005	0.005	0.007	7.98	12.08	66.01	6.84
4	07/10/04	20/11/04	0.008	0.000	0.000	36.89	42.56	86.68	10.15
4	20/11/04	18/12/04	0.012	0.021	0.005	43.93	60.31	72.85	3.92
4	18/12/04	18/01/05	0.000	0.028	0.000	50.29	60.56	83.04	4.57
4	18/01/05	16/02/05	0.010	0.023	0.001	43.82	55.21	79.36	4.05
4	16/02/05	23/03/05	0.014	0.015	0.013	35.85	47.65	75.24	6.13
4	23/03/05	28/04/05	0.007	0.007	0.009	21.42	28.51	75.13	6.55
4	28/04/05	30/05/05	0.013	0.008	0.024	16.53	22.55	73.31	5.61
4	30/05/05	30/06/05	0.004	0.008	0.000	15.08	17.65	85.43	5.08
4	30/06/05	08/08/05	0.001	0.000	0.007	10.57	15.59	67.82	6.26
4	08/08/05	13/09/05	0.010	0.004	0.000	22.99	33.24	69.18	5.24
5	07/10/04	20/11/04	0.015	0.014	0.003	25.45	32.02	79.46	12.74
5	18/01/05	16/02/05	0.014	0.014	0.001	25.91	36.38	71.23	4.69
5	16/02/05	23/03/05	0.012	0.007	0.003	28.52	30.71	92.87	9.66
5	23/03/05	28/04/05	0.018	0.003	0.017	21.05	17.78	118.35	14.39
5	28/04/05	30/05/05	0.013	0.000	0.012	13.87	15.46	89.73	12.73
5	08/08/05	13/09/05	0.018	0.011	0.003	13.02	17.00	76.59	15.94
7	01/08/04	01/09/04	0.009	0.006	0.012	16.49	19.16	86.05	14.07
7	01/09/04	07/10/04	0.006	0.006	0.009	18.28	21.80	83.88	14.20
7	07/10/04	20/11/04	0.016	0.012	0.004	31.76	46.60	68.14	10.98
7	20/11/04	18/12/04	0.022	0.013	0.000	43.94	58.41	75.22	10.04
7	18/12/04	18/01/05	0.017	0.014	0.002	39.16	42.39	92.38	9.55
7	18/01/05	16/02/05	0.049	0.030	0.021	120.88	135.95	88.91	9.27
7	16/02/05	23/03/05	0.011	0.008	0.003	29.35	34.71	84.56	9.12
7	23/03/05	28/04/05	0.010	0.006	0.000	19.28	21.26	90.73	13.12
7	28/04/05	30/05/05	0.013	0.005	0.000	13.34	15.02	88.83	12.04
7	30/05/05	30/06/05	0.008	0.012	0.005	14.10	15.14	93.09	7.62
7	30/06/05	08/08/05	0.004	0.004	0.003	10.45	11.37	91.88	8.59
7	08/08/05	13/09/05	0.016	0.005	0.003	15.60	16.84	92.66	14.82
8	03/08/04	01/09/04	0.019	0.019	0.017	20.41	22.86	89.31	26.72
8	01/09/04	07/10/04	0.024	0.015	0.025	25.41	28.16	90.24	26.86
8	07/10/04	20/11/04	0.064	0.036	0.037	54.08	52.68	102.65	36.62
8	20/11/04	18/12/04	0.033	0.023	0.010	40.63	53.44	76.04	14.82
8	18/12/04	18/01/05	0.039	0.027	0.013	58.08	61.67	94.17	21.42
8	18/01/05	16/02/05	0.091	0.054	0.111	78.49	94.61	82.96	20.80

Table A3 cont

Site	Date on	Date off	Zn $\mu g\ m^{-3}$	Br $\mu g\ m^{-3}$	Pb $\mu g\ m^{-3}$	Total elemental $\mu g\ m^{-3}$	Gravimetric Mass $\mu g\ m^{-3}$	% Total mass	% Fe
8	16/02/05	23/03/05	0.021	0.009	0.011	26.43	29.27	90.31	18.02
8	23/03/05	28/04/05	0.077	0.016	0.000	114.66	135.16	84.83	21.67
8 Cond	04/08/04	01/09/04	0.008	0.000	0.009	7.89	10.34	76.33	7.02
8 Cond	01/09/04	07/10/04	0.004	0.006	0.003	10.29	13.18	78.11	9.00
8 Cond	07/10/04	20/11/04	0.021	0.015	0.006	15.68	21.45	73.11	13.44
8 Cond	20/11/04	18/12/04	0.006	0.004	0.017	20.76	30.97	67.02	5.29
8 Cond	18/12/04	18/01/05	0.012	0.014	0.029	35.32	42.91	82.32	9.71
8 Cond	18/01/05	16/02/05	0.005	0.007	0.005	28.75	31.96	89.97	4.96
8 Cond	16/02/05	23/03/05	0.010	0.017	0.030	20.04	24.08	83.22	6.70
8 Cond	23/03/05	28/04/05	0.007	0.007	0.000	9.01	12.97	69.50	10.78
8 Cond	28/04/05	30/05/05	0.001	0.002	0.012	8.01	16.10	49.73	4.29
8 Cond	30/05/05	30/06/05	0.003	0.004	0.001	10.07	10.65	94.49	5.34
8 Cond	30/06/05	08/08/05	0.001	0.001	0.001	7.59	8.84	85.89	9.46
8 Cond	08/08/05	13/09/05	0.003	0.009	0.000	12.22	13.63	89.65	14.51
8Hi	04/08/04	02/09/04	0.059	0.085	0.126	74.57	86.37	86.34	34.57
8Hi	02/09/04	08/10/04	0.057	0.029	0.039	49.57	64.80	76.49	26.09
8Hi	08/10/04	30/11/04	0.201	0.130	0.107	71.18	96.57	73.70	25.53
8Hi	30/11/04	20/12/04	0.077	0.028	0.026	67.34	78.98	85.26	25.07
8Hi	20/12/04	20/01/05	0.033	0.037	0.037	49.05	52.97	92.59	22.78
8Hi	20/01/05	23/02/05	0.050	0.024	0.021	395.38	560.92	70.49	16.82
8Hi	23/02/05	31/03/05	0.041	0.034	0.037	44.31	49.29	89.90	25.43
8Hi	31/03/05	02/05/05	0.065	0.028	0.047	56.16	81.08	69.26	21.57
8Hi	02/05/05	09/06/05	0.065	0.010	0.037	81.31	81.42	99.87	42.87
8Hi	09/06/05	01/07/05	0.016	0.005	0.000	54.98	49.65	110.74	55.74
8Hi	01/07/05	09/08/05	0.007	0.006	0.004	68.70	82.04	83.74	42.41
8Hi	09/08/05	16/09/05	0.092	0.118	0.127	99.11	115.25	86.00	39.53

Table A4. Cation concentrations measured in TSP collected at various sites and pH and cation and anion sums of the TSP extracts.

Site	Date on	Date off	pH	Na^+ µg m^{-3}	NH_4^+ µg m^{-3}	K^+ µg m^{-3}	Mg^{2+} µg m^{-3}	Ca^{2+} µg m^{-3}	Cation Sum µeq l^{-1}	Anion Sum µeq l^{-1}
1	29/07/04	02/09/04	6.355	1.51	0.03	0.07	0.15	0.14	1122.6	1140.2
1	02/09/04	08/10/04	5.530	2.13	0.03	0.10	0.24	0.18	1575.3	1567.5
1	08/10/04	21/11/04	6.018	3.21	0.04	0.24	0.38	0.33	2732.0	2646.6
1	21/11/04	17/12/04	5.751	4.57	0.10	0.29	0.52	0.47	1461.0	1437.2
1	17/12/04	19/01/05	5.778	5.30	0.09	0.24	0.62	0.68	2317.5	2306.9
1	19/01/05	21/02/05	5.590	6.24	0.09	0.24	0.73	0.63	3294.3	3323.3
1	21/02/05	28/03/05	5.191	1.02	0.03	0.05	0.31	0.31	833.5	840.7
1	28/03/05	18/04/05	5.217	1.77	0.10	0.07	0.17	0.11	665.3	673.8
1	18/04/05	31/05/05	5.266	0.44	0.01	0.08	0.15	0.14	412.8	420.6
1	31/05/05	13/07/05	5.060	0.56	0.01	0.02	0.18	0.14	666.3	687.4
1	13/07/05	07/08/05	5.337	1.16	0.06	0.05	0.11	0.08	618.3	628.1
1	07/08/05	14/09/05	5.329	1.68	0.03	0.08	0.19	0.12	1339.7	1329.5
4	01/08/04	01/09/04	7.388	1.35	0.03	0.06	0.14	0.49	1088.6	1078.4
4	01/09/04	07/10/04	7.318	1.11	0.02	0.05	0.11	0.38	1001.0	998.6
4	07/10/04	20/11/04	7.360	2.76	0.10	0.20	0.26	1.49	487.0	515.6
4	20/11/04	18/12/04	7.635	4.00	0.12	0.27	0.44	2.34	1074.9	1057.9
4	18/12/04	18/01/05	7.678	4.78	0.12	0.22	0.54	2.48	1364.9	1352.8
4	18/01/05	16/02/05	7.766	5.40	0.07	0.21	0.62	1.88	2417.0	2454.9
4	16/02/05	23/03/05	7.743	3.60	0.09	0.16	0.42	1.24	2473.6	2510.3
4	23/03/05	28/04/05	7.771	1.74	0.08	0.08	0.20	1.16	1302.1	1300.1
4	28/04/05	30/05/05	7.425	1.36	0.09	0.12	0.12	0.85	571.3	588.3
4	30/05/05	30/06/05	6.177	2.37	0.04	0.11	0.23	0.26	777.5	785.4
4	30/06/05	08/08/05	6.869	1.14	0.06	0.05	0.09	0.36	421.4	433.4
4	08/08/05	13/09/05	7.847	1.68	0.05	0.07	0.18	1.54	940.1	972.5
5	07/10/04	20/11/04	6.453	2.92	0.07	0.24	0.33	0.46	1610.5	1554.9
5	18/01/05	16/02/05	5.541	4.48	0.08	0.17	0.51	0.52	1783.7	1791.2
5	16/02/05	23/03/05	6.479	2.42	0.05	0.12	0.28	0.41	1963.2	1983.7
5	23/03/05	28/04/05	6.415	1.22	0.04	0.06	0.13	0.24	1034.7	1016.4
5	28/04/05	30/05/05	5.740	0.99	0.04	0.12	0.11	0.18	756.2	730.2
5	08/08/05	13/09/05	6.355	1.52	0.02	0.08	0.17	0.21	1214.7	1206.4
7	01/08/04	01/09/04	7.056	1.46	0.03	0.07	0.15	0.26	1023.1	1046.4
7	01/09/04	07/10/04	6.941	1.76	0.03	0.09	0.20	0.37	1473.0	1458.1
7	07/10/04	20/11/04	7.267	3.04	0.07	0.24	0.35	0.72	1863.0	1823.6
7	20/11/04	18/12/04	7.087	3.96	0.14	0.29	0.43	1.00	1017.5	1009.2
7	18/12/04	18/01/05	7.024	4.27	0.07	0.22	0.47	0.83	1807.5	1823.5
7	18/01/05	16/02/05	6.965	14.70	0.25	0.58	1.66	2.25	2596.4	2616.1
7	16/02/05	23/03/05	6.636	2.66	0.05	0.12	0.31	0.49	2166.0	2186.1
7	23/03/05	28/04/05	7.173	1.39	0.06	0.07	0.15	0.39	1255.6	1253.3
7	28/04/05	30/05/05	5.989	1.22	0.03	0.12	0.13	0.23	925.1	883.0
7	30/05/05	30/06/05	5.846	2.12	0.02	0.09	0.23	0.18	1376.2	1385.8
7	30/06/05	08/08/05	6.664	1.13	0.05	0.05	0.11	0.17	991.6	1004.8
7	08/08/05	13/09/05	6.801	1.70	0.03	0.08	0.18	0.26	1365.7	1368.5
8	03/08/04	01/09/04	7.087	1.30	0.04	0.06	0.13	0.27	886.9	913.1
8	01/09/04	07/10/04	6.932	1.81	0.04	0.10	0.20	0.37	1532.0	1528.5
8	07/10/04	20/11/04	7.056	2.89	0.06	0.18	0.32	0.74	1286.5	1281.5
8	20/11/04	18/12/04	6.854	3.96	0.17	0.28	0.41	0.86	986.3	974.3
8	18/12/04	18/01/05	6.460	5.32	0.21	0.24	0.57	0.95	1145.0	1141.5
8	18/01/05	16/02/05	7.310	6.47	0.12	0.25	0.71	1.37	2204.1	2243.0
8	16/02/05	23/03/05	6.718	2.06	0.07	0.10	0.23	0.39	1704.3	1715.1
8	23/03/05	28/04/05	6.655	8.60	0.40	0.36	0.88	1.58	844.4	853.4
8 Con	04/08/04	01/09/04	6.071	0.85	0.05	0.04	0.06	0.11	193.3	204.5
8 Con	01/09/04	07/10/04	5.610	1.25	0.07	0.06	0.10	0.15	272.0	275.5
8 Con	07/10/04	20/11/04	5.592	1.17	0.23	0.26	0.08	0.18	204.2	198.9

Table A4 Continued

Site	Date on	Date off	pH	Na^+ $\mu g\ m^{-3}$	NH_4^+ $\mu g\ m^{-3}$	K^+ $\mu g\ m^{-3}$	Mg^{2+} $\mu g\ m^{-3}$	Ca^{2+} $\mu g\ m^{-3}$	Cation Sum $\mu eq\ l^{-1}$	Anion Sum $\mu eq\ l^{-1}$
8 Con	20/11/04	18/12/04	5.417	2.25	0.19	0.31	0.15	0.18	187.8	196.0
8 Con	18/12/04	18/01/05	5.934	3.09	0.21	0.15	0.26	0.48	411.3	417.4
8 Con	18/01/05	16/02/05	5.496	3.61	0.13	0.11	0.25	0.31	247.5	261.3
8 Con	16/02/05	23/03/05	5.430	1.90	0.16	0.09	0.17	0.24	430.6	440.5
8 Con	23/03/05	28/04/05	5.662	0.71	0.14	0.03	0.05	0.09	191.6	196.3
8 Con	28/04/05	30/05/05	5.283	0.96	0.12	0.10	0.08	0.11	411.4	398.7
8 Con	30/05/05	30/06/05	5.868	1.42	0.05	0.06	0.13	0.13	688.8	699.4
8 Con	30/06/05	08/08/05	6.397	0.70	0.08	0.03	0.06	0.14	480.9	479.0
8 Con	08/08/05	13/09/05	6.054	1.12	0.04	0.04	0.09	0.19	327.4	336.5
8Hi	04/08/04	02/09/04	7.172	1.68	0.07	0.06	0.16	0.76	490.9	503.1
8Hi	02/09/04	08/10/04	7.638	2.23	0.10	0.11	0.24	1.06	1306.6	1319.9
8Hi	08/10/04	30/11/04	7.918	3.36	0.14	0.22	0.38	1.05	2886.8	3149.7
8Hi	30/11/04	20/12/04	7.798	3.93	0.15	0.17	0.42	1.58	1537.0	1679.8
8Hi	20/12/04	20/01/05	6.880	4.41	0.17	0.20	0.47	0.95	1243.7	1248.1
8Hi	20/01/05	23/02/05	7.848	31.53	0.93	1.24	3.45	9.00	2416.8	2651.9
8Hi	23/02/05	31/03/05	7.389	2.29	0.16	0.10	0.24	0.86	1103.4	1157.6
8Hi	31/03/05	02/05/05	7.408	1.87	0.16	0.09	0.21	1.16	771.8	809.8
8Hi	02/05/05	09/06/05	6.941	1.17	0.17	0.09	0.10	0.65	245.3	253.2
8Hi	09/06/05	01/07/05	5.292	1.01	0.05	0.02	0.04	0.11	45.3	48.2
8Hi	01/07/05	09/08/05	5.756	0.83	0.17	0.03	0.04	0.17	64.0	71.0
8Hi	09/08/05	16/09/05	7.698	2.44	0.11	0.10	0.28	1.53	1113.0	1184.0

Table A5. Anion concentrations measured in TSP collected at various sites.

Site	Cl^- μeq m^{-3}	NO_3^- μg m^{-3}	SO_4^{2-} μg m^{-3}	$C_2O_4^{2-}$ μg m^{-3}	PO_4^{3-} μg m^{-3}	F^- μg m^{-3}	CH_3COO^- μg m^{-3}	$HCOO^-$ μg m^{-3}	$CH_3SO_3^-$ μg m^{-3}	HCO_3^- μg m^{-3}
1	2.40	0.31	0.68	0.07	<0.01	<0.01	<0.01	0.01	0.01	0.06
1	3.15	0.59	1.10	0.18	<0.01	<0.01	<0.01	0.01	0.02	0.01
1	4.32	0.96	2.06	0.35	0.01	<0.01	<0.01	0.01	0.04	0.02
1	6.65	1.49	2.44	0.35	<0.01	<0.01	0.01	0.03	0.07	0.03
1	7.71	2.01	3.03	0.41	0.01	<0.01	0.01	0.02	0.14	0.03
1	9.82	1.55	3.12	0.36	<0.01	<0.01	<0.01	0.02	0.12	0.01
1	1.25	0.65	1.96	0.29	<0.01	<0.01	<0.01	0.01	0.02	0.00
1	2.06	1.06	1.27	0.19	<0.01	<0.01	<0.01	0.01	0.02	0.01
1	0.47	0.30	1.18	0.35	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
1	0.93	0.07	0.29	0.04	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
1	1.52	0.58	0.73	0.07	<0.01	<0.01	<0.01	0.01	0.01	0.01
1	2.50	0.44	0.81	0.11	<0.01	<0.01	<0.01	0.01	0.01	<0.01
4	2.22	0.33	0.71	0.06	<0.01	0.01	0.01	0.04	0.01	0.68
4	1.79	0.34	0.53	0.06	<0.01	<0.01	0.01	0.02	0.01	0.50
4	4.11	0.90	2.06	0.31	<0.01	0.02	0.04	0.11	0.02	3.31
4	6.03	1.73	2.59	0.32	<0.01	0.01	0.04	0.13	0.07	4.25
4	7.28	2.02	3.00	0.41	<0.01	0.01	0.04	0.11	0.12	4.22
4	8.70	1.72	2.92	0.32	<0.01	0.02	0.06	0.10	0.10	2.92
4	5.34	1.83	2.27	0.25	<0.01	0.01	0.04	0.06	0.05	1.83
4	2.30	1.15	1.43	0.20	<0.01	<0.01	0.02	0.05	0.02	2.20
4	1.82	0.74	1.24	0.23	<0.01	0.01	0.02	<0.01	0.01	1.73
4	3.75	0.56	0.99	0.10	<0.01	<0.01	0.01	0.04	0.01	0.08
4	1.50	0.59	0.93	0.09	<0.01	<0.01	0.01	0.04	0.01	0.44
4	2.66	0.59	1.01	0.10	<0.01	0.01	0.02	0.08	0.01	3.95
5	3.81	1.03	2.11	0.39	<0.01	0.01	0.01	0.03	0.04	0.10
5	7.09	1.34	2.11	0.25	<0.01	<0.01	0.01	0.02	0.09	0.02
5	3.18	1.40	1.74	0.25	<0.01	<0.01	0.01	0.02	0.04	0.07
5	1.23	0.89	1.08	0.22	<0.01	<0.01	<0.01	0.02	0.02	0.06
5	0.95	0.57	0.96	0.27	<0.01	<0.01	<0.01	0.01	0.01	0.01
5	2.23	0.46	0.87	0.12	<0.01	<0.01	<0.01	0.02	0.01	0.05
7	2.37	0.33	0.65	0.07	<0.01	<0.01	0.01	0.03	0.01	0.32
7	2.71	0.60	0.95	0.15	<0.01	<0.01	0.01	0.02	0.02	0.21
7	4.27	1.10	2.15	0.34	<0.01	0.01	0.02	0.04	0.04	0.64
7	5.56	1.91	2.50	0.41	<0.01	0.01	0.03	0.07	0.07	1.02
7	6.53	1.55	2.35	0.33	<0.01	0.01	0.02	0.05	0.10	0.50
7	23.14	4.33	7.41	0.99	<0.01	0.01	0.03	0.14	0.26	1.01
7	3.69	1.43	1.76	0.24	<0.01	<0.01	0.01	0.03	0.04	0.11
7	1.64	0.97	1.11	0.22	<0.01	<0.01	0.01	0.02	0.02	0.36
7	1.37	0.61	1.00	0.26	0.01	<0.01	<0.01	0.01	0.01	0.03
7	3.48	0.46	0.78	0.07	<0.01	<0.01	0.01	0.02	0.01	0.02
7	1.54	0.52	0.73	0.09	<0.01	<0.01	<0.01	0.01	0.01	0.10
7	2.61	0.50	0.88	0.11	<0.01	<0.01	<0.01	0.02	0.01	0.15
8	2.09	0.34	0.63	0.07	<0.01	<0.01	0.01	0.03	0.01	0.36
8	2.71	0.68	1.10	0.15	<0.01	<0.01	<0.01	0.02	0.02	0.21
8	4.39	0.88	1.91	0.30	0.01	0.01	0.01	0.05	0.03	0.54
8	5.60	1.84	2.51	0.36	<0.01	0.01	0.02	0.08	0.07	0.60
8	7.96	2.12	3.15	0.41	<0.01	0.01	0.02	0.06	0.14	0.27
8	10.20	2.03	3.59	0.39	<0.01	0.01	0.01	0.09	0.12	1.21
8	2.80	1.21	1.42	0.19	<0.01	<0.01	<0.01	0.02	0.03	0.13
8	10.70	5.21	6.34	1.05	<0.01	<0.01	<0.01	0.01	0.01	0.11
8 Con	1.34	0.19	0.46	0.05	<0.01	0.01	<0.01	0.02	0.00	0.10
8 Con	1.81	0.44	0.72	0.10	<0.01	0.01	<0.01	0.02	0.01	0.04
8 Con	1.48	0.59	1.27	0.22	<0.01	0.01	0.01	0.02	0.02	0.05
8 Con	2.75	1.52	1.75	0.25	<0.01	0.01	<0.01	0.01	0.01	0.02

Table A5 Continued

Site	Cl^- µeq m^{-3}	NO_3^- µg m^{-3}	SO_4^{2-} µg m^{-3}	$C_2O_4^{2-}$ µg m^{-3}	PO_4^{3-} µg m^{-3}	F^- µg m^{-3}	CH_3COO^- µg m^{-3}	$HCOO^-$ µg m^{-3}	$CH_3SO_3^-$ µg m^{-3}	HCO_3^- µg m^{-3}
8 Con	4.34	1.48	1.98	0.28	<0.01	0.01	0.01	0.04	0.06	0.13
8 Con	5.57	1.09	1.68	0.13	<0.01	0.03	0.01	0.04	0.06	0.08
8 Con	2.47	1.02	1.46	0.18	<0.01	0.01	0.01	0.03	0.02	0.02
8 Con	0.75	0.55	0.73	0.13	<0.01	0.01	<0.01	0.02	0.00	0.04
8 Con	1.09	0.47	0.90	0.16	0.01	<0.01	<0.01	0.01	0.01	0.01
8 Con	2.20	0.41	0.61	0.06	<0.01	<0.01	<0.01	0.03	0.01	0.03
8 Con	0.83	0.44	0.60	0.07	<0.01	<0.01	<0.01	0.02	0.01	0.08
8 Con	1.64	0.42	0.63	0.08	<0.01	0.01	<0.01	0.03	0.01	0.07
8Hi	2.76	0.39	1.06	0.10	<0.01	0.01	0.01	0.10	0.01	1.22
8Hi	3.50	0.78	1.51	0.18	<0.01	0.02	0.02	0.06	0.02	1.84
8Hi	5.27	1.24	2.40	0.30	0.01	0.02	0.05	0.07	0.04	2.17
8Hi	6.50	1.09	2.37	0.33	<0.01	0.02	0.06	0.09	0.07	3.78
8Hi	6.70	1.67	2.76	0.33	<0.01	0.01	0.01	0.06	0.10	0.55
8Hi	51.83	8.78	18.31	2.44	<0.01	0.01	0.38	0.58	0.58	19.84
8Hi	3.14	1.65	1.90	0.21	0.02	0.01	0.02	0.05	0.03	1.20
8Hi	2.55	1.17	1.91	0.26	<0.01	0.02	0.02	0.29	0.02	1.73
8Hi	1.46	0.74	1.27	0.25	<0.01	0.01	<0.01	0.02	0.01	0.39
8Hi	1.73	0.27	0.53	0.05	<0.01	<0.01	<0.01	<0.01	<0.01	0.01
8Hi	1.23	0.50	0.84	0.09	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
8Hi	4.09	0.76	2.06	0.19	<0.01	0.02	0.03	0.07	0.02	2.98