Burrup Rock Art: Revised Modelling

BURRUP ROCK ART: REVISED MODELLING TAKING INTO ACCOUNT RECENT MONITORING RESULTS

- Final 1
- 12 January 2009

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1. Scope of Work

In 2002 the Western Australian Government established the independent Burrup Rock Art Monitoring Management Committee. The Committee oversees studies that are being conducted to establish whether industrial emissions could affect the ancient rock art (or petroglyphs) on the Burrup Peninsula, in the Pilbara region of Western Australia. The rock art is important to the region's and Western Australia's heritage. The Burrup Peninsula, as a part of the Dampier Archipelago was included on the Federal Government's National Heritage List in July 2007.

As part of studies to understand the potential for emissions from local industry to impact upon Burrup rock art petroglyphs, the Department of Industry and Resources (DOIR) has contracted Sinclair Knight Merz (SKM) to re-examine an earlier modelling assessment with particular reference to recent monitoring results.

The previously conducted air quality modelling is documented in the report "Burrup Rock Art Atmospheric Modelling – Concentrations and Depositions" (SKM, 2003a). A series of monitoring campaigns of pollutant concentrations in the vicinity of selected rock art sites have been undertaken by CSIRO as documented in the draft report "Burrup Peninsula Air Pollution Study" (CSIRO, 2008).

Specifically this project will:

- Revise the previous modelling study to cover the periods for which monitoring was undertaken (2004/5 and 2007/8).
- Revise estimates of industrial emissions using available public documentation of Burrup industrial developments, to represent actual industrial operations during the monitoring period.
- Analyse modelling results of concentrations and depositions of NO_2 and SO_2 and compare to the results from the monitoring program.

2. Pollutants and Air Quality Concerns

The ancient rock art (petroglyph) sites on the Burrup peninsula are of cultural significance to local indigenous people. Concerns have been raised that industrial development on the peninsula will negatively impact the petroglyphs in the area. Current ambient levels are well within National Environmental Protection Measure (NEPM) standards for ambient air quality (NEPC, 2003), although the NEPM standards are related to human health and amenity and do not necessarily reflective concentrations that may degrade the petroglyphs.

The CSIRO monitoring program studied seven petroglyphs using reflectance spectroscopy (CSIRO, 2007). The study concluded that there was no change to the mineralogy of the rock and there was no consistent perceptible increase in colour change over the 2004 to 2007 period.

Considerable research has been undertaken worldwide in determining causes of atmospheric decay to historical buildings and/or statues from limestone and marble. These results have been qualitative indicating that calcium loss is strongly correlated with sulphate concentrations in rain water run-off and this is enhanced in marine environments. Work by Zanardini et al. (Zanardini et al, 2000) is typical of the research in which correlations and mechanisms have been derived but little data exists as to the ambient concentration levels that contributed to the decay.

3. Existing Environment

The meteorology of the area was investigated during the Pilbara Airshed Study (Physick and Blockley, 2001; DEP, 2002). A summary of the surface-wind patterns for the Pilbara coast between Karratha and Port Hedland is provided below:

- In the months September through to April:
  - daytime – surface winds tend to be onshore from the NW quadrant; and
  - night time – winds tend to be offshore with a southerly component. The wind direction is usually in the SW sector but can turn to the SE in the transition months.
- During May to August:
  - daytime onshore winds are from the NE sector; and
  - night time winds are from the SE.
- At any time of the year:
  - there are days on which the wind direction rotates steadily through 360 degrees over 24 hours and analysis of pollution data suggests the existence of re-circulating flows.

Monthly wind roses for Karratha Aerodrome provided by the Bureau of Meteorology for 1993 through to 2005 are provided in **Appendix A**, together with wind roses predicted from TAPM* for the two periods.

Inspection of the wind roses predicted by the meteorological module of the TAPM model shows that winds are predominantly in the southern sector all year around. Clearly the coastal weather patterns described in Physick (2001) are quite different to these predictions. This has been reported in other studies, specifically the DEC 2002 study of Meteorology of the Pilbara region (DEC, 2002). It is postulated that local topographic forces are strongly influencing the local meteorology as the peninsula is surrounded by water on three sides and hence is much more strongly affected by sea and land breezes than the general synoptic conditions reported in the Physick study.

* TAPM, developed by CSIRO is a prognostic meteorological model with dispersion algorithms that is used extensively throughout Australia. It has been used previously for modelling NO_X, NO_2 and Ozone concentration and deposition on the Burrup Peninsula (HLA - Envirosciences, 1999; Physick and Blockley, 2001; SKM, 2002; URS, 2002).

4. Methodology

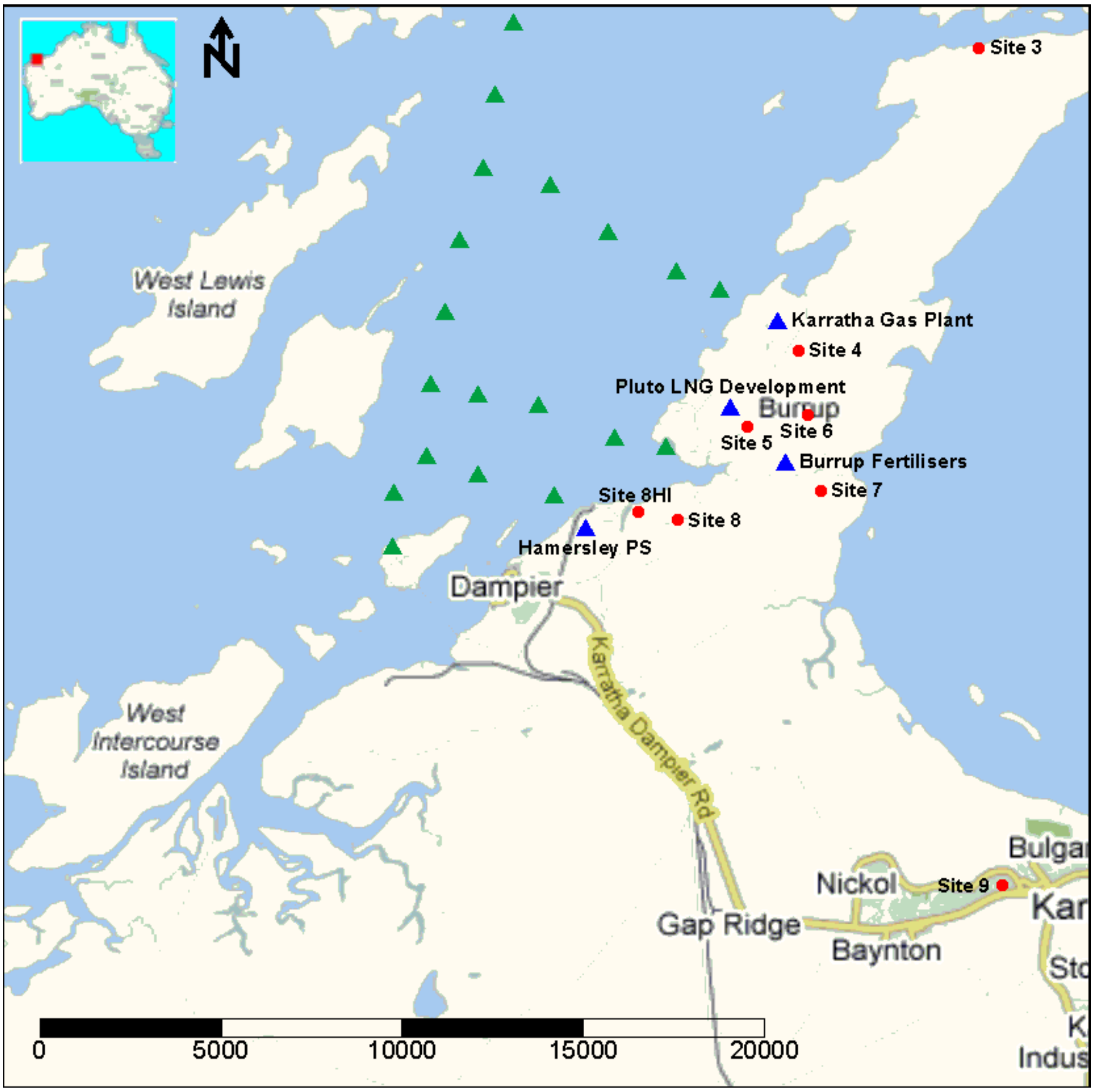
Air emissions were modelled for two scenarios. The “current” scenario includes emissions from industrial sources that were operating during the monitoring program. The “future” scenario also includes emissions from other industrial developments that have received regulatory approval and that are expected to proceed in the foreseeable future (DOIR pers. comm. 21/11/2008). Both the current and future emissions scenarios were modelled for the periods of the monitoring program. Emissions sources were necessarily limited to those that have been documented in the public domain, such as in Public Environmental Review and other regulatory documents.

Monitoring was conducted by CSIRO at ten sites as shown in **Figure 4-1**. The scope of the current study is restricted to using the model domain and non-industrial emissions data of SKM (2003a). As a result, monitoring sites 1 (Dolphin Island) and 10 (Mardie Station) lie beyond the innermost TAPM modelling domain (approximately 8 km north and 60 km south west of the domain respectively). As such, they have not been addressed by this study. Resource constraints preclude development of a new model domain.

The TAPM air pollution model was used to predict hourly concentrations and the deposition of nitrogen dioxide and sulphur dioxide.

4.1. TAPM Model Configuration

The TAPM model was used to predict nitrogen dioxide and sulphur dioxide concentrations and deposition in the Dampier region. Model configuration was as for SKM (2003a); incorporating area emissions as used by Physick and Blockley (2001) except that shipping sources were set explicitly as volume sources (see **Figure 4-1**). These volume sources are indicated as green triangles.



- **Figure 4-1 TAPM modelling domain with site locations**

4.2. Monitoring Data

To assess the possibility that air pollution from the industrial area may damage the petroglyphs an air pollution study (CSIRO, 2008) was carried out on the Burrup Peninsula by CSIRO Marine and Atmospheric Research between August 2004 and September 2005 and between February 2007 and September 2008.

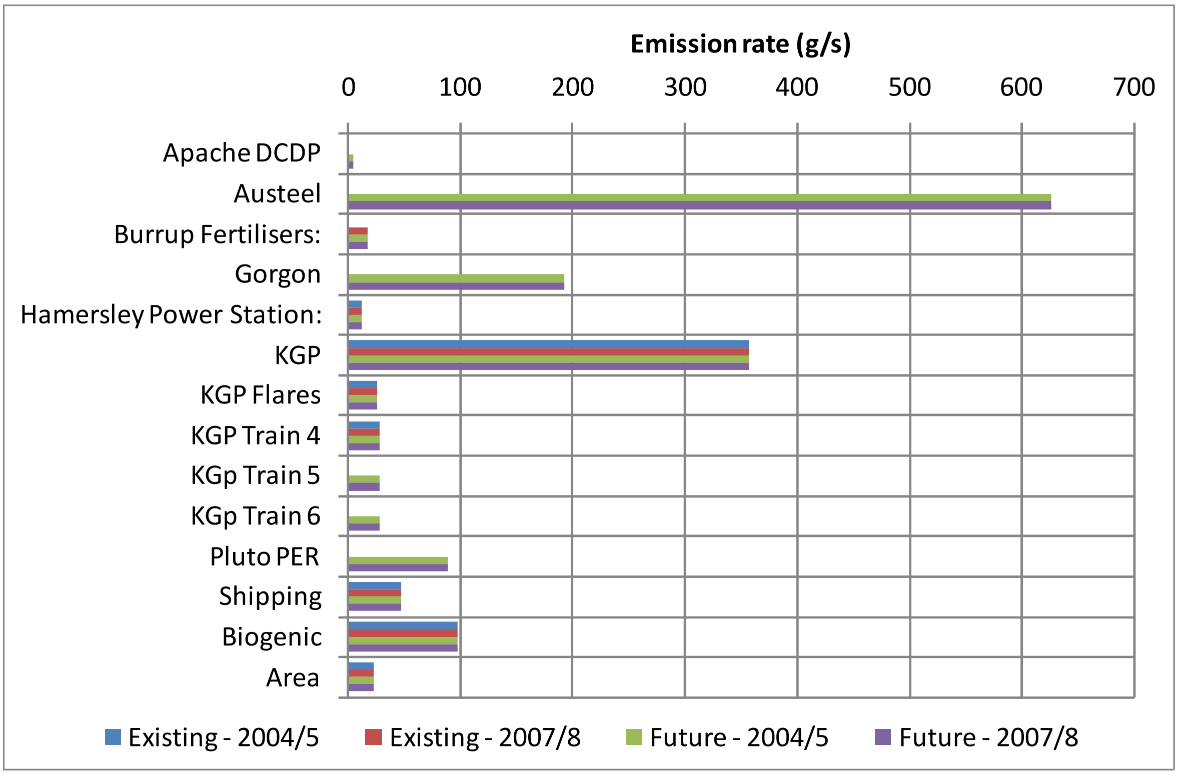
The study comprised a total of 10 sites; sites 1 and 3 were located on the northern Burrup Peninsula area and Site 10 at Mardie Station 81 km southwest of Dampier. Site 9 was located in the town of Karratha. These sites were considered to be representative of the local background concentrations of gases and particles. Five other sites were located on the lower Burrup Peninsula, near to the industrial areas (refer to **Figure 4-1**). Passive sampling of approximately monthly periods were utilised to measure gas concentrations.

In order to compare measured and modelled concentrations, some indication of the uncertainty of the measurements is required. In this regard, the uncertainty associated with passive sampling is significantly higher than direct gas measurements. Typical uncertainty of passive sampling is between 20% and 50%, while on-line measurement systems have an uncertainty ranging between 1% and 10%. Continuous gas analysers can also provide measurements over much shorter averaging periods, down to five or ten minutes, but at the cost of providing a mains power supply and air-conditioned enclosures. In contrast, passive sampling techniques can be readily applied in remote locations with limited access to power and other infrastructure, such as the petroglyph sites on the Burrup Peninsula.

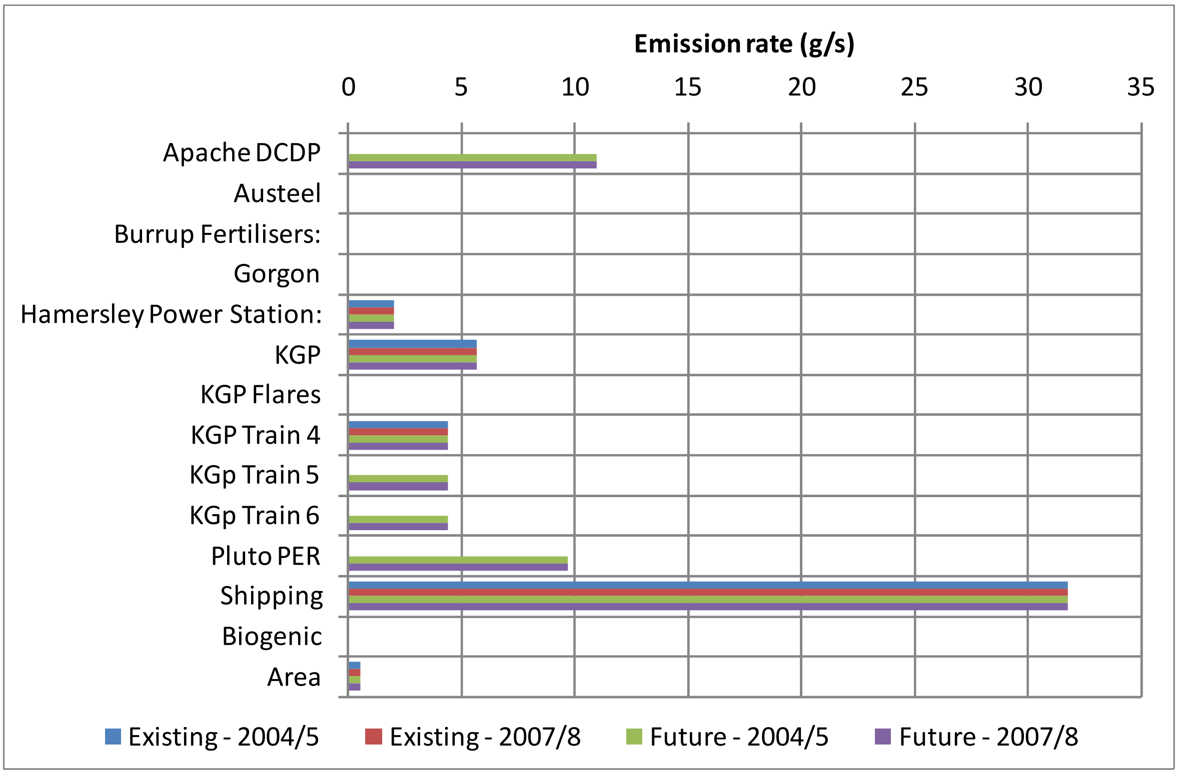
Data contained in the previous SKM report (SKM, 2003) show that the measured NO_2 average was 0.2 ppb with a maximum of 2.1 ppb, while for that study the TAPM model predicted a maximum of 4 ppb. This is comparable to the monthly average observed at the monitoring sites, which varied from 0.2 to 3.8 ppb for NO_X and 0.02 to 0.37 ppb for SO_2.

5. Emissions

Emissions characteristics were taken from SKM (2003) and revised in light of publicly available emissions data. Relevant emissions sources include contributions from industry as point sources, shipping represented as small volume sources and area emissions from biogenic and anthropogenic sources. **Figure 5-1** and **Figure 5-2** present the total emissions of NO_X and SO_2 from source groups. Details of emissions characteristics are presented in **Appendix B**. These show the current and future emissions for each of the two modelling time periods. The future scenario indicates the emission rates and ambient concentrations that would have been experienced over the modelling periods if proposed industrial projects in the Pilbara region were implemented.



▪ **Figure 5-1 Summary of NO_X emission per site**



- **Figure 5-2 Summary of SO_2 emission per site**

The emissions data were obtained from the following sources:

- Apache Devil Creek Development Project (DCDP), (SKM, 2008).
- North West Shelf Venture (NWSV) Karratha Gas Plant (KGP) Trains 1 – 5 (SKM, 2006).
- A hypothetical NWSV KGP Train 6 is a replication of KGP Train 5.
- NWSV KGP Flares (SKM, 2003b).
- Pluto PER (SKM, 2006).
- Hamersley Power Station (SKM, 2006).
- Burrup Fertilisers (SKM, 2006).
- Austeel Direct Reduced Iron (DRI) plant at Cape Preston (HGM, 2002).
- Gorgon Gas Development (EPA, 2006).
- Shipping emissions (SKM, 2003a).
- Biogenic emissions (SKM, 2003a).
- Anthropogenic (Area) emissions (SKM, 2003a).

6. Model Results

Ground level concentrations predicted from the modelling are summarised in **Table 6-1** showing: the Current (i.e. emission at the time of modelling), Future (planned new developments) and Measured data. The two background sites within the model domain (sites 3 and 9) have poor correlations. Site 3 is over predicting, possibly as a result of the background area sources being too high and Site 9 is under predicting, possibly as a result of underestimating anthropogenic diffuse emissions (e.g. motor vehicles).

Figure 6-1 and **Figure 6-2** presents the ratio between modelled and measured monthly averages for Burrup monitoring sites for NO_2 and SO_2 respectively. Both NO_2 and SO_2 concentrations appear to be over-estimated in summer months and under-estimated in winter.

Comparison of results from Current and Future scenarios shows that commissioning of planned industrial plant on the Burrup Peninsula is expected to increase longer term average concentrations of NO_2 by about 30%. In absolute terms, however, concentrations remain very small. For comparison, although not directly relevant to weathering of rock surfaces and petroglyphs, the Ambient Air NEPM standard for the protection of human health and amenity prescribes an annual average of 30 ppb, compared to the modelling results in the order of 3 ppb (NEPC, 2003).

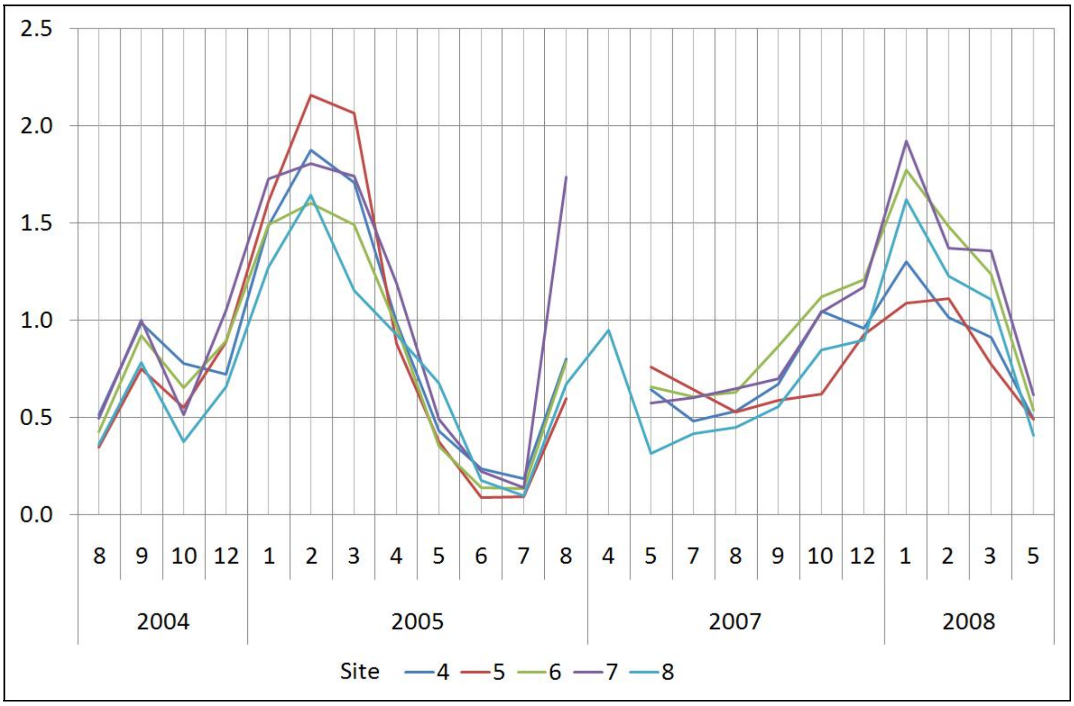
Contour plots of predicted average ground level concentrations of NO_2 are shown in **Figure 6-3** to **Figure 6-6** for each monitoring period and scenario, and for SO_2 in **Figure 6-7** to **Figure 6-10**. Overlaid on these graphs is the gridded monitored data (red dotted line). In comparing the data both the general isopleth line shapes and the actual values should be taken into consideration. The measured isopleths are based on limited datasets (5 points) and give only rough guidelines and hence smoother isopleths.

These figures show good agreement in both the shape of the isopleths and absolute values, although the predicted SO_2 values are higher than the measured results. Ambient concentrations of SO_2 are likely to be over-predicted by the model because the representation of ships as volume sources has not incorporated the effect of buoyant plume rise from the ship exhaust.

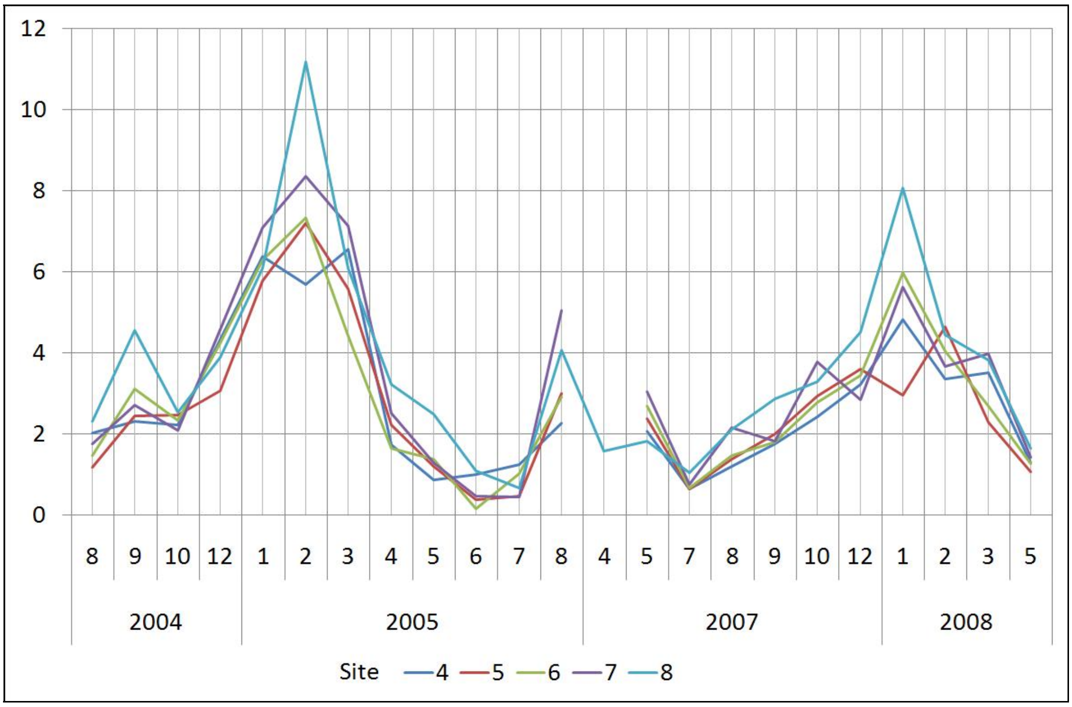
SKM

Table 6-1 Average (ppb) ground-level concentration across each site

Site	NO_2			SO_2		
	Current	Future	Measured	Current	Future	Measured
2004						
Site 3	1.62	2.51	0.85	0.34	0.41	0.15
Site 4	1.56	2.82	2.08	0.54	0.63	0.20
Site 5	1.67	2.60	2.65	0.64	0.69	0.27
Site 6	1.50	2.96	2.05	0.52	0.61	0.19
Site 7	1.25	1.93	1.65	0.49	0.54	0.18
Site 8	1.32	1.82	2.43	0.61	0.64	0.18
Site 9	0.40	0.75	2.08	0.07	0.10	0.08
2005						
Site 3	0.97	1.46	0.66	0.26	0.29	0.13
Site 4	1.62	2.39	1.60	0.54	0.60	0.17
Site 5	1.77	2.74	2.28	0.65	0.71	0.19
Site 6	1.53	2.52	1.75	0.55	0.63	0.17
Site 7	1.43	2.13	1.26	0.52	0.57	0.12
Site 8	1.68	2.20	1.99	0.76	0.79	0.15
Site 9	0.51	0.87	2.33	0.11	0.14	0.09
2007						
Site 3	1.09	1.23	0.79	0.21	0.14	0.16
Site 4	1.50	1.55	2.02	0.38	0.22	0.19
Site 5	1.76	1.63	2.67	0.45	0.24	0.21
Site 6	1.55	1.70	1.78	0.37	0.23	0.17
Site 7	1.09	1.13	1.35	0.36	0.19	0.15
Site 8	1.34	1.41	2.11	0.48	0.31	0.19
Site 9	0.37	0.56	2.23	0.06	0.06	0.10
2008						
Site 3	1.12	1.44	0.83	0.28	0.31	0.18
Site 4	2.16	2.68	2.28	0.66	0.71	0.19
Site 5	2.60	3.19	3.13	0.77	0.84	0.29
Site 6	2.17	2.91	1.73	0.65	0.74	0.18
Site 7	2.05	2.64	1.50	0.65	0.71	0.16
Site 8	2.19	2.65	2.15	0.89	0.93	0.19
Site 9	0.72	1.07	2.28	0.13	0.16	0.13
Average						
2004	1.33	2.20	1.97	0.46	0.52	0.18
2005	1.36	2.04	1.69	0.49	0.53	0.15
2007	1.24	1.32	1.83	0.33	0.20	0.17
2008	1.86	2.37	1.98	0.58	0.63	0.19

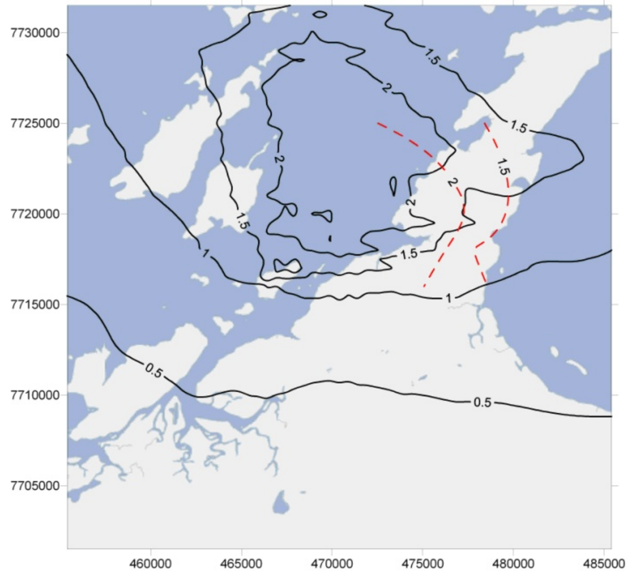


- **Figure 6-1 Ratio of predicted to measured NO_2 concentrations (Current)**

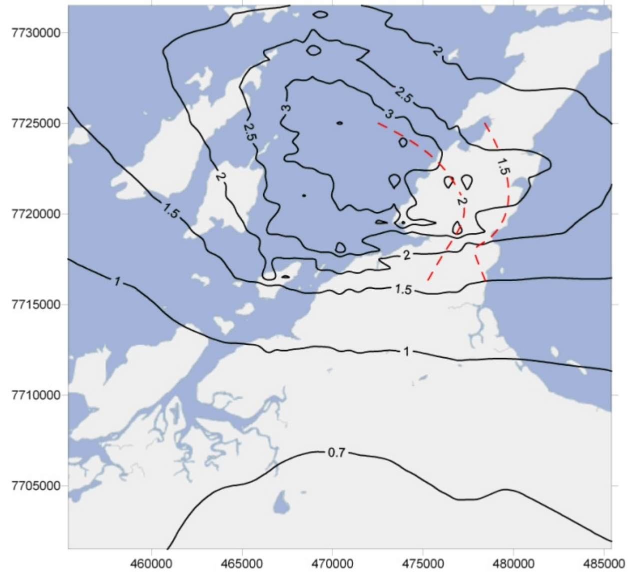


- **Figure 6-2 Ratio of predicted to measured SO_2 concentrations (Current)**

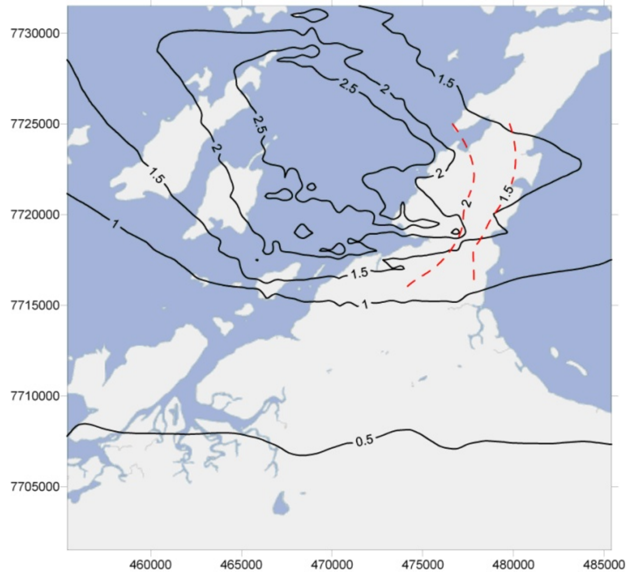
SKM



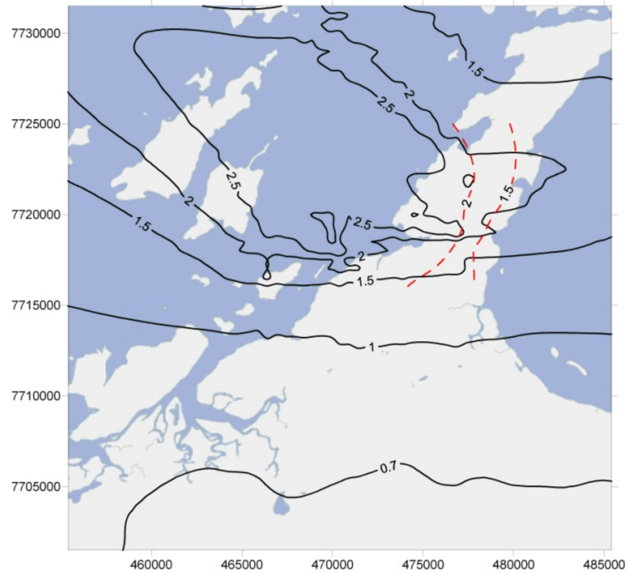
- **Figure 6-3 Existing 2004 NO_2 (ppb)**



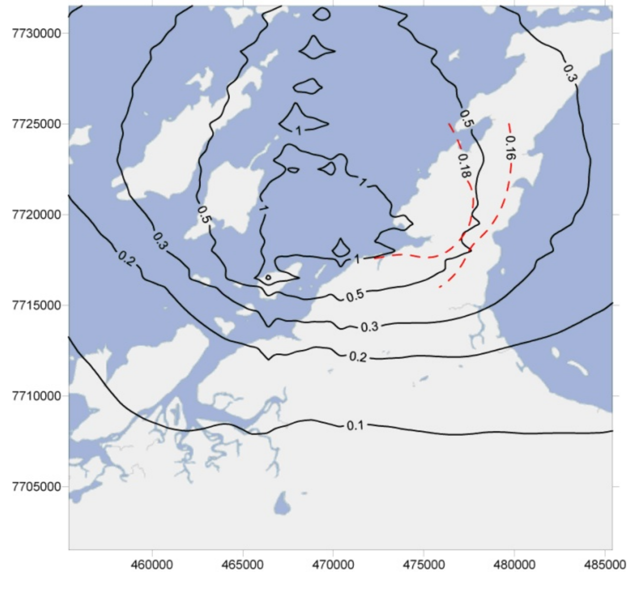
- **Figure 6-4 Future 2004 NO_2 (ppb)**



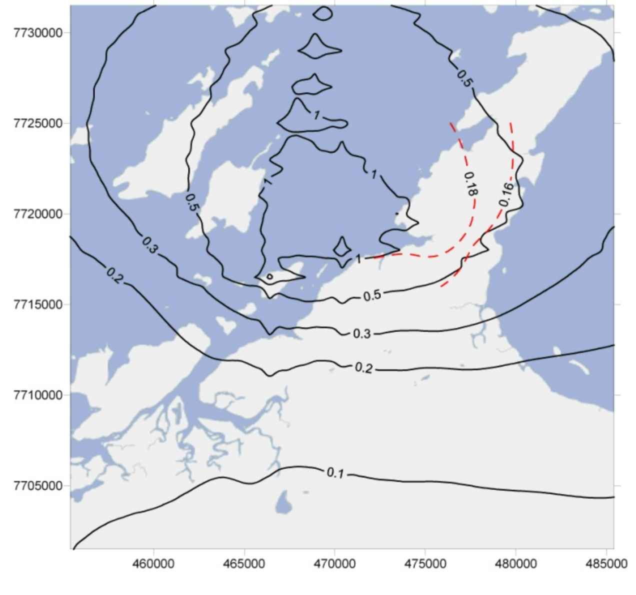
- **Figure 6-5 Existing 2007 NO_2 (ppb)**



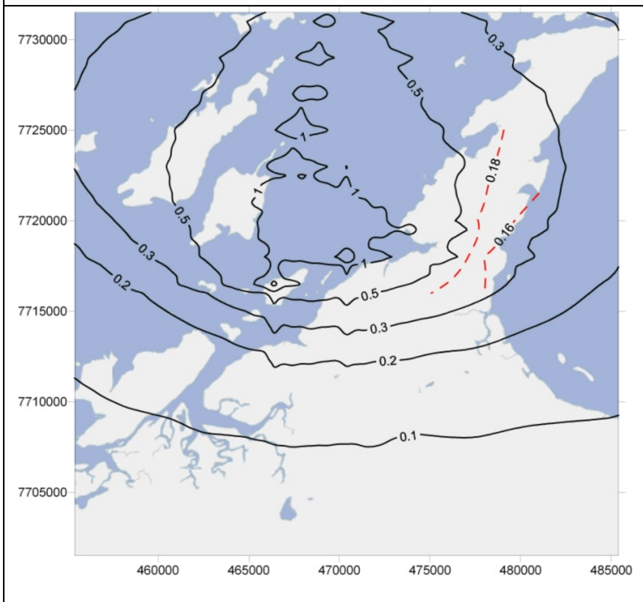
- **Figure 6-6 Future 2007 NO_2 (ppb)**



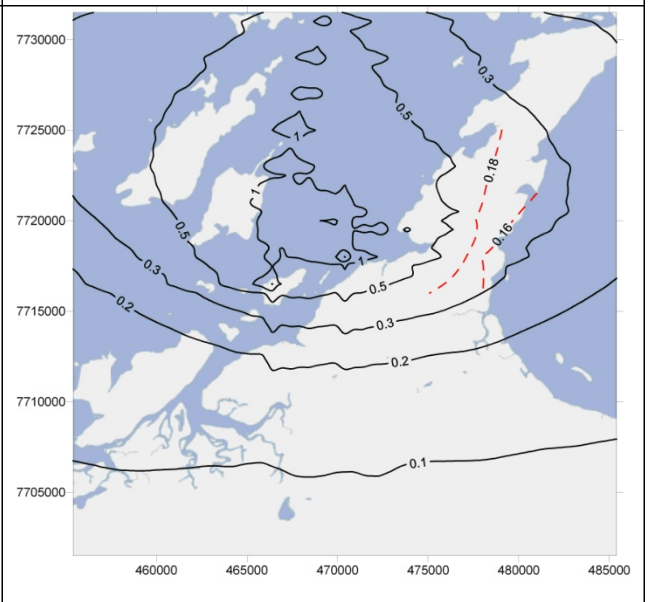
■ **Figure 6-7 Existing 2004 SO_2 (ppb)**



■ **Figure 6-8 Future 2004 SO_2 (ppb)**

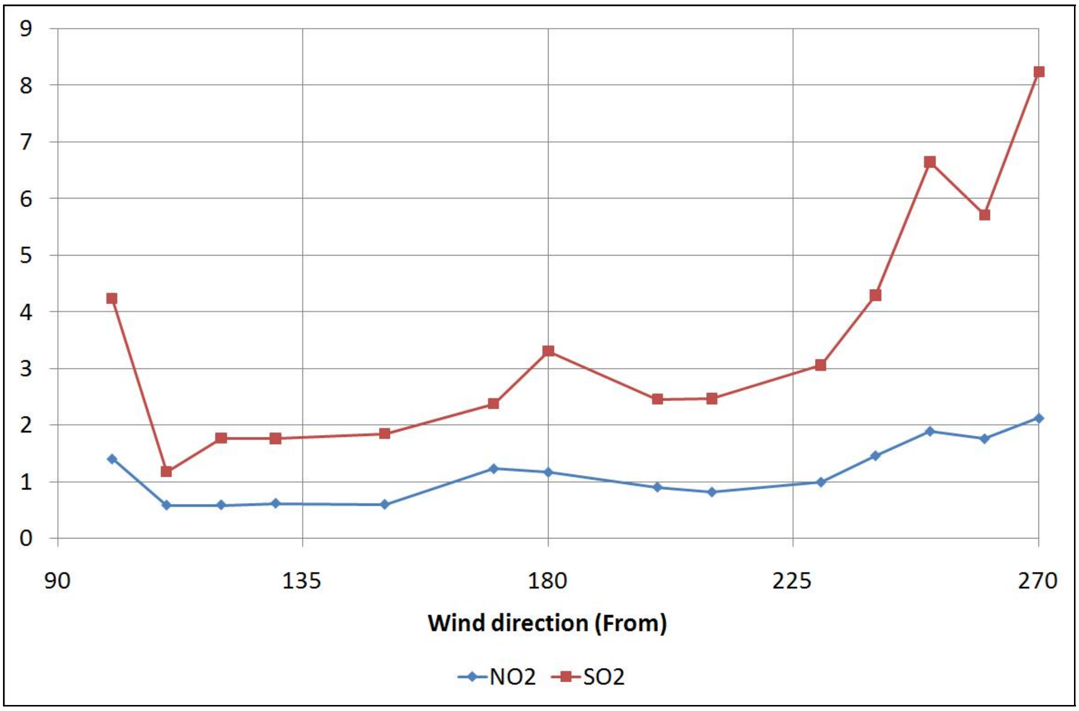


■ **Figure 6-9 Existing 2007 SO_2 (ppb)**



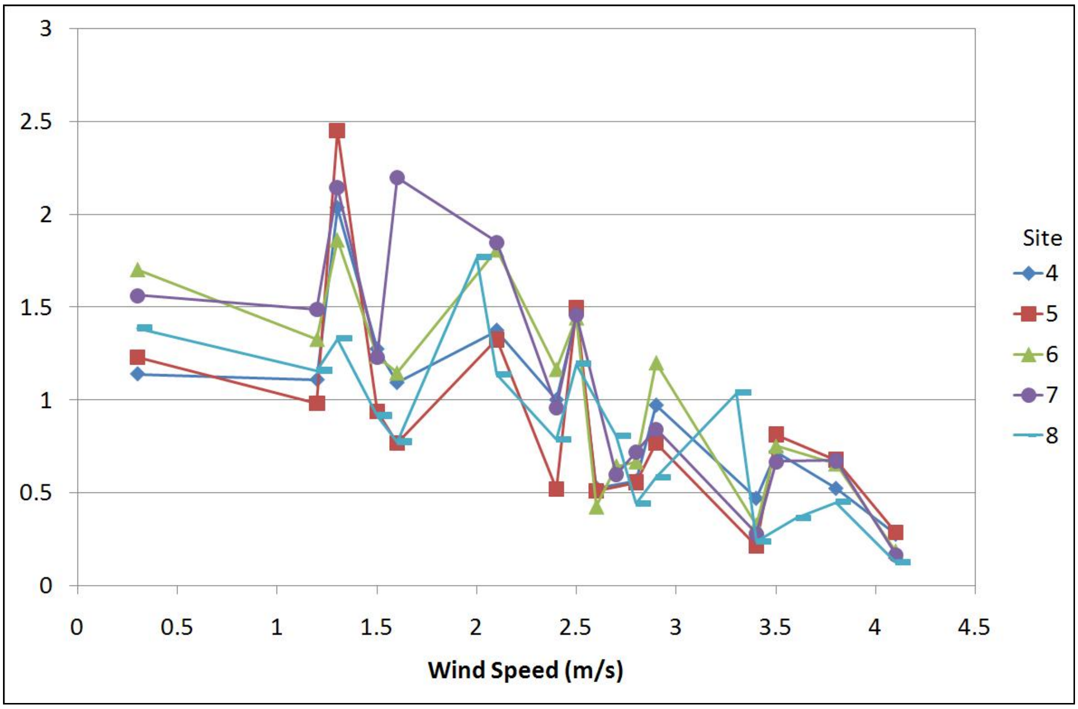
■ **Figure 6-10 Future 2007 SO_2 (ppb)**

Investigation of the five industrial monitoring sites (Sites 4 to 8, cf **Figure 4-1**) indicates that ratio of predicted to measured concentrations is dependent on wind direction and speed. **Figure 6-11** shows the variance as a function of wind direction for both NO_2 and SO_2. NO_2 has a better correlation than SO_2, although the SO_2 values are an order of magnitude smaller than the NO_2 values and so small discrepancies have been magnified. Both pollutants indicate that westerly winds yield the worst correlations. Major shipping lanes, to the west of the monitoring sites, are the most significant source of SO_2, which suggests that improved estimates of shipping emissions would lead to an overall improvement in correlation between predicted and measured concentrations.

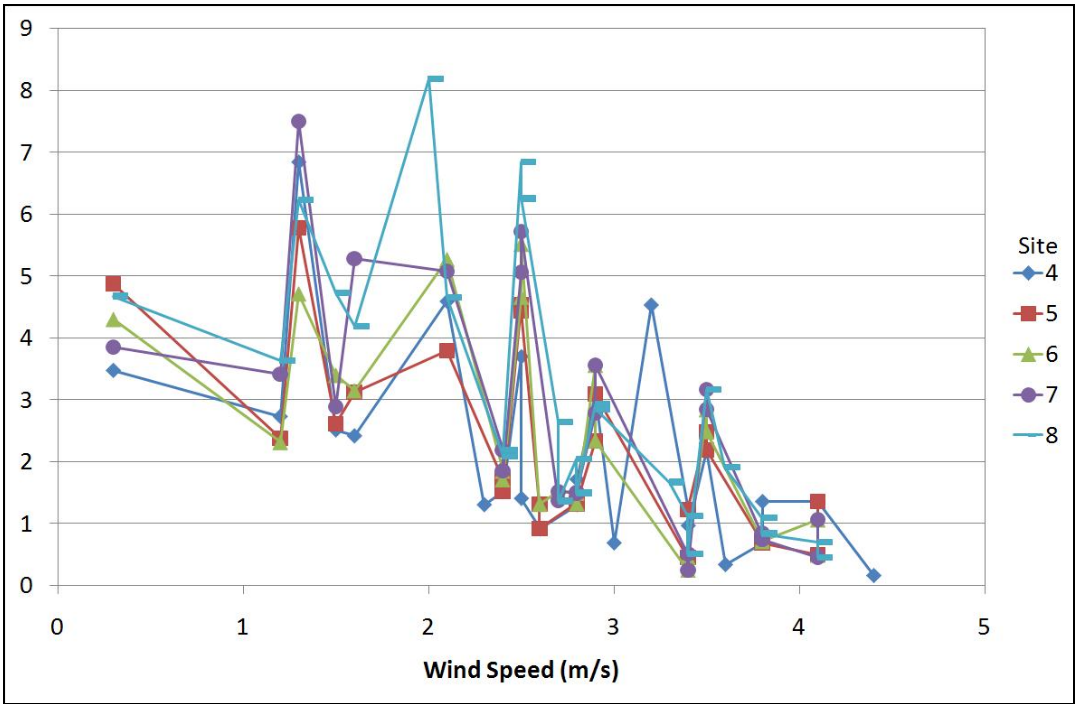


- **Figure 6-11 Ratio of predicted to measured concentrations with wind direction**

Similar results are obtained for the analysis of the wind speeds in that the SO_2 ratio is much higher than NO_2, again as a result of lower concentrations. There is a strong correlation of the ratio obtained with wind speed. It is known that the meteorological module of the TAPM model does not model low wind speed conditions well (Luhar and Hurley, 2008). Calm winds are associated with stagnation conditions that can lead to higher predicted ground level concentrations

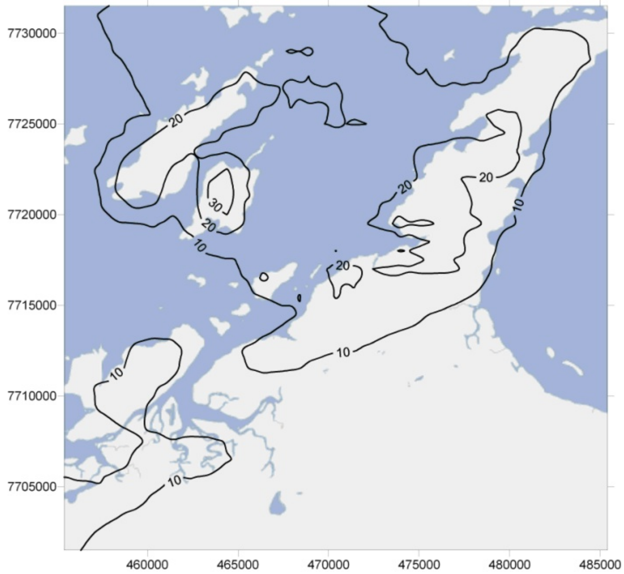


■ **Figure 6-12 Predicted/Measured NO_2 with wind speed**

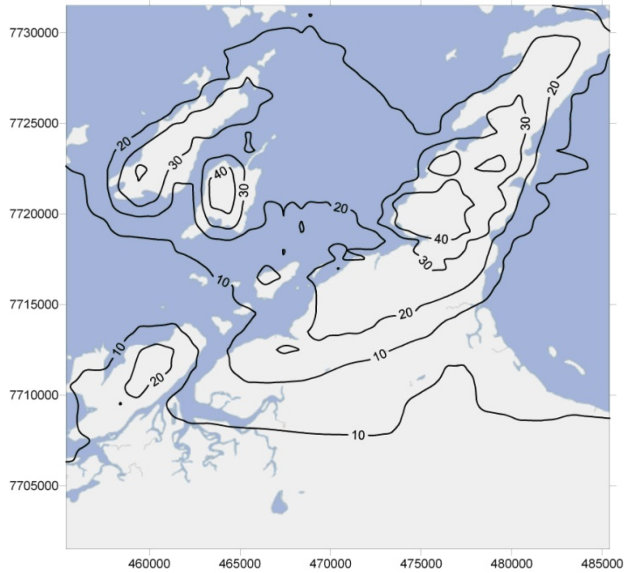


■ **Figure 6-13 Predicted/Measured SO_2 with wind speed**

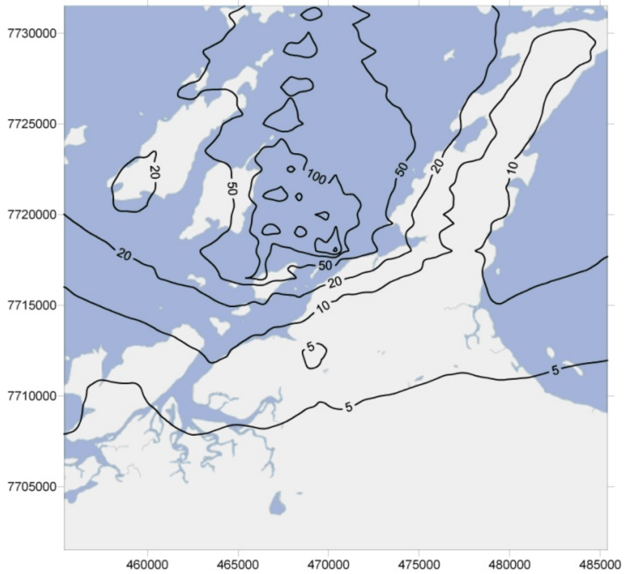
Figure 6-14 to **Figure 6-17** present predicted cumulative deposition of NO_2 and SO_2 for each modelling period. These figures suggest that NO_2 deposition on the Burrup Peninsula may be expected to increase by 50% to 80% with planned industrial development. The magnitude of these deposition rates remain at the level of some tens of milligrams per square metre per year. It is recommended that the Burrup Rock Art Monitoring Management Committee (BRAMMC) consider the implications of this scale of NO_2 deposition at each site in light of other results from the Rock Art Study.



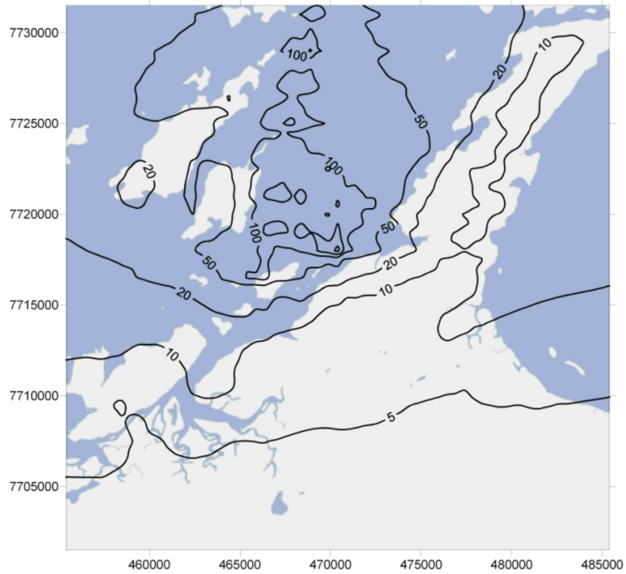
- **Figure 6-14 Existing 2004 NO_2 deposition (mg/m^2/year)**



- **Figure 6-15 Future 2004 NO_2 deposition (mg/m^2/year)**



- **Figure 6-16 Existing 2004 SO_2 deposition (mg/m^2/year)**



- **Figure 6-17 Future 2004 SO_2 deposition (mg/m^2/year)**

7. Conclusions

The scope of this project was to revisit the modelling study of SKM (2003) in the light of recent results from CSIRO monitoring of rock art sites. Industrial emission rates were revised to be consistent with industry plant operating at the time of the CSIRO rock art monitoring program. Emissions for proposed industrial plant were derived from publicly available documents such as Public Environmental Review and other regulatory assessment reports. Modelling results were compared to results from the CSIRO monitoring program.

As such, this study is not an impact assessment of any particular industrial development and modelling results do not directly relate to any regulatory assessment criteria. Modelling results suggest that future development proposals may lead to an increase in NO_2 deposition of between 50% and 80%. In absolute terms predicted concentrations remain small compared to air quality standards commonly applied in cities and other residential areas of Australia.

Modelled longer term average concentrations of both NO_2 and SO_2 are similar to measured concentrations at Burrup Peninsula monitoring sites, and the spatial distribution of modelled and measured results are broadly consistent between sites across the peninsula. However, modelled concentrations are much lower than measured concentrations at Site 9 in Karratha.

The ratio of modelled to measured concentrations of SO_2 is both greater and more variable than for NO_2. This may be attributed to an error in the zero reading of the monitored data, or from higher emissions in the modelling input data files. In particular, the most significant SO_2 sources are those associated with shipping, yet the estimates of these emissions are also the least certain. In contrast, emissions from industrial point sources have where possible been derived direct from source monitoring. It is recommended that future revisions of emissions inventories should revise shipping emission estimates, include vehicle emissions and refine the biogenic and anthropogenic area sources.

The ratio of predicted to measured ground level concentrations varies significantly with the wind direction and wind speed. Specifically in the case of the wind direction, TAPM is over predicting when the wind blows from the west. This may be attributed to an over-estimation of shipping emissions or an underestimation of dispersion of emissions from ships at berth. In contrast the ratio is strongly correlated with the inverse of the wind speed: low wind speeds are associated with an overestimate of concentrations.

A comparison was made between the predicted isopleths and the gridded measurements. Although gridding the five measurements yield smooth isopleths curves (due to the nature of gridding with limited points) very good agreement was obtained over the peninsula for NO_2 between 1.5 and 2 ppb. SO_2 isopleths matched better in shape but as discussed previously the predicted values are higher than the monitored data.

8. References

CSIRO (2008). *Burrup Peninsula Air Pollution Study: Report for 2004/2005 and 2007/2008*.

Delalieux, F.; Cardell-Fernandez, C.; Torfs, K.; Vleugels, G.; Van Grieken, R. (2002). *Damage functions and mechanism equations derived from limestone weathering in field exposure*. Water, Air, and Soil Pollution, Vol 139, 1-4, pg 75-94, 2002.

Department of Environment Protection (2002). *Monitoring of Ambient Air Quality and Meteorology during the Pilbara Air Quality Study*. Technical Series 113. DEP Perth WA Sept 2002.

Environmental Protection Authority (EPA) (2006). *Gorgon Gas Development Barrow Island Nature Reserve – Chevron Australia Report and Recommendations of the Environmental Protection Authority*. EPA Bulletin 1221, June 2006.

Halpern Glick Maunsell (HGM) (2002). *Iron Ore Mine and Downstream Processing, Cape Preston W.A. Supplementary Environmental Review*, February 2002. Unpublished report prepared for Mineralogy Pty Ltd.

HLA - Envirosciences (1999). *Syntroleum - Proposed Gas to Synthetic Hydrocarbons Plant. Burrup Peninsula, Western Australia*. Consultative Environmental Review.

Luhar, A.K. and P.J. Hurley (2003) *An Evaluation of TAPM for Low Wind-Speed Conditions, and Model Improvements* Final Report to Department of Environment and Conservation Western Australia

National Environment Protection Council (NEPC) (2003). *National Environment Protection (Ambient Air Quality) Measure*, Canberra, 7 July 2003.

Physick, W and Blockley; A (2001). *An evaluation of air quality models for the Pilbara region*. Joint CSIRO Atmospheric Research and Department of Environmental Protection report.

SKM (2002). *Public Environmental Review – Methanex Australia Pty Ltd –Methanol Complex Burrup Peninsula Western Australia*, April 2002.

SKM (2003a). *Burrup rock art atmospheric modelling – concentrations and depositions*, Report prepared for the Department of Industry and Resources (DOIR), June 2003.

SKM (2003b). *Cumulative Oxide of Nitrogen Emissions on the Burrup*. Final, 15 December 2003.

SKM (2006). *Pluto LNG Development Cumulative Air Quality Study*. Final, 9 October 2006.

SKM (2008). *Apache Energy Limited – Devil Creek Development Project, Air Quality Assessment*. Final, 13 February 2008.

URS (2002). *Plenty River Ammonia/Urea Project. Burrup Peninsula, Western Australia*. Supplement to 1998 Consultative Environmental Review, prepared for Plenty River Corporation Limited, May 2002.

Zanardini, E.; Abbruscato, P.; Ghedini, N.; Realini, M.; Sorlini, C. (2000). *Influence of atmospheric pollutants on the biodeterioration of stone*. International Biodeterioration and Biodegradation, Vol 45, 1-2, pg 35-42, 2000.

Appendix A Karratha Aerodrome Wind Roses (BoM)

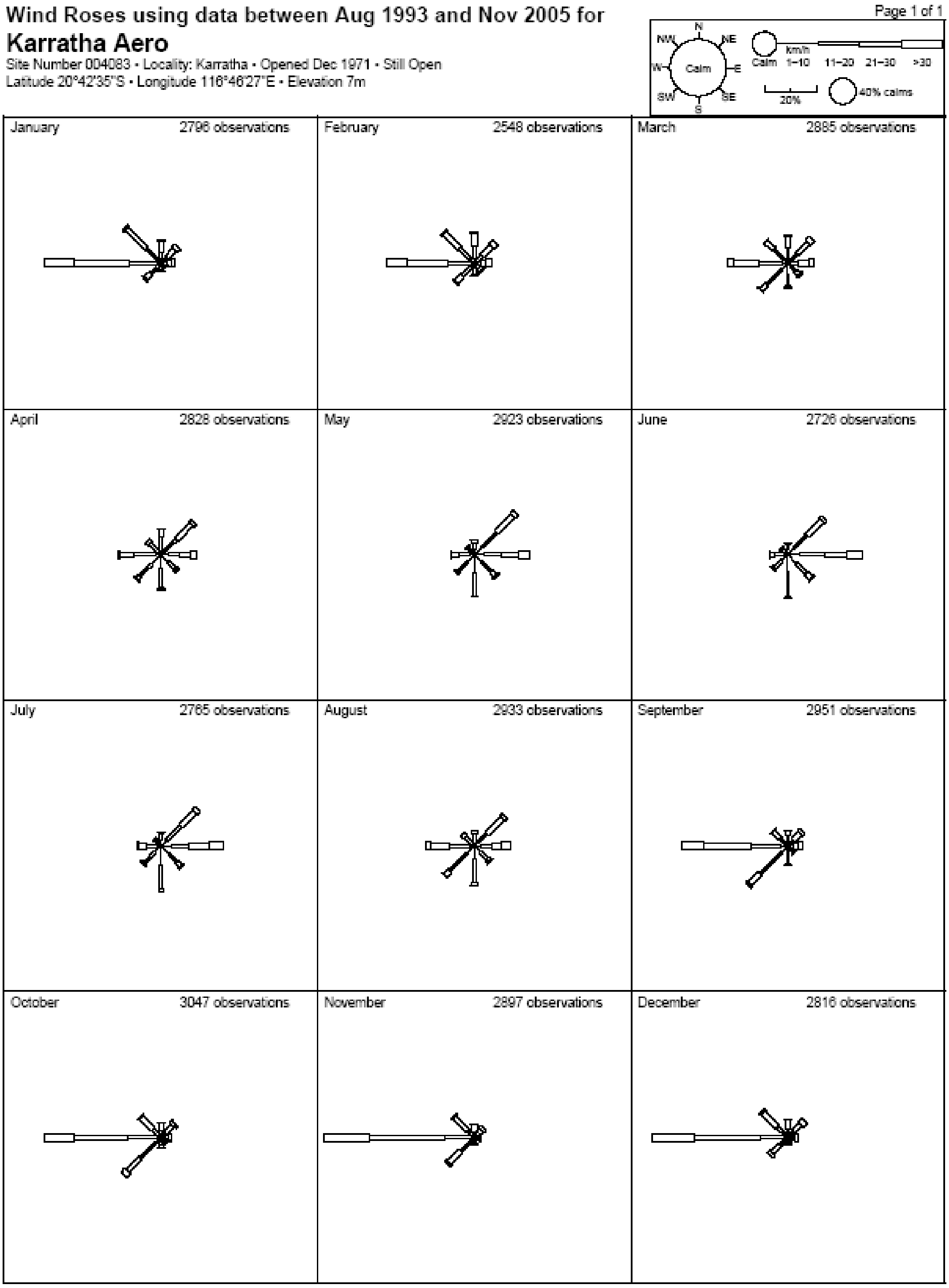


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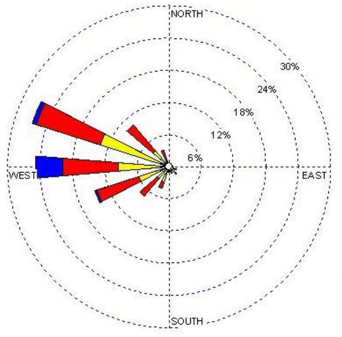
Table A-1 2004 - 2005 Period Monthly Wind Roses



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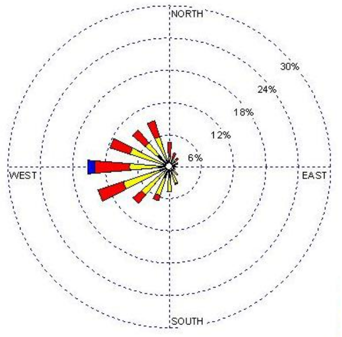

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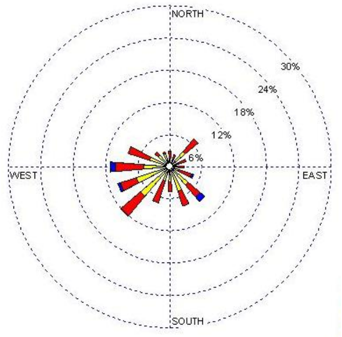

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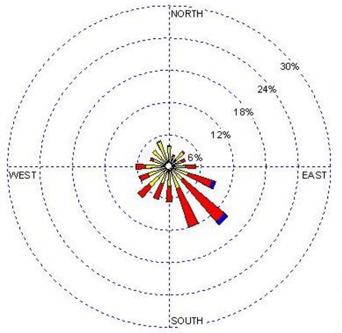

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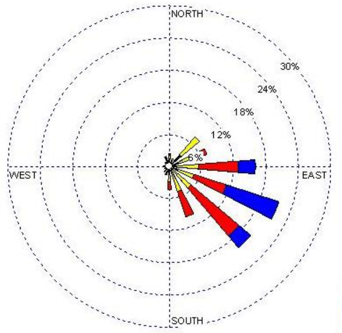

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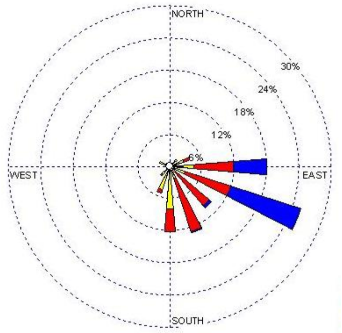

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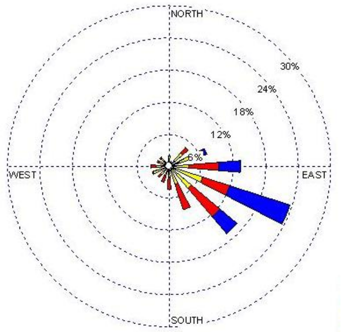

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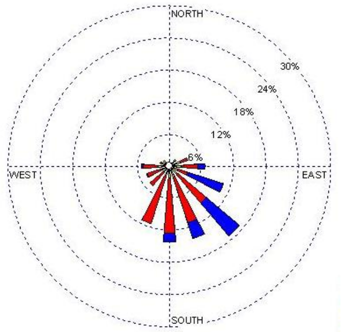

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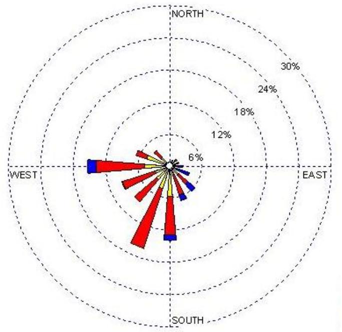

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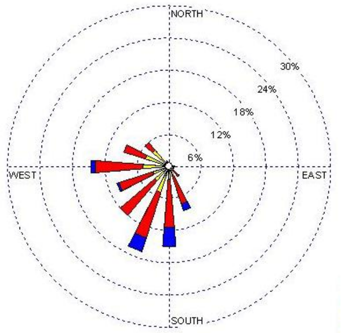

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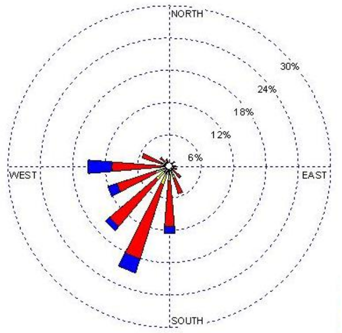

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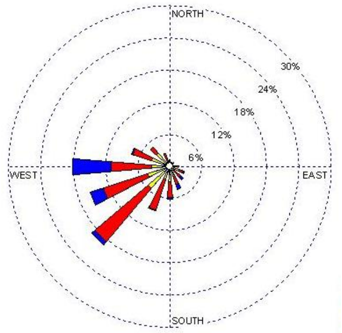

December

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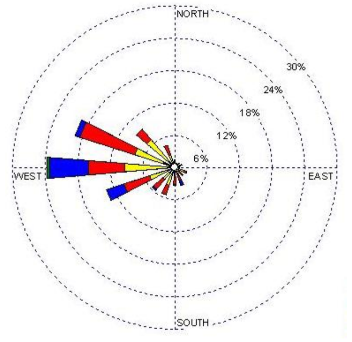
■ Table A-2 2007 - 2008 Period Monthly Wind Roses



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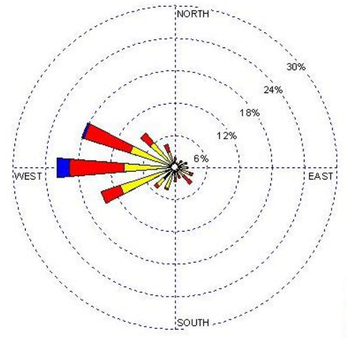

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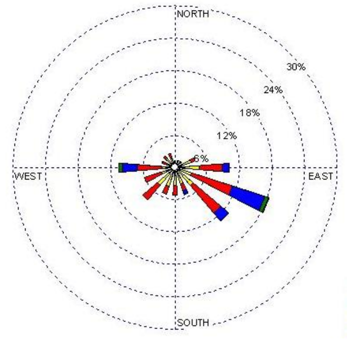

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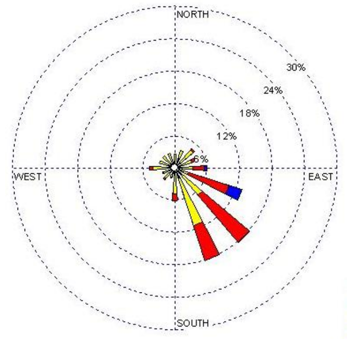

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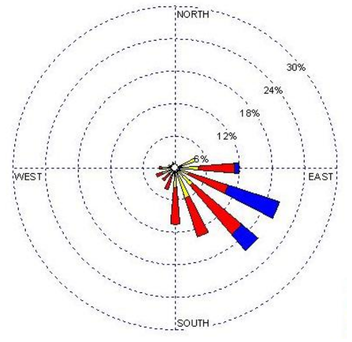

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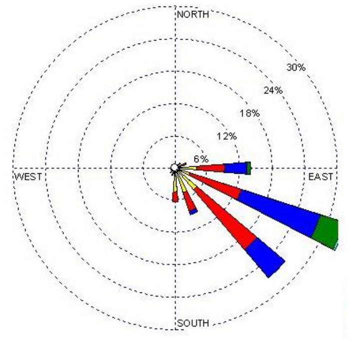
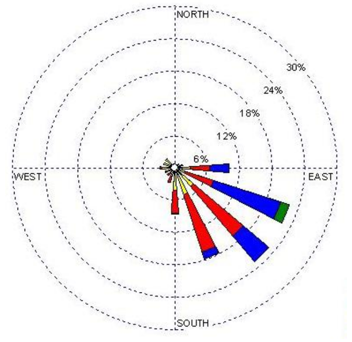


June



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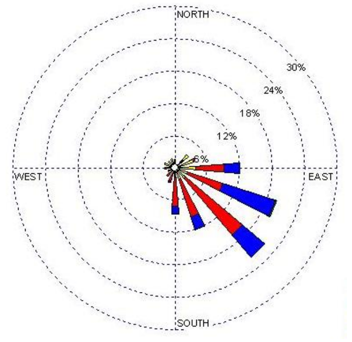
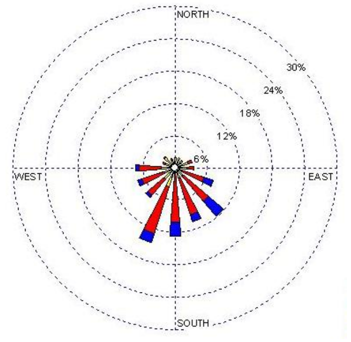
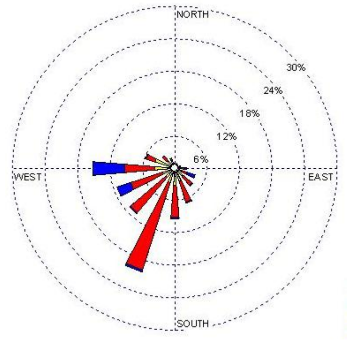


August



September



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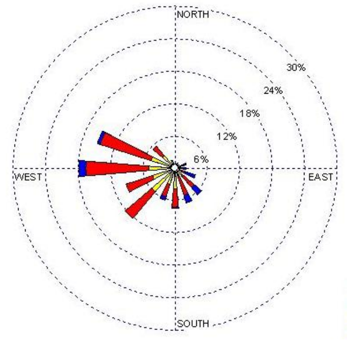

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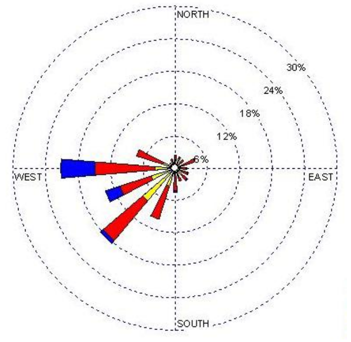

December

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Appendix B Industrial Emissions Characteristics

- **Table B-1 Existing 2004/2005 Emissions Characteristics**

Source	Location Coordinates		Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Exit Temperature (K)	Emission Rates (g/s)			
	Easting	Northing					PM_{10}	NO_X	SO_2	Rsmog
Karratha Gas Plant Trains 1 - 4										
GT4001	476910	7722765	40	1.98	20.2	777	0	13.5	0.2	0
GT4002	476910	7722800	40	1.98	20.2	777	0	13.46	0.24	0
GT4003	476910	7722810	40	1.98	20.2	777	0	13.46	0.24	0
GT4004	476910	7722845	40	1.98	20.2	777	0	13.46	0.24	0
GT4005	476910	7722855	40	1.98	20.2	777	0	13.46	0.24	0
GT4006	476910	7722890	40	1.98	20.2	777	0	13.46	0.24	0
1KT1410	476540	7722965	40	1.94	23.9	790	0	15.8	0.3	0
1KT1420	476590	7722965	40	1.94	23.9	790	0	15.6	0.27	0
1KT1430	476610	7722965	40	1.87	25.8	790	0	15.3	0.27	0
1KT1440	476660	7722965	40	1.87	26.3	806	0	15.5	0.27	0.4
1KT1450	476510	7722960	40	1.36	21.2	784	0	9.4	0.1	0
2KT1410	476540	7722845	40	1.94	23.9	790	0	15.8	0.3	0
2KT1420	476590	7722845	40	1.94	23.9	790	0	15.6	0.27	0
2KT1430	476610	7722845	40	1.87	25.8	790	0	15.3	0.27	0
2KT1440	476660	7722845	40	1.87	26.3	806	0	15.5	0.27	0.4
2KT1450	476510	7722840	40	1.36	21.2	784	0	9.4	0.1	0
3KT1410	476540	7722610	40	1.94	23.9	790	0	15.8	0.3	0
3KT1420	476590	7722610	40	1.94	23.9	790	0	15.6	0.27	0
3KT1430	476610	7722610	40	1.87	25.8	790	0	15.3	0.27	0
3KT1440	476660	7722610	40	1.87	26.3	806	0	15.5	0.27	0.4
3KT1450	476510	7722605	40	1.36	21.2	784	0	9.4	0.1	0
1F2001	477152	7722915	33	0.73	6	700	0	0.3	0	0
2F2001	477152	7722905	33	0.73	6	700	0	0.3	0.01	0
3F2001	477152	7722895	33	0.73	6	700	0	0.3	0.01	0
4F2001	476968	7722880	33	0.73	6	700	0	0.3	0.01	0
5F2001	476968	7722870	33	0.73	6	700	0	0.3	0.01	0
1KT2420	477035	7722698	24	1	40.7	816	0	9.4	0.1	0
1KT2430	477050	7722698	24	1.45	30.6	620	0	20.3	0.2	0
2KT2420	477065	7722698	24	1	40.7	816	0	9.4	0.1	0
2KT2430	477080	7722698	24	1.45	30.6	620	0	20.3	0.2	0
SealOil	476500	7722500	20	1	0	400	0	0	0	0.1
4KT1430a	476664	7722465	40	1.45	28.2	490	0	5	0.3	0
4KT1430b	476664	7722461	40	1.45	28.2	490	0	5	0.3	0
4KT1410	476650	7722461	40	3.05	23.4	814	0	10.6	0.6	0
1F1251	476933	7722944	40	1.46	21.3	1373	0	0.8	2.8	0
GT4007	476972	7722702	40	1.65	23	694	0	3.3	0.2	0
GT4008	476972	7722668	40	1.65	23	694	0	3.3	0.2	0

Source	Location Coordinates		Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Exit Temperature (K)	Emission Rates (g/s)			
	Easting	Northing					PM_{10}	NO_X	SO_2	Rsmog
Karratha Gas Plant Flares										
W-F-LN	477082	7722352	125	2.5	20	1273	0	6.5	0	0
W-F-OP	477092	7722511	46	2.5	20	1273	0	6.5	0	0
W-F-SL	476328	7722431	60	2.5	20	1273	0	6.5	0	0
W-FLPG	475943	7723061	50	2.5	20	1273	0	6.5	0	0
Hamersley Iron Power Station										
HAM_stack1	471500	7717000	60	1.3	7	393	0	5.7	1	0
HAM_stack2	471500	7717000	60	1.3	7	393	0	5.7	1	0

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Table B-2 Existing 2007/2008 Emissions Characteristics

Source	Location Coordinates		Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Exit Temperature (K)	Emission Rates (g/s)			
	Easting	Northing					PM_{10}	NO_X	SO_2	Rsmog
Karratha Gas Plant Trains 1 - 4										
GT4001	476910	7722765	40	1.98	20.2	777	0	13.5	0.2	0
GT4002	476910	7722800	40	1.98	20.2	777	0	13.46	0.24	0
GT4003	476910	7722810	40	1.98	20.2	777	0	13.46	0.24	0
GT4004	476910	7722845	40	1.98	20.2	777	0	13.46	0.24	0
GT4005	476910	7722855	40	1.98	20.2	777	0	13.46	0.24	0
GT4006	476910	7722890	40	1.98	20.2	777	0	13.46	0.24	0
1KT1410	476540	7722965	40	1.94	23.9	790	0	15.8	0.3	0
1KT1420	476590	7722965	40	1.94	23.9	790	0	15.6	0.27	0
1KT1430	476610	7722965	40	1.87	25.8	790	0	15.3	0.27	0
1KT1440	476660	7722965	40	1.87	26.3	806	0	15.5	0.27	0.4
1KT1450	476510	7722960	40	1.36	21.2	784	0	9.4	0.1	0
2KT1410	476540	7722845	40	1.94	23.9	790	0	15.8	0.3	0
2KT1420	476590	7722845	40	1.94	23.9	790	0	15.6	0.27	0
2KT1430	476610	7722845	40	1.87	25.8	790	0	15.3	0.27	0
2KT1440	476660	7722845	40	1.87	26.3	806	0	15.5	0.27	0.4
2KT1450	476510	7722840	40	1.36	21.2	784	0	9.4	0.1	0
3KT1410	476540	7722610	40	1.94	23.9	790	0	15.8	0.3	0
3KT1420	476590	7722610	40	1.94	23.9	790	0	15.6	0.27	0
3KT1430	476610	7722610	40	1.87	25.8	790	0	15.3	0.27	0
3KT1440	476660	7722610	40	1.87	26.3	806	0	15.5	0.27	0.4
3KT1450	476510	7722605	40	1.36	21.2	784	0	9.4	0.1	0
1F2001	477152	7722915	33	0.73	6	700	0	0.3	0	0
2F2001	477152	7722905	33	0.73	6	700	0	0.3	0.01	0
3F2001	477152	7722895	33	0.73	6	700	0	0.3	0.01	0
4F2001	476968	7722880	33	0.73	6	700	0	0.3	0.01	0
5F2001	476968	7722870	33	0.73	6	700	0	0.3	0.01	0
1KT2420	477035	7722698	24	1	40.7	816	0	9.4	0.1	0
1KT2430	477050	7722698	24	1.45	30.6	620	0	20.3	0.2	0
2KT2420	477065	7722698	24	1	40.7	816	0	9.4	0.1	0
2KT2430	477080	7722698	24	1.45	30.6	620	0	20.3	0.2	0
SealOil	476500	7722500	20	1	0	400	0	0	0	0.1
4KT1430a	476664	7722465	40	1.45	28.2	490	0	5	0.3	0
4KT1430b	476664	7722461	40	1.45	28.2	490	0	5	0.3	0
4KT1410	476650	7722461	40	3.05	23.4	814	0	10.6	0.6	0
1F1251	476933	7722944	40	1.46	21.3	1373	0	0.8	2.8	0
GT4007	476972	7722702	40	1.65	23	694	0	3.3	0.2	0
GT4008	476972	7722668	40	1.65	23	694	0	3.3	0.2	0

Source	Location Coordinates		Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Exit Temperature (K)	Emission Rates (g/s)			
	Easting	Northing					PM_{10}	NO_X	SO_2	Rsmog
Karratha Gas Plant Flares										
W-F-LN	477082	7722352	125	2.5	20	1273	0	6.5	0	0
W-F-OP	477092	7722511	46	2.5	20	1273	0	6.5	0	0
W-F-SL	476328	7722431	60	2.5	20	1273	0	6.5	0	0
W-FLPG	475943	7723061	50	2.5	20	1273	0	6.5	0	0
Hamersley Iron Power Station										
HAM_stack1	471500	7717000	60	1.3	7	393	0	5.7	1	0
HAM_stack2	471500	7717000	60	1.3	7	393	0	5.7	1	0
Burrup Fertilisers Plant										
BF1	476915	7718833	36	1.78	12.7	413	0.3	15.4	0	0
BF2	477060	7718820	15	0.85	5	450	0	1.3	0	0

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Table B-3 Future Emissions Characteristics for 2004/2005 and 2007/2008

Source	Location Coordinates		Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Exit Temperature (K)	Emission Rates (g/s)			
	Easting	Northing					PM_{10}	NO_x	SO_2	Rsmog
Karratha Gas Plant Trains 1 - 6										
GT4001	476910	7722765	40	1.98	20.2	777	0	13.5	0.2	0
GT4002	476910	7722800	40	1.98	20.2	777	0	13.46	0.24	0
GT4003	476910	7722810	40	1.98	20.2	777	0	13.46	0.24	0
GT4004	476910	7722845	40	1.98	20.2	777	0	13.46	0.24	0
GT4005	476910	7722855	40	1.98	20.2	777	0	13.46	0.24	0
GT4006	476910	7722890	40	1.98	20.2	777	0	13.46	0.24	0
1KT1410	476540	7722965	40	1.94	23.9	790	0	15.8	0.3	0
1KT1420	476590	7722965	40	1.94	23.9	790	0	15.6	0.27	0
1KT1430	476610	7722965	40	1.87	25.8	790	0	15.3	0.27	0
1KT1440	476660	7722965	40	1.87	26.3	806	0	15.5	0.27	0.4
1KT1450	476510	7722960	40	1.36	21.2	784	0	9.4	0.1	0
2KT1410	476540	7722845	40	1.94	23.9	790	0	15.8	0.3	0
2KT1420	476590	7722845	40	1.94	23.9	790	0	15.6	0.27	0
2KT1430	476610	7722845	40	1.87	25.8	790	0	15.3	0.27	0
2KT1440	476660	7722845	40	1.87	26.3	806	0	15.5	0.27	0.4
2KT1450	476510	7722840	40	1.36	21.2	784	0	9.4	0.1	0
3KT1410	476540	7722610	40	1.94	23.9	790	0	15.8	0.3	0
3KT1420	476590	7722610	40	1.94	23.9	790	0	15.6	0.27	0
3KT1430	476610	7722610	40	1.87	25.8	790	0	15.3	0.27	0
3KT1440	476660	7722610	40	1.87	26.3	806	0	15.5	0.27	0.4
3KT1450	476510	7722605	40	1.36	21.2	784	0	9.4	0.1	0
1F2001	477152	7722915	33	0.73	6	700	0	0.3	0	0
2F2001	477152	7722905	33	0.73	6	700	0	0.3	0.01	0
3F2001	477152	7722895	33	0.73	6	700	0	0.3	0.01	0
4F2001	476968	7722880	33	0.73	6	700	0	0.3	0.01	0
5F2001	476968	7722870	33	0.73	6	700	0	0.3	0.01	0
1KT2420	477035	7722698	24	1	40.7	816	0	9.4	0.1	0
1KT2430	477050	7722698	24	1.45	30.6	620	0	20.3	0.2	0
2KT2420	477065	7722698	24	1	40.7	816	0	9.4	0.1	0
2KT2430	477080	7722698	24	1.45	30.6	620	0	20.3	0.2	0
SealOil	476500	7722500	20	1	0	400	0	0	0	0.1
4KT1430a	476664	7722465	40	1.45	28.2	490	0	5	0.3	0
4KT1430b	476664	7722461	40	1.45	28.2	490	0	5	0.3	0
4KT1410	476650	7722461	40	3.05	23.4	814	0	10.6	0.6	0
1F1251	476933	7722944	40	1.46	21.3	1373	0	0.8	2.8	0
GT4007	476972	7722702	40	1.65	23	694	0	3.3	0.2	0
GT4008	476972	7722668	40	1.65	23	694	0	3.3	0.2	0

Source	Location Coordinates		Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Exit Temperature (K)	Emission Rates (g/s)			
	Easting	Northing					PM_{10}	NO_X	SO_2	Rsmog
GT4009	476972	7722626	40	1.65	23	694	0	3.3	0.2	0
GT4010	476972	7722592	40	1.65	23	694	0	3.3	0.2	0
5KT1430a	476664	7722335	40	1.45	28.2	490	0	5	0.3	0
5KT1430b	476664	7722331	40	1.45	28.2	490	0	5	0.3	0
5KT1410	476560	7722331	40	3.05	23.4	814	0	10.6	0.6	0
2F1251	476953	7722944	40	1.46	21.3	1373	0	0.8	2.8	0
GT4011	477172	7722626	40	1.65	23	694	0	3.3	0.2	0
GT4012	477172	7722592	40	1.65	23	694	0	3.3	0.2	0
6KT1430a	476864	7722335	40	1.45	28.2	490	0	5	0.3	0
6KT1430b	476864	7722331	40	1.45	28.2	490	0	5	0.3	0
6KT1410	476760	7722331	40	3.05	23.4	814	0	10.6	0.6	0
2F1261	477153	7722944	40	1.46	21.3	1373	0	0.8	2.8	0
Karratha Gas Plant Flares										
W-F-LN	477082	7722352	125	2.5	20	1273	0	6.5	0	0
W-F-OP	477092	7722511	46	2.5	20	1273	0	6.5	0	0
W-F-SL	476328	7722431	60	2.5	20	1273	0	6.5	0	0
W-FLPG	475943	7723061	50	2.5	20	1273	0	6.5	0	0
Hamersley Iron Power Station										
HAM_stack1	471500	7717000	60	1.3	7	393	0	5.7	1	0
HAM_stack2	471500	7717000	60	1.3	7	393	0	5.7	1	0
Burrup Fertilisers Plant										
BF1	476915	7718833	36	1.78	12.7	413	0.3	15.4	0	0
BF2	477060	7718820	15	0.85	5	450	0	1.3	0	0
Gorgon Gas Development										
	338372	7700255	40	2.75	34.5	736	0.6	31.5	0	0
	338418	7700255	40	2.75	34.5	736	0.6	31.5	0	0
	338464	7700255	40	2.75	34.5	736	0.6	31.5	0	0
	338510	7700040	40	2.75	34.5	736	0.6	31.5	0	0
	338850	7700040	40	2.75	14.9	423	0.6	16.7	0	0
	338850	7700040	40	2.75	14.9	423	0.6	16.7	0	0
	338850	7700040	40	2.75	14.9	423	0.6	16.7	0	0
	338850	7700040	40	2.75	14.9	423	0.6	16.7	0	0
Austeel DRI										
	412761	7670800	60	4.12	18	413	0	231	0	0
	412928	7670768	60	4.12	18	413	0	231	0	0
	412768	7671120	60	2.92	16	613	0	28.7	0	0
	412845	7671103	60	2.92	16	613	0	28.7	0	0
	412952	7671079	60	2.92	20	613	0	28.7	0	0
	412420	7671700	40	2.9	45.2	813	0	19.5	0	0
	412448	7671700	40	2.9	45.2	813	0	19.5	0	0
	412476	7671700	40	2.9	45.2	813	0	19.5	0	0

SKM

Source	Location Coordinates		Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Exit Temperature (K)	Emission Rates (g/s)			
	Easting	Northing					PM_{10}	NO_X	SO_2	Rsmog
	412504	7671700	40	2.9	45.2	813	0	19.5	0	0
Devils Creek Development Project										
	439210	7688350	13	0.8	23.5	783	0	0.75	0	0
	439220	7688340	13	0.8	23.5	783	0	0.75	0	0
	439300	7688280	13	0.8	16	633	0	0.75	0	0
	439330	7688310	13	0.8	16	633	0	0.75	0	0
	439620	7688420	21	0.9	14	1073	0	0	10.96	0
	439570	7688490	48	0.8	20	1273	0	0.77	0	0.1
	439620	7688420	20	0.8	20	1273	0	0.77	0	0.1
Pluto LNG Development										
PR Compressor Frame 7 Turbine	475609	7720460	40	1.75	23.5	493	0	3.85	0.3	0
PR Compressor Frame 7 Turbine	475621	7720466	40	1.75	23.5	493	0	3.85	0.3	0
MR Compressor Frame 7 Turbine	475509	7720422	40	2.5	23	816	0	7.7	0.6	0
Frame 6 Power Generator	475528	7720311	40	1.65	16.5	438	0	2.7	0.45	0
Frame 6 Power Generator	475565	7720329	40	1.65	16.5	438	0	2.7	0.45	0
Frame 6 Power Generator	475602	7720342	40	1.65	16.5	438	0	2.7	0.45	0
Frame 6 Power Generator	475646	7720360	40	2.25	16.6	821	0	2.7	0.45	0
Frame 6 Power Generator	475683	7720379	40	2.25	16.6	821	0	2.7	0.45	0
Frame 5 Liquefaction	475963	7720205	40	1.9	25	791	0	3	0.3	0
Thermal Oxidiser	475826	7720671	40	1.45	20	873	0	1.6	1	0
Fired Heater	475590	7720677	33	0.75	11	761	0	0.8	0.1	0
PR Compressor Frame 7 Turbine	475720	7720177	40	1.75	23.5	493	0	3.85	0.3	0
PR Compressor Frame 7 Turbine	475733	7720183	40	1.75	23.5	493	0	3.85	0.3	0
MR Compressor Frame 7 Turbine	475615	7720137	40	2.5	23	816	0	7.7	0.6	0
Frame 6 Power Generator	475547	7720280	40	1.65	16.5	438	0	2.7	0.45	0
Frame 6 Power Generator	475578	7720298	40	1.65	16.5	438	0	2.7	0.45	0
Frame 6 Power Generator	475621	7720317	40	1.65	16.5	438	0	2.7	0.45	0
Frame 6 Power Generator	475665	7720329	40	2.25	16.6	821	0	2.7	0.45	0
Frame 6 Power Generator	475702	7720348	40	2.25	16.6	821	0	2.7	0.45	0
Frame 5 Liquefaction	475851	7720106	40	1.9	25	791	0	3	0.3	0
Thermal Oxidiser	475975	7720301	40	1.45	20	873	0	1.6	1	0
Fired Heater	475739	7720727	33	0.75	11	761	0	0.8	0.1	0
Cold Dry Flare	475286	7720329	160	0.7	20	773	0.048	0.3	0	0.006
Warm Wet Flare	475311	7720329	160	0.7	20	773	0.048	0.3	0	0.006
Marine Flare	475106	7720966	36.6	1.525	20	1273	3.26	20	0.016	0.41