Department of Industry & Resources

BURRUP ROCK ART

ATMOSPHERIC MODELLING - CONCENTRATIONS AND DEPOSITIONS

- Final
- 24/06/2003

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1. Introduction

As part of studies to understand the impact of industry on Burrup rock engravings, the Department of Industry & Resources has contracted Sinclair Knight Merz (SKM) to undertake dispersion modelling of the atmospheric pollutants considered to be of most concern.

This work was originally undertaken in 2002 (SKM, 2002a) using the model TAPM to predict annual average concentrations and deposition of nitrogen dioxide and sulphur dioxide. However, in undertaking this assessment a number of shortcomings in the model set up and input data were identified. These were:

- How the ship emissions were specified as a source within TAPM by CSIRO. These were specified in the area emission file and assumed uniformly mixed over the lowest two grid cells. This resulted in excessive annual concentrations and depositions near the shipping berths, especially the King Bay public wharf.
- How the emission parameters used for Woodside facilities were approximated, i.e. the locations of stacks.
- The modelling did not account for the merging of close plumes and therefore the increased plume rise and the resultant decrease in ground level concentrations that would occur; and
- The modelling did not account for the effects of building structures on the Woodside emissions.

To this end, SKM along with CSIRO, undertook to improve the accuracy of the data (stack locations in SKM, (2003a), ship emissions in SKM, (2003b) and plume merging in Hurley, (2003)). In addition, Woodside identified errors in the emission data, which have been revised and are incorporated in this assessment.

As such, this report presents an update of the concentration and deposition estimates undertaken in 2002 with revised Woodside parameters and improved estimate of ship emissions using the model TAPM.

Further, as the EPA recommended in the assessment of the Methanex proposal that

"*The EPA considers that there is a need to provide verification of the deposition scheme (within TAPM) and that estimates should be tested against estimates from other models such as ISC3*" (EPA, 2002)

another model CALPUFF has been used to verify the concentration and deposition predictions. This model incorporates the same deposition algorithms as ISC3.

As the emissions from the major source of oxides of nitrogen and reactive organics (Woodside) have changed, SKM was also requested to update the cumulative "smog" modelling to assess whether there was space in the "airshed" for potential new industries. Therefore, this report presents updated:

- Estimates of annual concentrations and deposition of nitrogen dioxide and sulphur dioxide for existing and future industry and shipping from TAPM and CALPUFF;

- Estimates of the annual concentrations and deposition of ammonia from existing industry and future industry scenario; and
- Estimates of nitrogen dioxide for one-hour and ozone for one and four-hour averages to assess the levels at Hearson Cove, Conzinc Bay, Dampier and Karratha.

With this assessment it is noted that CSIRO is currently updating the air quality modelling for the Woodside expansion and as part of that study are reviewing many of the assumptions and parameterisations used within TAPM. As such, it is likely that they will propose a more optimised model for the area than used here and the predictions may change slightly. However, given that these results will not be available for several more months, this preliminary assessment has been undertaken.

2. Modelling Methodology

To predict annual concentrations and the deposition of nitrogen dioxide, sulphur dioxide and ammonia, the models TAPM and CALPUFF have been used.

TAPM – (The Air Pollution Model) 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 (2002b) and URS (2002)).

CALPUFF (the Californian Puff Model) is a diagnostic model (requiring observations of wind and temperature) that has regulatory status with US EPA for long range dispersion.

2.1 TAPM Model Settup

The model TAPM, was used to predict ozone, nitrogen dioxide and sulphur dioxide concentrations and nitrogen dioxide and sulphur dioxide deposition in the Dampier region. The model set up and emissions were as used by Physick and Blockley (2001) apart from the following:

- Three grids with a 30, 10 and 3 km meteorological grid spacing with 25 by 25 grid points each. The pollution grid was configured with a resolution twice that of the meteorological grid such that the smallest grid size was 1.5 km with 51 by 51 grid points. A grid of 25 by 25 was chosen to resolve the area with peak ozone concentrations SW of Dampier unlike the earlier modelling using a 21 by 21 grid;
- Emissions of NO_X from area sources (biogenic, shipping, aeroplanes etc) were set to a constant across the grid, with no sources from ships or towns. Sources from ships were set explicitly as volume sources; and
- Setting the landuse to tall very sparse shrubland so as to give a roughness length of 0.2m and an overall leaf area index of 0.475.

2.2 CALPUFF Model Settup

The model CALPUFF was used to predict concentrations and deposition rates of gaseous NO_2, SO_2 and NH_3 across the Burrup Peninsula. CALPUFF is a lagrangian dispersion model that simulates pollutant emissions as a series of continuous releases of puffs. It is the preferred model of the US EPA for the long-range transport of pollutants. The model differs from traditional gaussian plume models, in that it can model spatially varying wind and turbulence fields that are important in complex terrain, long-range transport and near calm conditions.

In the modelling the following was used:

- Surface wind data from the DEP's Karratha site, just south of the Dampier Salt evaporation ponds. This was used in preference to the DEP's Dampier site due to the problems of shielding of the wind by obstructions in certain directions. Upper wind and temperature were provided by TAPM. Over-water surface data and the sea surface temperature as required, were also predicted by TAPM. It is noted that this data could be refined by using the extensive data collected by Woodside in the area, which were not available at the time; and

- Two model runs were used. One for the wider area with a coarse grid of 1.5 km for the landuse with pollution and deposition predicted on a 0.75 km as per TAPM. The other finer grid, for the Burrup Peninsula used a 0.5 km landuse grid with a 0.25 km pollution grid.

2.3 Modelled Scenarios

To predict the annual concentrations and deposition, the meteorology of 1999 was used, as was the case in previous modelling for the Burrup. The assessment was for two scenarios;

1) Existing sources including:

- Woodside Onshore Treatment Plant (OTP) with the recent revised emissions;
- Hamersley Iron Power Station; and
- Ships.

2) A future case including:

- Woodside OTP with trains 4 and 5;
- Hamersley Iron Power Station;
- Methanex (two 2Mtpa trains), GTL, Burrup Fertilisers, Dampier Nitrogen, Japan DME and two other industries (at HI Land) equivalent to Japan DME and Dampier Nitrogen; and
- Current and potential shipping.

3. Atmospheric Emissions

Atmospheric emissions from existing and proposed facilities are presented in **Table 3-1** along with emissions for the future scenario modelled presented in **Table 3-2** and **Table 3-3**.

■ Table 3-1 Existing Burrup Emissions

Tag	Sources	Easting (m)	Northing (m)	Height (m)	Radius at tip (m)	Velocity (m/s)	Temp (deg K)	Rsmog (g/s)	NOX (g/s)	SO2 (g/s)	Ammonia (g/s)
Hamersley Power Station											
Stack1	Gas Turbine	470,910	7,716,750	52.0	1.320	11.1	388	0.00015	6.90	1.2	
Stack2	Gas Turbine	470,850	7,716,700	52.0	1.320	11.1	388	0.00015	6.90	1.2	
							Total Hamersley	**0.0003**	**13.80**	**2.40**	
Existing Woodside											
GT4001	Power Generation Gas Turbine (Normally only 5 operating)	476,910	7,722,765	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT4002	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,804	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT 4003	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,809	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT4004	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,847	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT 4005	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,852	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT 4006	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,890	40.0	1.975	20.2	777	0.000	13.5	0.00	
1KT1410	TRAIN 1 - GAS TURBINE PROPANE COMPRESSOR (361 days/yr)	476,539	7,722,963	40.0	1.940	23.9	790	0.000	15.8	0.27	
1KT1420	TRAIN 1 - GAS TURBINE PROPANE COMPRESSOR (361 days/yr)	476,589	7,722,963	40.0	1.940	23.9	790	0.000	15.6	0.27	
1KT1430	TRAIN 1 - Gas turbine mr compressor (361 days operating)	476,603	7,722,963	40.0	1.870	25.8	790	0.000	15.3	0.27	
1KT1440+1V1104	TRAIN 1 - Gas turbinr me compressor + acid gas vent (361 days/yr)	476,665	7,722,963	40.0	1.870	26.3	806	0.634	15.5	0.27	
1KT1450	TRAIN 1 - GAS TURBINE End Flash COMPRESSOR (361 days/yr)	476,510	7,722,959	40.0	1.360	21.2	784	0.000	9.4	0.12	
2KT1410	TRAIN 2 - GAS TURBINE PROPANE COMPRESSOR	476,539	7,722,843	40.0	1.940	23.9	790	0.000	15.8	0.27	
2KT1420	TRAIN 2 - GAS TURBINE PROPANE COMPRESSOR	476,589	7,722,843	40.0	1.940	23.9	790	0.000	15.6	0.27	
2KT1430	TRAIN 2 - GAS TURBINE MR COMPRESSOR	476,603	7,722,843	40.0	1.870	25.8	790	0.000	15.3	0.27	
2KT1440+2V1104	TRAIN 2 - GAS TURBINE MR COMPRESSOR + ACID GAS VENT	476,665	7,722,843	40.0	1.870	26.3	806	0.634	15.5	0.27	
2KT1450	TRAIN 2 - GAS TURBINE End Flash COMPRESSOR	476,510	7,722,839	40.0	1.360	21.2	784	0.000	9.4	0.12	
3KT1410	TRAIN 3 - GAS TURBINE PROPANE COMPRESSOR	476,539	7,722,608	40.0	1.940	23.9	790	0.000	15.8	0.27	
3KT1420	TRAIN 3 - GAS TURBINE PROPANE COMPRESSOR	476,589	7,722,608	40.0	1.940	23.9	790	0.000	15.6	0.27	
3KT1430	TRAIN 3 - GAS TURBINE MR COMPRESSOR	476,603	7,722,608	40.0	1.870	25.8	790	0.000	15.3	0.27	
3KT1440+3V1104	TRAIN 3 - GAS TURBINE MR COMPRESSOR + ACID GAS VENT	476,665	7,722,608	40.0	1.870	26.3	806	0.634	15.5	0.27	
3KT1450	TRAIN 3 - GAS TURBINE End Flash COMPRESSOR	476,510	7,722,604	40.0	1.360	21.2	784	0.000	9.4	0.12	
1F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	477,152	7,722,915	33.0	0.730	6.0	700	0.000	0.3	0.01	
2F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	477,152	7,722,905	33.0	0.730	6.0	700	0.000	0.3	0.01	
3F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	477,152	7,722,895	33.0	0.730	6.0	700	0.000	0.3	0.01	
4F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	476,968	7,722,880	33.0	0.730	6.0	700	0.000	0.3	0.01	
5F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	476,968	7,722,870	33.0	0.730	6.0	700	0.000	0.3	0.01	
1KT2420	Domgas Gas Turbine Compressor (361 days/yr operating)	477,035	7,722,698	24.0	1.000	40.7	816	0.000	9.4	0.12	
1KT2430	Domgas Gas Turbine Compressor (361 days/yr operating)	477,050	7,722,698	24.0	1.450	30.6	620	0.000	20.3	0.25	
2KT2420	Domgas Gas Turbine Compressor (361 days/yr operating)	477,065	7,722,698	24.0	1.000	40.7	816	0.000	9.4	0.12	
2KT2430	Domgas Gas Turbine Compressor (361 days/yr operating)	477,080	7,722,698	24.0	1.450	30.6	620	0.000	20.3	0.00	
Seal Oil	Compressor seal oil systems (assume central location)	476,500	7,722,500	20.0	1.000	0.0	400	0.229	0.00	0.00	
							Total Existing Woodside	**2.132**	**356.4**	**5.4**	**0.0**
Ships					**Sigma Y**	**Sigma Z**					
Wberth	Woodside Berth	475,200	7,723,600	70.0	75.000	10.0		0.00	0.95	0.16	
EIlbrt	EII Berth	466,170	7,716,500	70.0	75.000	10.0		0.00	3.49	3.5	
Pbrt	Parker Point berth	470,600	7,717,900	70.0	75.000	10.0		0.00	3.01	2.85	
Kbrt	King Bay Berth	473,700	7,719,250	50.0	75.000	10.0		0.00	1.59	0.95	
							Ships at Berths	**0.00**	**9.04**	**7.46**	
Ch1	Main channel Source 1	469,500	7,731,000	70.0	300.000	15.0		0.00	2.1	1.3	
Ch2	Main channel Source 2	469,000	7,729,000	70.0	300.000	15.0		0.00	2.1	1.4	
Ch3	Main channel Source 3	468,650	7,727,000	70.0	300.000	15.0		0.00	1.5	1.2	
Ch4	Main channel Source 4	468,000	7,725,000	70.0	300.000	15.0		0.00	1.5	1.2	
Ch5	Main channel Source 5	467,600	772,300	70.0	300.000	15.0		0.00	1.5	1.2	
Ch6	Main channel Source 6	467,200	7,721,000	70.0	300.000	15.0		0.00	1.5	1.2	
Ch7	Main channel Source 7	467,100	7,719,000	70.0	300.000	15.0		0.00	1	1	
Chee1	Channel to EEI	466,200	7,718,000	70.0	250.000	15.0		0.00	0.8	0.8	
CHpp1	Channel to PP	468,500	7,718,500	70.0	250.000	15.0		0.00	0.6	0.5	
CHkb1	Channel to King Bay1	468,500	7,720,700	50.0	300.000	15.0		0.00	0.3	0.4	
CHkb2	Channel to King Bay2	470,200	7,720,400	50.0	300.000	15.0		0.00	0.3	0.4	
Chkb3	Channel to King Bay3	472,300	7,719,500	50.0	300.000	15.0		0.00	0.3	0.4	
CHw1	Channel to Woodside 1	470,500	7,726,500	70.0	300.000	15.0		0.00	0.8	0.1	
Chw2	Channel to Woodside 2	472,100	7,725,200	70.0	300.000	15.0		0.00	0.8	0.1	
Chw3	Channel to Woodside 3	474,000	7,724,100	70.0	300.000	15.0		0.00	0.8	0.1	
							Ships in Channels	**0.00**	**15.9**	**11.3**	
							Total Existing Ships	**0.00**	**24.94**	**18.76**	
							TOTAL SOURCES	**2.13**	**395.2**	**26.57**	

Note: Woodside Train 1 to 3 locations estimated

■ Table 3-2 Future Scenario Emissions (part 1)

Tag	Sources	Easting (m)	Northing (m)	Height (m)	Radius at tip (m)	Velocity (m/s)	Temp (deg K)	Rsmog (g/s)	NOX (g/s)	SO2 (g/s)	Ammonia (g/s)
Hamersley Power Station											
Stack1	Gas Turbine	470,910	7,716,750	52.0	1.320	11.1	388	0.00015	6.90	1.2	
Stack2	Gas Turbine	470,850	7,716,700	52.0	1.320	11.1	388	0.00015	6.90	1.2	
						Hamersley Total		**0.0003**	**13.80**	**2.40**	
Existing Woodside											
GT4001	Power Generation Gas Turbine (Normally only 5 operating)	476,910	7,722,765	40.0	1.975	20.2	777	0.000	13.5	0.24	
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GT 4003	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,809	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT4004	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,847	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT 4005	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,852	40.0	1.975	20.2	777	0.000	13.5	0.24	
GT 4006	Power Generation Gas Turbine (Operating 304 days/yr)	476,910	7,722,890	40.0	1.975	20.2	777	0.000	13.5	0.00	
1KT1410	TRAIN 1 - GAS TURBINE PROPANE COMPRESSOR (361 days/yr)	476,539	7,722,963	40.0	1.940	23.9	790	0.000	15.8	0.27	
1KT1420	TRAIN 1 - GAS TURBINE PROPANE COMPRESSOR (361 days/yr)	476,589	7,722,963	40.0	1.940	23.9	790	0.000	15.6	0.27	
1KT1430	TRAIN 1 - Gas turbine mr compressor (361 days operating)	476,603	7,722,963	40.0	1.870	25.8	790	0.000	15.3	0.27	
1KT1440+1V110	TRAIN 1 - Gas turbinr me compressor + acid gas vent (361 days/yr)	476,665	7,722,963	40.0	1.870	26.3	806	0.634	15.5	0.27	
1KT1450	TRAIN 1 - GAS TURBINE End Flash COMPRESSOR (361 days/yr)	476,510	7,722,959	40.0	1.360	21.2	784	0.000	9.4	0.12	
2KT1410	TRAIN 2 - GAS TURBINE PROPANE COMPRESSOR	476,539	7,722,843	40.0	1.940	23.9	790	0.000	15.8	0.27	
2KT1420	TRAIN 2 - GAS TURBINE PROPANE COMPRESSOR	476,589	7,722,843	40.0	1.940	23.9	790	0.000	15.6	0.27	
2KT1430	TRAIN 2 - GAS TURBINE MR COMPRESSOR	476,603	7,722,843	40.0	1.870	25.8	790	0.000	15.3	0.27	
2KT1440+2V110	TRAIN 2 - GAS TURBINE MR COMPRESSOR + ACID GAS VENT	476,665	7,722,843	40.0	1.870	26.3	806	0.634	15.5	0.27	
2KT1450	TRAIN 2 - GAS TURBINE End Flash COMPRESSOR	476,510	7,722,839	40.0	1.360	21.2	784	0.000	9.4	0.12	
3KT1410	TRAIN 3 - GAS TURBINE PROPANE COMPRESSOR	476,539	7,722,608	40.0	1.940	23.9	790	0.000	15.8	0.27	
3KT1420	TRAIN 3 - GAS TURBINE PROPANE COMPRESSOR	476,589	7,722,608	40.0	1.940	23.9	790	0.000	15.6	0.27	
3KT1430	TRAIN 3 - GAS TURBINE MR COMPRESSOR	476,603	7,722,608	40.0	1.870	25.8	790	0.000	15.3	0.27	
3KT1440+3V110	TRAIN 3 - GAS TURBINE MR COMPRESSOR + ACID GAS VENT	476,665	7,722,608	40.0	1.870	26.3	806	0.634	15.5	0.27	
3KT1450	TRAIN 3 - GAS TURBINE End Flash COMPRESSOR	476,510	7,722,604	40.0	1.360	21.2	784	0.000	9.4	0.12	
1F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	477,152	7,722,915	33.0	0.730	6.0	700	0.000	0.3	0.01	
2F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	477,152	7,722,905	33.0	0.730	6.0	700	0.000	0.3	0.01	
3F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	477,152	7,722,895	33.0	0.730	6.0	700	0.000	0.3	0.01	
4F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	476,968	7,722,880	33.0	0.730	6.0	700	0.000	0.3	0.01	
5F2001	Stabiliser Overheads Reboil Furnace (361days/yr operating)	476,968	7,722,870	33.0	0.730	6.0	700	0.000	0.3	0.01	
1KT2420	Domgas Gas Turbine Compressor (361 days/yr operating)	477,035	7,722,698	24.0	1.000	40.7	816	0.000	9.4	0.12	
1KT2430	Domgas Gas Turbine Compressor (361 days/yr operating)	477,050	7,722,698	24.0	1.450	30.6	620	0.000	20.3	0.25	
2KT2420	Domgas Gas Turbine Compressor (361 days/yr operating)	477,065	7,722,698	24.0	1.000	40.7	816	0.000	9.4	0.12	
2KT2430	Domgas Gas Turbine Compressor (361 days/yr operating)	477,080	7,722,698	24.0	1.450	30.6	620	0.000	20.3	0.00	
Seal Oil	Compressor seal oil systems (assume central location)	476,500	7,722,500	20.0	1.000	0.0	400	0.229	0.00	0.00	
						Total Existing Woodside		**2.132**	**356.4**	**5.4**	**0.0**
LNG4	**Under Construction**										
4KT1430	Propane Refrigerant Compressor Train 4	476,664	7,722,465	40	1.45	28.2	490		5.0	0.3	
		476,664	7,722,461	40	1.45	28.2	490		5.0	0.3	
4KT1410	MR Refrigerant Compressor Train 4	476,560	7,722,461	40	3.05	23.4	814		10.6	0.6	
1F1251	Acid Gas Incinerator	476,933	7,722,944	40	1.46	21.3	1373	0.000	0.8	1.3	
GT4007	Power Generation Gas Turbine	476,972	7,722,702	40	1.65	23.0	694		3.3	0.2	
GT4008	Power Generation Gas Turbine	476,972	7,722,668	40	1.65	23.0	694		3.3	0.2	
LNG5	**Proposed**										
5KT1430	Propane Refrigerant Compressor Train 5	476,664	7,722,335	40	1.45	28.2	490		5.0	0.3	
		476,664	7,722,331	40	1.45	28.2	490		5.0	0.3	
5KT1410	MR Refrigerant Compressor Train 5	476,560	7,722,331	40	3.05	23.4	814		10.6	0.6	
2F1251	Acid Gas Incinerator	476,953	7,722,944	40	1.46	21.3	1373	0.000	0.8	6.4	
GT4009	Power Generation Gas Turbine	476,972	7,722,626	40	1.65	23.0	694		3.3	0.2	
GT4010	Power Generation Gas Turbine	476,972	7,722,592	40	1.65	23.0	694		3.3	0.2	
						Future Total Woodside		**2.132**	**412.2**	**16.4**	**0.0**
Methanex:											
mt1	Flue Gas1	477,950	7,719,750	50	1.85	20.0	433		20.80		
mt2	Gas Turbine 1	477,795	7,719,805	20	1.50	15.0	753		0.80		
mt3	Auxiliary Boiler 1	477,855	7,719,850	50	1.85	15.0	463		6.40		
mt4	Flue Gas 2	478,225	7,719,960	50	1.85	20.0	433		20.80		
mt5	Gas Turbine 2	478,060	7,720,010	20	1.50	15.0	753		0.80		
mt6	Auxiliary Boiler 2	478,140	7,720,060	50	1.85	15.0	463		6.40		
Dampier Nitrogen:											
dn1	Reformer	476,525	7,718,860	35	1.50	17.0	450		11.00		-
dn2	LP Absorber	476,247	7,718,852	56	0.15	27.6	321		-		0.20
dn3	AP Absorber	476,273	7,718,859	56	0.10	1.1	319		-		1.00
dn4	Granulation Plant	476,202	7,718,877	51	2.00	26.6	315		-		23.60
dn5	Gas Turbine 1	476,574	7,718,856	30	1.50	17.9	463		5.60		-
dn6	Gas Turbine 2	476,573	7,718,834	30	1.50	17.9	463		5.60		-
dn7	Auxiliary Boiler	476,620	7,718,840	30	1.00	14.0	463		1.50		-

■ Table 3-3 Future Scenario Emissions (Continued)

Tag	Sources	Easting (m)	Northing (m)	Height (m)	Radius at tip (m)	Velocity (m/s)	Temp (deg K)	Rsmog (g/s)	NOX (g/s)	SO2 (g/s)	Ammonia (g/s)
GTL											
gtl1	Auxilliary Boiler	478,096	7,722,768	30	1.50	14.5	493	-	2.42	0.014	
gtl2	Reformer Waste Heat Stack	478,093	7,722,710	35	2.70	20.4	465	-	10.72	0.056	
gtl3	Pilot Burner Flare	478,181	7,722,713	65	-	-	-	Traces	0.00	Trace	
gtl4	Diesel Generator	478,046	7,722,743	10	0.50	12.5	533	-	0.25	0.056	
gtl5	ProcessCondensate stripper	478,039	7,722,811	15	0.60	10.6	373	0.11	-	-	
Burrup Fertilisers											
BF1	Primary Reformer	476,915	7,718,833	36	3.56	12.7	413		15.40	-	
BF3	Package Boiler	477,060	7,718,820	15	1.69	5.0	450		1.30	0.020	
Japan DME											
JDME1	Main Stack	477,750	7,719,000	50	2.65	20	673				
									101.00	0.063	
Replicate Japan DME											
JDME2		473,450	7,716,400	50	2.65	20	673		101.00	0.063	
Replicate Dampier Nitrogen											
dn12	Reformer	473,525	7,716,860	35	1.50	17.0	450		11.00		-
dn22	LP Absorber	473,247	7,716,852	56	0.15	27.6	321		-		0.20
dn32	AP Absorber	473,273	7,716,859	56	0.10	1.1	319		-		1.00
dn42	Granulation Plant	473,202	7,716,877	51	2.00	26.6	315		-		23.60
dn52	Gas Turbine 1	473,574	7,716,856	30	1.50	17.9	463		5.60		-
dn62	Gas Turbine 2	473,573	7,716,834	30	1.50	17.9	463		5.60		-
dn72	Auxiliary Boiler	473,620	7,716,840	30	1.00	14.0	463		1.50		-
					Total Future Additional Industries				**335.49**	**0.27**	**49.60**
Ships					**Sigma Y**	**Sigma Z**					
Wberth	Woodside Berth	475,200	7,723,600	70.0	75.000	10.0		0	1.9	0.32	
EIlbrt	EII Berth	466,170	7,716,500	70.0	75.000	10.0		0	3.49	3.5	
Pbrt	Parker Point berth	470,600	7,717,900	70.0	75.000	10.0		0	6.02	5.7	
Kbrt	King Bay Berth	473,700	7,719,250	50.0	75.000	10.0		0	5.1	0.95	
							Ships at Berths	**0**	**16.51**	**10.47**	**0**
Ch1	Main channel Source 1	469,500	7,731,000	70.0	300.000	15.0		0	**3.77**	2.3	
Ch2	Main channel Source 2	469,000	7,729,000	70.0	300.000	15.0		0	**3.77**	2.3	
Ch3	Main channel Source 3	468,650	7,727,000	70.0	300.000	15.0		0	**2.70**	2.2	
Ch4	Main channel Source 4	468,000	7,725,000	70.0	300.000	15.0		0	**2.70**	2.2	
Ch5	Main channel Source 5	467,600	772,300	70.0	300.000	15.0		0	**2.70**	2.2	
Ch6	Main channel Source 6	467,200	7,721,000	70.0	300.000	15.0		0	**2.70**	2.2	
Ch7	Main channel Source 7	467,100	7,719,000	70.0	300.000	15.0		0	**1.80**	1.8	
Chee1	Channel to EEI	466,200	7,718,000	70.0	250.000	15.0		0	**1.80**	0.8	
CHpp1	Channel to PP	468,500	7,718,500	70.0	250.000	15.0		0	**1.20**	1	
CHkb1	Channel to King Bay1	468,500	7,720,700	50.0	300.000	15.0		0	**0.97**	1.23	
CHkb2	Channel to King Bay2	470,200	7,720,400	50.0	300.000	15.0		0	**0.97**	1.23	
Chkb3	Channel to King Bay3	472,300	7,719,500	50.0	300.000	15.0		0	**0.97**	1.23	
CHw1	Channel to Woodside 1	470,500	7,726,500	70.0	300.000	15.0		0	**1.60**	0.2	
Chw2	Channel to Woodside 2	472,100	7,725,200	70.0	300.000	15.0		0	**1.60**	0.2	
Chw3	Channel to Woodside 3	474,000	7,724,100	70.0	300.000	15.0		0	**1.60**	0.2	
							Ships in Channels	**0.00**	**15.9**	**21.29**	**0**
							Total Future Ships	**0.00**	**31.8**	**31.76**	**0**
							TOTAL SOURCES	**2.13**	**793.33**	**50.85**	**49.60**

Emissions of both existing and future sources were provided by Woodside and the DEP. In modelling all emissions, a constant emission rate as specified for the entire year was modelled. The exception to this was for Woodside's power generation gas turbines where 5 turbines were assumed to run continuously, with 1 not in operation for the entire year.

Existing ship emissions were estimated based on a review of estimates from the Pilbara NPI study SKM (2000) and from the Karratha – Dampier and Burrup Peninsula Emissions Inventory (DEP, 2002).

- **Table 3-4 Ship Emissions (tpa) for 1999 in the Dampier Region as recommended by SKM (2003a)**

Source	NO_X			SO_2		
	DEP (2002)	SKM (2000)	Used Here	DEP (2002)	SKM (2000)	Used Here
Shipping Channels	856	665 (3)	500	485	500 (3)	350
Woodside	27	71 (1) (129) (2)	30	29	74 (1) 77 (2)	5
King Bay, Dampier Public Wharf	277	48 (2)	50	78	31 (2)	30
Parker Point	62	95 (1) (95) (2)	95	53	91 (1) 91 (2)	90
EII/MI	64	113 (1) (160) (2)	110	52	111 (1) 113 (2)	110
Total	**1337**	**989 (1096)**	**785**	**806**	**807 (812)**	**585**

Notes:

1) The length of shipping channels covered in the SKM (2000) study is approximately 25% greater than in the DEP study as the SKM estimates were from Anchorage points to Berth. As such, the SKM estimates should be approximately 25% more.
2) The notes in the table on the SKM estimates refer to the tables in Appendix B of SKM (2002b). Values in brackets are with the inclusion of tugboat emissions.
3) DEP (2002) estimates of total NO_X and SO_2 for the region from all sources are 8933 tpa and 1045 tpa respectively, such that shipping accounts for 15 and 77% of the total emissions in the area.
4) The NO_X emissions at the highest grid cells used by Bill Physick in his model comparison to observations were reduced by a factor of 2 to apparently provide better agreement.

Note that the recommended emissions ("Used Here" column) have been supplied to the DEP for comment. As yet, no written confirmation that they are considered the best estimates has been received.

Future ship emissions were estimated based on an approximate doubling of ships to both Parker Point and Woodside, and the expected volume of ships accessing the expanded King Bay facility (Simms, 2002).

In modelling NO_2 using CALPUFF, 30% of the NO_X emitted was assumed to be in the form of NO_2 at ground level. This is based on the NO_X measurements at Dampier which indicate typically that 40% of the NO_X is NO_2 (see **Section 4**). As the areas of interest on the Burrup Peninsula are closer to the major sources where the NO_X emitted is typically 5% by weight NO_2, a NO_2 percentage of around 30% is considered appropriate for the Burrup region. This approach may over-predict the conversion and resultant NO_2 levels adjacent to the major sources and under-predict the conversion further from the major sources and therefore NO_2 at receptors such as Dampier. For the SO_2 and NH_3, no chemical transformation is considered though SO_2 will be converted into sulphates, and NH_3 is reasonably rapidly converted to particulate with a conversion rate of 29%/hr quoted by Asman (2001).

Emissions of NH_3 from the proposed Plenty River plant were as detailed in Tables 3.9 to 3.11 of URS (2002). This indicates three sources of NH_3 from the plant with emissions of 0.2, 1.0 and 23.6 g/s and stacks 51 to 56m high. For these stacks no building affects have been assumed which is valid if nearby buildings are below 22m.

For both models, the enhancement due to buoyancy was neglected as a conservative assumption and also as there are some questions pertaining to the accuracy of the available plume merging schemes. Initial modelling with the incorporation of plume merging indicated that this would decrease concentrations significantly. An assessment of the importance of plume merging is being conducted by Woodside in their assessment. In addition, the effect of building structures has been neglected. An initial assessment of concentrations predicted from the Woodside OTP using TAPM indicated that this had little effect on the maximum concentrations. For the other industries, plume downwash has generally been minimised by appropriate stack height design.

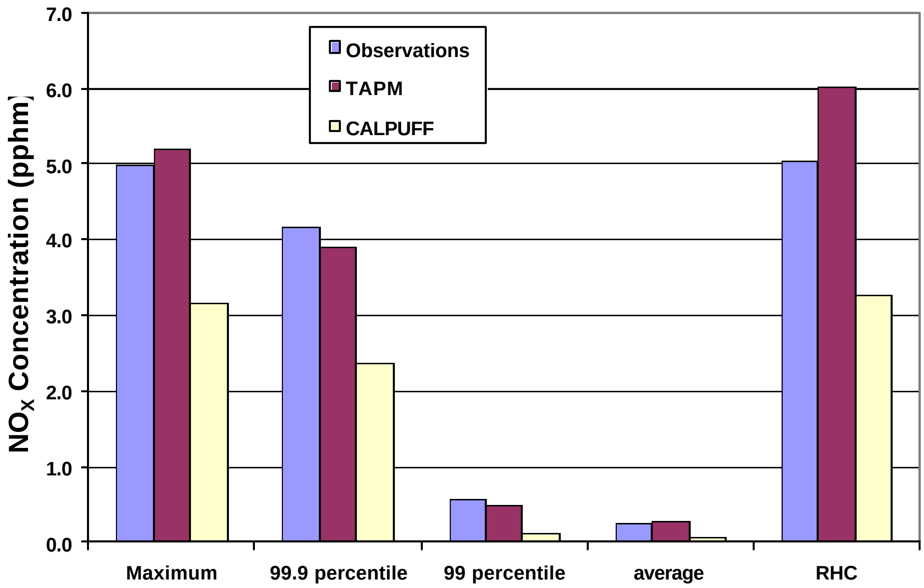
4. Model Validation

To assess, the capability of the two models, comparison of predicted and observed concentrations of NO_X and NO_2 at Dampier are made. Other stations such as King Bay have been neglected as the concentrations measured there are thought to be low and are currently being checked by Woodside.

4.1 NO_X Comparison

The results of the NO_X comparison are summarised in **Figure 4-1**. The statistics compared are the:

- Maximum hourly concentration for the year;
- 99.9 percentile hourly concentration (the 9th highest concentration for a year with 8760 hours);
- 99 percentile hourly concentration (the 88th highest hourly concentration for a year with 8760 hours);
- Average concentration; and
- The RHC, the robust highest concentration as detailed by Hurley et al (2002). This is a more robust measure of the maximum concentration.



■ **Figure 4-1 Predicted and Observed NO_X Concentrations**

The results presented in **Table 4-1** indicate that:

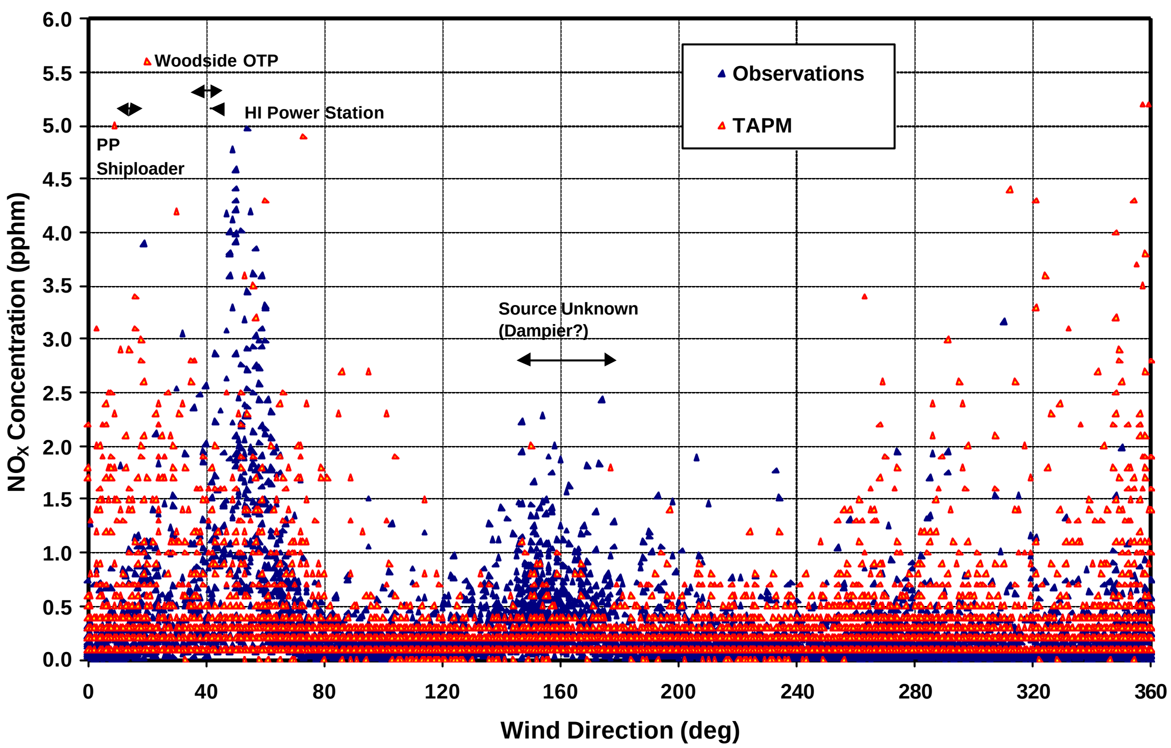
- TAPM has good skill in replicating observations and is generally slightly conservative;
- CALPUFF under-predicts. This under-prediction is partially due to lack of meteorological data used as inputs to the model. This should be improved with access to Woodside offshore data for winds and sea temperatures.

The apparent good agreement between TAPM and the observations however is a little fortuitous in that TAPM unlike the observations, predicts the highest NO_X concentrations to occur for a range of wind directions from 320 to 90 degrees (see

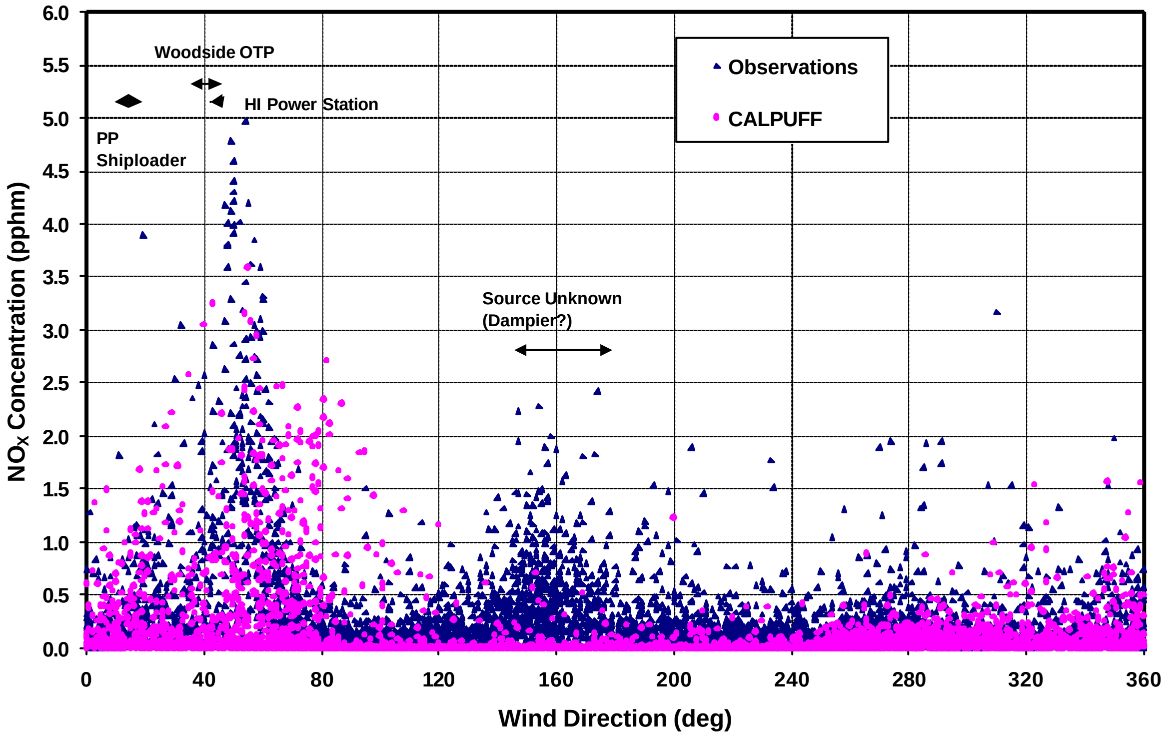
Figure 4-2). CALPUFF on the other hand predicts the highest concentrations for a narrower band of wind directions more like the observations (see **Figure 4-3**). The reason for the maximum NO_X concentrations from TAPM occurring on a wider arc is probably due to TAPM predicting that recirculation is more frequent than the observations suggest. That is, the mechanism where the plumes from Woodside are carried offshore under an easterly wind and brought to Dampier with the arrival of a north westerly sea breeze (see **Appendix A** for an example).

In general, the monitoring data indicates that the highest twenty 1-hour NO_X concentrations impacts at Dampier occur under:

- Wind directions in a narrow wind arc from 45 to 60 degrees;
- Wind speeds from 6 to 8 m/s;
- Between 1200 to 1600 WST; and
- Pasquill Gifford stabilities of either C of D class.

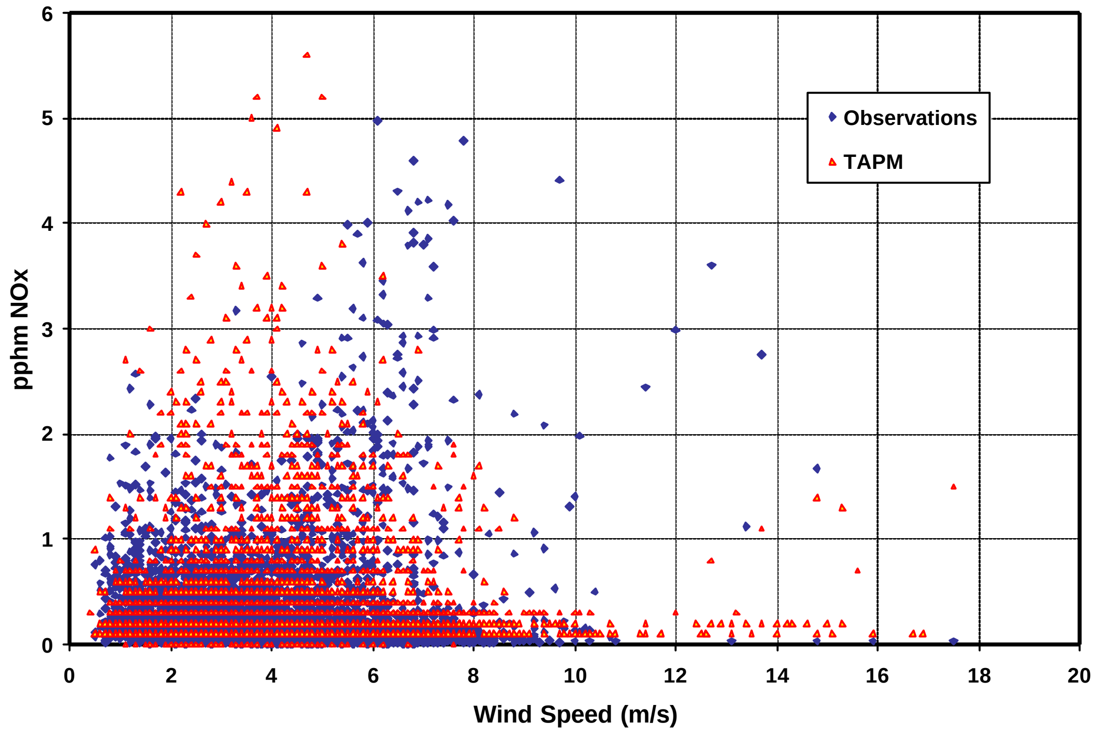


■ **Figure 4-2 Observed NO_X concentrations at Dampier versus predicted concentrations from TAPM**

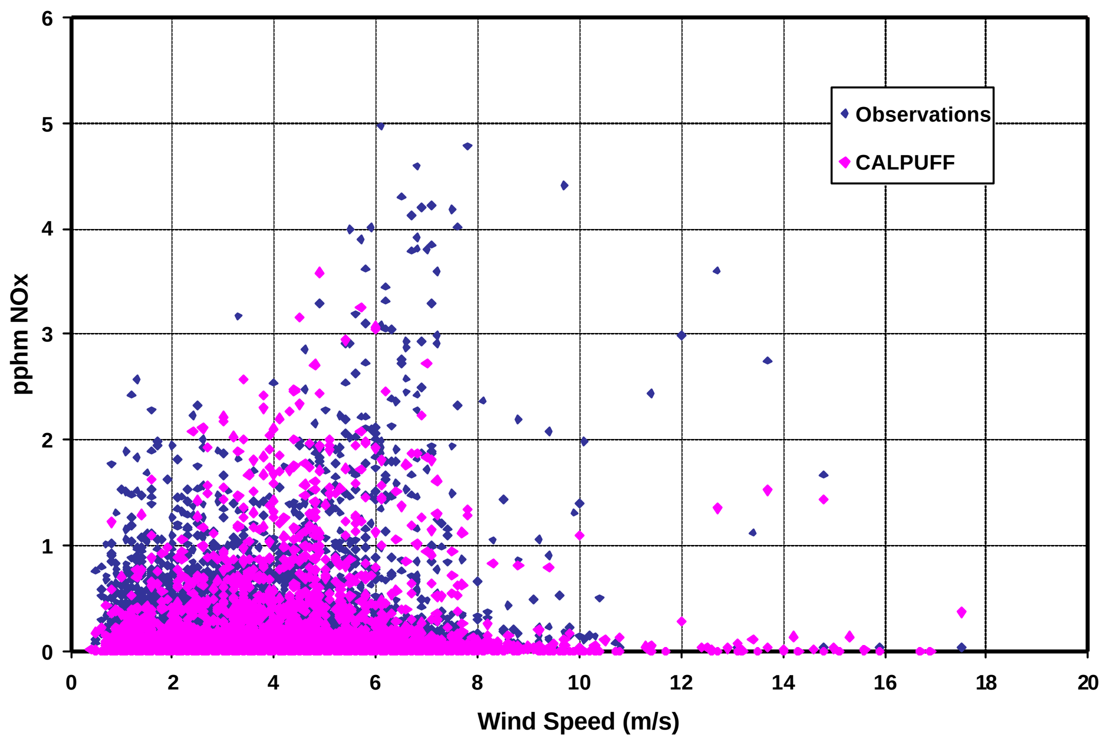


■ **Figure 4-3 Observed NO_X concentrations at Dampier versus predicted concentrations from CALPUFF**

Figure 4-4 and **Figure 4-5** present the concentrations from TAPM and CALPUFF and the observations predicted as a function of the wind speed measured at Dampier. This indicates that the maximum 1-hour concentrations from TAPM occur for observed wind speeds in the range of 3 to 5 m/s whilst the observed maximums occur in the wind speed range of 6 to 8 m/s. CALPUFF predicts the maximums to occur at higher wind speeds from 4 to 6 m/s. Therefore TAPM tends to predict the maximums at lower wind speeds than the observations and from a much wider wind direction arc, whilst CALPUFF though underestimating the magnitude of the concentrations predicts them more in line with the conditions.



■ **Figure 4-4 Observed and predicted concentrations from TAPM as a function of wind speed**

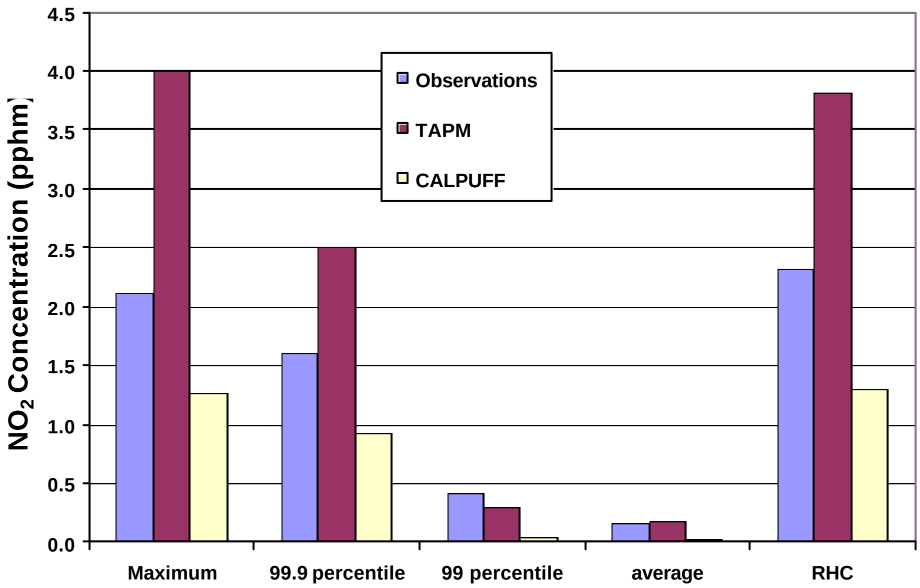


■ **Figure 4-5 Observed and Predicted concentrations from CALPUFF as a function of wind speed**

4.2 NO_2 Comparison

The predicted and observed NO_2 concentrations at Dampier are presented in **Figure 4-6**. This indicates that:

- TAPM over-predicts NO_2 for the hourly statistics; and
- CALPUFF under predicts for all the averaging times. Note that the CALPUFF NO_2 concentrations were predicted using a 40% conversion at Dampier as is found from the observations (see **Figure 4-9**).



- **Figure 4-6 Predicted and Observed NO_2 Concentrations**

The high predicted TAPM NO_2 concentrations at Dampier appear to be the result of TAPM over-predicting the rate of conversion of NO to NO_2. For air that is transported directly to Dampier the percentage of NO_X as NO_2 is 60% (**Figure 4-8**) when the percentage should be around 40% (see **Figure 4-7**). **Figure 4-8** also indicates that TAPM predicts the highest 1-hour NO_2 concentration to occur with nearly 100% conversion of NO to NO_2. This event was found to be due to the plume from Woodside being advected under a light easterly wind in the afternoon, and then blown across Dampier at around 1700-1800 WST (see **Appendix A**) with the advent of a light sea breeze. The very high conversion rate in this event is considered to be overstated and is possibly due to the reaction mechanism within TAPM and/or that the grid cells used in this modelling are too coarse.

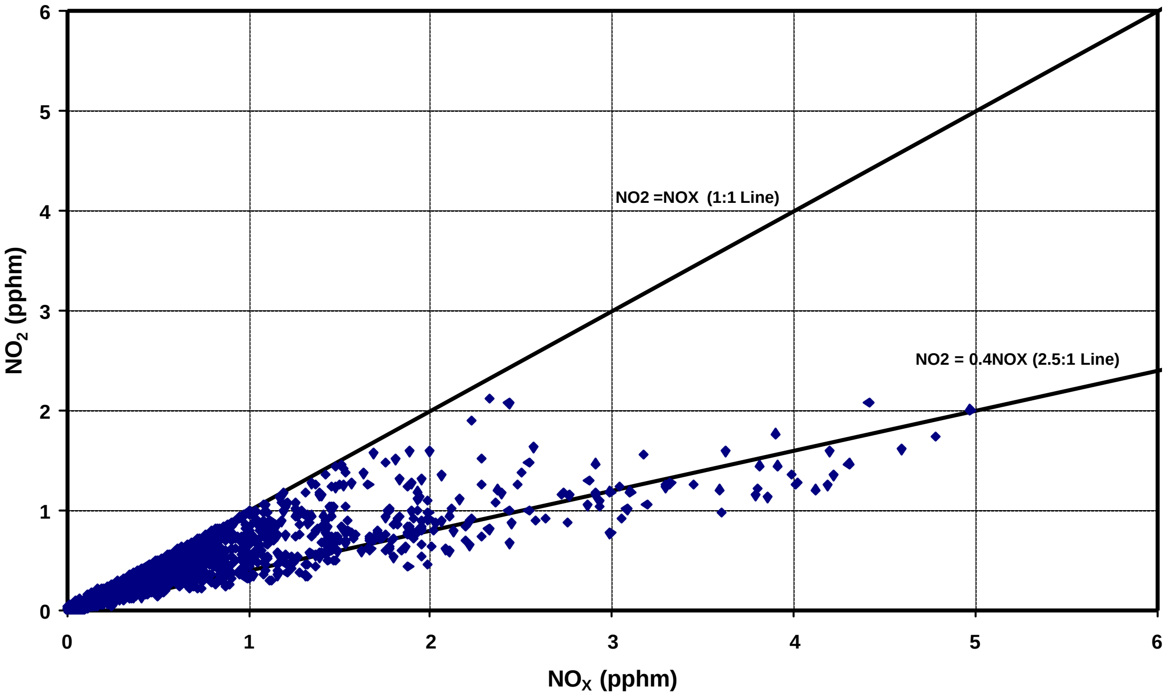
4.3 Other NO_2 Sources

As indicated in **Section 4.1** the predominant source of high NO_X concentrations at Dampier is indicated to be Woodside's OTP. This is due primarily to the NO component of this source as shown in **Figure 4-9**. In terms of NO_2 concentrations however, **Figure 4-10** indicates that there is a source to the south southeast of the monitor which leads to high NO_2 concentrations that are as high as that from Woodside. In any model validation of NO_2 this source needs to be accounted for, either by removing the NO_2 data for this wind direction, or explicitly modelling this source.

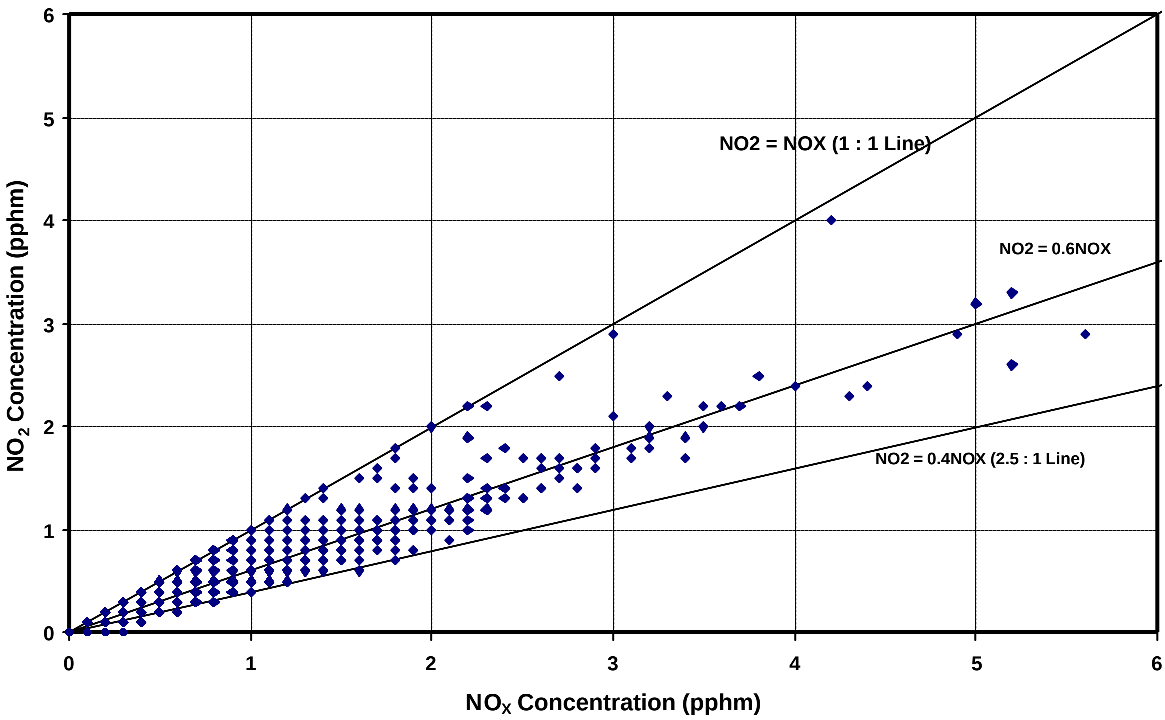
4.4 Summary

From the above brief analysis, the following is concluded:

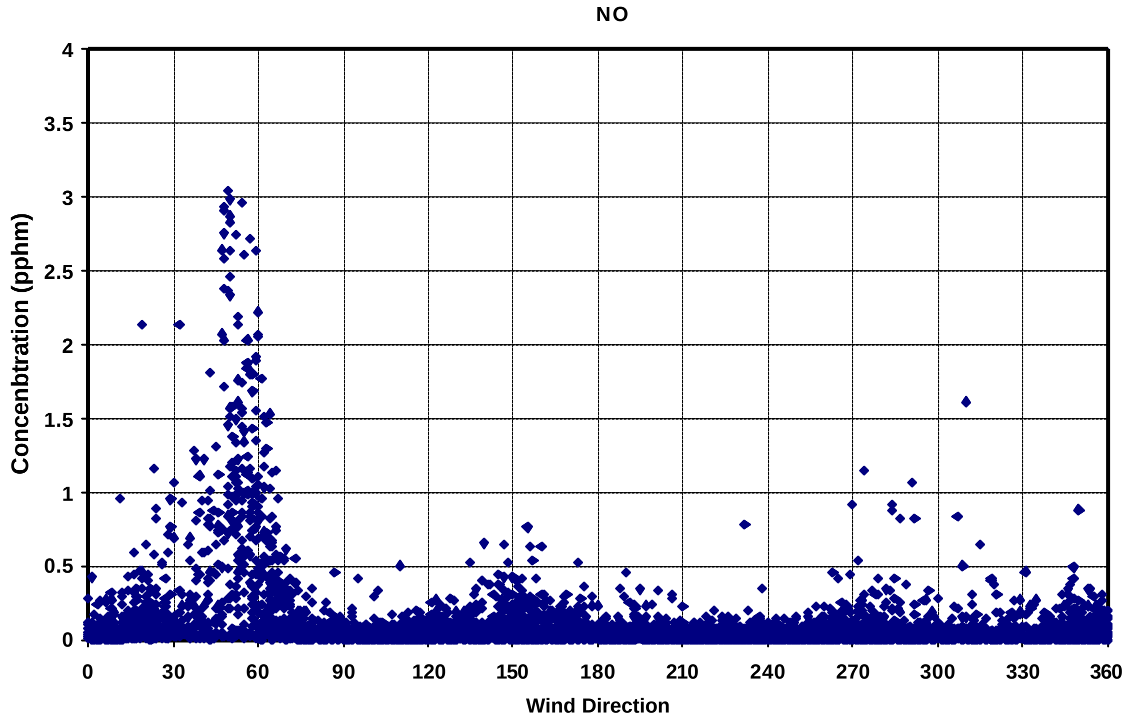
- Generally TAPM as configured here, reproduces the NO_X statistics at Dampier, though over-predicting the NO_2 concentrations. The over-prediction of the NO_2 is considered due to TAPM predicting the reaction of NO to NO_2 proceeds too fast. As such, annual predictions of NO_2 concentrations and as a result the NO_2 depositions are likely to be over-predicted; and
- CALPUFF under-predicts the NO_X and NO_2 concentrations at Dampier. The reason for this is not known, but the predictions could possibly be improved with the use of more meteorological data such as from Woodside's off-shore buoys. As such, CALPUFF predictions of pollutants, except for the near field (within several kilometres of the source) are likely to be underestimates.



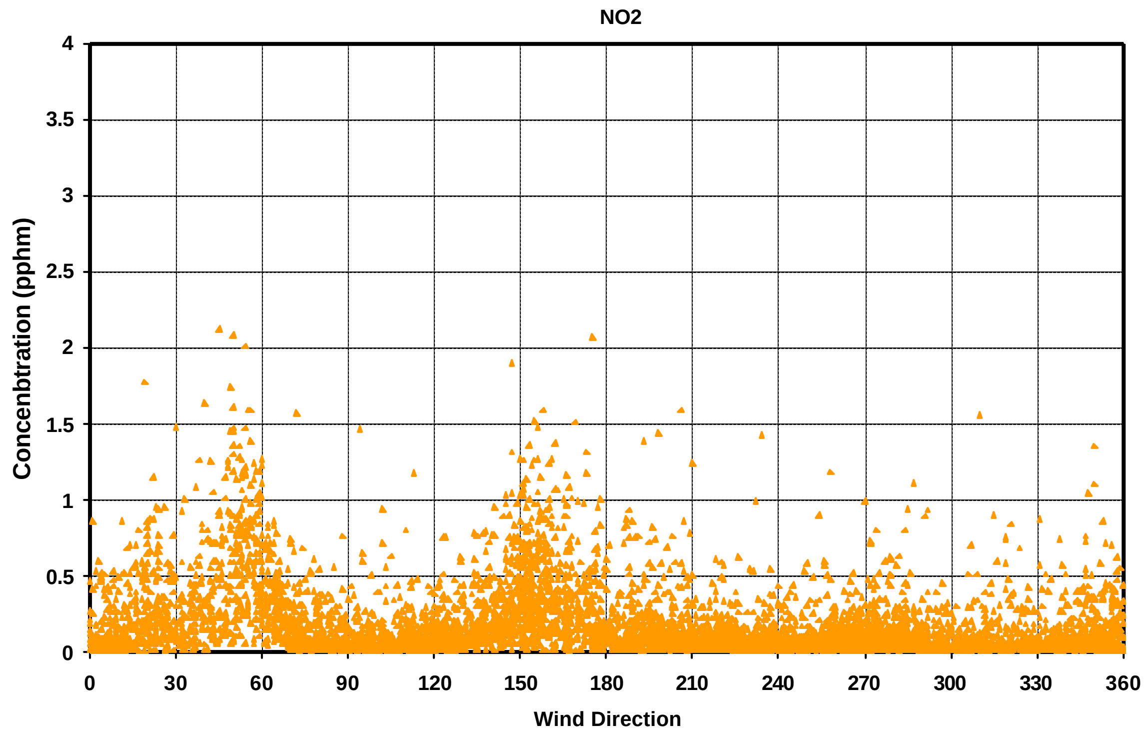
■ **Figure 4-7 Observed NO_2 versus NO_X concentrations at Dampier for 1999**



■ **Figure 4-8 TAPM Predicted NO_2 versus NO_X concentrations at Dampier for 1999**



■ **Figure 4-9 Observed 1-hour NO concentrations at Dampier for 1999**



■ **Figure 4-10 Observed 1-hour NO_2 concentrations at Dampier for 1999**

5. Predicted Annual Concentrations And Depositions

5.1 Predicted Existing Levels

5.1.1 Nitrogen dioxide

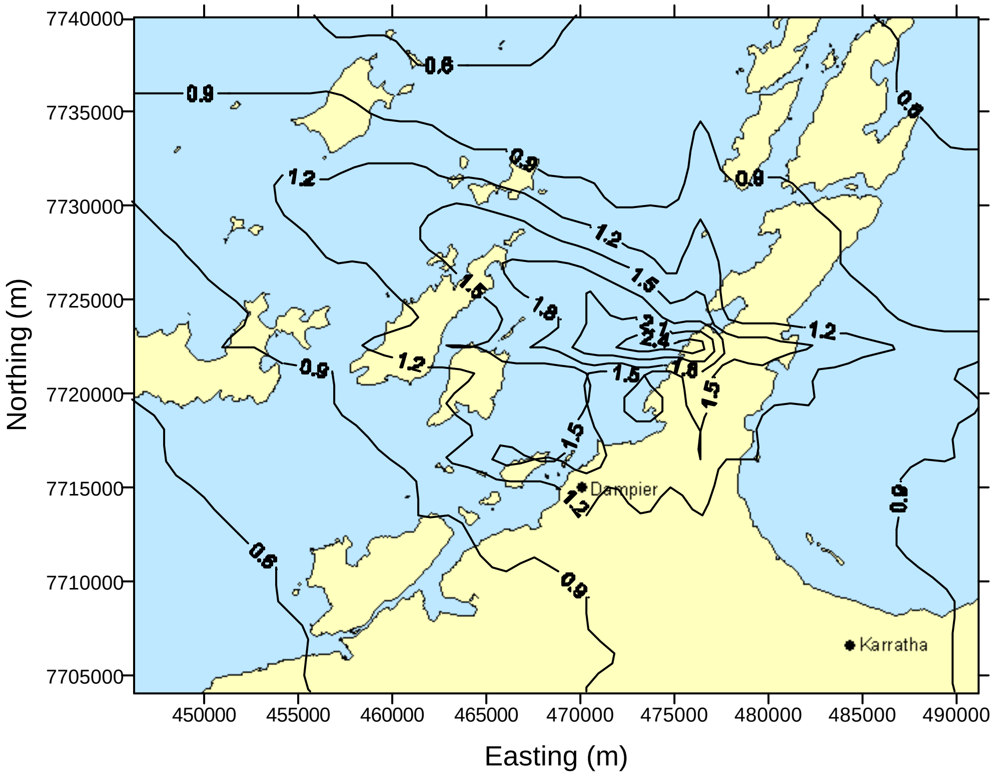
Predicted annual average ground level concentrations and the total deposition to the ground (vegetation, soil/rock and any water bodies) from TAPM are presented in **Figure 5-1** and **Figure 5-2.** These indicate that:

- Highest NO_2 concentrations occur around the Woodside OTP facilities;
- Smaller maximums occur around the shipping berths;
- Comparison to the WHO (2000) critical level for NO_X for natural vegetation of 30 μg/m^3 (14.6 ppb), (note that NO_2 is presented here, not NO_X) indicates that the predicted concentrations (max of 2.7ppb on Woodside land) are well below these criteria;
- The highest NO_2 deposition rates occur over water. This is considered to be primarily due to the deposition to vegetation being dependent on daylight and the photosynthesis process and that TAPM uses a moderately high solubility factor for NO_2; and
- Over land on the Burrup Peninsula, the maximum deposition rates are around 0.85 kg NO_2/ha/year occurring at Woodside's OTP.

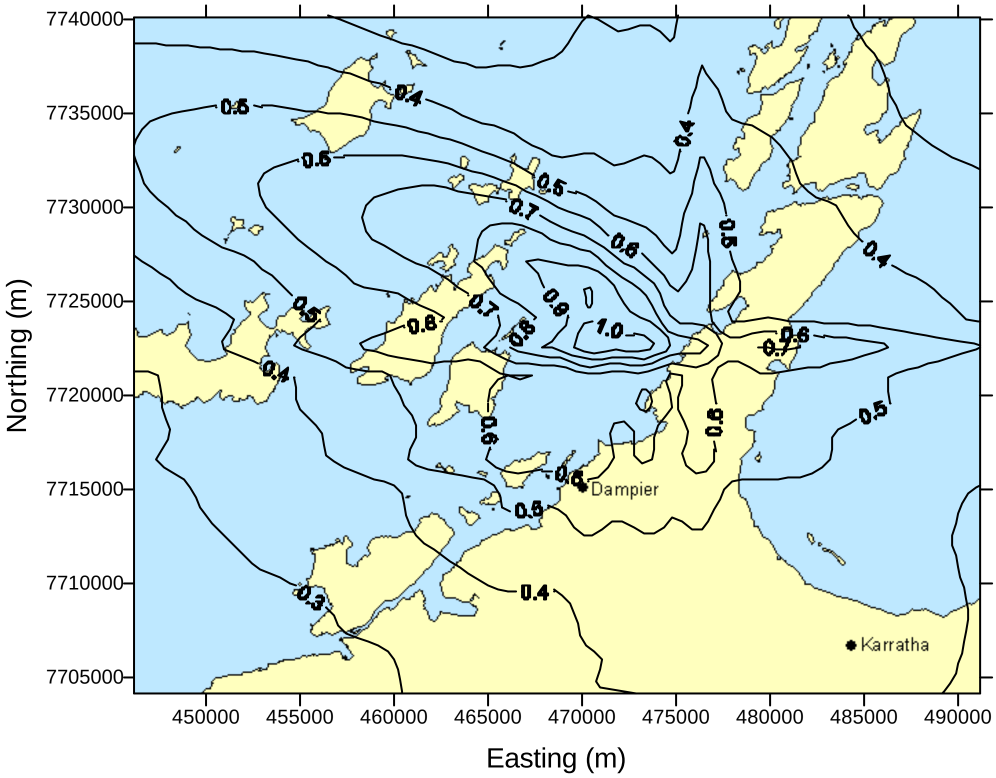
The predicted annual average concentrations and deposition rates of NO_2 from CALPUFF are presented in **Figure 5-3** and **Figure 5-4**. These indicate:

- Lower concentrations than predicted by TAPM, though the same spatial pattern with the highest concentrations extending towards the west and to a lesser extent the east and decreasing most quickly in the south and north direction. The lower NO_2 concentrations predicted by CALPUFF are considered to be a combination that TAPM tends to over-predict NO_2 concentrations and that CALPUFF tends to under-predict NO_X and NO_2 concentrations.
- The deposition rates from CALPUFF are lower than from TAPM with a maximum deposition of 0.65 kg NO_2/ha/year. CALPUFF unlike TAPM predicts the highest depositions on land with low deposition rates over water due to the much lower NO_2 solubility used in the model.

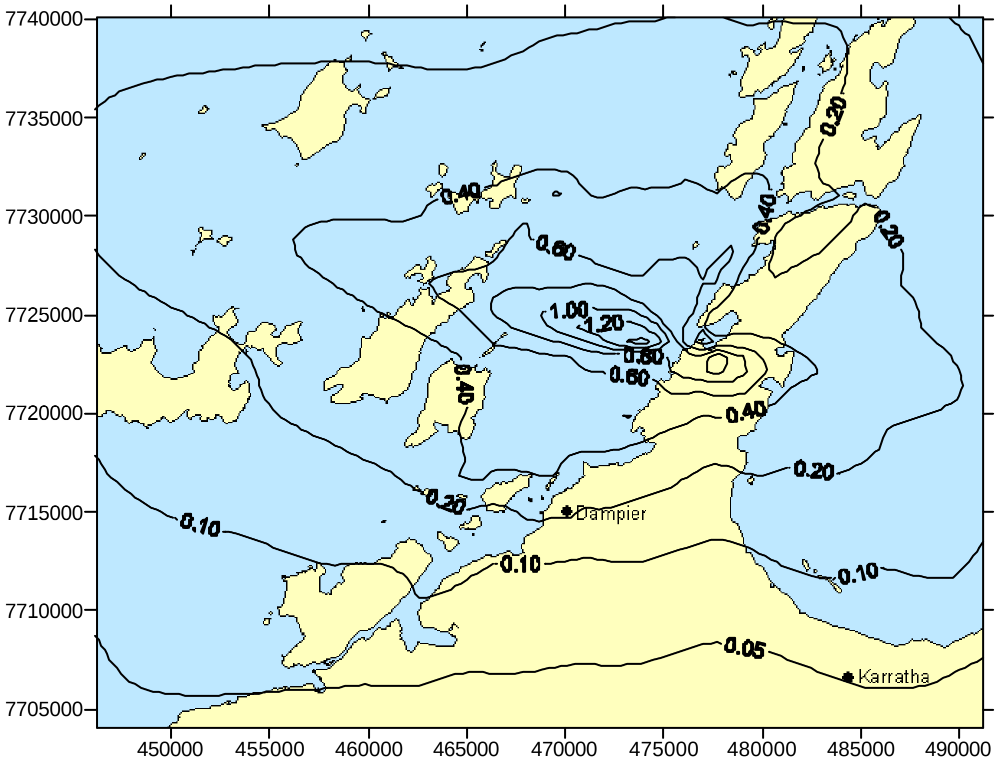
Comparison to the WHO (2000) critical load for N deposition of 15-20 kg/ha/year for dry heathland, indicates that the deposition over land of between 0.65 to 0.85 kg NO_2/ha/year (0.20 to 0.26kgN/ha/year) is relatively insignificant (1.3-1.7% of the criteria).



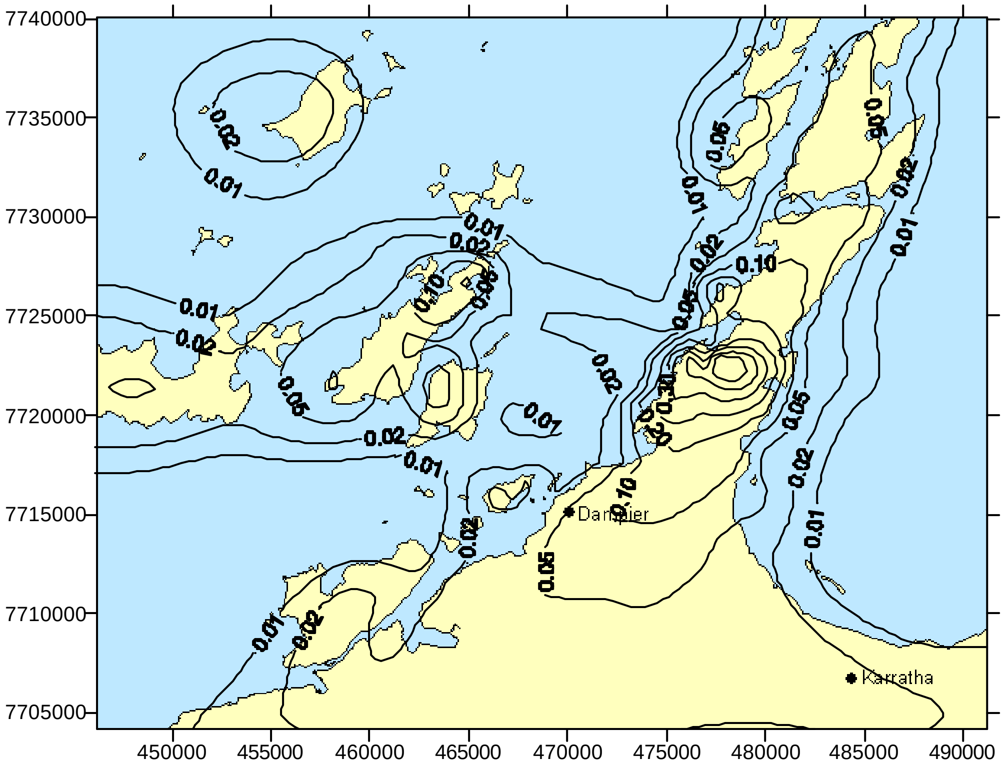
■ **Figure 5-1 TAPM Predicted Annual NO_2 Concentrations (ppb) for Existing Industry**



■ **Figure 5-2 TAPM Predicted Annual NO_2 Deposition (kg/ha/yr) for Existing Industry**



■ **Figure 5-3 CALPUFF Predicted Annual NO_2 Concentrations (ppb) for Existing Industry**



■ **Figure 5-4 CALPUFF Predicted Annual NO_2 Deposition (kg/ha/yr) for Existing Industry**

5.1.2 Sulphur Dioxide

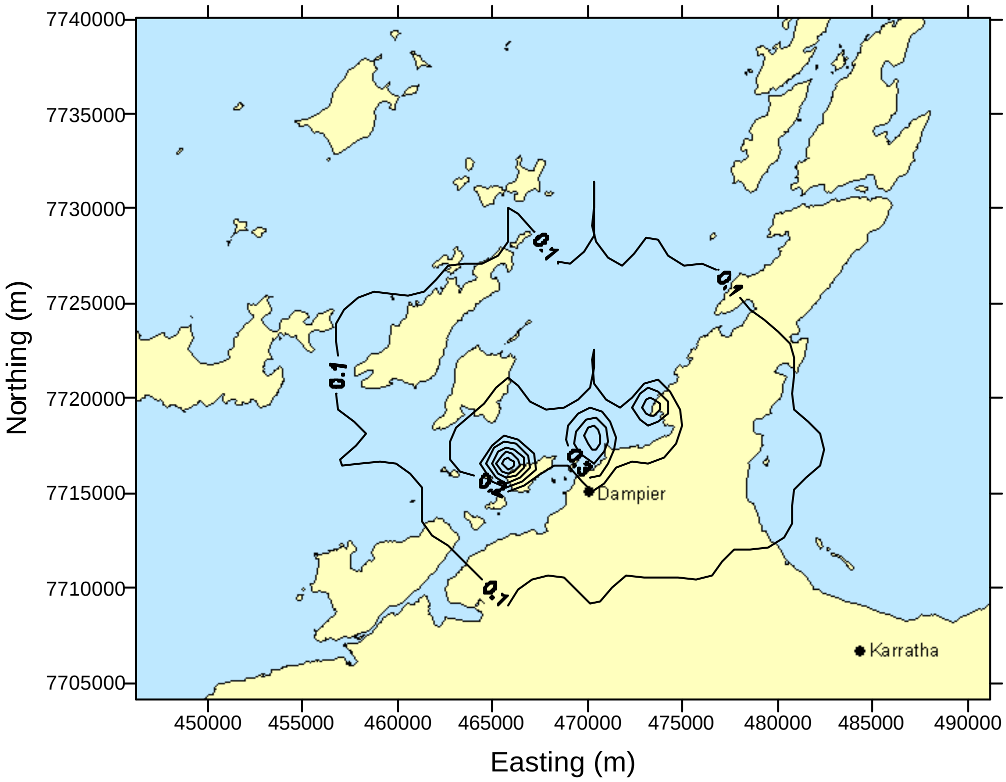
Predicted annual average concentrations and deposition rates from TAPM and CALPUFF are presented in **Figure 5-5** to **Figure 5-8**. These indicate:

- Relatively low concentrations are predicted over land (at least a factor of 5 lower than the NO_2 concentrations) with maximums of up to 0.5ppb occurring near the water's edge. The highest concentrations occur over water near the ship berths as it is estimated that ships not industry are the largest source, due to the use of high sulphur content fuel oil by ships. Note, the concentrations near Woodside berths are lower due to the predominate use of natural gas as the fuel in the LNG ships;
- Comparison to critical annual load levels of 20 $\mu g/m^3$ for natural vegetation and 10 $\mu g/m^3$ for lichens indicates that the predicted maximum of 0.5ppb (1.43 $\mu g/m^3$) that occur at the water's edge near the King Bay and EII berths are well below this level;
- The highest depositions occur near the berths and over water due to the high solubility of SO_2. The maximum deposition rates over land are predicted to be 1.7 kg SO_2/ha/year occurring right adjacent to the berths; and
- Comparison between the models indicates higher SO_2 concentrations from CALPUFF with similar deposition rates predicted by the two models

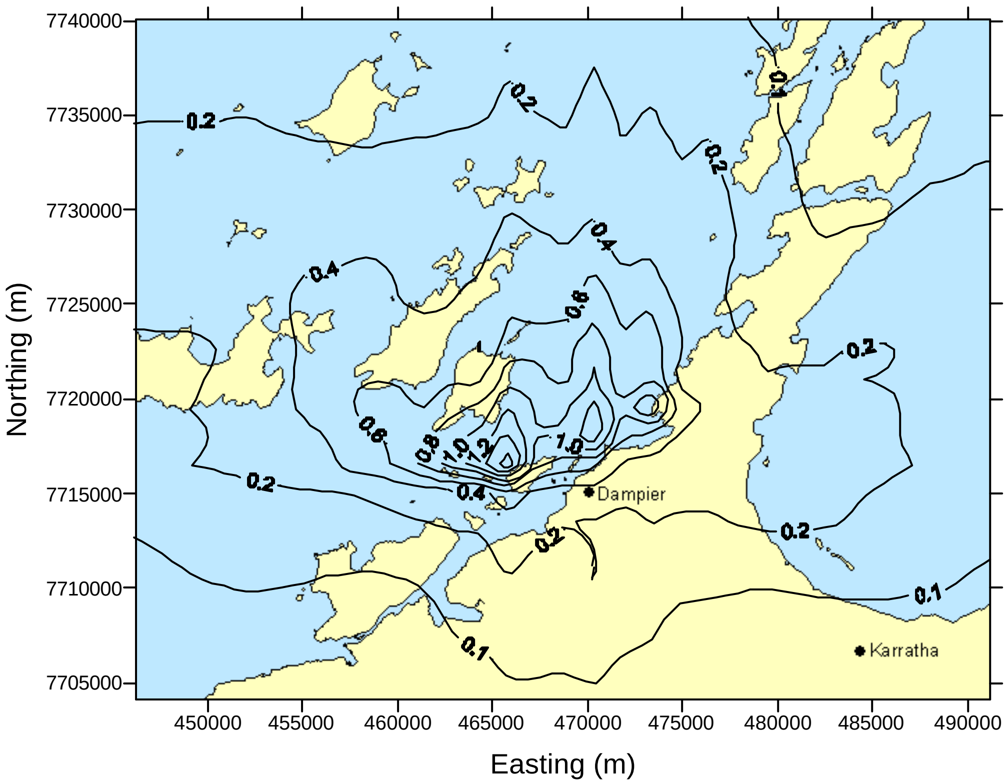
5.1.3 Comparison to Previous Deposition Estimates

Comparison to the previous estimates in SKM (2002b and 2002c) indicate that maximum deposition rates predicted here of 0.85 kg NO_2/ha/year and 1.7 kg SO_2/ha/year are:

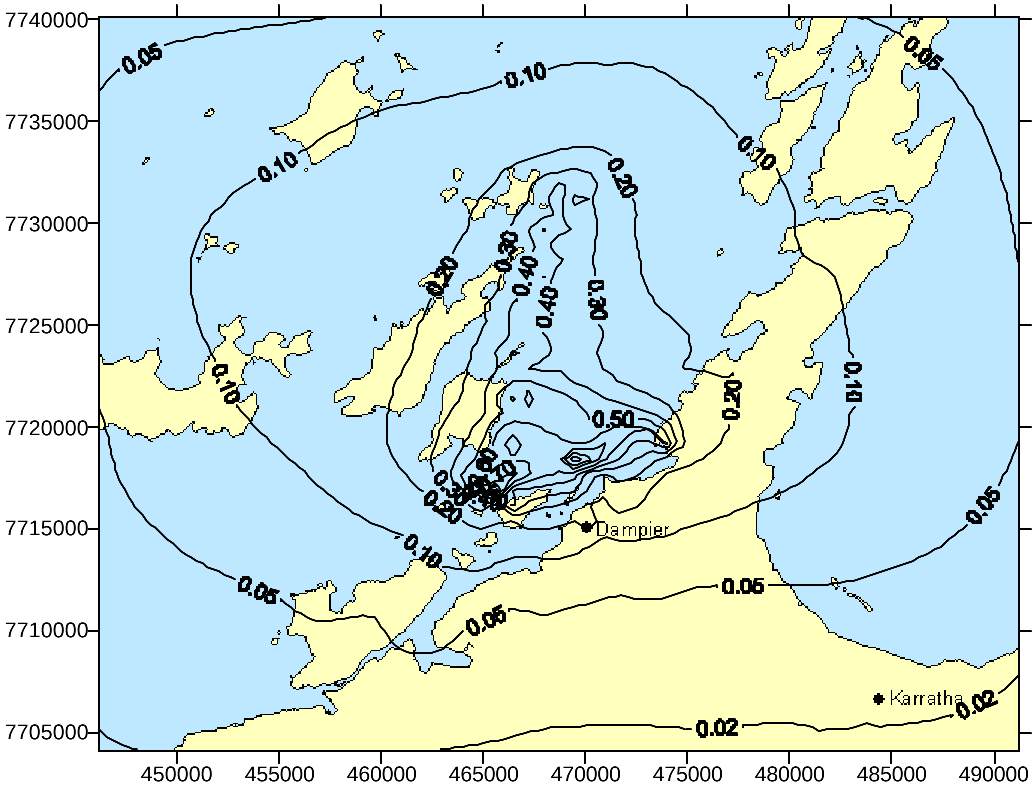
- Well below the "back of the envelope" calculations in SKM (2002b) of 4.8 g/m^2/year (48 kg/ha/year) of NO_X, but above the SO_2 deposition rate predicted of 0.07 g/m^2 (0.7 kg/ha/year). The lower SO_2 predicted is due to the assessment within SKM (2002b) not accounting for ship emissions in their estimates; and
- Below the predictions made using TAPM in SKM (2002c) of a maximum on land of 0.29g/m^2/year (2.9 kg/ha/year). This higher value in SKM (2002c) was due to the modelling of the ship emissions being overly conservative as specified in the CSIRO set up used by SKM.



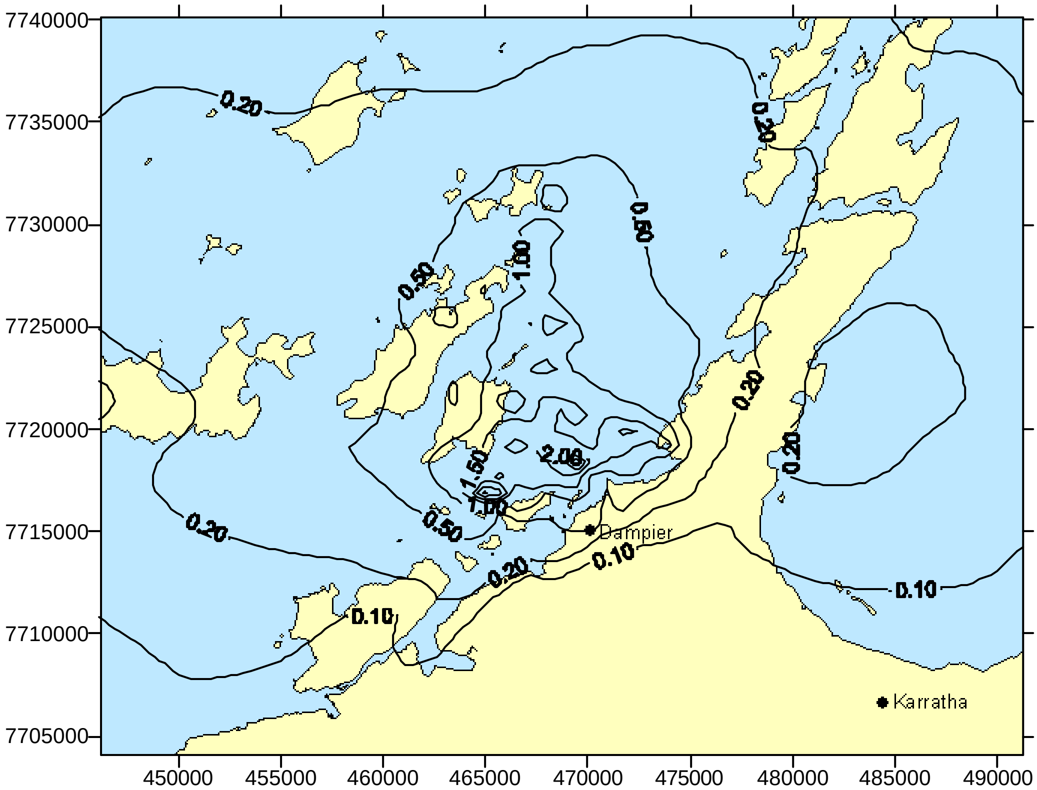
■ **Figure 5-5 TAPM Predicted Annual SO_2 Concentrations (ppb) for Existing Industry**



■ **Figure 5-6 TAPM Predicted Annual SO_2 Deposition (kg/ha/yr) for Existing Industry**



■ **Figure 5-7 CALPUFF Predicted Annual SO_2 Concentrations (ppb) for Existing Industry**



■ **Figure 5-8 CALPUFF Predicted Annual SO_2 Deposition (kg/ha/yr) for Existing Industry**

5.2 Predicted Future Levels

This section presents annual concentrations and depositions for a future scenario with the expansion of Woodside and addition of another seven industries and their associated shipping on the Burrup (see **Section 2**). To simplify the analysis only results from TAPM are presented for this hypothetical scenario.

5.2.1 Nitrogen Dioxide

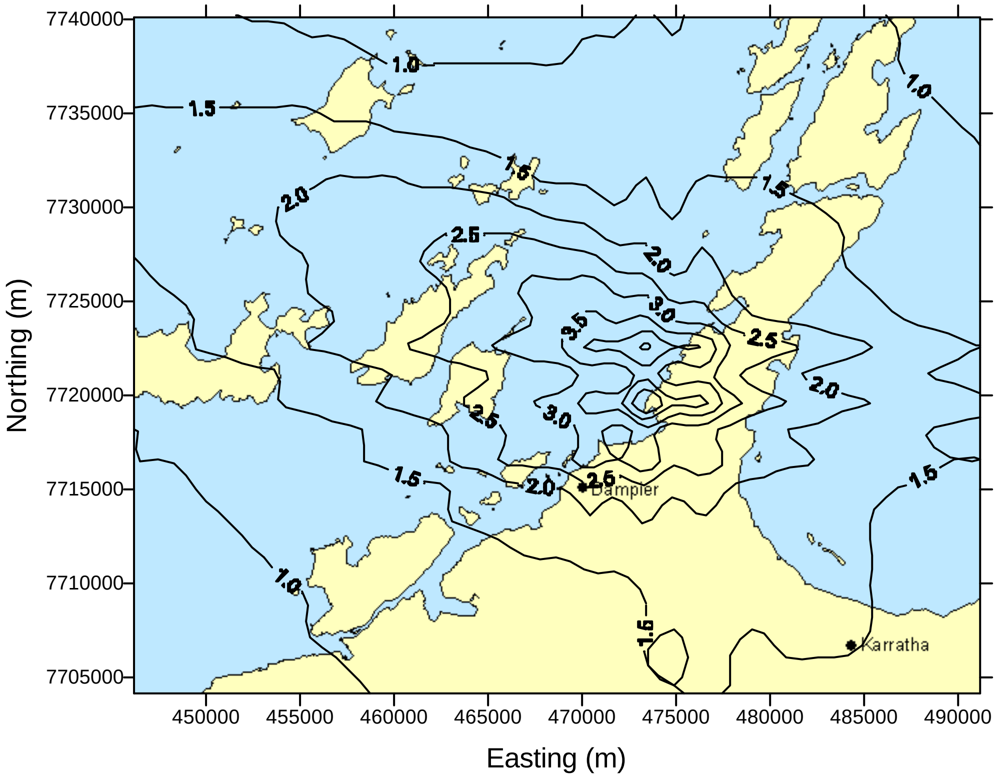
Figure 5-9 and **Figure 5-10** present the predicted annual average concentration and annual deposition of sulphur dioxide to the Burrup. This indicates:

- Predicted higher concentrations than for the existing case, particularly around the Dampier Public wharf. The concentrations at this site are considered to be likely over-predicted as the increased emissions from ships were estimated based solely on the number of ships with no consideration of ship size and is thought to be too high;
- Comparison to the WHO critical level for NO_X on natural vegetation (note NO_X not NO_2 presented here) of 30 $\mu g/m^3$ (14.6 ppb) indicates that the predicted concentrations (max of 5.2ppb adjacent to the Dampier public wharf) are well below these criteria;
- The predicted NO_2 deposition rates are higher than at present, with values of deposition of up to 2.1 kg/ha/year; and
- Comparison to the critical load for N for dry heathlands for Europe of 15 to 20 kg N/ha/year indicates that the deposition rate of N of up to 0.64 kg/ha/year will be well below this.

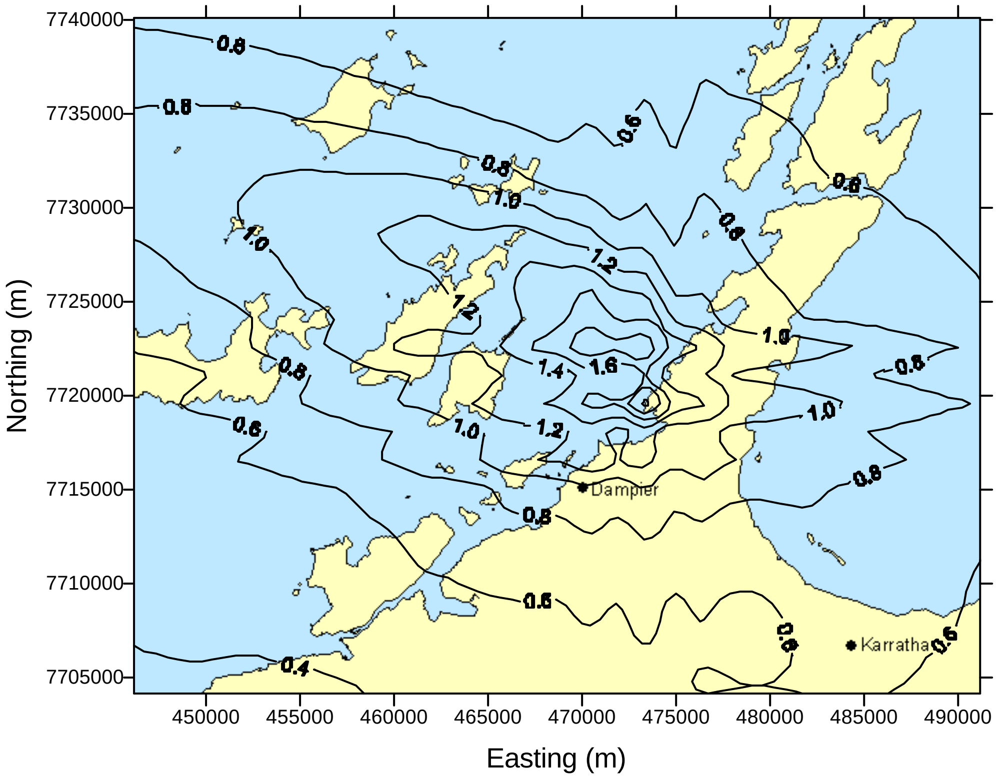
5.2.2 Sulphur Dioxide

Predicted annual average SO_2 concentrations and deposition rates are presented in **Figure 5-11** and **Figure 5-12**. These indicate that:

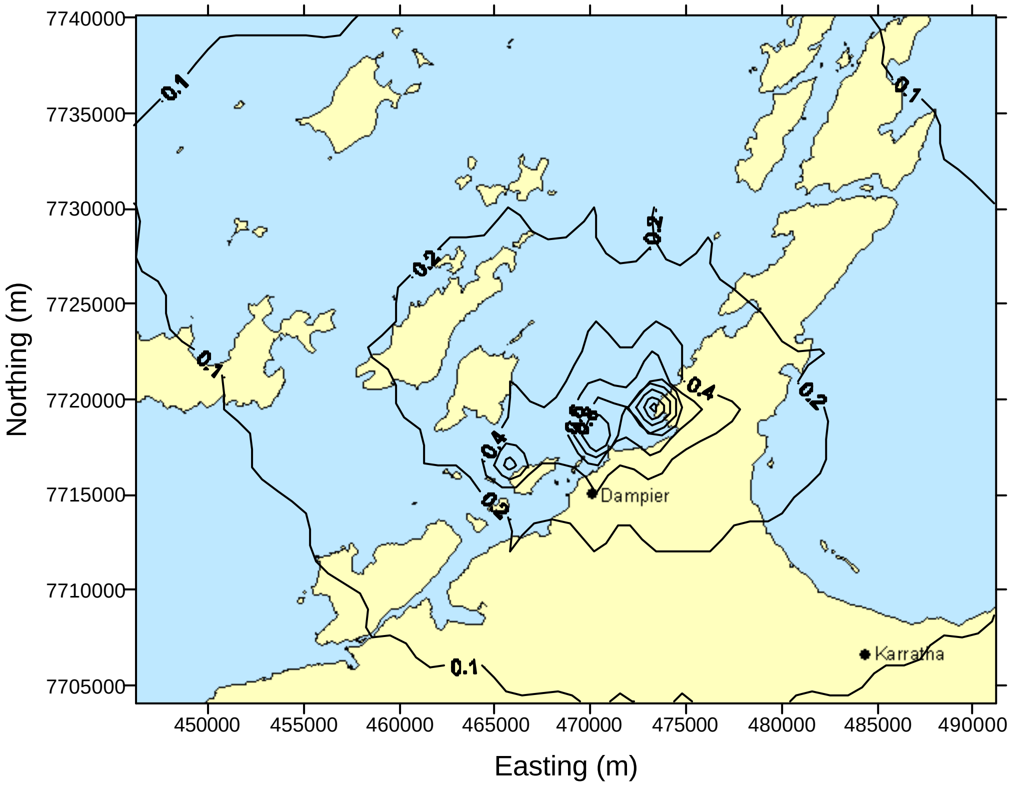
- Maximum concentrations up to 1.6ppb are predicted to occur near the water's edge at King Bay;
- Comparison to the critical annual load levels of 20 $\mu g/m^3$ for natural vegetation and 10 $\mu g/m^3$ for lichens indicates that the predicted maximum of 1.6ppb (4.6 $\mu g/m^3$) is below this level. It is noted that this occurs for a small area near the public wharf, and that the concentrations are considered to be conservative due to over-estimating the ship emissions; and
- The highest depositions occur near the berths and over water due to the high solubility of SO_2. The maximum deposition rates over land are predicted to be 2.6 kg SO_2/ha/year occurring right adjacent to the berths at King Bay.



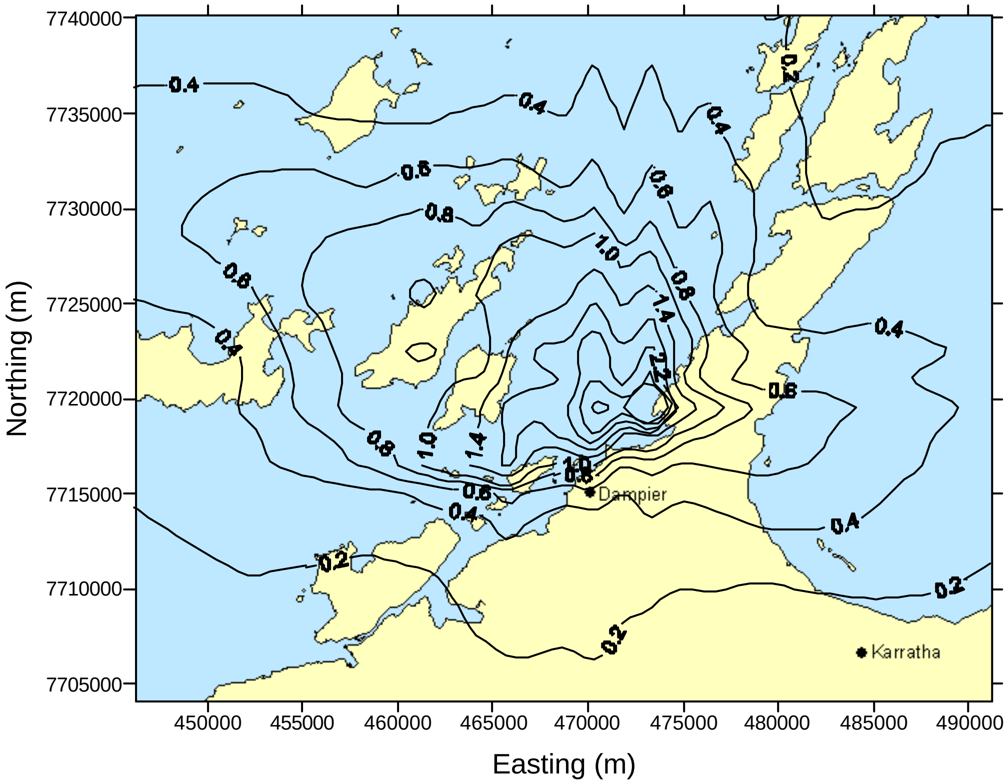
■ **Figure 5-9 TAPM predicted annual NO_2 concentrations (ppb) for the Future Industry Scenario**



■ **Figure 5-10 TAPM predicted NO_2 deposition rates (kg/ha/yr) for future scenario**



■ **Figure 5-11 TAPM predicted annual SO_2 concentrations (ppb) for the Future Industry Scenario**

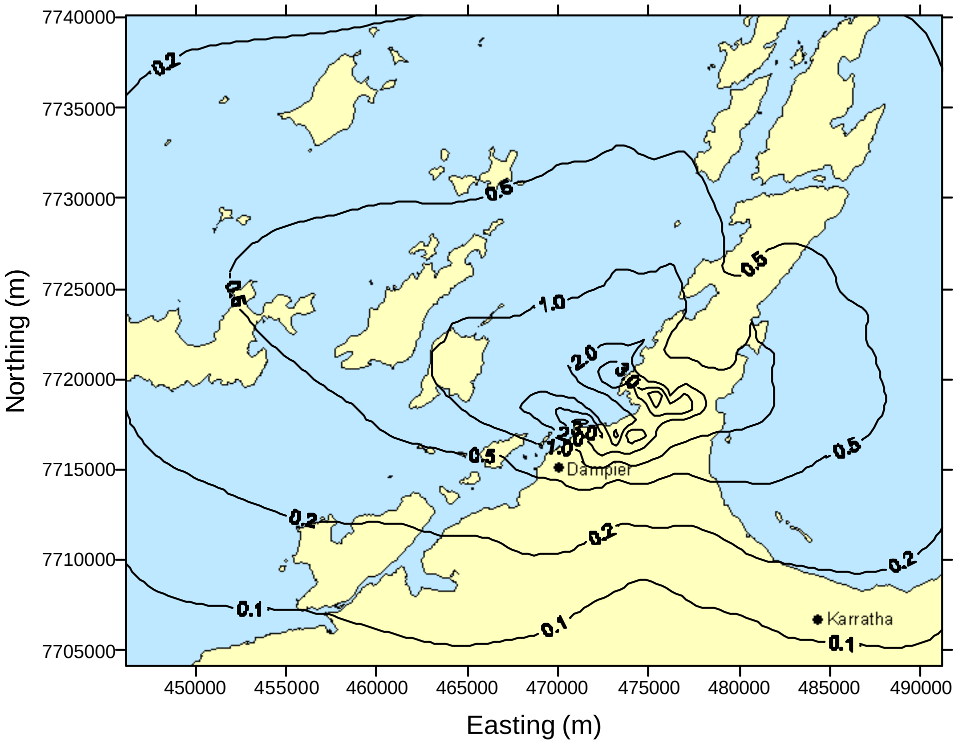


■ **Figure 5-12 TAPM predicted SO_2 deposition rates (kg/ha/yr) for future scenario**

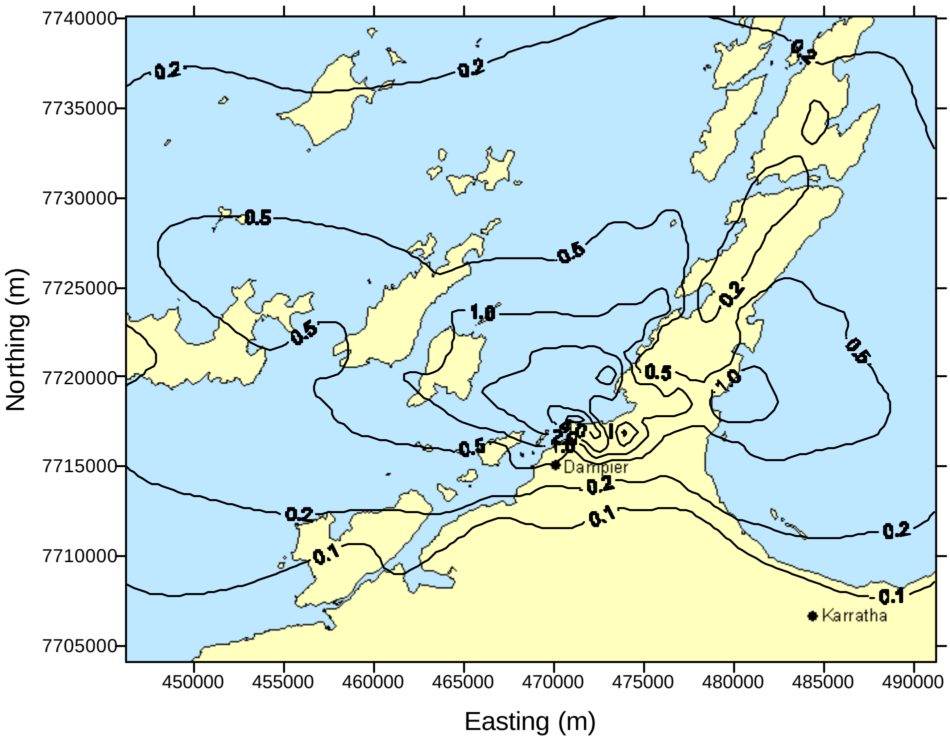
5.2.3 Ammonia

CALPUFF predicted annual average ammonia concentrations and annual deposition rates with two Dampier Nitrogen sized plants are presented in **Figure 5-15** and **Figure 5-16**. TAPM predictions are not presented as TAPM does not include the code to predict ammonia deposition. The CALPUFF predictions indicate that:

- Maximum concentrations and depositions occur over water, due to the high solubility of ammonia;
- The concentrations and depositions extend furthermost in an east/west direction as for nitrogen dioxide and sulphur dioxide; and
- The maximum deposition of ammonia is 6.7 kg/ha/year occurring over sea. Over land, the deposition apart from an area within 500m of the stacks is generally below 4 kg/ha/year. A 4 kg/ha/year deposition equates to 3.3kgN/ha/year, which compares to the critical load for N of 15-20 kg/ha/year for dry heathland. That is, the deposition is not an insignificant contributor and needs to be considered in the total N deposition to the Burrup, along with the deposition of particulate urea, which has not been assessed here but is presented in URS (2002).



■ **Figure 5-13 CALPUFF Predicted Annual Average Gaseous NH_3 Concentration (ppb) for the Future Industry Scenario**



■ **Figure 5-14 CALPUFF Predicted Annual Deposition of Gaseous NH_3 (mg/m^2/year) for the Future Industry Scenario**

5.3 Summary of Spatial Variation of NO_2 and SO_2 Concentrations and Deposition

As the model predictions presented previously for deposition are considered to be approximate, due to the fairly simple deposition algorithms used and the uncertainty in some of the empirical constants, it is considered that the model results should be primarily used for determining the relative concentrations and depositions over the region.

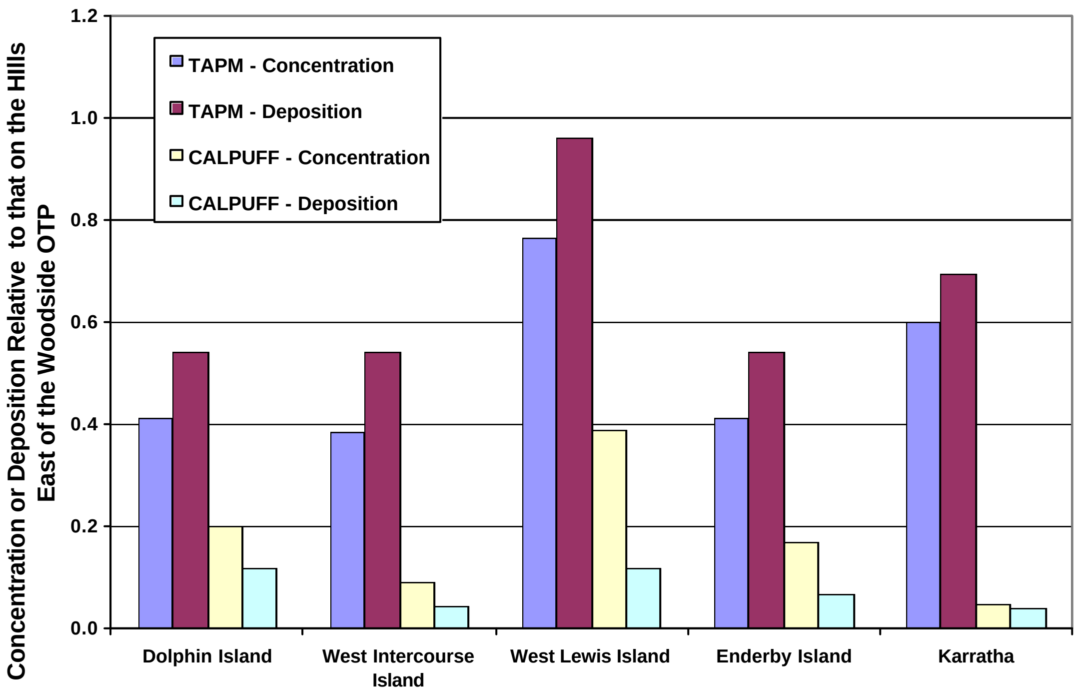
The relative variation has been summarised in **Figure 5-15** and **Figure 5-16** which indicates how the concentrations and depositions compare to the area to the east of Woodside's OTP which generally has the highest depositions and concentrations on land.

Figure 5-15 indicates that for NO_2 that:

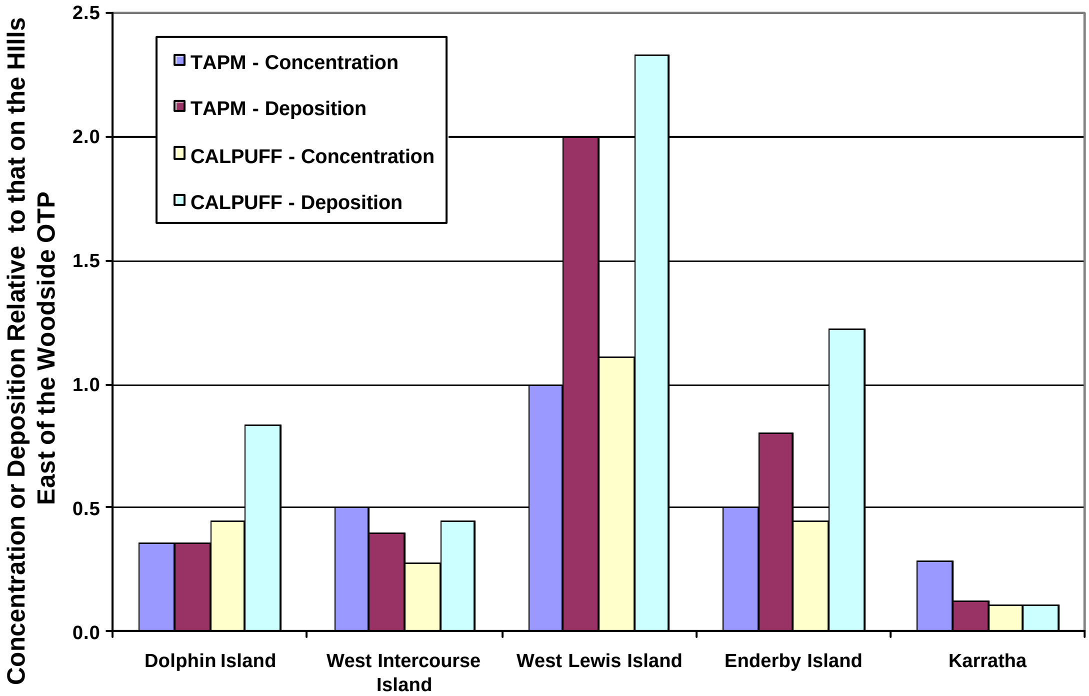
- CALPUFF predicts a greater decrease in concentrations and deposition rates from those predicted on the hills east of Woodside to the other locations than from TAPM. In general, both the concentration and deposition are predicted to decrease more rapidly with distance with CALPUFF than with TAPM;
- Both models show West Lewis Island has relatively high concentrations/depositions compared to the other locations;
- The results from CALPUFF indicates Karratha should have lowest concentrations/depositions followed by West Intercourse Island; and
- The results from TAPM indicate that the lowest concentrations/depositions are on West Intercourse Island, Dolphin Island and Enderby Island (with very little difference between these three).

Figure 5-16 indicates that for SO_2 that:

- Both models show better agreement in the relative variation in the concentrations and depositions;
- Both models show West Lewis Island will have the highest relative concentrations and depositions; and
- Both models show that the lowest concentrations and depositions occur at Karratha followed by West Intercourse and Dolphin Island.



■ **Figure 5-15 Predicted Relative Concentrations and Depositions of NO_2 Relative to that on the Hills to the East of the Woodside OTP**



■ **Figure 5-16 Predicted Relative Concentrations and Depositions of NO_2 Relative to that on the Hills to the East of the Woodside OTP**

6. Predicted Health Impacts

Predicted health impacts due to the expansion of Woodside and addition of new industries on the Burrup have been assessed for ozone and nitrogen dioxide, the pollutants of most concern and for the shorter averaging periods less than 1 day. TAPM has been used to predict ozone and nitrogen dioxide impacts on the 1.5 km pollution grid. It is considered that although CSIRO may change some of the parameters used due to findings from their current review of TAPM modelling on the Burrup, the results presented here should be reasonably accurate. The nitrogen dioxide concentrations however, are considered to be over-predictions given that the conversion of NO to NO_2 is considered to proceed too rapid as shown in **Section 4**. Furthermore, CALPUFF has been used to predict NO_2 concentrations assuming 30% of the NO_X is NO_2. This will result in overestimates of NO_2 concentrations within 5 km of the Woodside OTP, but will probably underestimate concentrations at distances greater than this. To assess the impacts of grid size, CALPUFF has been run with a fine pollution grid of 0.25km as well as the standard 0.75km pollution grid used in the deposition modelling.

6.1 TAPM Predictions

Predicted ozone and nitrogen dioxide concentrations from TAPM are presented in **Figure 6-1** to **Figure 6-3** for the existing situation and for the future scenario in **Figure 6-4** to **Figure 6-6** and summarised in **Table 6-1**.

■ **Table 6-1 Summary of Modelling Results**

Scenario	Location	Existing (ppb)	Existing (% of NEPM standard)	Future (ppb)	Future (% of NEPM standard)
Ozone – Maximum 1-hour	Anywhere on grid	82	82	74	74
Ozone – Maximum 4-hour	Anywhere on grid	58	73	52	65
Nitrogen Dioxide – Maximum 1-hour	Anywhere on grid	70 (61) [98]	58 (51) [82]	82 (88)	68 (73)
	Dampier **Dampier Observed**	40 (12) [9] **21**	33 (10) [7.5] **18**	59 (18) -	49 (15) -
	Karratha	40 (4) -	33 (3)	60 (9)	50 (8)
	King Bay	40 (18) [14]	33 (15) [12]	55 (30)	46 (25)
	Hearson Cove	55 (19) [17]	46 (16) [14]	70 (23)	58 (19)
	Cowrie Cove	45 (25) [28]	38 (21) [23]	60 (30)	50 (25)

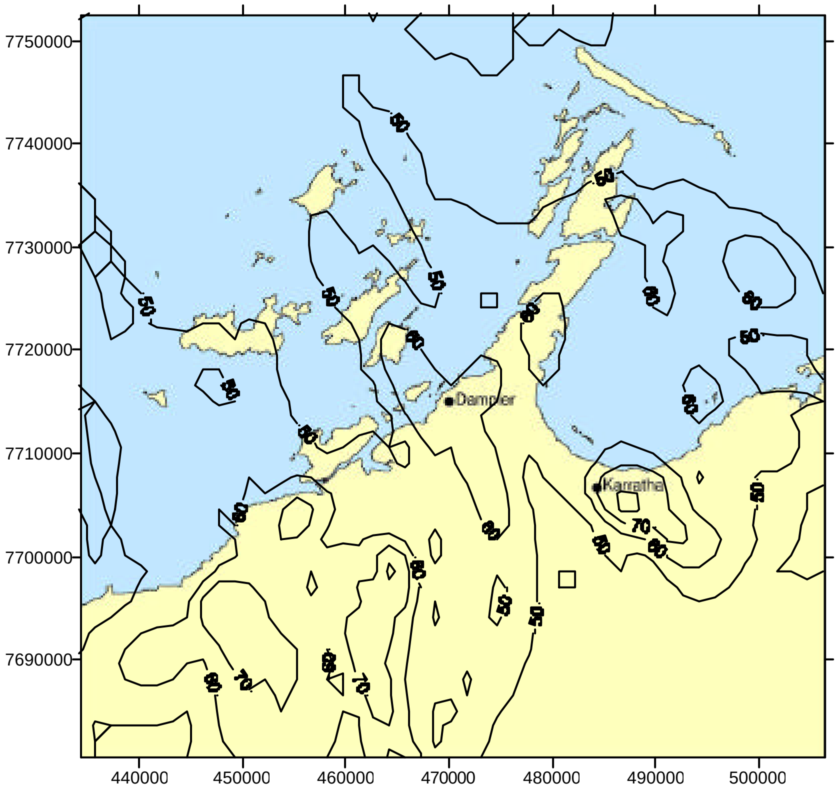
Notes:

1) The first value given is from TAPM, the second in round brackets is from CALPUFF and the third if applicable is from CALPUFF with the fine grid.

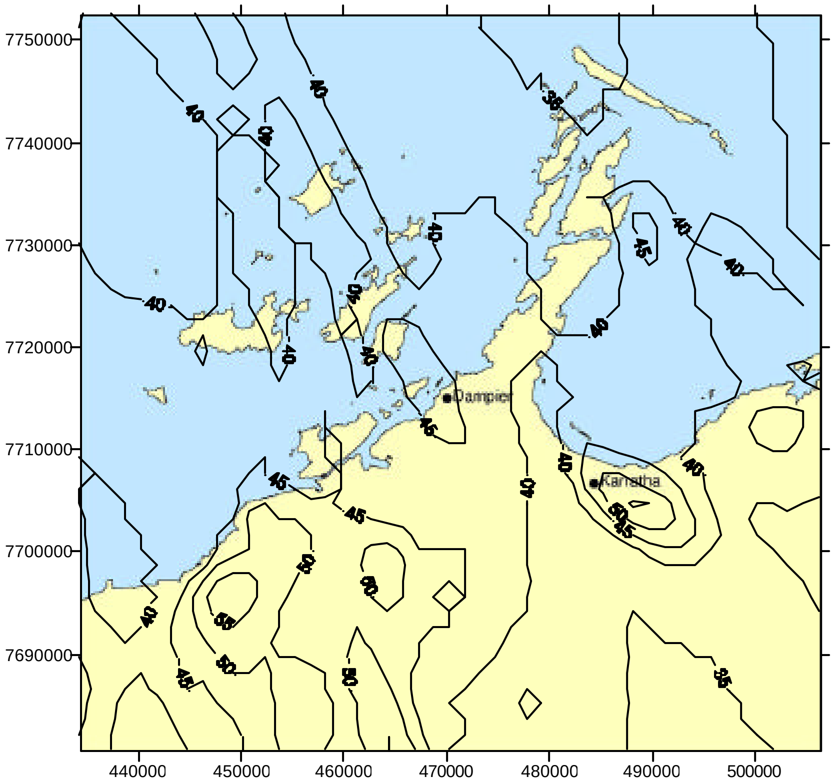
2) The future scenario includes 7 additional industries and the expansion of Woodside and Hamersley Iron ship loading operations.

3) NEPM goals are for a 1-hour NO_2 standard of 120ppb and 1 and 4 hour Ozone standards of 100ppb and 80ppb with a goal of no more than 1 day per year

This indicates that concentrations of ozone will fall with the addition of new sources. The maximum 1-hour and 4-hour concentration predicted anywhere on the grid decrease from 82 and 73% of the NEPM standard to 74 and 65% of the standard. This result occurs as these new sources are estimated to emit principally NO_X and negligible reactive organic compounds, such that the additional NO_X will suppress ozone formation. This result is very dependent on the amount of reactive organics emitted, with a simulation where Woodside expansion was modelled without incineration of their acid vent stream (and therefore large amounts of reactive organics) resulting in much higher ozone concentrations that the existing case.



■ **Figure 6-1 TAPM Predicted Maximum 1-hour Ozone Concentrations (ppb) from Existing sources**

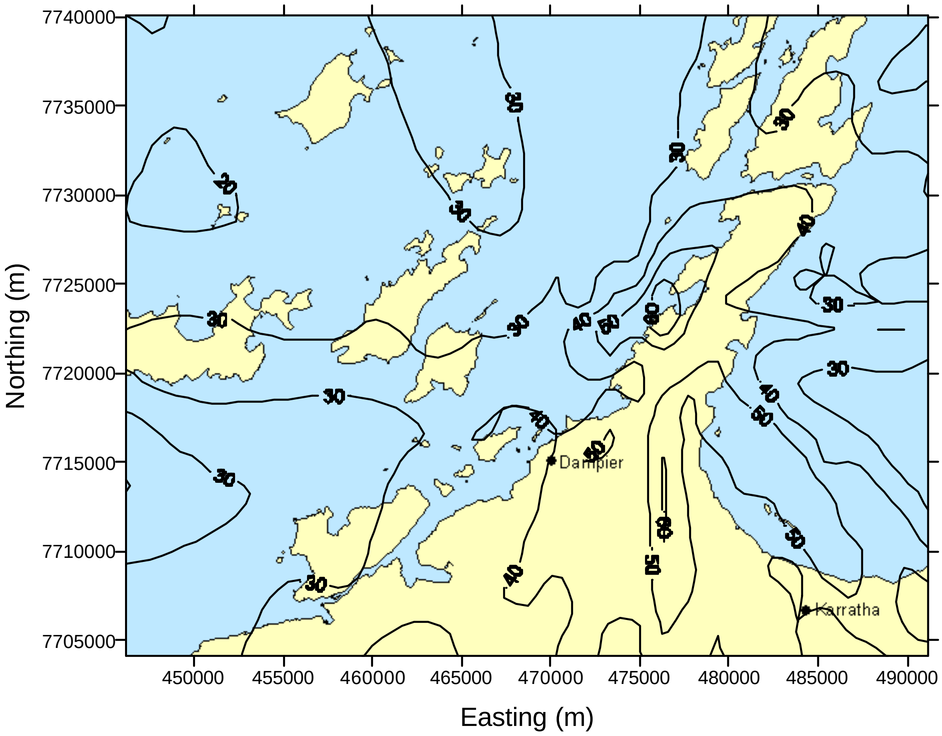


■ **Figure 6-2 TAPM Predicted Maximum 4-hour Ozone Concentrations (ppb) from Existing sources**

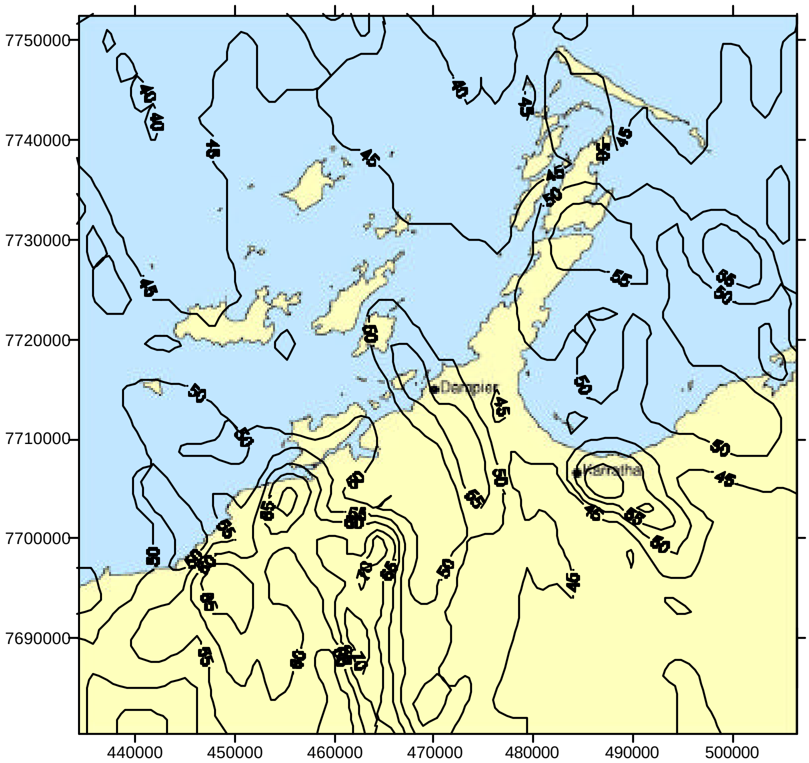
Modelling of nitrogen dioxide concentrations by TAPM indicates that:

- Concentrations are predicted to increase at all locations, with the maximum anywhere increasing from 58 to 62% of the NEPM standard; and
- The maximum concentrations at residential sites or where people may congregate increases from 46 to 58% of the NEPM.

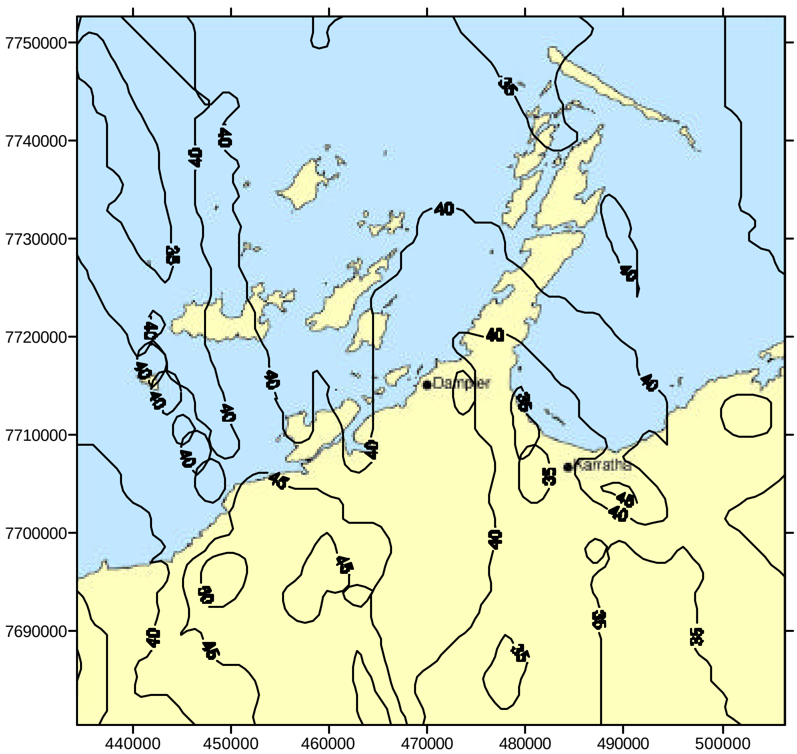
It is noted again that this prediction is considered to be overly conservative due to the higher than expected conversion of NO to NO_2 within TAPM.



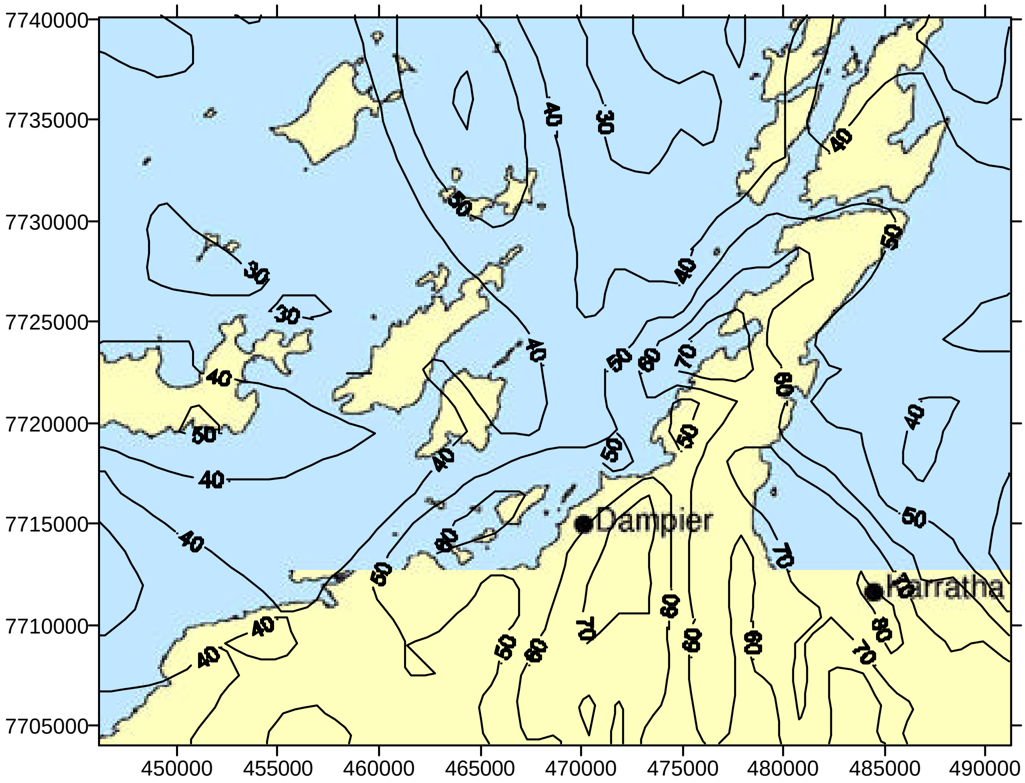
■ **Figure 6-3 TAPM Predicted Maximum 1-hour Nitrogen Dioxide Concentrations (ppb) from Existing sources**



■ **Figure 6-4 TAPM Predicted Maximum 1-hour Ozone Concentrations (ppb) for the Future Scenario**



■ **Figure 6-5 TAPM Predicted Maximum 4-hour Ozone Concentrations (ppb) for the Future Scenario**



■ **Figure 6-6 TAPM Predicted Maximum 1-hour Nitrogen Dioxide Concentrations (ppb) for the Future Scenario**

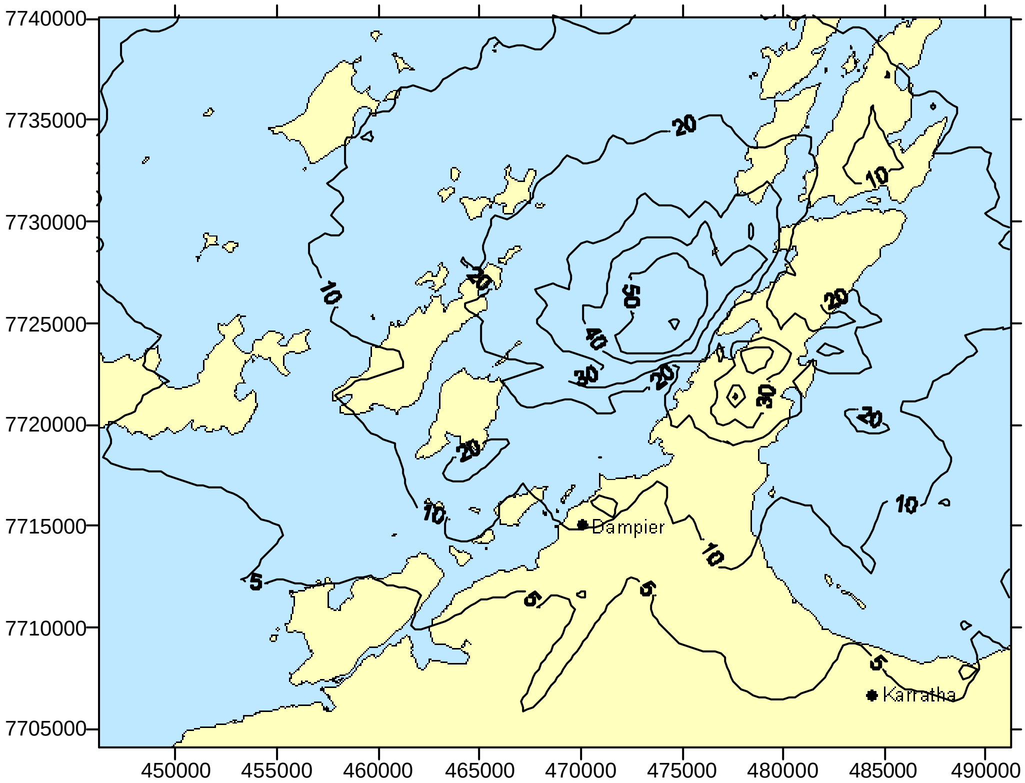
6.2 CALPUFF Predictions

Predicted nitrogen dioxide concentrations from CALPUFF are presented in **Figure 6-7** to **Figure 6-9** and summarised in **Table 6-1**. These indicate that:

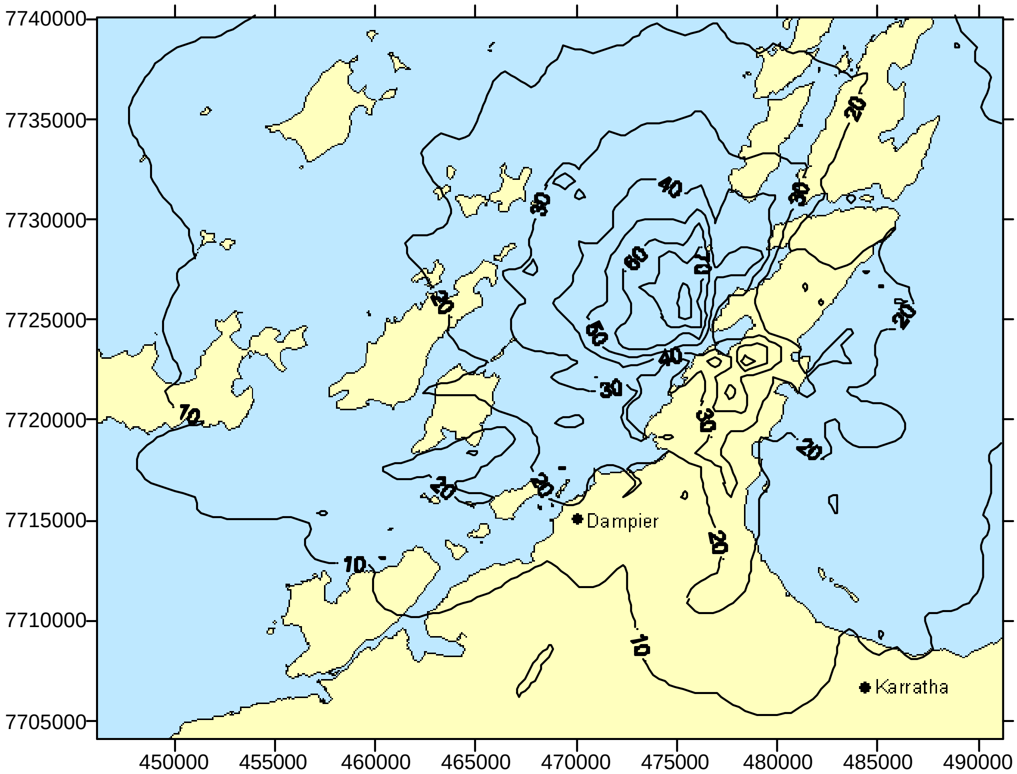
- The maximum concentrations predicted anywhere on the grid are similar to that from TAPM with the maximums increasing from 51 to 73% of the standard with the increase in the number of industries. CALPUFF, however predicts that the maximums occur within several kilometres to the west of the Woodside OTP (out to sea), whilst TAPM predicts the highest concentrations can occur up to 15-km from Woodside;

- The maximum concentrations at residential sites or where people may congregate are around half that predicted from TAPM, increasing from 21 to 30% of the NEPM for the future scenario; and

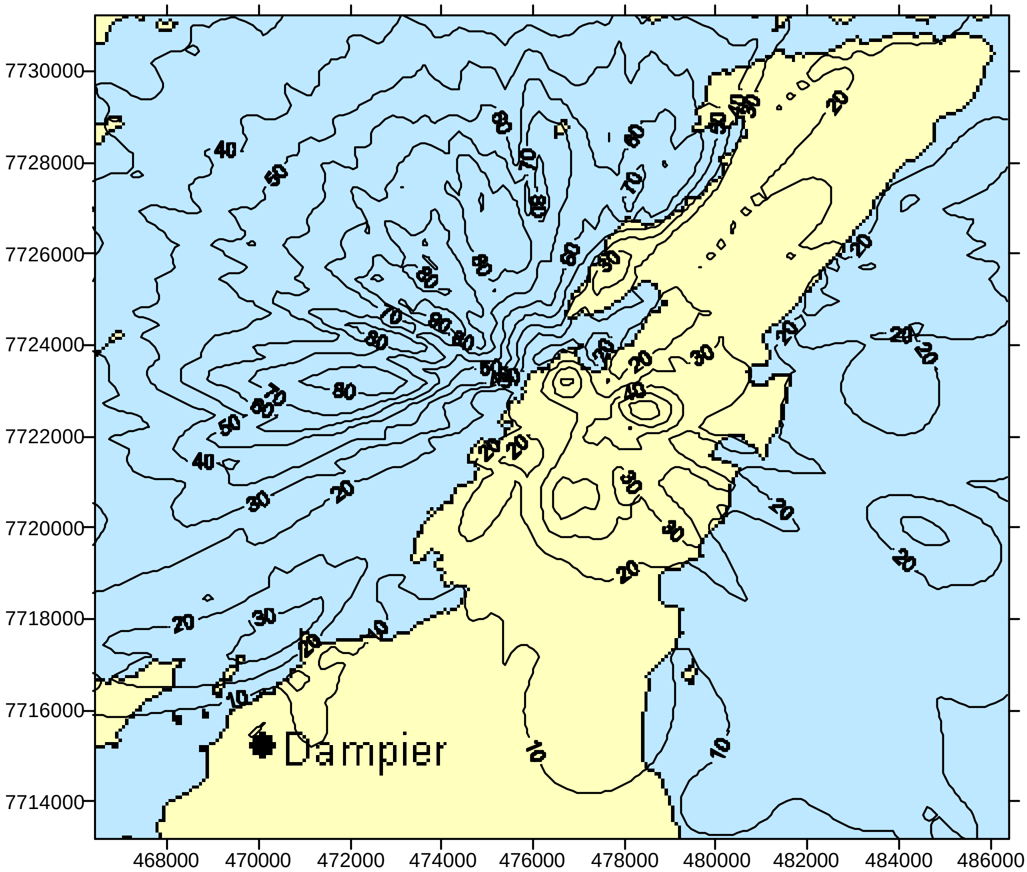
- Using a finer grid for the existing sources, increases the maximum concentrations which occur out to sea, but on land and at the locations where people congregate or live were similar to that from the coarse grid. The high concentrations predicted by CALPUFF at sea are due to fumigation when cool air from the land is blown over the warmer sea. That this phenomenon is not as evident in the TAPM predictions warrants investigation and may be due to using air temperatures from the mainland and not the Burrup in the CALPUFF modelling. As such, these concentrations may be over-predicted.



■ **Figure 6-7 CALPUFF Predicted Maximum 1-hour Nitrogen Dioxide Concentrations (ppb) from Existing sources**



■ **Figure 6-8 CALPUFF Predicted Maximum 1-hour Nitrogen Dioxide Concentrations (ppb) for the Future Scenario**



■ **Figure 6-9 CALPUFF Predicted Maximum 1-hour Nitrogen Dioxide Concentrations (ppb) from Existing Sources for Small Grid**

7. Conclusions

Using the dispersion models TAPM and CALPUFF, concentrations and depositions of the pollutants of concern to Burrup rock engravings and public health were assessed for the existing situation and a future industry scenario.

To determine the accuracy of the models, the model predictions were initialy compared to monitored NO_X data at Dampier. This brief comparison showed that:

- Generally TAPM as configured here, reproduces the NO_X statistics at Dampier, though over-predicting the NO_2 concentrations. The over-prediction of the NO_2 concentrations is considered a result of TAPM over-predicting the conversion of NO to NO_2. As such, annual predictions of NO_2 concentrations and as a result the NO_2 depositions, are likely to be over-predicted; and
- CALPUFF under-predicts the NO_X and NO_2 concentrations at Dampier. The reason for this is not known, but the model's predictive capability could possibly be improved with the use of additional meteorological data such as from Woodside's, off-shore buoys. As such, CALPUFF predictions of pollutants, except for the near field over land (within several kilometres of the source) are likely to be under-estimates.

Using both the models TAPM and CALPUFF annual concentrations and deposition rates were then predicted for the existing emissions and for a future scenario which included the Woodside and Hamersley Iron expansions and 7 new industries and the associated increase in shipping.

The model results for nitrogen dioxide, which is primarily emitted from industry indicates that:

- Highest concentrations and depositions occur near the Woodside OTP, extending in a general westward and eastward direction in line with the prevailing easterly and westerly winds. The concentrations and depositions decreased most rapidly in roughly a north/south direction;
- CALPUFF predicts a more rapid decrease in concentrations with distance than TAPM;
- Both models show West Lewis Island has relatively high concentrations/depositions compared to the other locations; and
- CALPUFF indicates Karratha should have lowest concentrations/depositions followed by West Intercourse Island, whilst TAPM indicated that the lowest concentrations/depositions are on West Intercourse Island, Dolphin Island and Enderby Island (with not much difference between the three)

The model results for sulphur dioxide, which is primarily emitted from ships showed:

- Highest concentrations and depositions occurred over water near the shipping berths;
- Both models indicate that West Lewis Island will have the highest relative concentrations and depositions; and

- Both models show that the lowest concentrations and depositions occur at Karratha followed by West Intercourse and Dolphin Island.

To determine the impacts on public health, TAPM was run for both the existing and a future industry scenario to predict ozone concentrations. The results indicate that concentrations of ozone will fall with the addition of new sources. The maximum 1-hour and 4-hour concentrations anywhere on the grid were predicted to decrease from 82 and 73% of the NEPM standard to 74 and 65% of the standard.

This decrease in ozone concentrations occurs as these sources are estimated to emit principally NO_X and negligible amounts of reactive organic compounds, such that the additional NO_X will suppress ozone formation. This result is very dependent on the amount of reactive organics emitted, with a simulation where Woodside expansion was modelled without incineration of their acid vent stream (and therefore large amounts of reactive organics) resulting in much higher ozone concentrations that the existing case.

Modelling of 1-hour average nitrogen dioxide concentrations by TAPM indicates that:

- Concentrations are predicted to increase at all locations, with the maximum anywhere increasing from 58 to 62% of the NEPM standard; and
- The maximum concentrations at residential sites or where people may congregate increase from 46 to 58% of the NEPM.

It is noted again that this prediction is considered to be overly conservative due to the higher than expected conversion of NO to NO_2 within TAPM.

Modelling of nitrogen dioxide using CALPUFF indicated:

- The maximum concentrations predicted anywhere on the grid are similar to that from TAPM with the maximums increasing from 51 to 73% of the standard with increase in the number of industries. CALPUFF, however predicts that the maximums occur within several kilometres to the west of Woodside OTP (out to sea), whilst TAPM predicts the highest concentrations can occur up to 15-km from Woodside;
- The maximum concentrations at residential sites or where people may congregate are around half that predicted from TAPM, increasing from 21 to 30% of the NEPM for the future scenario; and

As such, for the future industry scenario considered, ozone levels decreased, whilst nitrogen dioxide levels increased, though remaining below the NEPM standard at all locations and especially at locations where people live or may congregate.

8. Recommendations

To further refine the predicted concentrations and deposition rates if required, the following is recommended:

- The reaction of NO to NO_2 within TAPM needs further investigation as it is suggested that this conversion is too high for the plumes modelled here;
- CALPUFF modelling could be improved with the incorporation of more data, principally over water winds, sea temperatures and air temperatures from the Burrup Peninsula;
- The differences in the constants used in the solubility of nitrogen dioxide between the two models should be investigated; and
- The importance of plume merging and building wakes effects needs to be quantified.

9. References

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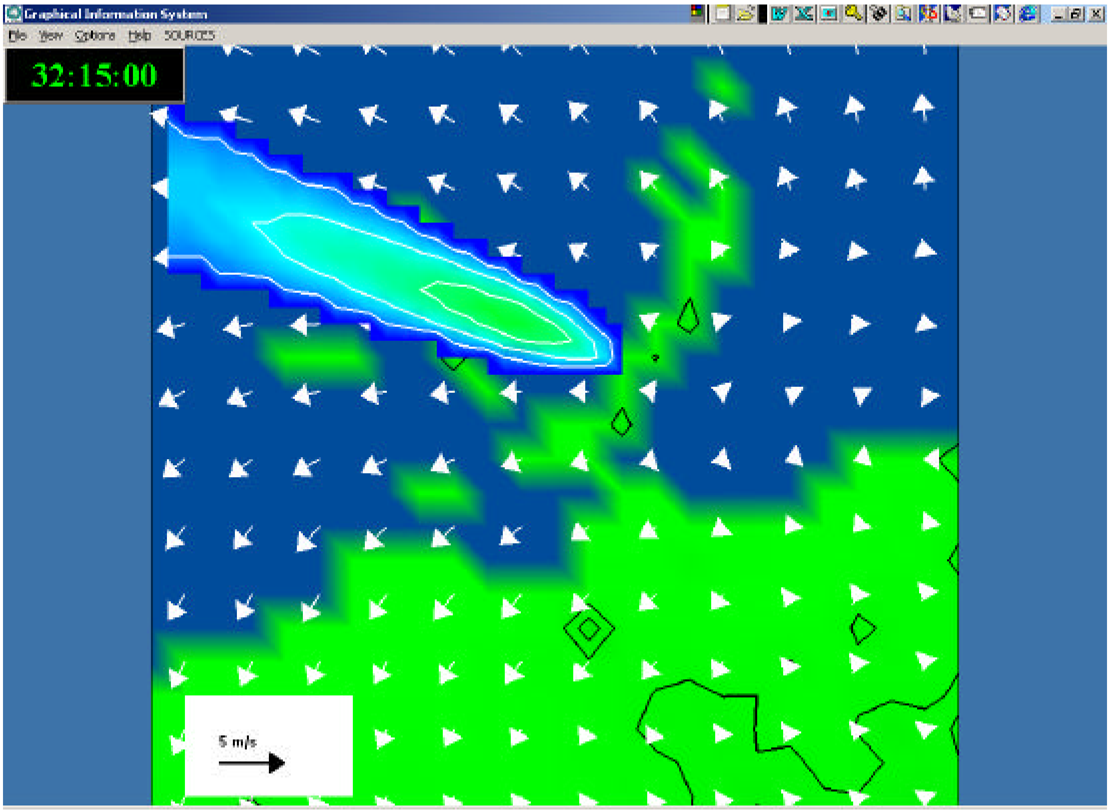
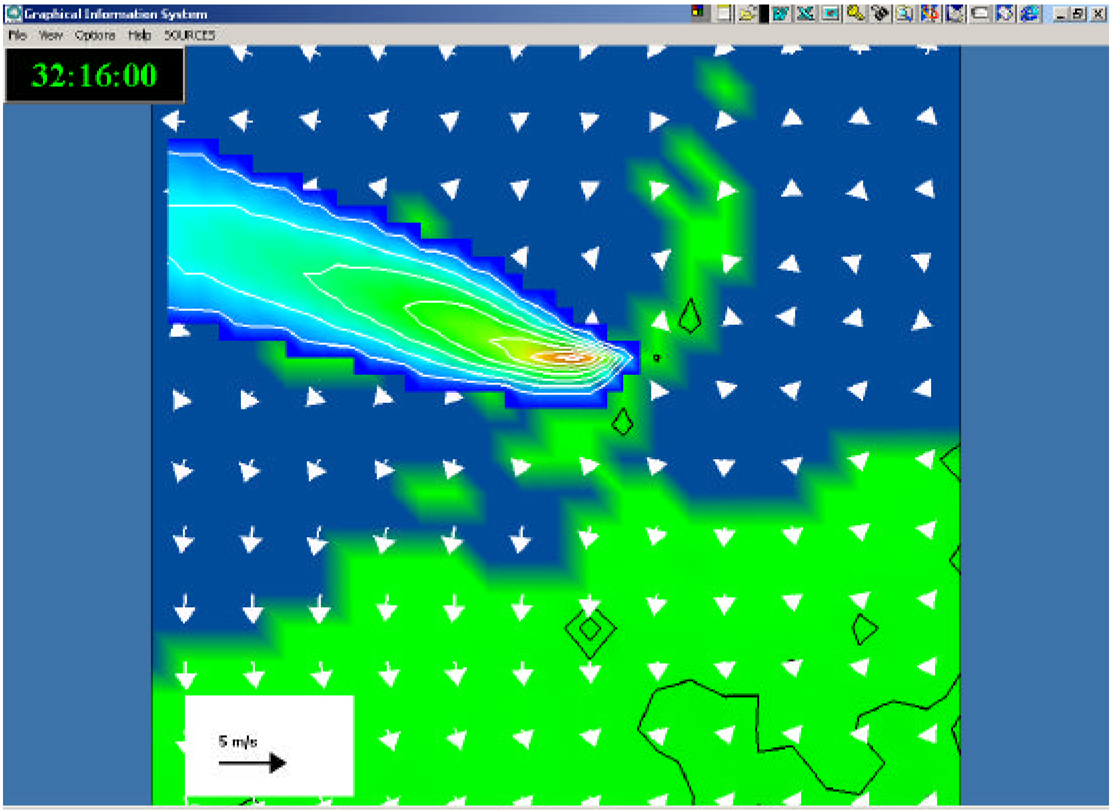
Appendix A TAPM Predicted NO_2 Concentrations on 1/8/99

The following plots present hourly contours of NO_2 concentrations predicted by TAPM on the 1/8/99. The first slide is for the hour ending 1500 WST, with subsequent plots at 1600, 1700 and 1800 WST. The arrows represent the wind speed and direction with spacing between arrows of 6km. The green area represents land with the blue area representing water or salt evaporation ponds. The maximum concentrations of NO_2 occurred at 1800WST (1700-1800), with a NO_2 concentration of 40ppb and NO_X concentration of 42ppb. This event is apparently due to the plume from Woodside being advected out to sea and then inland in the late afternoon by a weak sea breeze, where the majority of the NO was converted through to NO_2.



SKM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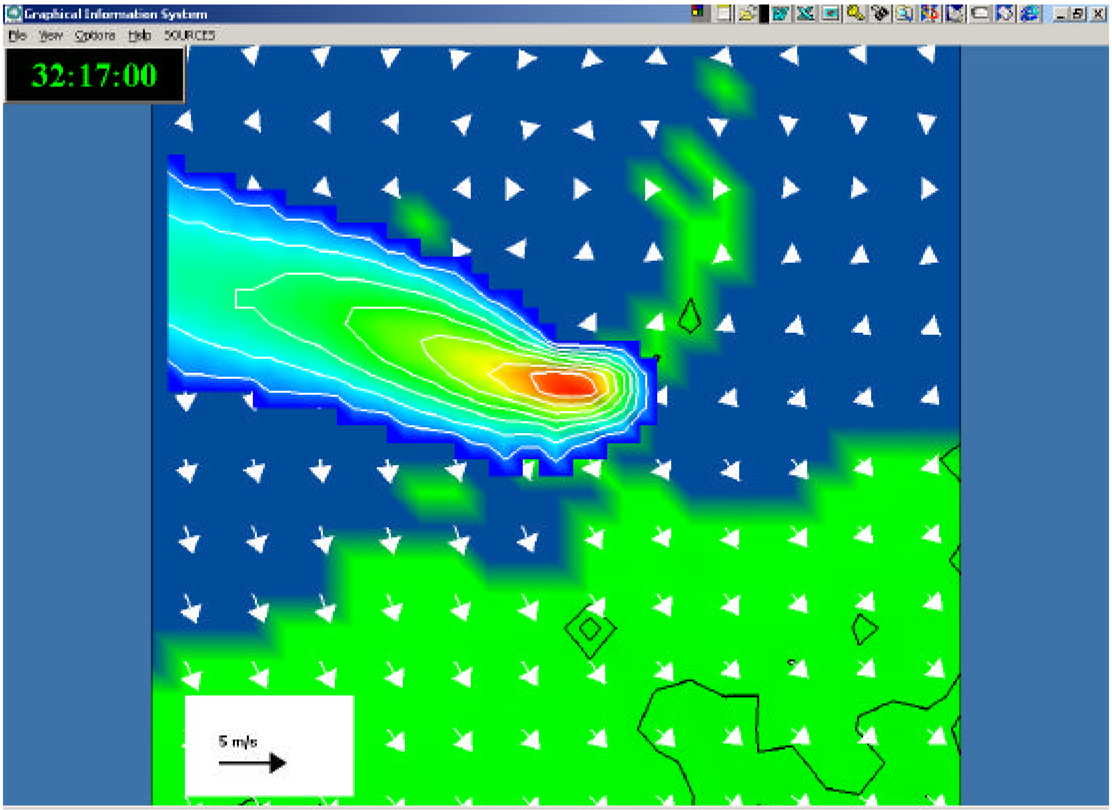
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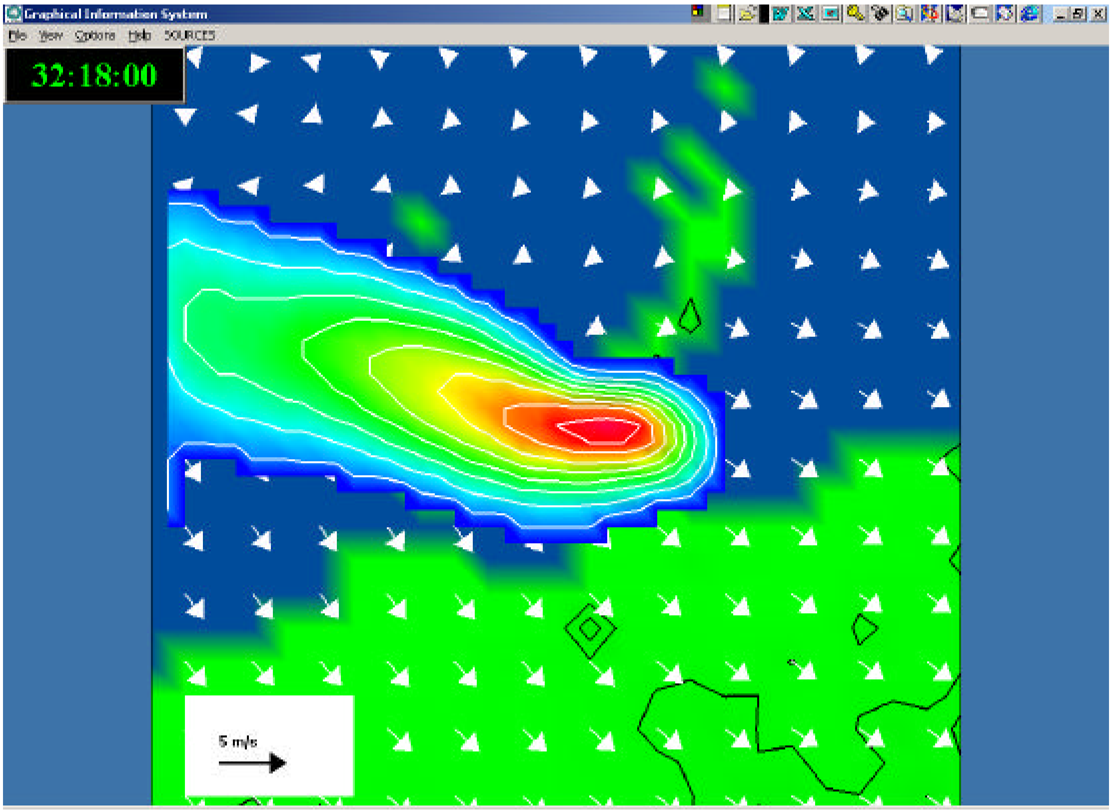
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Appendix B Further Comments on Modelling

Subsequent to the release of the draft report, two issues were raised with regards to the modelling. These were:

- Why are there significant differences in the deposition of NO_2 over the land and water between TAPM and CALPUFF?;
- What is the annual background NO_2 concentration; and
- How representative was 1999 from a meteorological viewpoint as a basis for modelling?.

Responses to these questions are detailed below.

Why are there significant differences in the deposition of NO_2 over the land and water between TAPM and CALPUFF?

The differences between the two models appear primarily in the deposition rates of NO_2 over water. This difference is due to the differing parameters used in the deposition estimations. The CALPUFF parameters are listed in **Table B-1** and were supplied to CSIRO (Greg Ayers) for review.

- **Table B-1 Deposition Parameters used in CALPUFF**

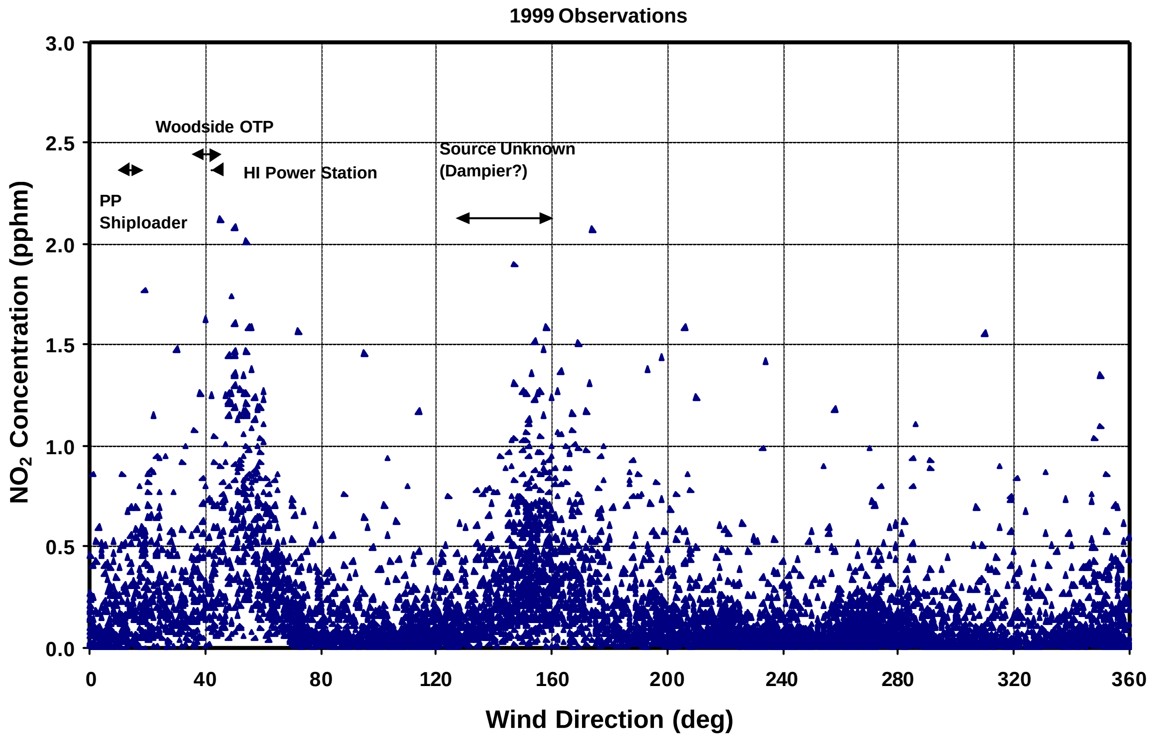
Parameter	Units	NO_2	SO_2
Molecular Diffusivity	(cm^2/s)	0.1656	0.1509
Alpha	Dimensionless	1.0	1000
Reactivity	Dimensionless?	8	8
Mesophyll resistance	(s/cm)	500	0
Henrys law constant	No units given	3.5	0.04

In response to the data, CSIRO responded (Bill Physick, e-mail of 29 May 2003). "Greg Ayers asked me to ring you and talk about deposition results from TAPM. A couple of months ago after the Rock Art weekend at Karratha, and at Greg's instigation, Peter Hurley and I checked over the formulation of dry deposition for various gases in TAPM. The short story is that we are happy with how it is done in the model and that the various resistances to deposition for each gas over soil, vegetation and water are consistent with what appears in the literature. However I should say that there is some variation in the literature values and we have used our judgement as to what is most appropriate".

As such, the differences between the two methodologies have not been resolved, though it is indicated that there is a higher degree of uncertainty in the deposition predictions than in concentration predictions due to uncertainty in the deposition parameters. Therefore as stated in the report, the deposition results are best used in a qualitative sense to determine the spatial distribution of deposition over land.

What is the annual background NO_2 concentration

As shown in **Figure B-1** there are distinct directions from which elevated NO_2 levels occur at Dampier.



■ **Figure B-1 NO_2 Concentrations Versus Wind Direction at Dampier**

These directions with elevated NO_2 concentrations occur for winds from around 20 to 70 degrees, where the source is assumed to be Woodside, the HI power station and the Parker Point ship berth, 140 to 180 degrees from the town of Dampier, with possibly another source at 270 degrees, corresponding to the activities on East Intercourse Island. As such, to determine background concentrations, the average and median concentrations for directions where there are no sources were derived and are presented in **Table B-2**.

■ **Table B-2 Background NO_2 Concentrations (pphm) at Dampier for 1999**

Statistic	Wind Direction (deg)			Overall Background
	80-120	220-250	300-340	
Average	0.08	0.06	0.10	0.08
Median	0.05	0.04	0.05	0.047

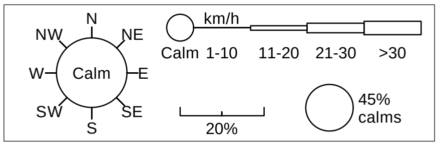
Therefore, an overall annual average background concentration, taking into account smoke from fires is estimated to be around 0.08pphm (0.8ppb) for the Dampier region.

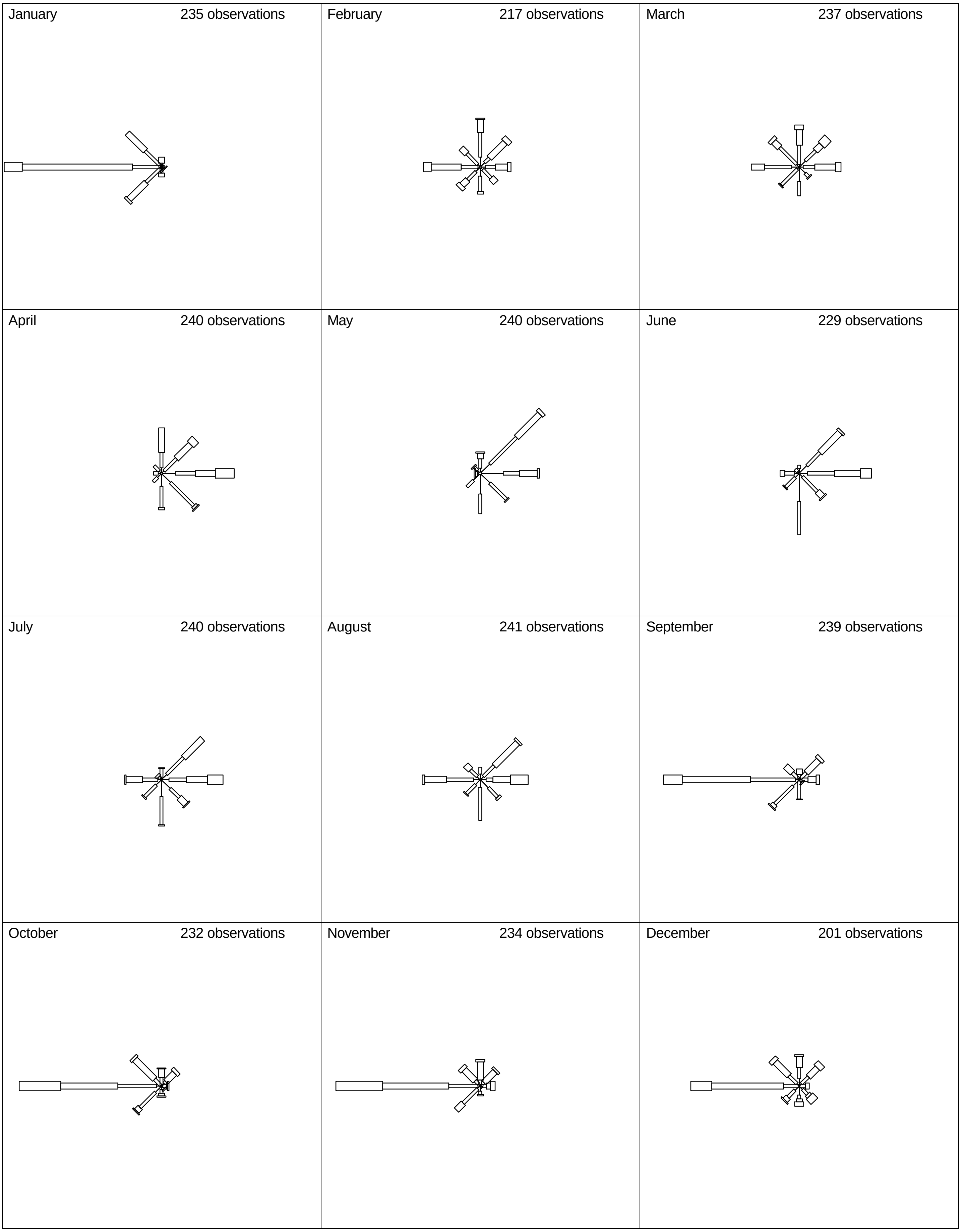
How Representative was 1999 as a basis for modelling?

The year 1999 was used in the modelling as it contained the only year with good quality emission, meteorological and monitoring data to enable model validation work to be performed. This year was used by CSIRO for their model evaluation work (Physick and Blockley, 2001) and has subsequently been used in all modelling assessments in the area. A quantitative analysis of its representativeness to our understanding has not been performed to date. A qualitative comparison of the winds can be made by comparing the 1999 monthly wind roses to average 1993-2003 monthly wind roses at Karratha airport in the following figures. This generally shows good agreement indicating that there will be relatively small differences in the distribution of annual average concentrations and depositions.

Wind Roses using available data between 1999 and 1999 for
KARRATHA AERO

Site Number 004083 • Locality: KARRATHA • Opened Dec 1971 • Still Open
Latitude 20°42'35"S • Longitude 116°46'27"E • Elevation 7m





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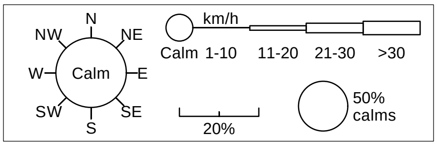
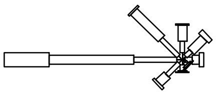
Wind Roses using available data between 1993 and 2003 for
KARRATHA AERO

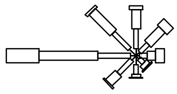
Site Number 004083 • Locality: KARRATHA • Opened Dec 1971 • Still Open
Latitude 20°42'35"S • Longitude 116°46'27"E • Elevation 7m



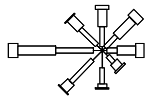
January 2300 observations



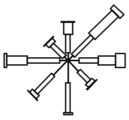
February 2092 observations



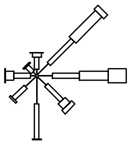
March 2390 observations



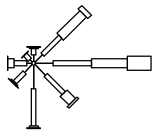
April 2349 observations



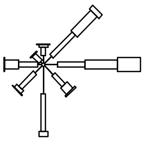
May 2248 observations



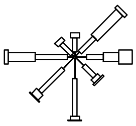
June 2009 observations



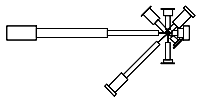
July 2023 observations



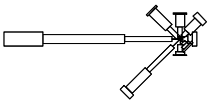
August 2195 observations



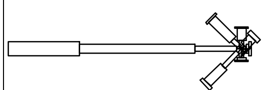
September 2235 observations



October 2304 observations



November 2275 observations



December 2320 observations