Appendix 19

Onshore air quality study

ICHTHYS GAS FIELD DEVELOPMENT PROJECT

ONSHORE AIR QUALITY STUDY

- WV03600-MV-RP-0002
- INPEX Document No. C036-AH-REP-0030 Rev H
- 09 March 2010

SKM
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Limitations Statement

The purpose of this report and the associated services performed by SKM is to assess the potential air quality impact of the proposed Ichthys land side development in accordance with the scope of services set out in the contract between SKM and INPEX. That scope of services, as described in this report, was developed with INPEX.

In preparing this report, SKM has relied upon, and presumed accurate, certain information (or absence thereof) provided by INPEX and other sources. Except as otherwise stated in the report, SKM has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

SKM derived the data in this report from information sourced from INPEX, available in the public domain, and facilitated by SKM at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report. SKM has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose of the project and by reference to applicable standards, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by SKM for use of any part of this report in any other context.

This report has been prepared on behalf of, and for the exclusive use of INPEX, and is subject to, and issued in connection with, the provisions of the agreement between SKM and INPEX. SKM accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

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Executive Summary

Project Description

INPEX Browse Ltd (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys gas field situated about 220 km off Western Australia's Kimberley coast and about 820 km west-south-west of Darwin. The field encompasses an area of 800 km^2 in water depths ranging from 235 to 275 m.

For the Ichthys Project, the company plans to install offshore extraction facilities at the field and a subsea gas pipeline from the field to onshore facilities at Blaydin Point in Darwin Harbour. A two-train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site on Blaydin Point. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

This report details the air quality assessment undertaken as part of the environmental approvals for the Ichthys Project. It comprises an assessment of the air quality impacts predicted from the construction and operation of the onshore development of gas processing facilities at Blaydin Point, Darwin Harbour in the Northern Territory.

Overview of Project

The gas processing and associated onshore facilities are to be located at Blaydin Point on the central tip of Middle Arm Peninsula, within the Darwin Harbour. The shore site (Hundred of Ayers, Wickham Point, Parcel Nos 1813, 1814) is currently unallocated Crown land, but zoned for development as an industrial area under the Northern Territory Planning Scheme specifically for LNG (DPI 2008).

The main infrastructure components to be constructed at Blaydin Point are the onshore processing facilities; onshore storage for hydrocarbon condensate, LPG and LNG; a module offloading facility (MOF); product offloading jetty (POJ); emergency gas flare system, power generation and a wastewater treatment system. Support facilities including administration buildings will be located south of Blaydin Point on the central part of Middle Arm Peninsula.

The key atmospheric emission of concern during the construction phase of the proposed development is dust. Other atmospheric emissions during the three to four year construction phase will be associated with marine vessel engines, additional airline flights and from vehicles and equipment required to support the construction crew at site. However, the volume and duration of the emissions during construction will not be significant in comparison to emission levels during the operation of the Development. Furthermore, they will not be concentrated in a single location

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for any extended period of time. Air dispersion modelling has therefore not been undertaken for the construction phase. The focus of the modelling is on the longer term operational phase impacts that are expected to last at least 40 years.

The proposed onshore processing facilities will consist of two trains for LNG, LPG and hydrocarbon condensate production processes; acid gas removal; dehydration; mercury removal; LPG recovery; fractionation; liquifaction and refrigeration to create LNG; an emergency flare system and associated utilities (water treatment, power generation etc.).

The key air emissions of concern from operating the proposed gas processing facility will be from the combustion of fuel gas in the process and power generation plant gas turbines and by flaring hydrocarbons during routine and non-routine plant operations.

The key emissions from natural gas combustion include carbon dioxide (CO_2) and oxides of nitrogen (nitrogen dioxide (NO_2) as a measure of NO_x), together with some carbon monoxide (CO) and volatile organic compounds (VOCs) from non-combusted hydrocarbons. There will also be small amounts of particulate matter and oxides of sulfur (sulfur dioxide (SO_2) as a measure of SO_x). The potential contribution of the emission of NO_x and its contribution to the creation of photochemical smog (measured as ground level ozone (O_3) is also of interest. The emissions that will be modelled in this air quality study therefore include airborne particulate matter (as PM_{10}), NO_x (as NO_2), SO_2, VOCs and O_3.

A review around Woodside's LNG facilities by Hurley *et al* (2003a, 2003b) regarding modelling for existing and proposed emissions on the Burrup Peninsula in Western Australia indicated that air quality impacts from emissions of VOCs, such as benzene, toluene ethyl-benzene and xylenes (BTEX) are unlikely to cause significant air quality impacts. These findings can be expected to be representative of the Darwin region, where there is minimal existing infrastructure contributing air pollutants. For these reasons the emissions of BTEX group of compounds from the INPEX operations has not been considered as a significant future air pollutant and has not been considered in future modelling scenarios.

Atmospheric emissions from the gas processing facility will vary depending on the operating and tanker loading conditions.

To assess the effects of existing and predicted emissions on human health, the environment and occupational health requires comparisons with legislated air quality criteria. Legislated air quality criteria provide the framework to assess the effects of existing and predicted emissions on human health, the environment and occupational health. In the Northern Territory, the Department for Natural Resources, Environment, The Arts and Sport (NRETAS) requires that air contaminant levels meet the national environment protection standards set by the National Environmental

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Protection Measure (NEPM) for ambient air quality (NEPC 2003). New industrial projects are assessed in terms of their stack emissions and how the resultant ambient ground level concentrations compare with the Ambient Air Quality NEPM. The NEPM standards are intended to apply across all areas of Australia in both urban and regional areas, but excluding industrial areas and residence free buffer zones (NEPC 2007). As such, and in the absence of standards of air quality assessment specific to the Northern Territory, it is considered appropriate to use these standards as the criteria for comparison in this air quality assessment.

The effects of emissions on human health are determined with reference to sensitive receptors in the community.

Existing Air Quality

Existing (non-industrial) air quality, being the contribution of emissions from biogenic sources and vehicle emissions in the region, is well below the applicable NEPM criteria for both NO_2 and O_3.

Atmospheric emissions from the existing industrial operations (including non-industrial emissions) in the region also have an influence on predicted existing air quality. The 1-hour and annual predicted concentrations for NO_x are higher than those predicted in the background case but remain well within the NEPM criteria. The 1-hour and annual predicted concentrations for SO_2 are also well within the NEPM criteria. The predicted maximum concentrations for both the 1-hour and 4-hour ground level ozone concentrations are within the NEPM criteria and occur out to sea.

Summary of results

Atmospheric emissions from the proposed INPEX facility will contribute to a relatively small increase in predicted ground level concentrations of O_3, NO_x and SO_x. Also, particulate concentrations remain well within the NEPM criteria.

This assessment has shown that for NO_2, SO_2 and particulates (as PM_{10}) no exceedences of the relevant assessment criteria are expected as a result of operating the proposed facility. This is the case during both normal and specified upset conditions of the plant. The highest predicted concentration for any pollutant represented 68% of the NEPM criteria is for the 4-hourly ozone concentration (under normal future operations).

Deposition of SO_2 and NO_2 for the region surrounding the proposed INPEX facility on Blaydin Point, incorporating all emissions associated with existing sources and the proposed gas processing facility, indicates that 'typical high' SO_2 and NO_2 deposition in the region around Darwin are 4 kg/ha/annum and 6 kg/ha/annum respectively. These levels are well under WHO (2000) guidelines for assessing the risks of impacts on vegetation; that is, WHO guidelines 8 to 16 kg/ha/annum (SO_2) and 49 to 66 kg/ha/annum (NO_2).

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Conclusions

This air quality assessment concludes with the following key findings:

- Normal and non-routine onshore Ichthys Gas Field Development operations are not expected to cause any significant air quality impacts within the study area.
- Throughout any year, no exceedences of the relevant air quality standards are expected for any of the pollutants studied.
- This assessment provides the following conclusions on predicted air quality impacts from the depositions of SO_2 and NO_2 due to emissions from the proposed INPEX facility:
    - NO_2 depositions due to emissions from the proposed gas processing facility on Blaydin Point will be insignificant.
    - The very low sulfur emissions from the proposed development contribute insignificantly to SO_2 deposition in the region surrounding Blaydin Point.

This study has found that modelled concentrations of all emissions from the Ichthys Gas Field Development are within criteria limits and are likely to be considered acceptable.

1. Introduction

This section of the report describes the content and structure of this air quality assessment.

1.1. Overview

This report details the air quality assessment undertaken as part of the environmental approvals for the Ichthys Project. This study comprises an assessment of the air quality impacts predicted from the construction and operation of the on shore development of gas processing facilities at Blaydin Point, Darwin Harbour in the Northern Territory.

The detailed proposal is described in the Environmental Impact Statement (EIS). The details of the project considered relevant to undertaking calculations for the air quality assessment only, are provided below.

1.2. Description of the Proposal

INPEX Browse, Ltd. (INPEX) proposes to develop the natural gas and associated condensate contained in the Ichthys Field situated about 220 km off Western Australia's Kimberley coast and about 820 km west-south-west of Darwin. The field encompasses an area of 800 km^2 in water depths ranging from 235 to 275 m.

The two reservoirs which make up the field are estimated to contain 12.8 tcf (trillion cubic feet) of sales gas and 527 MMbbl (million barrels) of condensate. INPEX proposes to process the reservoir fluids to produce liquefied natural gas (LNG), liquefied petroleum gases (LPGs) and condensate for export to overseas markets.

For the Ichthys Project, the company plans to install offshore extraction facilities at the field and a subsea gas pipeline from the field to onshore facilities at Blaydin Point in Darwin Harbour. A two-train LNG plant, an LPG fractionation plant, a condensate stabilisation plant and a product loading jetty will be constructed at a site on Blaydin Point. Around 85% of the condensate will be extracted and exported directly from the offshore facilities while the remaining 15% will be processed at and exported from Blaydin Point.

In May 2008 INPEX referred its proposal to develop the Ichthys Field to the Commonwealth's Department of the Environment, Water, Heritage and the Arts and the Northern Territory's Department of Natural Resources, Environment and the Arts. The Commonwealth and Northern Territory ministers responsible for environmental matters both determined that the Project should be formally assessed at the EIS level to ensure that potential impacts associated with the Project are identified and appropriately addressed.

Assessment will be undertaken in accordance with the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) and the *Environmental Assessment Act* (NT). It was agreed that INPEX should submit a single EIS document to the two responsible government departments in the Northern Territory and the Commonwealth for assessment.

Sinclair Knight Merz Pty Limited (SKM) was commissioned to carry out environmental work associated with INPEX's preparation of the EIS and this technical report, *Ichthys Gas Field Development Project: Onshore Air Quality Study*, was prepared in part fulfilment of that commission.

1.2.1. Construction

The main infrastructure components to be constructed at Blaydin Point will be:

- onshore processing facilities
- onshore storage for hydrocarbon condensate, LPG and LNG
- a module offloading facility (MOF)
- a product offloading jetty (POJ)
- emergency gas flare system
- power generation
- wastewater treatment system

Support facilities including administration buildings will be located south of Blaydin Point on the central part of Middle Arm Peninsula.

1.2.2. Operations

The proposed onshore processing facilities will accommodate two trains for LNG, LPG and hydrocarbon condensate production processes, including:

- Gas and liquid reception (slug catcher and pig receiving)
- Condensate treatment
- Acid gas removal
- Dehydration
- Mercury removal
- LPG recovery
- Fractionation

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- Liquifaction and refrigeration to create LNG
- Emergency flare system

1.2.3. Air Quality Assessment Scope and Objectives

The objectives of the air quality assessment are to review the existing air quality in the vicinity of the onshore facilities, establish the background (and including existing industrial sources) air quality in the project area, and to provide an assessment of the likely future impact of atmospheric discharges on air quality during the construction and operational phases of the onshore facilities.

To achieve these objectives the following tasks have been undertaken and are reported:

- review of air quality issues relevant to the construction and operation of the proposal (**Section 2**).
- outline of the ambient air quality criteria relevant to the proposal (**Section 4**).
- analysis and description of the local meteorology (**Section 5**), including
  - climate
  - prevailing meteorological conditions
  - cyclones
- analysis and description of existing ambient air quality in the region, including discussion on Area Based Emission Estimation for model input (**Section 6**)
- estimation of emissions of NO_x, O_3, SO_2 and PM_{10} from the proposal at its maximum expected level of operations and during upset conditions (**Section 8**).
- determination of air quality impacts by air dispersion modelling for the maximum operational phase and during upset conditions (**Section 9**).

2. Project Overview and Air Quality Issues

This section briefly describes the key elements of the proposal, and places the project in context with its location and environmental (air quality) setting. The air pollutants expected to arise from the construction and operation of the gas processing plant at Blaydin Point are also identified.

2.1. Overview

The gas processing and associated onshore facilities are to be located at Blaydin Point on the eastern tip of Middle Arm Peninsula, within the Darwin Harbour. The shore site (Hundred of Ayers, Wickham, Parcel Nos 1813, 1814) is currently unallocated Crown land, but zoned for development as an industrial area under the Northern Territory Planning Scheme specifically for LNG (DPI 2008).

2.2. Project Setting

The land area at Blaydin Point is relatively low-lying with a gentle undulating terrain (Fogarty, Lynch and Wood 1984). There are no existing buildings or other infrastructure at the site. Nearby on the Middle Arm Peninsula there is an access road to the Darwin LNG Plant on Wickham Point. The Channel Island power station is also located nearby, about 6 km to the south-west of the Project area.

The onshore development area involves a development footprint of approximately 300 ha. This includes the onshore gas-processing facilities, the storage and product export area, the onshore pipeline route with a 50 m wide buffer, the administration facilities, and the construction lay down and future expansion areas.

2.3. Project Implementation

The onshore gas processing facilities are designed to treat gas to remove hydrocarbon liquids, water, carbon dioxide and other impurities prior to the liquefaction of the gas to produce LNG. LNG along with other separated products (condensate and LPG) will be stored in tanks prior to export via international shipping from Darwin Harbour. The treatment process will produce some atmospheric emissions, principally NO_2, sulfur dioxide (SO_2), particulate matter and VOCs.

Key project characteristics relevant to the air quality assessment are summarised in **Table 2-1**.

■ **Table 2-1 Project characteristics for On Shore Gas Treatment Facilities**

Description	Detail
Location	Blaydin Point
Number of LNG trains	2
Size of LNG train	4.2 ±10% million tonnes per annum (MTPA)
LNG tank (cryogenic) size	2 x 150 000 m^3
Compression turbines - Process refrigeration power (per train)	4 x Frame 7 gas turbines, all equipped with dry low NO$_x$ (DLN)
Power generation turbines	9 x Frame 6 gas turbine generators equipped with DLN burners 7 running, 1 hot-standby and 1 cold-standby
Flares	Main plant flare (shielded) - Ground flare 1 (warm); Ground flare 2 (cold); Ground flare 3 (spare) (burners positioned at 4 m above grade); 2 x Enclosed Tank flare (30 m)
LPG production rate	4 400 tonnes per day equivalent to 1.6 MTPA
Propane tank size	100 000 m^3
Butane tank size	85 000 m^3
Condensate production rate onshore	15 000 standard barrels per day (bpd) Exported from the Blaydin Point jetty
Condensate tank (ambient) sizes	2 x 45 000 m^3
Incinerators (AGRU)	2
Hot oil furnaces	2

2.3.1. Construction Phase

The key atmospheric emission of concern during the construction phase of the proposed development is dust. Dust generation will be associated with all the construction activities for the facility, including clearing of vegetation, soil and fill, excavation activities including blasting, should this be required, for site levelling and trenching, loading and dumping of material, wheel-generated dust from all vehicles active on site and wind erosion from exposed surfaces and stockpiles.

Other atmospheric emissions during the three to four year construction phase will be associated with marine vessel engines, additional airline flights to and from Darwin and from vehicles and equipment required to support the construction crew at site. Incidental to this will be the increased traffic. These sources will contribute to overall emission levels.

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However, the volume and duration of the emissions during construction will not be significant in comparison to emission levels during the operation of the Development. Furthermore, they will not be concentrated in a single location for any extended period of time.

Air dispersion modelling has not been undertaken for the construction phase. The focus of the modelling is on the longer term operational phase impacts.

2.3.2. Operations Phase

The proposed onshore processing facilities consist of the slug catcher, inlet facilities (condensate and LPG extraction), acid gas removal units (AGRUs) and LNG plant, with the slug catcher, inlet facilities and AGRUs being upstream of the LNG trains. Gas compression drivers will be industrial gas turbines with dry low NO_x (DLN) technology. Power generation will be achieved using gas turbines with DLN technology.

The key sources of air emissions during the Operations phase include:

- Power generation gas turbines
- Process area (refrigerant compressor driver) gas turbines
- Flaring of hydrocarbons
- Emissions from shipping (LNG, LPG and condensate tanker movements)

The key air emissions of concern from the proposed gas processing facility will be from the combustion of fuel gas in the process and power generation plant gas turbines and by flaring hydrocarbons during routine and non-routine plant operations. The key air pollutants from natural gas combustion include NO_x (nitrogen dioxide (NO_2) as a measure of NO_x), together with some non-combusted hydrocarbons or VOCs. There may also be traces of particulate matter and oxides of sulfur (SO_2 as a measure of SO_x). The potential contribution of the emission of NO_x and its contribution to the creation of photochemical smog (measured as ground level ozone (O_3)) are also of interest.

3. Air Pollutants and Effects

This section outlines the health and environmental effects of airborne particulate matter, oxides of nitrogen (NO_x), sulfur dioxide (SO_2), air toxics (including applicable volatile organic compounds (VOCs)) and ozone (O_3).

3.1. Overview

The pollutants addressed here are considered the most relevant to the assessment, based on the nature of the works to be undertaken during the overall development and operation of the onshore facilities for the Ichthys gas field development. These pollutants (with the exception of air toxics) are listed in the National Environment Protection (Ambient Air Quality) Measure (NEPC 1998), and national air standards have been prescribed.

3.2. Oxides of Nitrogen

NO_x is the collective term for nitric oxide (NO) and nitrogen dioxide (NO_2). Lightning and the oxidation of ammonia can form NO_x naturally. A major anthropogenic source, (the main source), of NO_x is from the combustion of fossil fuels, primarily in urban areas from automobiles and electricity production, and in INPEX's case, from the combustion of fuel gas. Nitrogen oxide is colourless and odourless but can oxidise in the atmosphere to form NO_2 and NO_3. For most sources NO_2 accounts for 90% of NO_x with NO contributing the remaining 90%. For brevity, only NO_2 is presented in this study but the full NO_x emissions are included in the modelling.

3.2.1. Human Health Impacts (NO_2)

Nitrogen dioxide (NO_2) is a pungent, brown, acidic, highly corrosive gas and has significant effects on human health. NO_2 can have detrimental effects on the human respiratory tract, leading to increased susceptibility to asthma and respiratory infections. NO_3^- oxidises iron in the blood rendering it incapable of carrying oxygen.

3.2.2. Environmental Impacts (NO_2)

Vegetation is adversely affected by exposure to NO_2, in the form of retarded growth rates and crop yields from very high concentrations. NO_2 is also one of the main contributors to ozone production and can also contribute to acid rain by the formation of nitrous and/or nitric acid in airborne water droplets.

3.3. Ozone

Ozone (O_3) is a colourless gas that is naturally found in the upper atmosphere. O_3 is also formed as a secondary pollutant at ground level by the reaction of nitrogen dioxide (NO_2) and VOCs in the

presence of sunlight which forms nitric oxide (NO) and a single oxygen atom (O). This oxygen atom (O) then combines with molecular oxygen (O_2) to form O_3.

Photochemical smog is characterised by the reaction of NO_x and VOCs in sunlight. It can form a layer of visible, brown or white haze in the sky. Photochemical smog is a regional, and not localized, phenomenon in that ozone is produced relatively slowly over several hours after exposure to sunlight has been sufficient for the series of reactions to be completed. Maximum ozone concentrations therefore tend to occur downwind of the main source areas of precursor emissions, and can become re-circulated within local and regional circulation patterns.

3.3.1. Human Health Impacts (O_3)

The human health effects of exposure to ozone in the lower atmosphere include irritation of the eyes and exacerbation of respiratory problems.

3.3.2. Environmental Impacts (O_3)

Ozone is a strong oxidant and it can affect plants, including the retardation of growth and damage to leaf surfaces.

3.4. Sulfur dioxide

Sulfur dioxide is a colourless gas with an irritating odour that can contribute to or exacerbate respiratory illnesses (such as asthma or bronchitis), especially in elderly or young people.

3.4.1. Human Health Impacts (SO_2)

Sulfur dioxide has also been linked with the aggravation of existing heart and lung diseases (USEPA 2004). Sulfur dioxide can attach itself to small ambient particulates, which can then be inhaled deep into the lungs; this can intensify the health effects of sulfur dioxide.

3.4.2. Environmental Impacts (SO_2)

Sulfur dioxide can also have detrimental effects on the environment. Sulfur dioxide can contribute to the formation of acid rain, damaging crops, ecosystems, monuments and historic buildings.

3.5. Airborne Particulate Matter

Airborne or suspended particulate matter can be defined by its size, chemical composition or source. Particles can also be defined by whether they are primary particles, such as a suspension of the fine fraction of soil by wind erosion, sea salt from evaporating sea spray, pollens, soot particles from incomplete combustion; or secondary particles such as are formed from gas to particle conversion of sulphate and nitrate particles from SO_2 and NO_2.

For the assessment of impacts to human health, particulate matter is characterised by its size. The particulate size ranges specified in ambient air criteria are total suspended particulate (TSP), particulate matter less than 10 μm in aerodynamic diameter (PM_{10}) and particulate matter less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$).

3.5.1. Human Health Impacts (PM_{10})

The health effect of particulates in the PM_{10} range is the exacerbation of pre-existing respiratory problems. The population that is most susceptible include the elderly, people with existing respiratory and/or cardiovascular problems and children (NEPC 2002). The majority of larger particles, greater than 10 μm in aerodynamic diameter, do not pass further than the upper respiratory tract (nose and throat).

3.5.2. Environmental Impacts (PM_{10})

Particulate matter can also enhance some chemical reactions in the atmosphere and reduce visibility. The deposition of larger particles can have the following consequences: staining and soiling of surfaces; aesthetic or chemical contamination of water bodies or vegetation; and effects on personal comfort, amenity and health (DEP 2000).

3.6. Air Toxics

Air toxics are gaseous, aerosol or particulate pollutants which are present in the air in very low concentrations. All have the potential to be hazardous to human, plant or animal life. The main sources of air toxics are derived from human activities (anthropogenic), though emissions also arise from sources such as bushfires and biogenic sources. In Australia, the term "air toxics" is taken to exclude those pollutants covered by the Ambient Air Quality NEPM (NEPC 1998). Air toxics present significant risk even at low concentrations. Air toxics can be separated into the broad pollutant categories of:

- metals
- pesticides
- polycyclic aromatic hydrocarbons (PAHs)
- VOCs
- persistent organic pollutants
- dioxins and furans
- asbestos

The air toxics of interest for a development such as that proposed at Blaydin Point are certain VOCs.

3.6.1. VOCs

Volatile organic compounds (VOCs) are a group of carbon based chemicals, with a high vapour pressure at room temperature. Fuels, oil-based paints, solvents, wood preservers, benzene, toluene, ethyl-benzene, xylene(s) and perchloroethylene (the principal dry cleaning solvent) are all common VOCs. VOCs can react with NO_x in the presence of sunlight to form ozone.

3.6.2. Human Health Impacts (VOC)

The extent to which individual VOCs can cause health problems depends on their toxicity, concentration and the duration of exposure. Some are known to be carcinogenic, while others can cause reactions such as coughing or eye irritations at very high concentrations.

3.6.3. Environmental Impacts (VOC)

VOCs cover a wide range of compounds and can cause many different environmental impacts ranging from death or disfiguration in plants and vegetation to visibility problems related to photochemical reactions giving rise to ozone.

4. Air Quality Objectives in Northern Territory

This section outlines the ambient air quality objectives relevant to this assessment. It also identifies the criteria against which the modelling results will be assessed to determine whether the specified pollutants may be considered harmful to human health and/or the environment.

4.1. Criteria for Assessing Impacts to Human Health

The Ambient Air Quality NEPM (NEPC 1998) was created to provide a benchmark to ensure that people throughout Australia have protection from the potential health effects of air pollution. The standards were developed by taking into account the most current information that was available regarding health related air pollution research from around the world, and the information available on the state of Australia's major airsheds. The final standards represent a high degree of consensus among leading health professionals, varied to reflect what can be realistically achieved in Australia within a ten year timeframe.

As NEPM standards are intended to apply to general ambient air in both urban and regional areas, the pollutants of most concern identified for inclusion in the Ambient Air Quality NEPM were determined to be O_3, NO_2, PM_{10}, CO, SO_2 and lead. In 2003 the NEPM was extended to include an advisory reporting standard for particulates as $PM_{2.5}$. The pollutants of key interest in this proposal are O_3, NO_2 as a measure of NO_x, PM_{10} and SO_2.

These pollutants are listed in **Table 4-1**, along with their associated NEPM standard. These specify maximum concentrations and compliance goals.

■   Table 4-1 National Environment Protection Standards used as assessment criteria

Pollutant	Averaging Period	Maximum Concentration	Compliance Goal for exceedences
NO_2	1 hour	120 ppb (246 $\mu g/m^3$)	1 day per year
	1 year	30 ppb (62 $\mu g/m^3$)	None
Photochemical oxidants (as O_3)	1 hour	100 ppb (214 $\mu g/m^3$)	1 day per year
	4 hours	80 ppb (171 $\mu g/m^3$)	1 day per year
SO_2	1 hour	200 ppb (572 $\mu g/m^3$)	1 day per year
	1 day	80 ppb (227 $\mu g/m^3$)	1 day per year
	1 year	20 ppb (57 $\mu g/m^3$)	None
Particles as PM_{10}	1 day	50 $\mu g/m^3$	5 days per year

4.2.   Criteria for Assessing Impacts to Vegetation

4.2.1.   Deposition of Oxides of Nitrogen and Sulfur Dioxide

Acid deposition occurs when SO_2 and NO_2 react with water, oxygen and other oxidants in the atmosphere to form acidic compounds. These acid compounds precipitate out in rain, snow and fog (wet deposition), or as gases and particles (dry deposition). The SO_2 and NO_2 gases, their particulate matter derivatives, sulfate and nitrate aerosols; have the potential to contribute to acid deposition. The potential impacts include the acidification of lakes and streams, damage to forest ecosystems and acceleration of the decay of building materials (USEPA 2007).

Deposition processes in the study region are expected to be dominated by dry deposition during the dry season and a combination of wet and dry deposition during the wet season.

Previous deposition studies undertaken by SKM on the Burrup Peninsula, which is located in the Pilbara region of Western Australia, have indicated that there are large uncertainties with the depositions predicted by modelling (SKM 2003b, SKM 2005). The uncertainties in the modelled depositions are due to uncertainties in the water, soil and vegetation surface resistances employed in the calculations (Hurley 2005). To reduce these uncertainties, further programs would be required including deposition measurements and model validations. As such, the deposition quantities provided in this assessment are considered indicative of what may occur.

4.2.2.   WHO Guidelines for Air Quality Impacts on Vegetation

WHO (2000) provides critical loads for deposition of nitrogen and sulfur. Critical load is an estimate of exposure in the form of deposition, below which significant harmful effects on specified sensitive elements of the environment do not occur to the best present knowledge (WHO 2000).

The WHO (2000) sulfur critical load is 250–1500 eq/ha/annum (units are 'acid equivalents' per hectares per year), depending on the type of soil and ecosystem. The ecosystem example used for this assessment is, for sulfur critical load:

- 250–500 eq/ha/annum for fluvial and marine sediment
- 4–8 kg/ha/annum as elemental sulfur
- 8–16 kg/ha/annum as SO_2 (acid)

The WHO (2000) nitrogen critical load is 5–35 kg/ha/annum, depending on the type of soil and ecosystem. The ecosystem example used for this assessment is:

- 15–20 kg/ha/annum for heath/shrub lands as elemental nitrogen
- 49–66 kg/ha/annum as NO_2 (acid)

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4.3. Summary of Criteria Used in this Assessment

For the purposes of this assessment the criteria summarised in **Table 4-2** will be used to compare against modelled concentrations of air pollutants.

▪ **Table 4-2 National Environment Protection Standards used as assessment criteria**

Pollutant	Averaging Period	Maximum Concentration	Outcome
NO_2	1 hour 1 year	246 $\mu g/m^3$ 62 $\mu g/m^3$	Protection of human health
	1 year	49–66 kg/ha as NO_2	Protection of vegetation
Photochemical oxidants (as O_3)	1 hour 4 hours	214 $\mu g/m^3$ 171 $\mu g/m^3$	Protection of human health
SO_2	1 hour 1 day 1 year	572 $\mu g/m^3$ 227 $\mu g/m^3$ 57 $\mu g/m^3$	Protection of human health
	1 year	8–16 kg/ha as SO_2	Protection of vegetation
Particles as PM10	1 day	50 $\mu g/m^3$	Protection of human health

5. Existing Environment

This section provides a description of environmental characteristics of the project area relevant to the air quality assessment, including the prevailing meteorological conditions influencing the air dispersion, and the meteorological data of Darwin used for the air dispersion modelling.

5.1. Climate and Dispersion Modelling

Two major atmospheric pressure systems affect Darwin: a subtropical ridge of high pressure cells (highs or anticyclones), and a broad tropical low pressure region called the monsoon trough (BoM 2008). The monsoon trough is a broad area of low atmospheric pressure running east-west through the tropics in the summer months that can deposit large amounts of rain when passing near or over land. Seasons are characterised by a cooler 'dry' season between May and September, gradually changing to a hot 'wet' season during October to April.

5.1.1. Temperature

The temperature of the Darwin can be expected to follow the pattern illustrated by **Figure 1**. The mean maximum monthly temperature fluctuates between 30°C and 33°C with the maximum reaching as high as 39°C during the wet season. The dry season temperatures can drop as low as 10°C and is shown to have a lower mean minimum by 5°C compared to the wet season, although mean maximums are comparable to the wet season.
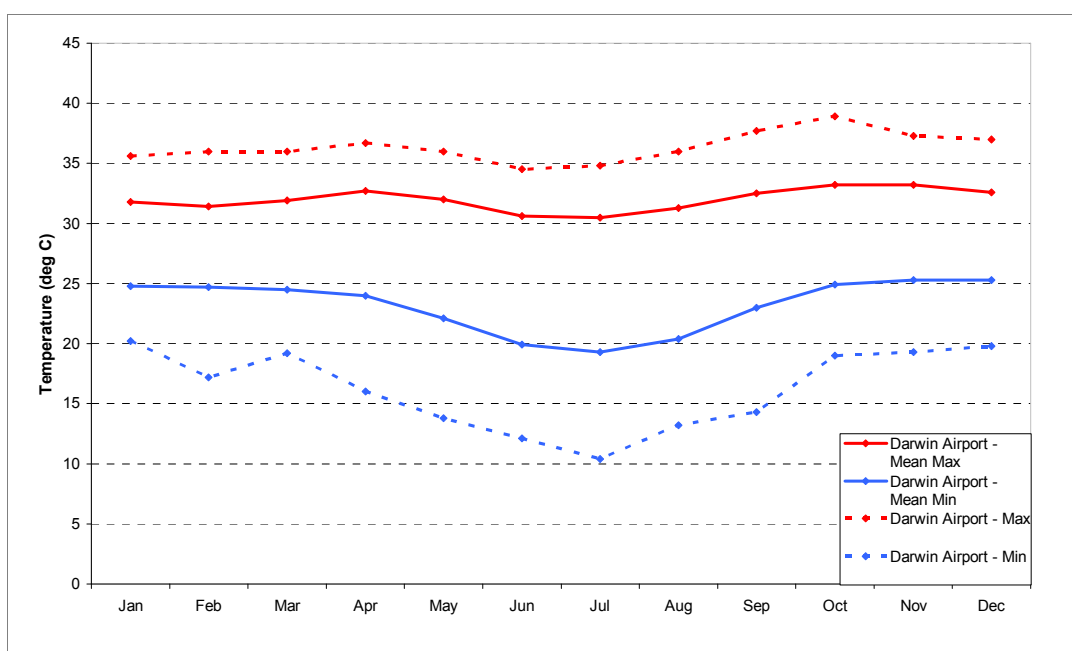
■ **Figure 1 Maximum and minimum monthly temperatures Darwin (°C)**

5.1.2. Rainfall

The average monthly rainfall for the Darwin is presented in **Figure 2**. From this figure it can be seen that the rainfall in this region is seasonal, with the majority occurring between December and March with April, October and November being transitional months. Very little rainfall occurs during the dry season months from May to October.
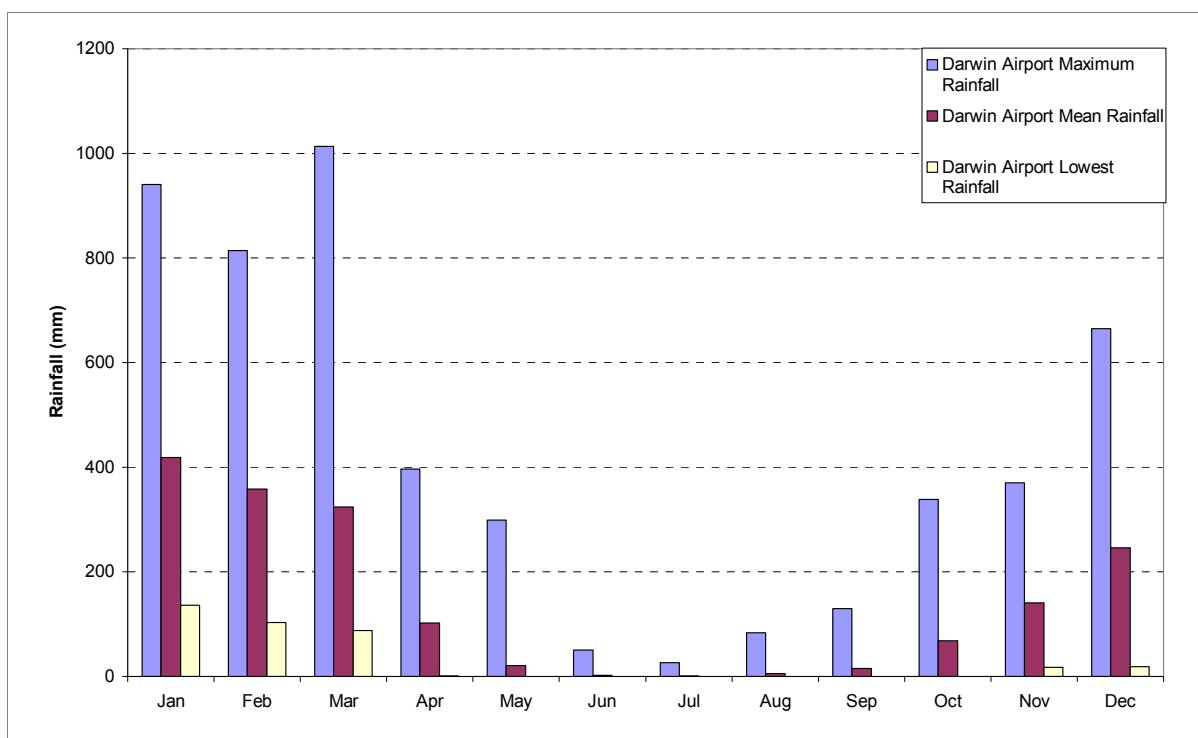
- **Figure 2 Average monthly rainfall for Darwin (mm)**

It is noted that the Darwin region is subject to cyclonic conditions and as such there is the potential for significant amounts of rain to fall in the region over short periods of time. This is highlighted by the large maximums when compared to the mean rainfall, indicating periods of extreme weather conditions.

5.1.3. Relative Humidity

The relative humidity experienced in Darwin is illustrated in **Figure 3.** This figure presents the mean 9am and 3pm relative humidity from Darwin. Inland stations would be expected to exhibit significantly warmer conditions in the afternoon as the land heats up, increasing the capacity of the air to hold water and hence decreasing the relative humidity. The humidity is higher during the wet season than in the dry season, mirroring rainfall patterns.

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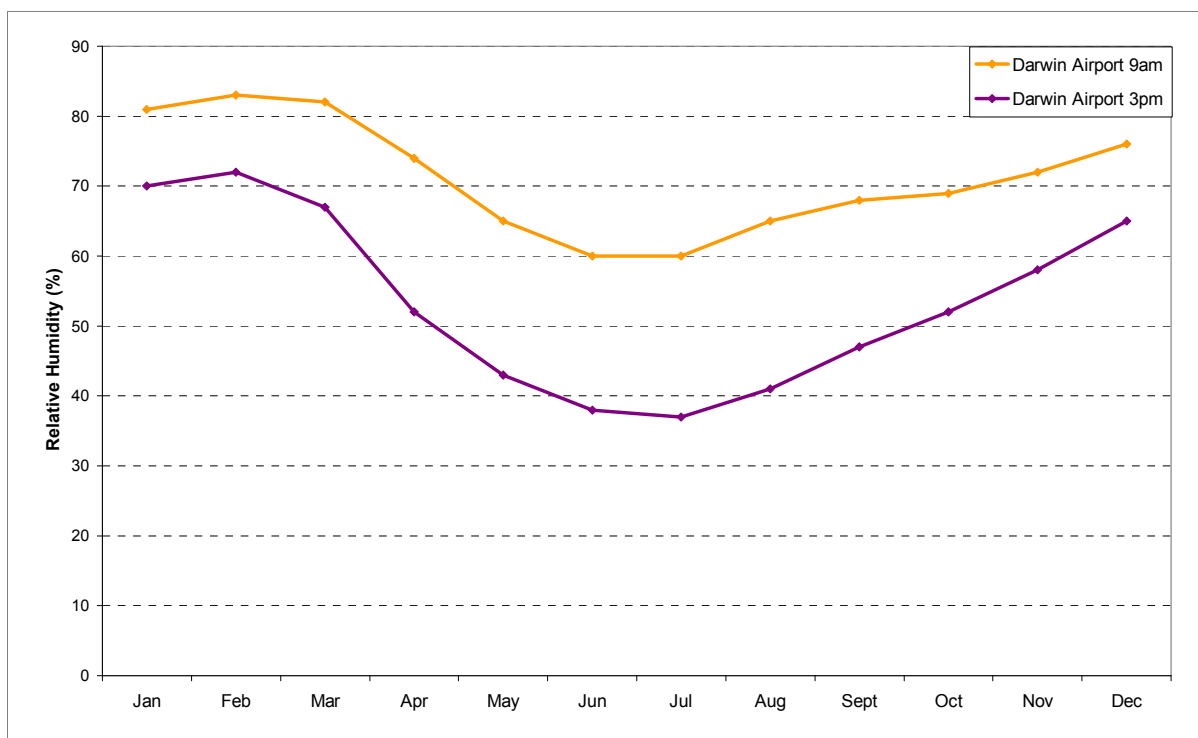
- **Figure 3 Relative Humidity for Darwin (percentage)**

5.1.4. Wind

The wet season (November to April) wind rose for Darwin for the period 2000 to 2007 is presented in **Figure 4**. The wind rose for the dry season is presented in **Figure 5**. From these figures it can be seen that:

- During the wet season Darwin is dominated by westerly and west-north-west winds.
- During the dry season Darwin has winds varying from the southeast through to the north.

■ **Figure 4 Wind Rose for Darwin during the wet season (2000 – 2007)**	■ **Figure 5 Wind Rose for Darwin during the dry season (2000 – 2007)**
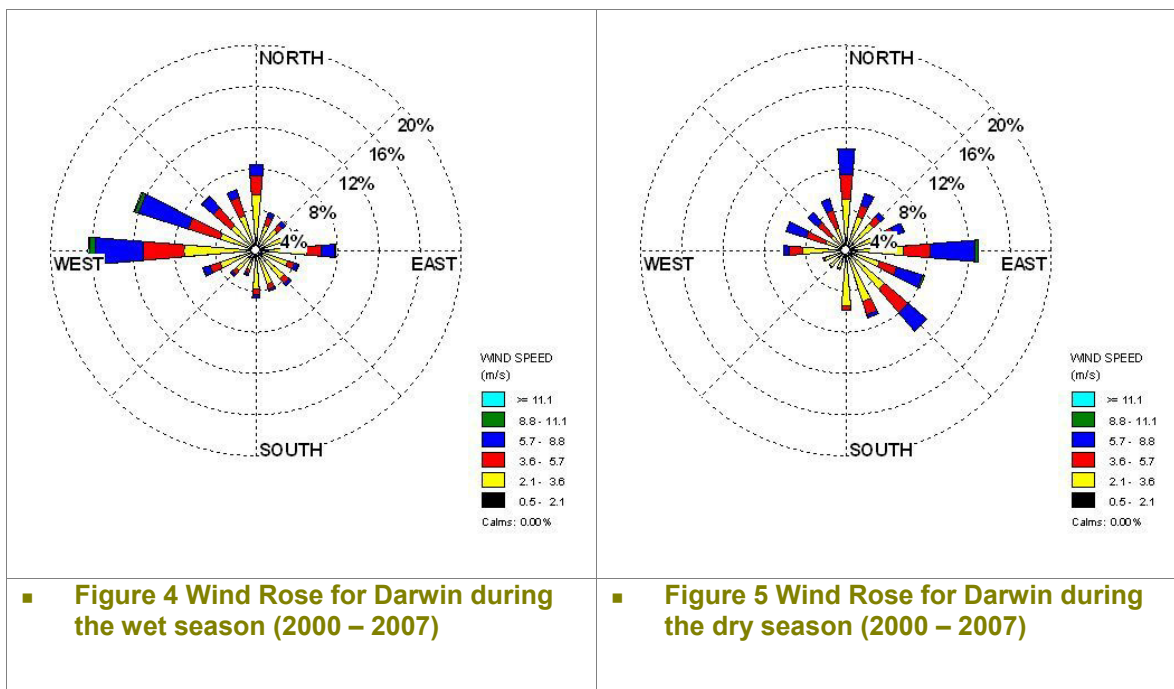
5.2. Cyclones

A cyclone is an intense low pressure system that is formed in maritime tropical air masses. The cyclone season in Australia starts in November and continues through to April, with the most severe storms occurring later in the season. **Figure 6** shows the locations of land-crossings by tropical cyclones from 1970 to 2002. There are many examples of cyclones crossing the coast near Darwin, but the intensity of these cyclones is less than those that cross the coast in the Pilbara region in Western Australia. The average number of cyclones to pass through locations in the Southern Indian Ocean and South Pacific Ocean each year is shown in **Figure 7**.
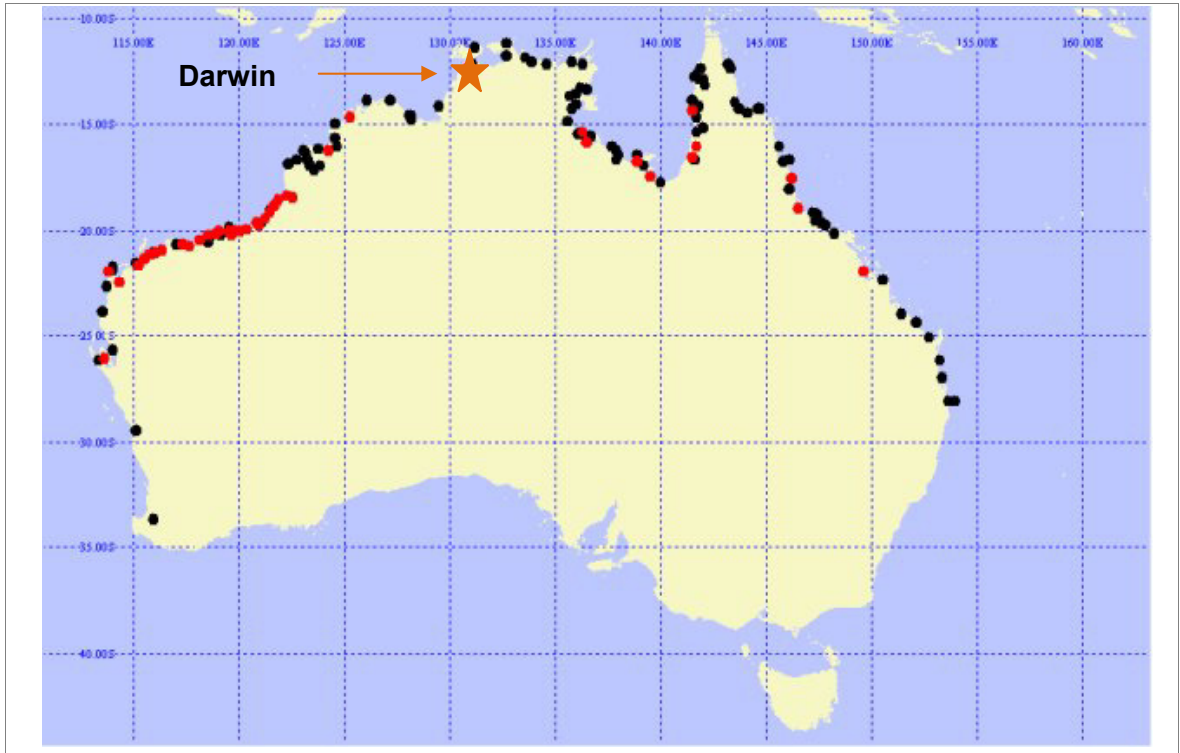
- **Figure 6 Location of land crossings by tropical cyclones from 1970 to 2002 (BoM 2006)**

Note: Red dots indicate severe cyclones (category 3-5) and black dots represent non-severe cyclones (below category 3). BOM (2006)
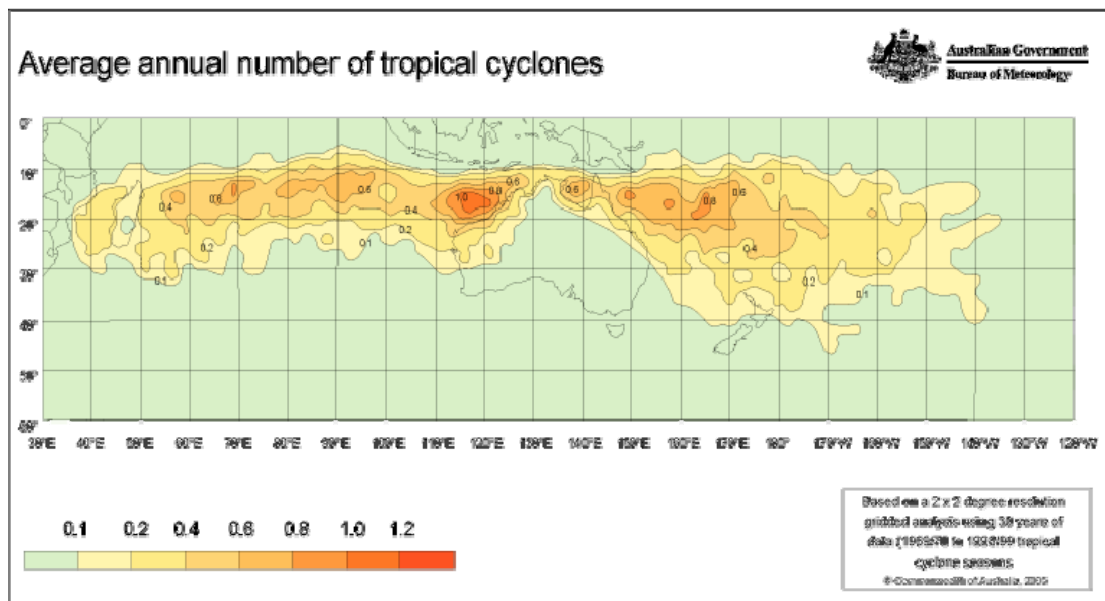
- **Figure 7 Average number of tropical cyclones per year (BoM 2007)**

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6. Background Air Quality Assessment

This section describes the results from a desk study estimating the emissions in the local and regional airshed relevant to the project. The desktop study concentrated on biogenic emissions from vegetation and soils (VOC and NO_2) and emissions associated with motor vehicles (NO_2, SO_2 and VOC).

Bush fires burn about 30% of the vegetation of the NT each year and contribute mostly CO and particulates. They have been excluded from the study due to a number of reasons including:

- the complexity of determining emissions from bushfires
- the difficulty in modelling the variable short term impact of fires on an annual basis.

Emissions from existing industrial sources are treated separately to highlight the background emissions from biogenic and vehicular sources.

6.1. Overview

Based on the regional setting, ambient air quality in the Darwin region is expected to be influenced by ocean sources, biogenic emissions and regional smoke from wild fires and prescribed burning activities, including the potential for photochemistry activity to occur throughout much of the year. The extent of the relevant area is shown in **Figure 8**.

Information regarding the local ambient air quality experienced in the Darwin region is confined to a study conducted by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) from 2000 – 2001 and two NEPM monitoring reports completed by the Department of Natural Resources, Environment, The Arts and Sport (NRETAS) for the 2006 and 2007 annual reporting periods.

During 2000 the CSIRO conducted a pilot study of air quality in the Darwin region to monitor pollutants listed in the NEPM criteria (**Section 4**). The pollutants of interest were PM_{10}, NO_2, SO_2 and O_3. The findings of this study include:

- 24-hour averaged PM_{10} concentrations varied by season with the wet season typically recording concentrations below $10 \, \mu g/m^3$ whilst the dry season tends to have higher concentrations averaging approximately $20 \, \mu g/m^3$.
- High PM_{10} concentrations recorded during the dry season coincided with days of reduced visibility due to smoke derived from burning.

- NO_2 concentrations ranged between 1 ppbv to 8 ppbv with an average of 4.3 ppbv (CSIRO 2001) which is well within the NEPM criteria of 120 ppb (1-hour) and 30 ppb (annual average).
- The maximum ozone concentration was 26 ppbv over 6-days which are well within the 80 ppb specified in the NEPM criteria.

In the Darwin region NRETAS operates one Tapered Element Oscillating Microbalance (TEOM) monitor for PM_{10} and a Partisol dichotomous sampler for PM_{10} and $PM_{2.5}$. Both of these monitors are located at the Charles Darwin University at Casuarina. Monitoring at this site has been continuous since 2006 and the results indicate that:

- There were significant issues with the TEOM during 2006 that resulted in poor data availability. These issues have since been rectified and the 24-hour concentrations recorded by the TEOM during 2007 indicate that there were no excursions above the NEPM criteria for PM_{10} (**Section 4**).
- The 24-hour PM_{10} concentrations from the Partisol monitor indicate that there were no excursions of the NEPM criteria during 2006 and there was one potential excursion during 2007.
- The Partisol monitoring indicates that there five potential excursions of the $PM_{2.5}$ advisory reporting standard during 2006 and four during 2007 and these can be attributed to smoke derived from bushfires (NRETAS 2007, NRETAS 2008).

Due to limited amount of available monitoring data, estimating the emissions in the local and regional airshed has been necessary. This estimation has focused on biogenic emissions from vegetation and soils (VOC and NO_2) and emissions associated with motor vehicles (NO_2, SO_2 and VOC).
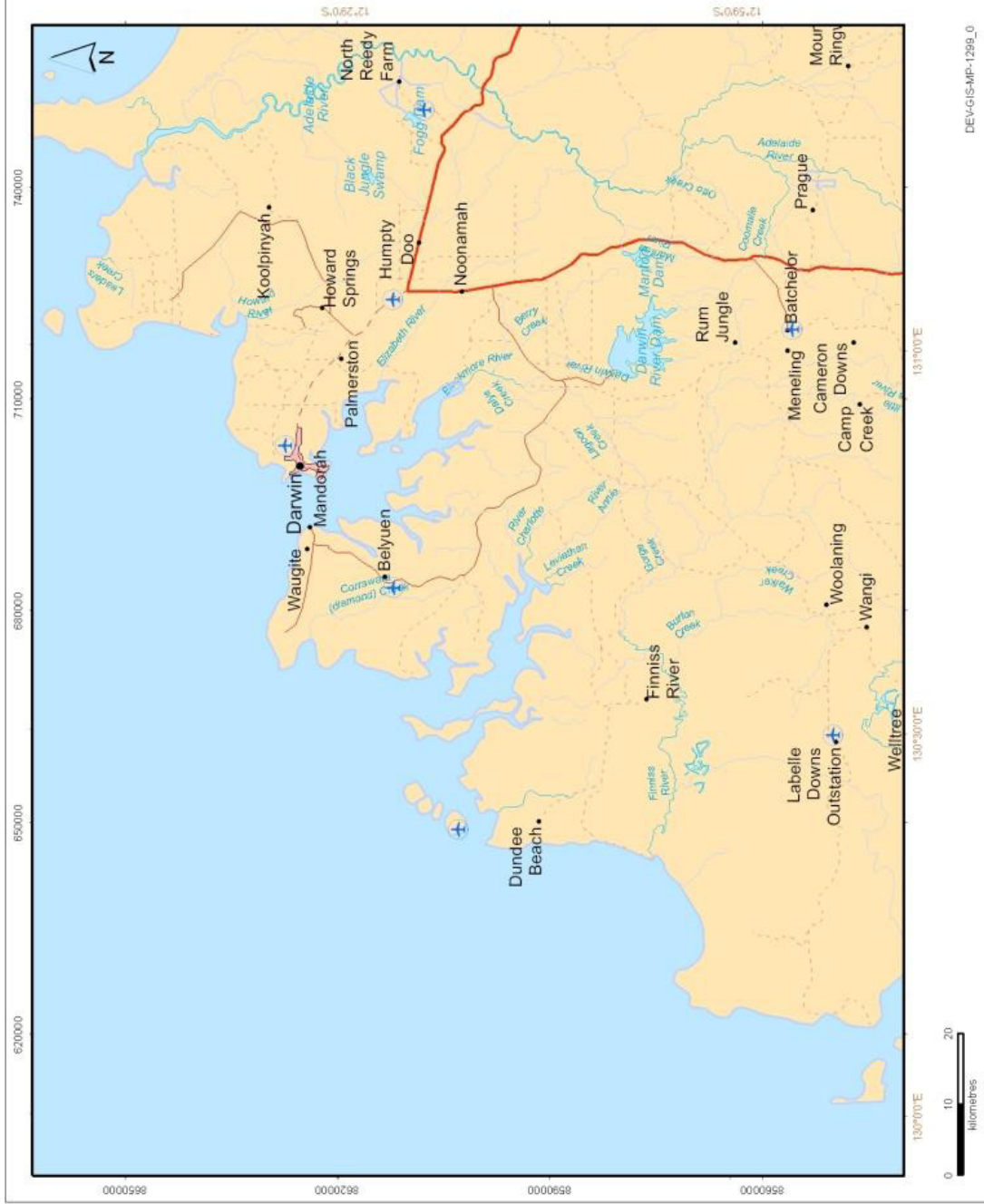
Figure 8 The extent of the study area for the air quality assessment

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6.2. Biogenic Emissions

Emissions of VOCs and NO_2 occur from both anthropogenic (human derived) and biogenic (natural) sources. The main source of biogenic VOCs is vegetation (Lamb et al 1993) while biogenic NO_2 sources include soil, biomass burning and lightning (Yienger and Levy 1995). Estimates by Lamb et al (1987) indicate that VOC emissions by vegetation account for half of the estimated total VOC emissions in the USA and two-thirds of the global VOC emissions.

Due to the high reactivity of biogenic VOCs towards the hydroxyl radical (OH), NO_3^- and O_3, the chemistry of the lower troposphere is strongly influenced by these emissions (Hakola 2001). In the presence of sufficient NO_2 the oxidation of biogenic VOCs, especially isoprene and monoterpenes, can produce ozone, though if NO_2 levels are low these VOCs will react with ozone and therefore reduce the concentrations (Sanderson 2002). Biogenic VOCs (BVOCs) also have the potential to form secondary organic aerosols (Hakola 2001).

6.2.1. Volatile organic compounds

It has long been recognised that biogenic VOC emissions contribute a significant amount of the total hydrocarbon emissions into the atmosphere (Guenther *et al* 1993) and that these emissions vary between plant species as well as by temperature, levels of photosynthetically active radiation (PAR) (Sanderson 2002) and the physiological activity of plants (Fall 1999). It is also noted in Guenther *et al* (1995) that of the estimated 90% of global biogenic isoprene emissions approximately 50% are derived from tropical ecosystems. This is primarily due to a combination of the large quantities of vegetation and consistently warm temperatures. However the studies on tropical VOC emissions have been limited to isoprene in Puerto Rico and Panama and isoprene and monoterpenes in Central Africa and South Africa (Lerdau and Keller 1997, Keller and Lerdau 1999, Klinger *et al* 1998, Guenther *et al* 1996 and Guenther *et al* 1999 in Geron *et al* 2002). No studies have been conducted on VOC emissions from tropical vegetation in the Darwin region.

As is noted in the BEWA 2000 study (Steinbrecher 2006) the key processes of biogenic VOC emissions are not well understood and this has led to large uncertainties in inventories on both global and regional scales. These uncertainties are a result of:

- variations in emissions caused through source strength, climate and synergistic effects between plant species and emitted species
- land use and distribution
- lack of suitable emission factors for specific endemic species

6.2.1.1.   Data Collection and Information Sources

The methodology adopted for the calculation of VOC emissions from vegetation in the study region is the same as that used in the Aggregated Emission Inventory for the Pilbara Airshed (SKM 2003). This methodology is based on Lamb *et al* (1987) and estimates the major VOCs emitted (isoprene, 1 8-cineole, and monoterpenes) from vegetation based on a temperature dependant function and a vegetation density index. This methodology is simpler than that adopted for other Australian studies such as MAQS (Carnovale *et al* 1996) and for the Dandenong, Launceston and Port Pirie in the NPI Trial (EPAV 1996). The methodology for these studies requires additional data on biomass density (mass on a dry basis of leaf per unit area of ground) as well as using a more complicated temperature factor and radiation factor that varies with the sun angle.

For this study, given that there is neither biomass density data nor specific VOC measurements for the vegetation types in the study region, the simpler (Lamb *et al* 1987) approach will be sufficient.

To supplement this approach, a passive sampling program was carried out in the project area. This program collected BVOCs and ozone data from six sites over a wet and a dry season. Sampling locations were based on geographical location, vegetation types and areas anticipated to show ozone concentrations. The study found no significant difference in the mangrove and bush emission factors to the defaults used, which do not differ significantly between each other either. The urban emission factors are higher than initially utilised from generic values owing to a denser vegetation that in the default land use categories due to the tropical nature of the region.

Data required for emission estimates are vegetation types, classification of the vegetation density and meteorological data for the Darwin region. The vegetation type and coverage was obtained from NRETAS through INPEX. The required temperature data was obtained from the Bureau of Meteorology's automatic weather stations at Darwin airport.

6.2.1.2.   Emission Estimation

Emissions of VOCs from vegetation were calculated using **Equation 6.1** from Lamb *et al* (1987), as used in SKM (2003) and EPAV (1996).

Equation 6.1

$$E_j = pq10^r$$

Where: E_j is the mass emission flux (g/m^2/hr) of a volatile organic compound j at an ambient temperature of T°C
p and r are empirical coefficients
q is the vegetation density index (ranging from 0 to 5)

The empirical constants used in EPAV (1996) are listed in **Table 6-1**. For this study the empirical scaling constant p was modified, as new data (Congrong *et al*, 1999) indicates that the emissions from a heavily wooded forest of eucalyptus trees (as used for a vegetation index of 5) are higher than that derived in MAQS and used in the above studies. In MAQS, a maximum emission rate per land area of 1.8 mg/m^2/hr was used, which equates to a *p* value of 0.0268. This value has subsequently been found to be too low, with Cope (in SKM 2003) indicating that a value up to twice this may be more appropriate for the Sydney area. Measurements by Congrong *et al* (1999) for 15 Eucalypt species gave an average rate of approximately 12 mg/m^2/hr (based on a leaf biomass density of 350 g/m^2 (EPAV 1995)). These measurements were taken from small plants that were well watered and fertilised and may be over-estimates of emissions from mature plants that undergo water stress. For the Perth Photochemical Smog Study (Western Power Corporation and DEP 1996) values of around 4.7 to 5.7 g/m^2/hr were predicted using branch level isoprene values of 13.1 μg C/g/h, as suggested by Cope (2000). These values were thought to result in emissions that were slightly higher than actual from comparison of predicted ozone levels (Cope in SKM 2003). As such, based on the above Australian studies a value of 3.6 mg/m^2/hr (or a *p* value 2.0 times that quoted by EPAV 1996) has been adopted for a dense canopy of trees in the study area.

- **Table 6-1 Empirical equations for Biogenic VOCs from EPAV (1996)**

Pollutant	Time and Temperature	P[1]	r
Isoprene	Day, T<40°C	0.0268	0.0416T – 3.109
	Day, T>40°C	3.52 – 0.064T	-3
	Night[2]	0	n.a.
1,8-Cineole	Day/night	0.0302	0.0416T – 3.109
Monoterpenes	Day/night	0.0133	0.0416T – 3.109

Notes:

1.   In this study *p* value 2 times these have been adopted.
2.   Night was defined as from 6pm to 6am.

For areas with 100% grass coverage a value 0.4 mg/m^2/hr has been adopted from the open savannah measurements of Klinger *et al* (1998). This value is higher than values for temperate grasses used in the USA of 0.15 mg/m^2/hr (Carnovale *et al* 1997, based on a quoted value of 300 μg/m^2/hr of total non methane hydrocarbons consisting of 50% isoprene). The higher value is considered appropriate as the grasslands consist primarily of spinifex (known to have high oil content). With no measurements of such grasses in Australia, the African savannah results have been adopted.

Vegetation densities were assigned (*q* = 0 to 5) based on the percentage of coverage of trees and percent coverage of grasses. For shrubs and trees with 50% coverage or less, a 30% coverage by grasses underneath was assumed. This is approximately mid-range between the maximum grass

coverage of 50% and the lower grass coverages. As per EPAV (1996) mangroves were assumed to emit negligible isoprene and cineoles, whilst monoterpenes were assumed to be emitted at approximately the same rate as for other isoprene emitting species. Therefore, as an approximation to estimate total VOCs, emissions of isoprene, cineoles and monoterpenes were reduced by one third. Mangroves were taken to have a biomass density of half that of a forested area. Therefore a q factor of 0.83 was adopted for them. A description of each category is presented in **Table 6-2**.

■ **Table 6-2 Vegetation categories**

Description	Vegetation Index (q)
Closed forest	0.8
Closed Tussock Grassland	Assumed 30% coverage
Mangrove	0.83
Mid Closed forest	0.6
Open Forest	0.44
Rainforest Dry	0.8
Rainforest Riparian	1
Rainforest spring	1.1
Sparse Samphire scrubland	Assumed 10% coverage
Tussock grassland	Assumed 30% coverage

Notes:

1. Emission rate normalised to 30^0 C and photosynthetically active radiation of 1000 μmol/m^2/s.
2. Grasses and samphire have an emission rate of 0.4 mg/m^2/hr for 100% coverage

Using the methodology outlined above together with a map of vegetation type and coverage, typical of the region, obtained from INPEX, the total VOC emissions were determined on a 1 km by 1 km grid basis for the entire study region. The breakdown of each vegetation type across the study region is presented in **Appendix A**. The total VOC emissions by each vegetation category are presented in **Table 6-3** and the spatial allocation of emissions across the study region is presented **Figure 9**. It should be noted that biogenic VOC emissions are derived from vegetation therefore no emissions were assigned to water bodies (oceans/inlets) or bare open areas.

- **Table 6-3 Total VOC emissions from each vegetation category**

Description	Area (km^2)	Emission factor pg10^r (t/yr/km^2)	VOC Emissions (t/yr)	Contribution (%)
Closed forest	40.6	5.3	213	0.85
Closed Tussock Grassland	638.4	0.6	351	1.40
Mangrove	425.3	4.9	2 084	8.29
Mid Closed forest	56.5	3.6	201	0.80
Open Forest	8 284	2.6	21 538	85.69
Rainforest Dry	92.4	4.8	439	1.75
Rainforest Riparian	19.4	6.0	115	0.46
Rainforest spring	25.5	6.5	166	0.66
Sparse Samphire scrubland	84.7	0.2	17	0.07
Tussock grassland	21.4	0.5	11	0.04
TOTAL	9,688		25 135	100%
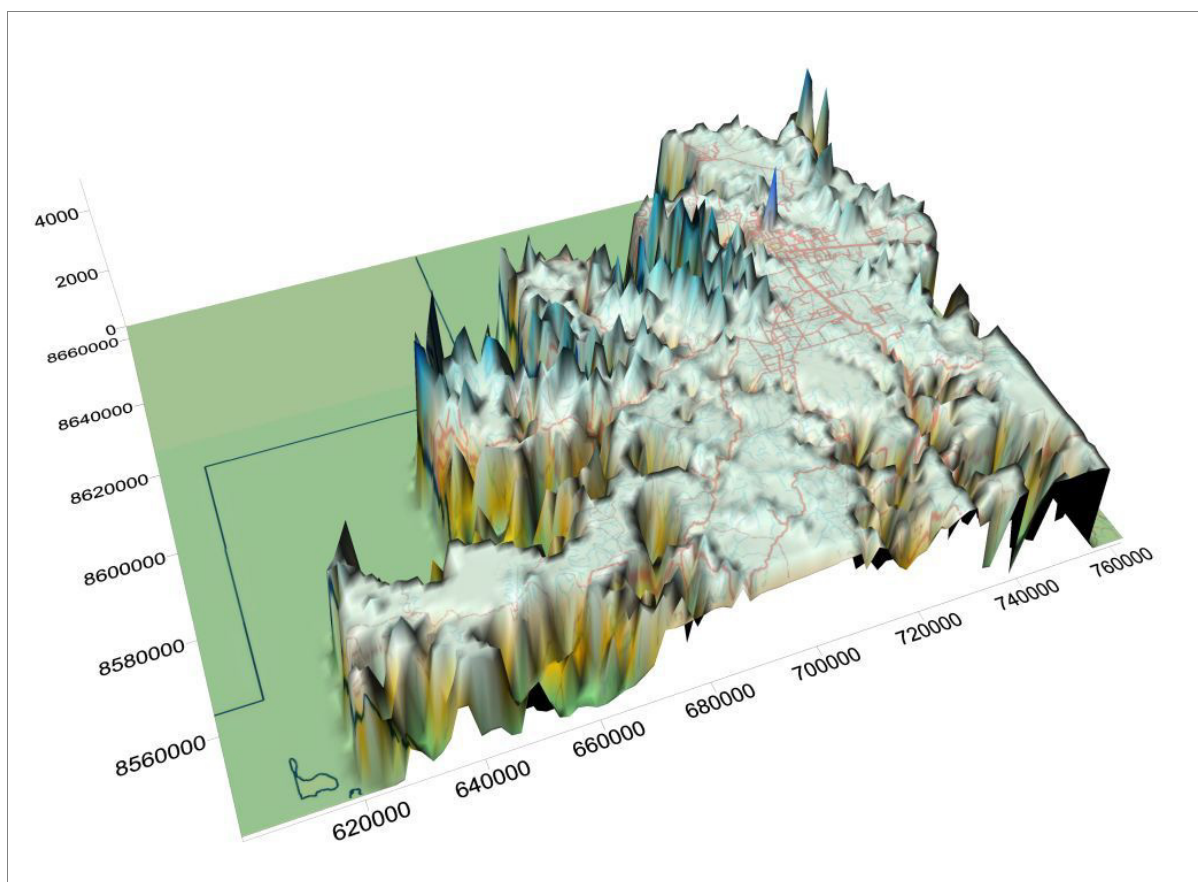
- **Figure 9 Spatial allocation of VOC emissions (kg/year) in the Darwin region**

It must be noted that there are large uncertainties associated with biogenic VOC emissions. This includes the assignment to a vegetation type (error in q) and in the emission factors (error in p and r). In order to reduce the uncertainty in the emission estimates a comparison to estimates in other published materials was made (**Section 6.2.1.3**). In addition, INPEX commissioned a two-season passive sampling program to assess VOC and ozone concentrations at six sites across the project area (**Section 6.2.1.4**).

6.2.1.3. Comparison to Other Studies

A comparison of the emission estimates from this assessment to emission estimates from other Australian studies is presented in **Table 6-4**. From this table it can be seen that the VOC emissions for the Darwin region are lower than that calculated for other regions within Australia, with the exception of the Dandenong study.

▪ **Table 6-4 VOC emissions from vegetation compared to other Australian studies**

Region	VOC (t/km²/yr)
Darwin	2.6
Kimberley[1]	6.6
Pilbara[2]	5.5
Dandenong[2]	0.7
Port Pirie[2]	14
Newcastle[2]	5.2
Kalgoorlie[2]	5.1

Notes:
1. Source: SKM (2007)
2. Source: SKM (2003)

6.2.1.4. Passive Sampling Study

To supplement the emission estimation process, a passive sampling program was carried out in the project area. This program collected BVOCs and ozone data from six sites over a wet and a dry season. Sampling locations were based on geographical location, vegetation types and areas anticipated to show ozone concentrations. The intent was to sample at sites thought to best represent concentrations in that area.

The main vegetation types in the project area were designated as mangroves, open bush, urban and grasslands field types. Grasslands only occur in a small area to the north west of the region. Based on the calculated emission factors grasslands were considered to contribute minimally to expected ozone precursors in the region and was therefore excluded from the sampling protocol.

Sites representative of the Cox Peninsula, Middle Arm Peninsula and the Darwin area were selected. Within these general areas, sites anticipated to represent both high and low predicted ozone regions were chosen based on previous modelling studies (SKM 2008). As urban areas are expected to contribute significantly to ozone formation no low ozone urban area were selected.

The final sites selected for sampling are detailed in **Table 6-5**.

- **Table 6-5 Passive sampling sites representative of the project area**

Location	Vegetation	Anticipated ozone representation
Cox Peninsula	Bush	Low ozone
Cox Peninsula	Mangrove	Low ozone
INPEX site	Mangrove	Intermediate ozone
INPEX site	Bush	Intermediate ozone
University 1 (CSIRO)	Urban (bush surrounding)	High ozone
University 2	Urban (bush surrounding)	High ozone

To accommodate for potential seasonal variation a fortnightly sampling regime using Radiello desorber tubes was established in the wet season (summer) and the dry season (winter) during 2009. Each sampling season was monitored for two consecutive periods, each of two-week duration (Jan/Feb 2009 and May/June 2009).

Analysis of desorber tubes was undertaken by the Chemistry Centre of Western Australia, an organisation nationally accredited for both the ozone and VOC analysis methods. As the focus of the sampling was to determine only ozone formation and BVOC precursors, a full qualification of all the species present in the samples that would not be expected to contribute to ozone formation was not undertaken for all samples. One sample was, however subject to preliminary in depth qualification. This sample showed that the other VOCs present were mostly alkanes and ethers and do not contribute significantly to the photochemical ozone formation.

The measured isoprene concentrations from the four passive sample trials are presented in **Table 6-6**. Isoprene is the dominant BVOC species of interest as reflected in both literature and the monitoring results. Values are at or near the detection limit for most of the other VOC contaminants. Hence it would lead to larger inaccuracies if all VOC compounds were included.

■ **Table 6-6 Measured Isoprene Concentrations (μg/m^3)**

Site	WS1-Rad	WS2-Rad	DS1-Rad	DS2-Rad
Cox Peninsula (bush)	1.4	0.32	0.47	0.28
Cox Peninsula (mangroves)	0.78	0.11	0.22	0.5
INPEX site (mangroves)	0.39	0.08	0.44	0.25
INPEX site (bush)	0.37	0.06	0.29	0.38
University 1 (CSIRO)	0.31	0.05	0.16	0.13
University 2	0.24	0.05	0.12	0.07

Concentrations must be converted back to emission rates using a reverse of the Gaussian plume dispersion and the emission rates must then be converted for standard reference temperatures and radiation. The calculated emission rates are shown in **Table 6-7.**

■ **Table 6-7 Calculated Isoprene emission factor (g/km^2/hr)**

Site	WS1	WS2[1]	DS1	DS2	Average[1]
Cox Peninsula (bush)	1.01	0.23	1.12	0.67	0.93
Cox Peninsula (mangroves)	0.56	0.08	0.52	1.19	0.76
INPEX site (mangroves)	0.28	0.06	1.05	0.59	0.64
INPEX site (bush)	0.27	0.04	0.69	0.90	0.62
University 1 (CSIRO)	0.22	0.04	0.38	0.31	0.30
University 2	0.17	0.04	0.29	0.17	0.21

Notes:
1.   WS2 excluded from the average calculation as isoprene concentrations at this site were rain affected.

There is significant fluctuation in the data as a result of the measured data being close to the detection limit of the instrument. Notwithstanding this, there is good correlation with published data of 0.86 for mangroves and 0.8 g/km^2/hr for bush. This includes the approximation of only using isoprene instead of total BVOCs, analytical accuracy at low concentrations and errors in the dispersion back calculation. The BVOC analysis has shown the general accuracy of the emission factor. Furthermore equating measurements directly to emission factors are assuming that no photochemical reactions occur from the moment of release until the detector.

The ozone data was also compared between measured and previously modelled results. Ozone is at much higher concentrations and significantly above the detection limit giving results with much higher confidence levels. This indicated that the modelling was giving excessively high predicted concentrations and it was decided to reduce the photochemical reactivity coefficient (Rsmog),

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which was calculated to represent motor vehicles in an urban environment (Hurley 2008) and rerun the model. A 50% reduction was chosen as a conservative approach based on the measured to predictive concentrations even though ozone is non-linear in the response of precursors to concentration. Using the revised reactivity coefficient the model was rerun and results are compared to the measured results in **Table 6-8**.

- **Table 6-8 Ozone results (μg/m^3)**

Site	WS1	WS2	DS1	DS2	Average	Annual average predicted	Measured to predicted
Cox Peninsula (bush)	12	21	20	33	21.5	33	65%
Cox Peninsula (mangroves)	10	16	16	27	17.25	35	49%
INPEX site (mangroves)	11	19	19	27	19	30	63%
INPEX site (bush)	13	19	17	29	19.5	30	65%
University 1 (CSIRO)	19	25	23	30	24.25	35	69%
University 2	16	29	19	30	23.5	35	67%
Average (all sites and time period)					21	33	64%

These results are showing the average concentration measured over two months and comparing to the annual average. It is assumed that the two seasons are representative of the year and hence it is sufficient to compare the two months data to the annual average. Based on the results presented in **Table 6-8** it is apparent that the model is still over predicting the ozone concentrations, however further changes in the reactivity coefficient are not required as the over prediction ensures that the model remains conservative.

The findings from the passive sampling program were:

- There are minimal variations in emissions between mangrove and bush types.
- Slightly lower ozone concentrations recorded at the rural sites.
- Existing slightly elevated ozone concentrations in Darwin city is most likely due to vehicular activity rather than BVOC emissions.
- Calculated BVOC emission rates are essentially unchanged from published rates.
- Ozone values measured are less than modelling results would indicate, even though BVOC inputs into the model are correct.
- A change in the photochemical reactivity coefficient is required to ensure that the modelled ozone concentrations are aligned with monitored ozone concentrations.

6.2.2. Nitrogen Dioxide - Background

One of the principal natural sources of NO_2 has been found to be biogenic emissions from soils (Williams *et al* 1987, Guenther *et al* 2000). In rural areas, soil biogenic emissions of NO_2 account for a larger fraction of the total NO_2 source than anthropogenic emissions (Yienger and Levy 1995).

Natural NO_x emissions are strongly influenced by the landscape. In soil, NO_2 emissions result from microbial and chemical processes from both denitrifying bacteria in anaerobic environments and nitrifying bacteria in aerobic environments (Williams *et al* 1987). In water bodies, NO_2 emissions result from nitrite photolysis. Guenther et al (2000) reports that (in general) wetlands and tundra have low NO_2 emissions, forests have moderate emissions, and agricultural and grasslands have the highest emission rates. Yienger and Levy (1995) believe that (in general) grassland emissions are an order of magnitude greater than those of forests, while heavily fertilised soils are an order of magnitude greater than those of grasslands.

Biogenic NO_2 emission activity can be seen to be a function of both short term and long term effects. Long term effects include soil texture, organic matter content, soil pH and nitrate levels. In the short term, the effects are primarily soil temperature and moisture content. Soil NO_2 emission rates generally increase with the application of nitrogen based fertilisers, soil temperature and optimal soil moisture conditions (Guenther et al, 2000).

6.2.2.1. Data Collection and Information Sources

Previous Australian inventories, such as the Victorian trial (EPAV 1996), the Kalgoorlie Mining NPI Trial (Coffey 1999) and the Melbourne Air Quality Study (MAQS) (Carnovale *et al* 1997) have used a temperature dependence of NO_2 emissions derived by Williams et al (1992) which is based on a series of land use categories.

The approach used in this study is adopted by SKM (2003) in the Aggregated Emissions Inventory for the Pilbara Airshed and is based on the approach developed by Yienger and Levy (1995). This methodology introduces the concept described as 'pulsing'. When a very dry soil is wetted, a large burst or 'pulse' occurs and then decays rapidly over a period of time. Typically, the flux begins at 10 to 100 times the background level and decays over a period of a few days to a few weeks, depending on the duration of the dry period and amount of rainfall. Yienger and Levy (1995) believe that the strongest impact of pulsing will be in the tropics where there are extended dry seasons followed by wet seasons. One of the main features of the model developed by Yienger and Levy (1995) is the inclusion of separate exponential temperature dependence for wet soils and linear dependence for dry soils, and an optimal temperature above which the NO_2 emission rate becomes temperature independent.

Emissions of NO_2 for the study region in the Darwin region have been estimated using the empirical relationship used by Yienger and Levy (1995) as presented in **Equation 6.2**.

Equation 6.2

$E_{NOx} = f_{w/d}$ (soil temperature, $A_{w/d}$) x P (precipitation)

Where: $f_{w/d}$ is a function with the subscript w/d representing the soil moisture state, either dry or wet;
$A_{w/d}$ is a coefficient used to distinguish between different landscapes
P is a function of the magnitude and duration of the precipitation, and is a scalar factor varying between 1 and 15.

A soil is considered dry in the sense that it will pulse when wetted. A dry soil is classified as having received less than 1cm of precipitation in the previous 2 weeks.

The function f_w (w, when the soil is wet) is described by three soil temperature intervals: cold-linear (0 to 10°C), exponential (>10 to 30°C), and optimal (>30°C).

Equation 6.3

$$f_w = \begin{cases} 0.28\,A_w T & 0 < T < 10 \\ A_w e^{0.103\,T} & \\ 21.97\,A_w & 10 < T < 30 \\ & T > 30 \end{cases}$$

Where: f_w is measured in $kg/km^2/hr$,
A_w is estimated at 1.296×10^{-3} $kg/km^2/hr$ (the average of 13 grassland/savannah landscapes)
T is the soil temperature in °C.

Soil temperature (T °C) is approximated by air temperature (T_A°C) after Williams *et al* (1992) and shown in **Equation 6.4**.

Equation 6.4

$T = 0.66 T_A + 8.8$

In dry soils, two temperature regimes are defined: cold-linear (0-30°C) and optimal (>30°C), as shown in **Equation 6.5**.

Equation 6.5

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$$f_d = \begin{cases} \dfrac{A_d T}{30} & 0 < T < 30 \\ A_d & T > 30 \end{cases}$$

With A_d estimated at 9.54×10^{-3}.

Estimates of P are determined from the rainfall rate and determine the magnitude and duration of the NO_2 pulse.

- **Table 6-9 NO_2 Emissions as a Function of Rainfall**

Rain Rate (mm/day)	Pulse Description	Function
< 1.0	No pulse (assume evaporation)	P = 1.0
1.0 to 5.0	'sprinkle', a 3-day pulse with exponential decay starting x5	$P = 11.19e^{-0.805t}$ (1<t<3)
5.0 to 15	'shower', 1-week pulse with exponential decay starting x10	$P = 14.68e^{-0.384t}$ (1<t<7)
> 15	'heavy rain', 2-week pulse with exponential decay starting x15	$P = 18.46e^{-0.208t}$ (1<t<14)

For water bodies, Yienger and Levy (1995) provide no methodology as their study was concerned with estimating a global biogenic inventory. For the purposes of this study, NO_2 emissions from water bodies due to nitrite photolysis were calculated using **Equation 6.6,** as used by the Victorian trial (EPAV 1996), the Kalgoorlie Mining NPI Trial (Coffey 1999) and the MAQS study (Carnovale *et al* 1997).

Equation 6.6

$$E_{NOx} = 0.002[10^{(0.049T_A - 0.83)}]$$

Where T_A is the ambient air temperature.

6.2.2.2.   Emission Estimation

Emissions of NO_2 for the study region were estimated using the following methodologies:

- Emissions of NO_2 over land were estimated using daily rainfall and average daily temperatures from the BoM station at Darwin airport. These were calculated using the methodology outlined in **Section 6.2.2.1**.

- NO_2 emissions over water were estimated using the hourly temperature from the BoM station at Darwin airport and **Equation 6.6**. Hourly temperatures were used as, according to Williams et al (1992), water bodies only emit NO_2 during daylight hours. For the purpose of this study daylight was taken from 6am to 6pm for the entire year.

The calculated emission rate of NO_2 for water, islands and land are presented in **Table 6-10** and the spatial allocation of emissions across the study region is presented in **Figure 10**.

- **Table 6-10 Average NO_2 emission rates for each region**

Source	Area (km²)	Total Emission Rate (t/yr)	Average Emission Rate (kg/km²/yr)
Water	9 097	340	37.4
Land	10 952	7 305	667.0
Total	**20 049**	**7 645**	**381.3**
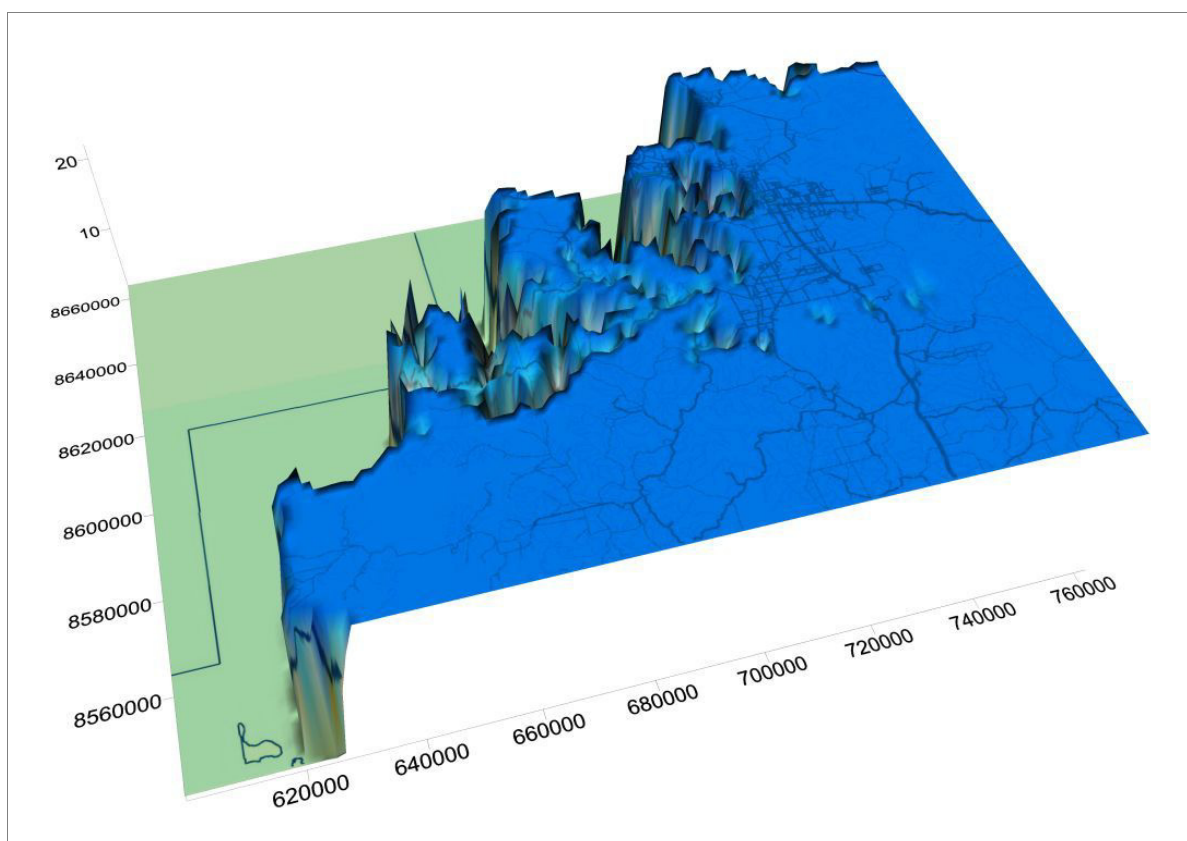
- **Figure 10 Spatial allocation of biogenic NO_2 emission rate (kg/yr)**

6.2.2.3. Comparison to Other Studies

A comparison of the estimated biogenic NO_2 emission rates from this study are compared to estimates from other studies within Australia, and is shown in **Table 6-11**. From this table it is

apparent that the calculated NO_2 emissions for the Darwin region are higher than that calculated for both the Kimberley and Pilbara region. This is due to a number of factors including:

■ The higher rainfall that occurs in the Darwin region when compared to the Pilbara and Kimberley studies.

■ A lower variation in the temperatures as both the Pilbara and Kimberley studies utilised inland temperatures with lower dry season temperatures.

■ The Darwin study had a greater percentage of the calculations occurring over land which results in a higher emission rate for the study region.

■ **Table 6-11 Comparison to other studies**

Region	NO_2 (kg/km^2/yr)
Darwin	381
Kimberley[1]	110
Pilbara[2]	112
Dandenong[2]	190
Port Pirie[2]	491
Newcastle[2]	135
Launceston[2]	122
Kalgoorlie[2]	304
Bunbury[2]	609

Notes:
1.   Source: SKM (2007)
2.   Source: SKM (2003)

6.3.   Motor Vehicles

6.3.1.   Introduction

Emissions from motor vehicles arise as the by-products of the combustion process and from evaporation of the fuel itself. The combustion process results in a range of pollutants being emitted including VOCs, NO_2, CO, SO_2 and PM_{10}. Evaporative emissions result in VOCs and may occur through diurnal, running, hot soak and resting losses.

The principal factors affecting vehicle emissions are:

■ vehicle type

■ type and composition of the fuel used by a vehicle

■ age of vehicle

■ type of roads on which a vehicle travels

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The approach used to estimate emissions from motor vehicles closely follows the method documented in the EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia 2000). Emission estimates have been prepared for 2005 for the following vehicle classes and fuel types:

- petrol, diesel and liquefied petroleum gas (LPG)-fuelled passenger vehicles
- petrol, diesel and LPG-fuelled light commercial vehicles
- petrol, diesel and LPG-fuelled heavy duty vehicles
- petrol-fuelled motorcycles

For the purpose of this study all petrol vehicles are assumed to be using lead replacement petrol and consequently lead is not an issue of concern in this project.

LPG-fuelled vehicles are not treated separately but are grouped generically as LPG/liquefied natural gas (LNG)/dual fuelled vehicles. As recommended in the EET Manual, emission factors for LPG have been applied to all vehicles using this group of fuels.

6.3.2. Data Collection and Information Sources

Data collected for the estimation of emissions included:

- traffic count data from the NT Department of Planning and Infrastructure (DPI)
- spatial road centrelines with road type information from the NT DPI and the Darwin City Council (DCC)

6.3.3. Emission Estimation

6.3.3.1. General Approach

The method used for the estimation of motor vehicle emissions closely follows the approach documented in the EET Manual (Environment Australia 2000). The methodology involves estimating vehicle kilometres travelled (VKT) and applying emission rates for the various NPI substances emitted. The broad steps followed for this study were:

- Traffic volume estimates were allocated to road centreline segments for each road in the study region.
- Traffic volumes were sub-divided by vehicle class and fuel type.
- Road type details and location (i.e. length of road segments in each grid) were calculated from the spatial road centreline information.

- Grid-based VKT estimates were calculated (i.e. traffic volume × segment length in grid).
- Emission rates were developed for the representative vehicle class, fuel type, and road type categories.
- Emission rates were applied to the grid based VKT including speciation of VOCs and PM_{10} emissions.

Equation 6-7 (sourced from the EET Manual) shows how the motor vehicle emissions are calculated on a grid cell basis:

- **Equation 6-7**

$$E_c = 365 \times 0.001 \times \sum_r \left\{ v_{r,c} \times \sum_m \sum_f \sum_p \left(x_{r,m,f} \times e_{r,m,f,p} \right) \right\}$$

Where:

E_c	=	Annual emissions from motor vehicles in grid cell c (kg/yr)
$v_{r,c}$	=	Average daily VKT for road type r in grid cell c (km/day)
$\chi_{r,m,f}$	=	Relative VKT of vehicle type m and fuel type f on road type r (km/day)
$e_{r,m,f,p}$	=	Emission factor for vehicle type m, fuel type f and emission process type p (exhaust, evaporative, or tyre and brake wear) on road type r (g/km)
365	=	Conversion factor from day to year (days/yr)
0.001	=	Conversion factor from grams to kilograms (kg/g)

Detailed methodology information can be obtained from the EET Manual. The application of the EET Manual methodology for this study is discussed below.

6.3.3.2. Grid Based Vehicle Kilometres Travelled Estimates

A spatial data set of road segment centrelines (in MapInfo format) was developed by SKM for this study and was used as the basis for the location of traffic activity information. The dataset included road type categories of freeway, primary distributors A and B, residential major and residential minor.

Traffic counts were entered into the MapInfo centreline data set for the appropriate road segments. As there were no traffic count data for the residential major and minor categories, these road types were assigned traffic counts of 3 000 and 300 per day respectively. These average traffic volumes were sourced from the known range of traffic volume typically expected in roads of these categories (access street for minor and local distributor/neighbourhood connector for major), as given in the MRWA Metropolitan Functional Road Hierarchy and Liveable Neighbourhoods Operational Policy edition 3 produced by the Western Australian Planning Commission (WAPC 2004a). This may result in an over-estimation of emissions from these sources but ensures that the modelling remains conservative.

Default traffic volumes were developed from this traffic count data by grouping the traffic counts into road hierarchy classifications as listed in **Table 6-12**. For the minor unsealed roads and tracks, no count data was available. Defaults determined were based on estimates used in the Pilbara airshed 1999/2000 study conducted by SKM (SKM 2003b). These default values were then assigned to all roads without actual count data.

Manual checking and adjustment of traffic volumes was conducted to match counts between adjacent road segments. This overall procedure was used to allocate a traffic volume for all road segments in the study area such that traffic counts, manual inspection and defaults based on hierarchy group traffic count averages were used to refine estimates of traffic activity.

A "spatial overlay" process was applied to the road centreline segments to divide whole segments into lengths within individual grid cells. The estimates of VKT were then simply calculated as the product of length of the road segment in the grid and the traffic volume on the original whole road segment.

6.3.3.3.   Relative VKT per Vehicle Category

Traffic volume proportions obtained from NT DPI for the Darwin region did not distinguish between vehicle types, and defaults suggested by road type in the EET Manual (Environment Australia 2000) were used for this assessment. The spatial allocation of the VKT across the study region is presented in **Figure 11**. It is important to note that all roads within this grid have been allocated VKT although due to the high volume of traffic on the major highways and within Darwin they are not visible in this figure.
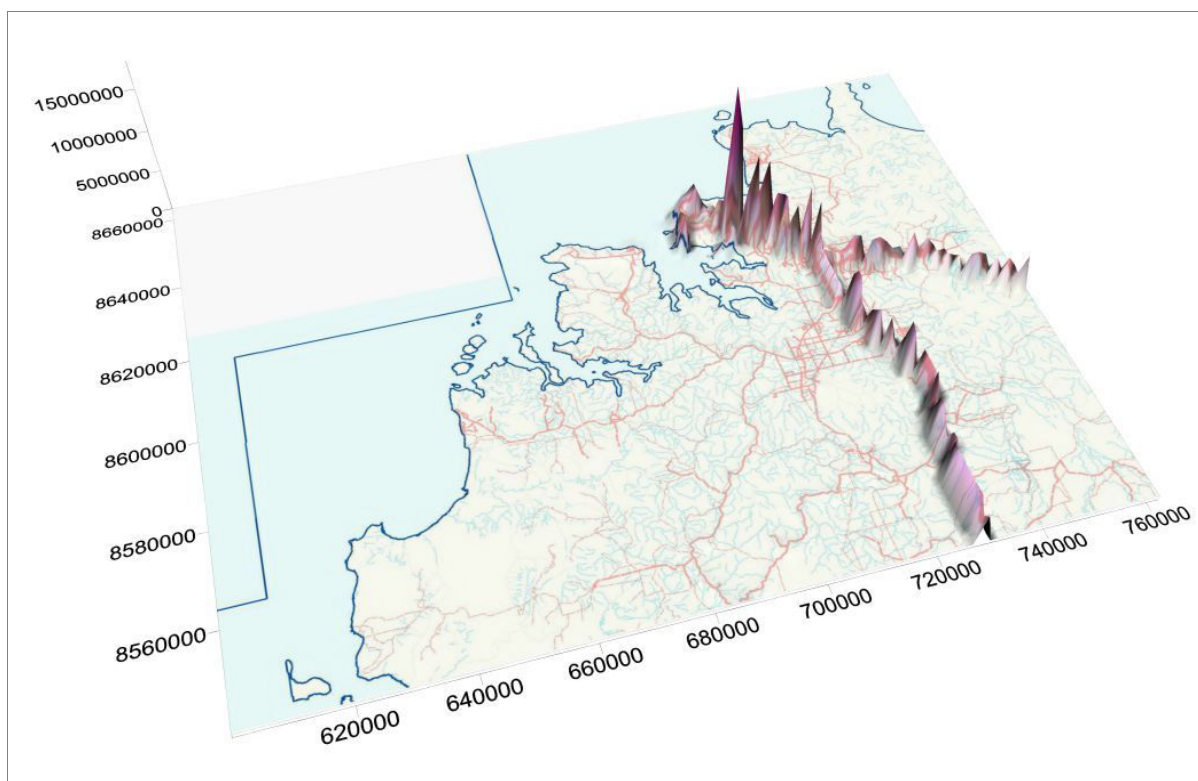
- **Figure 11 Spatial allocation of VKT**

6.3.3.4. Emission Factors for CO, NO$_2$ and Total VOCs

The EET Manual (Environment Australia 2000) contains a detailed methodology for the derivation of CO, NO$_2$ and total VOCs emission factors for the various vehicle class, road type and fuel type categories. Application of this detailed approach was not possible for the Darwin region due to a general lack of detailed information specific to the area. The default values from the EET Manual have been used. These are provided in **Table 6-12**.

- **Table 6-12 Emission Rates for CO, NO$_2$ and VOCs**

Vehicle Class	Fuel Type	Emission Rate (g/km) by Road Type[1]		
		Arterial	Freeway	Residential
		CO		
Passenger	Petrol	19.3	18.8	22.3
	Diesel	0.637	0.516	1.13
	LPG	24.5	24.0	27.9
Light commercial	Petrol	17.2	13.9	30.6
	Diesel	0.81	0.656	1.44
	LPG	19.1	15.4	34

Vehicle Class	Fuel Type	Emission Rate (g/km) by Road Type[1]		
		Arterial	Freeway	Residential
Heavy duty	Petrol	53.7	43.4	95.6
	Diesel	4.42	3.58	7.87
	LPG	59.7	48.3	106
Motorcycle	Petrol	9.04	7.32	16.1
NO$_x$				
Passenger	Petrol	1.53	1.98	1.78
	Diesel	0.785	1.33	1.02
	LPG	1.1	1.37	1.23
Light commercial	Petrol	1.32	2.24	1.73
	Diesel	1.03	1.75	1.35
	LPG	0.878	1.49	1.15
Heavy duty	Petrol	3.08	5.21	4.02
	Diesel	6.69	11.3	8.73
	LPG	2.04	3.46	2.66
Motorcycle	Petrol	0.428	0.724	0.558
Total VOCs (exhaust)				
Passenger	Petrol	1.26	1.24	1.45
	Diesel	0.331	0.31	0.513
	LPG	1.53	1.51	1.73
Light commercial	Petrol	1.64	1.53	2.53
	Diesel	0.554	0.517	0.857
	LPG	1.75	1.63	2.7
Heavy duty	Petrol	3.08	2.88	4.77
	Diesel	1.01	0.941	1.56
	LPG	3.29	3.07	5.09
Motorcycle	Petrol	1.23	1.15	1.9
Total VOCs (evaporative)				
Passenger	Petrol	0.535	0.241	0.535
	LPG	1.07	0.483	1.07
Light commercial	Petrol	0.586	0.275	0.586
	LPG	1.17	0.55	1.17
Heavy duty	Petrol	2.91	2.15	2.91
	LPG	5.81	4.29	5.81
Motorcycle	Petrol	0.803	0.803	0.803

Note:

1. Source: Table 11 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia 2000).

It has been assumed that emission factors for petrol from the EET Manual (Environment Australia, 2000) apply to vehicles using unleaded and lead replacement petrol. Evaporative emissions from

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diesel have not been estimated in accordance with the EET manual due to its comparatively low evaporative emissions (a result of its low volatility).

6.3.3.5. Emission Factors for SO_2

The emission factors for SO_2 based on scaling the EET Manual defaults are given in **Table 6-13**. Emission factors for SO_2 for diesel have been scaled from the default EET Manual values, which depict national average sulfur contents in 2000, to a lower of 0.5 g/L which is representative of the sulfur content in Australian diesel fuel in 2005.

The EET Manual provides separate values for rigid, articulated, non-freight trucks and buses; unfortunately these data were not available and as such have not been included in this assessment. A weighted value for heavy-duty vehicles has been calculated from the defaults, assuming rigid trucks and articulated trucks comprise 65% and 35% of heavy-duty vehicles respectively.

Table 6-13 Emission Factors for SO_2

Vehicle Type	Fuel	Emission Factors (g/km)[1]		
		Arterial	Freeway	Residential
Passenger	Lead replacement petrol	0.025	0.018	0.025
	Unleaded petrol	0.024	0.016	0.024
	Diesel	0.009	0.007	0.009
	LPG	0.003	0.002	0.003
Light commercial	Lead replacement petrol	0.029	0.021	0.029
	Unleaded petrol	0.027	0.019	0.027
	Diesel	0.010	0.007	0.010
	LPG	0.003	0.002	0.003
Heavy duty	Lead replacement petrol	0.062	0.043	0.062
	Unleaded petrol	0.032	0.022	0.032
	Diesel	0.027	0.019	0.027
	LPG	0.008	0.005	0.008
Motorcycle	Lead replacement petrol	0.012	0.009	0.012
	Unleaded petrol	0.013	0.009	0.013

Note:

1. Source: Table 15 of EET Manual for Aggregated Emissions from Motor Vehicles (Environment Australia 2000) with adjustments to reflect revised fuel sulfur content.

6.3.4. Spatial Allocation

The spatial allocation was performed based on the grid-based VKT estimates discussed in **Section 6.3.3.2**. The spatial allocation for NO_2 is presented in **Figure 12**.
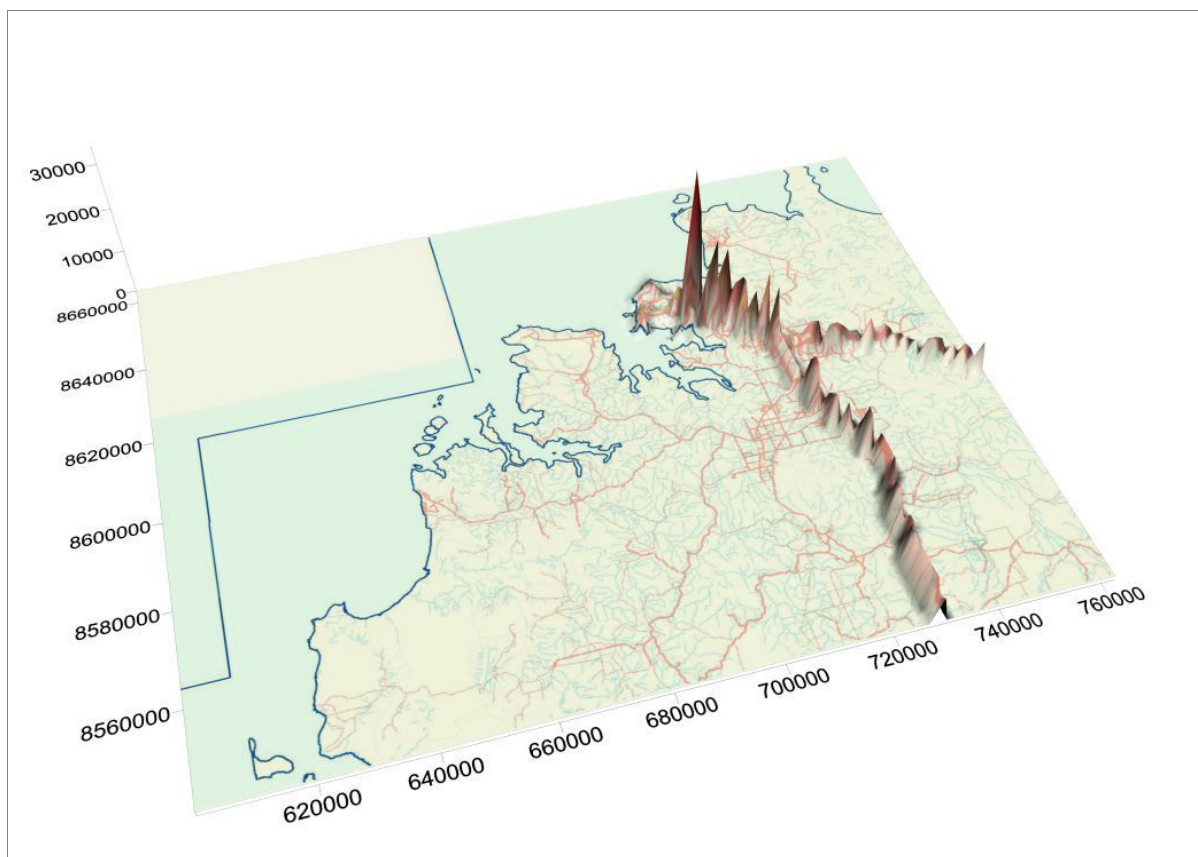
■ **Figure 12 Spatial distribution of NO_2 emissions from motor vehicles (kg/yr)**

6.3.5. Emission Estimates

The emissions from motor vehicles in the Darwin region for 2005, calculated using the above methodology, are provided in **Table 6-14**.

■ **Table 6-14 Emissions from Motor Vehicles**

NPI Substance	Total Emissions (t/yr)
NO_2	1 919
SO_2	44.4
VOCs	489

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6.3.6. Comparison to Other Studies

Comparisons of emissions from motor vehicles in the Darwin region calculated in the assessment on a per capita basis with diffuse emissions studies for Bunbury (2002/2003), Perth (1998/1999), Pilbara (1999/2000), Darwin and Alice Springs (1997/1998) airsheds are provided in **Table 6-15**.

When the results of the calculated emissions from this study are compared to previous studies in the region it is evident that this study recorded lower emissions than that recorded previously. The difference in the calculated emission rates results from a variety of causes including:

- The difference in the emission calculation methodology

- Variations in sulfur content of the fuels

- The variations in VKT determination.

- **Table 6-15 Comparison of Emissions from Motor Vehicles in the Darwin region with Other Airsheds**

NPI Substance	Emission Rates per Capita (kg/yr/person)					
	Darwin (INPEX)	Darwin[1]	Alice Springs[1]	Perth (1998/99)[2]	Bunbury regional (2002/03)[3]	Pilbara (1999/2000)[4]
NO_2	16.3	52.3	27.3	21.4	27.2	14.2
SO_2	0.4	1.1	0.92	0.6	0.512	1.5
Total VOCs	4.2	10.0	5.7	15.3	21.1	8.0

Notes:

1. Source: NT Department of Infrastructure, Planning and Environment (2003).
2. Source: DEP (2003).
3. Source: SKM (2003a).
4. Source: SKM (2003b)

6.4. Shipping Emission Sources

6.4.1. Data Collection

To determine the emissions of the substances listed in **Section 6.4** that are derived from commercial shipping, the EET Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats Ver. 1 (Environment Australia 1999a) was utilised. This manual outlines how to calculate emissions from these sources and contains a series of emission factors to assist in completing this process. The manual distinguishes between ships and boats by describing the former as cargo ships, chemical tankers, colliers and naval ships while the latter includes fishing boats, tugs and other small commercial activity craft. The emissions for ships are calculated on a per hour basis and depend upon time at berth and anchorage and speed and length of time in shipping channels.

The number of ships was obtained from the Darwin Port Corporation annual reports (DPC 2008) and for this assessment a total 1 167 ships during 2005 were utilised. This included 796 vessels below 1 000 tonnes, 44 vessels between 10 000 and 50 000 tonnes and 327 greater than 50 000 tonnes.

6.4.2. Commercial Shipping Calculations

Emissions from commercial shipping were calculated based on the prescribed methodology in the EET Manual (Environment Australia 1999b). **Equation 6-8** was used to estimate emissions at berth.

■ **Equation 6-8**

$$E_b = t_b * \sum_i \left(n_i * a_i \right)$$

Where,
E_b = Annual emission at Berth from commercial ships (kg/yr)
t_b = Average time of ships at berth (hr)
n_i = Number of commercial ships visiting the port each year in the tonnage range i (/yr)
a_i = Emission factor for auxiliary engines for ships in the tonnage range i (kg/hr)

The estimated number of commercial ships that were berthed at Darwin Port during 2005 is presented in **Table 6-16**. The emission factors used to determine emissions from commercial ships are taken from the EET Manual (Environment Australia 1999a) and are presented in **Table 6-17**.

■ **Table 6-16 Commercial shipping**

Tonnage	Movements/year	Time at Berth/ship (hours)
<1 000	796	33
1 000 – 5 000	-	-
5 000 – 10 000	-	-
10 000 – 50 000	44	33
>50 000	327	33

■ **Table 6-17 Emission factors for commercial shipping**

Substance	Emission Factor (kg/hr) for Commercial Ships of Different Tonnage Ranges[1]				
	< 1 000	1 000 to 5 000	5 000 to 10 000	10 000 to 50 000	> 50 000
Auxiliary Engines					
CO	1.19	1.19	1.19	1.19	1.19
NO_x	6.66	6.66	6.66	6.66	6.66
SO_2	1.42	2.83	4.25	5.66	7.08
TSP	0.12	0.12	0.12	0.9	0.9
VOCs	0.436	0.436	0.436	0.436	0.436

Notes:

1. Source: Table 4 of EET Manual for Aggregated Emissions from Commercial Ships/Boats and Recreational Boats (Environment Australia 1999a).

6.4.3. Commercial Shipping Results

NPI substance emission estimates for the Darwin region from commercial shipping activities are summarised in **Table 6-18**.

■ **Table 6-18 Emission summary for commercial shipping/boating (tonnes per year)**

Pollutant	Commercial Shipping
NO_2	256
SO_2	122
VOCs	16.8

7. Air Quality Model

The following sections describe the meteorological and air dispersion model employed for this project and the modelling methodology.

7.1. Model Selection

For pollutants released in near coastal environments, the following four dispersion processes are considered important:

- Dispersion under convective conditions when the buoyant plumes can be mixed to ground level within a short distance of the stacks.
- The influence of the sea breeze with the creation of the Thermal Internal Boundary layer (TIBL) where onshore winds can lead to complex vertical dispersion.
- The influence of the buildings and structures around facilities that may lead to increased dispersion and reduced plume rise from the stacks.
- The presence of terrain features like hills and ridges in the surrounding area that can impact on dispersion and be subject to elevated concentrations.

Two models accepted for use by the regulator in similar situations in Australia are available to assess all four processes; TAPM and CALPUFF.

CALPUFF (the Californian puff model) is a Lagrangian dispersion model that simulates pollutant releases as a series of continuous releases of puffs. It is the preferred model of the US Environmental Protection Agency for the long-range transport of pollutants and for complex terrain (TRC, 2007). 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. CALPUFF has the ability to model the effect of the TIBL both through fumigation and plume trapping.

TAPM is a prognostic three-dimensional model designed by CSIRO that can be used to predict meteorological and air pollution parameters on an hourly basis (Physick and Blockley 2001). The model predicts flows that are of importance to local-scale air pollution such as sea breezes and terrain induced flows (Hurley 2005). The meteorological parameters predicted by the model have been compared to actual readings recorded during the Kwinana Coastal Fumigation study (Hurley and Luhar 2000) and the Pilbara Air Quality Study (Physick and Blockley 2001). It was found that the model predicts near-surface parameters very well while the upper parameters were also well predicted.

For the purpose of this study the CSIRO model TAPM will be used to assess the potential ground level concentrations of pollutants as this model can also be used to predict the photochemical processes.

7.2.   Model Setup

The TAPM modelling package consists of a model and databases of synoptic meteorology, terrain and land use categories for the Australasian region. For this assessment TAPM was configured as follows:

- Four grid domains (30 km, 10 km, 3 km and 1 km) with 31 by 31 cells per domain. The four grid domains are presented from **Figure 13** to **Figure 16**.

- All grids were centred at 130°55.5'E and 12°31'S, which correspond to 708990E and 8615020N in the local grid.

- The TAPM land/sea database was derived from the 9" Digital Elevation Model (DEM) data (Geoscience Australia, 2002) and was modified using the 1:100 000 topographical maps for the region (RASC 1972). This involved incorporating the Darwin region into the lower two grid domains within TAPM (3 km and 1 km) and assigning the appropriate soil and vegetation cover.

- Standard 25 vertical levels from 10 metres to 8 000 metres in height.

- The default sea surface and deep soil temperatures were used. Default sea surface temperatures were checked against the recorded sea surface temperatures from the BoM (2006). Examples of the sea surface temperatures for January and June are available in **Figure 17** and **Figure 18** respectively.

- Meteorological runs from 30 December 2004 to 31 December 2005, with the output only after 1 January 2005 being used in the assessment.
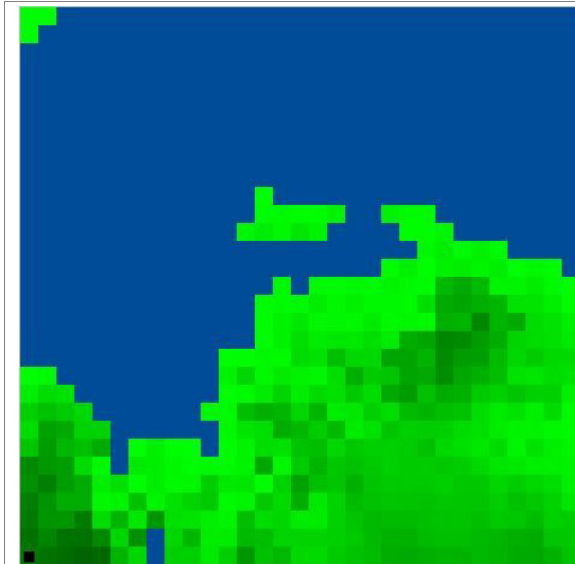
- **Figure 13 TAPM topography file at 30 000m grid spacing**
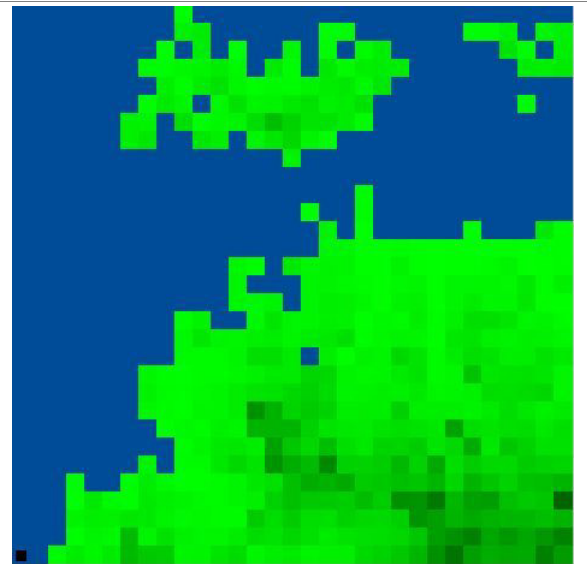
- **Figure 14 TAPM topography file at 10 000m grid spacing**
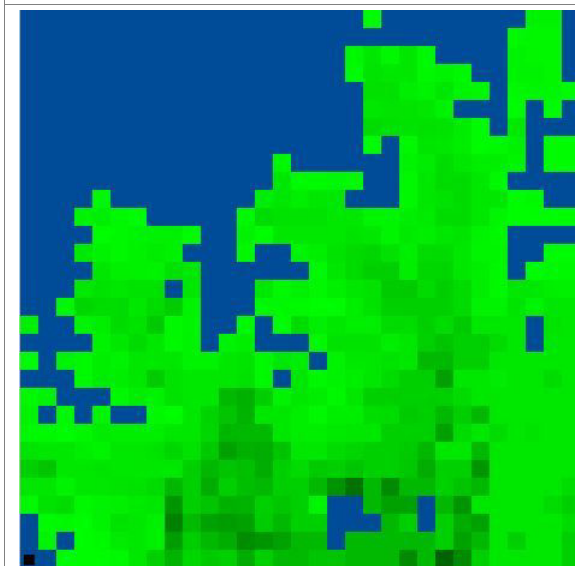
- **Figure 15 TAPM topography file at 3 000m grid spacing**
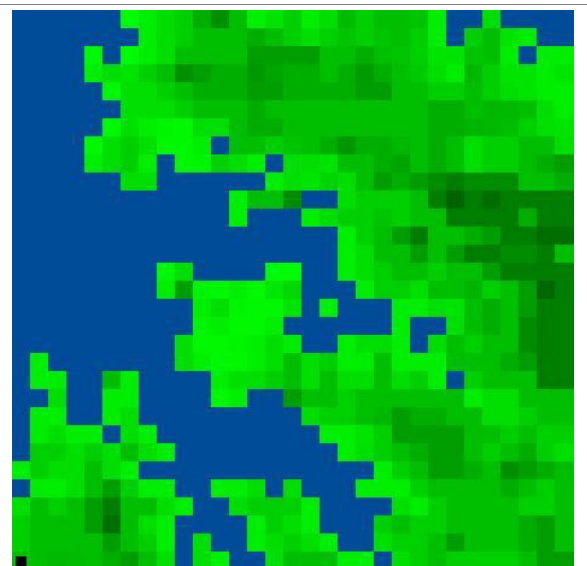
- **Figure 16 TAPM topography file at 1 000m grid spacing**

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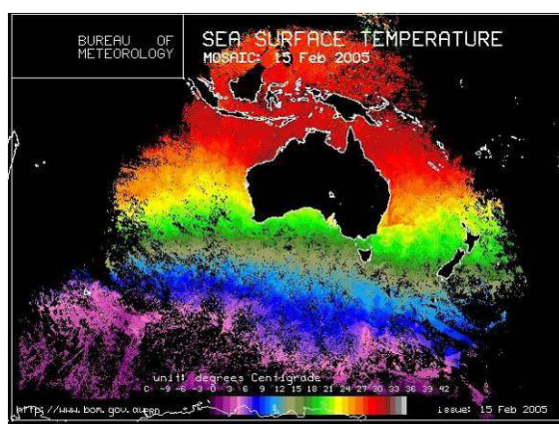
- **Figure 17 Sea surface temperature 15/2/2005 (BoM 2008)**
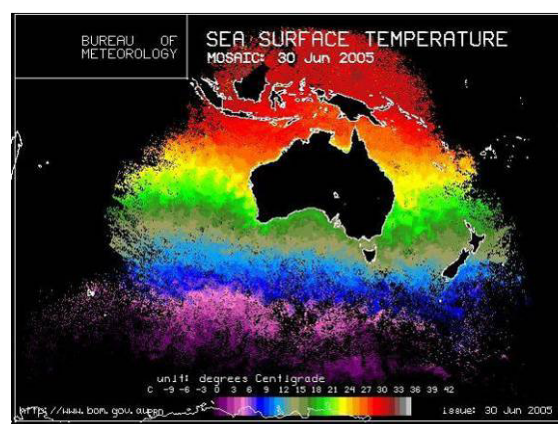
- **Figure 18 Sea surface temperature 30/6/2005 (BoM 2008)**

For atmospheric modelling of pollutants the following parameters were used:

- regional gridded emission sources (*.gse)

- atmospheric chemistry modelling mode with APM (Airborne Particulate Matter, PM_{10}), NO_2, NO_2, O_3, SO_2 and FPM (Fine Particulate Matter, $PM_{2.5}$)

- background ozone level – 20 ppb (from stratospheric ozone entrainment and global recirculation)

- background Rsmog – 0.2 g/s (Rsmog, is the efficiency factor of VOCs to generate smog (refer to Hurley *et al* (2005b)))

- background FPM ($PM_{2.5}$) – 5 $\mu g/m^3$ (estimate for clean air)

- pollution grid (inner), 49 x 49 (omitting boundary to reduce 'edge effects'), with resolution of 500 m

8. Emission Parameters

This section of the report describes the future air pollutant emission sources from the proposed Blaydin Point gas processing operations.

8.1. Overview

The most significant air pollution emissions from the proposed INPEX gas processing facility in terms of potential air quality impacts will be from the combustion of fuel gas in the gas turbines and by flaring associated with the gas processing plant. The main (non-greenhouse gas) products of combustion of fuel gas in gas turbines, in terms of quantities produced, are carbon monoxide (CO) and NO_2. However, the key air pollutants in terms of risk are NO_2, PM_{10} and subsequent formation of ozone. Small quantities (trace amounts) of other pollutants are also emitted such as VOCs and SO_2.

Benzene, toluene, ethyl-benzene and xylenes (BTEX) are among a wide variety of VOCs that typically exist in relatively low concentrations in ambient air. Emissions of BTEX represent a fraction of the compounds emitted from the combustion of fossil fuels. A review of Hurley *et al* (2003a) and Hurley *et al* (2003b) regarding modelling for existing and proposed emissions on the Burrup Peninsula indicated that air quality impacts from emissions of VOCs, such as BTEX are unlikely to cause significant air quality impacts. These findings can be expected to be representative of the Darwin region, where there is currently minimal existing infrastructure contributing to air pollutants.

For these reasons the emissions of the BTEX group of compounds from the INPEX operations has not been considered as a significant future air pollutant and has not been considered in future modelling scenarios.

8.2. Area Based Emission File

An area based emission file for TAPM was compiled to account for existing diffuse emissions in the Darwin region. The diffuse emissions that could potentially impact on the air quality of the region include:

- NO_2
- VOCs

These emissions would be derived primarily from biogenic emissions in the region. This section outlines how the diffuse emissions were calculated and incorporated into an area based emission file for modelling purposes.

8.2.1. Biogenic VOC

The methodology to calculate biogenic VOC is outlined in **Section 6**. To convert these emission estimates a smog reactivity (Rsmog) constant of 0.0067 was used as per the recommendation by Hurley (2005) and Physick and Blockley (2001).

8.2.2. Biogenic NO$_2$

The methodology to calculate biogenic NO$_2$ is addressed in detail in the background air quality assessment (**Section 6.2.2**).

8.3. Mobile Emissions

8.3.1. Vehicles

The methodology to calculate emissions from motor vehicles is outlined in **Section 6.3**. The emissions rates were then converted into the appropriate emission format suitable for TAPM modelling:

- Vehicle petrol exhaust emissions were converted into the appropriate TAPM format (*.vpx) at a temperature of 25°C for VOC and NO$_2$.
- Vehicle diesel exhaust emissions were converted into the appropriate TAPM format (*.vdx) for VOC and NO$_2$.
- Vehicle LPG exhaust emissions were converted into the appropriate TAPM format (*.vlx) at a temperature of 25°C for VOC and NO$_2$.
- Vehicle petrol evaporative emissions for VOC at 25°C were converted into the appropriate TAPM format (*.vpv).

Similar to biogenic estimates, the vehicle file formats for VOC emissions were converted to Rsmog using a reactivity constant of 0.0067 as per the recommendation by Hurley (2005) and Physick and Blockley (2001).

The SO$_2$ emissions from motor vehicles were incorporated into the same area based emission file as the biogenic emissions.

8.3.2. Shipping emissions

The SO$_2$ emissions from commercial shipping were modelled as stack sources within TAPM using parameters obtained from the "Container Category" of Table III-3 from the ARB Report (2000). These parameters are presented in **Table 8-1**.

■ **Table 8-1 Model Inputs**

Stack Parameter	Value
Stack Height	37.6 m
Stack Diameter	2.0 m
Exit Velocity	25.8 ms^{-1}
Temperature	222 °C
SO$_2$	3.85 g/s

8.4.　Existing Industrial Operations

The industrial activities existing in the Darwin region that emit significant quantities of air pollutants and which have been included in the air pollutant dispersion modelling are:

■ Conoco Phillips gas processing plant including the gas power generation station (at a maximum approved rate of 10 MTPA, current production rate is about 3.5 MTPA) (Bechtel 2001).

■ Channel Island Power Station - The emission parameters were obtained from the Northern Territory Power and Water Corporation (Vaghela 2009) while the emission rates were derived from the NPI emission estimates (NPI 2009a).

■ Weddell Power Station - The emission parameters were obtained from the Northern Territory Power and Water Corporation (Vaghela 2009) while the emission rates were derived from the NPI emission estimates (NPI 2009b).

■ Emissions from ships berthing.

The emissions and stack data for these existing air emission sources are provided in **Table 8-2**. The columns of data are:

■ locations as easting and northing in Map Grid Australia 94 (MGA94) co-ordinates

■ heights and radius of stacks in metres

■ plume exit velocities (m/s), temperatures (degrees Kelvin)

■ air pollutant emission rates -

– PM$_{10}$ (g/s) (particulate matter with aerodynamic diameters less than 10 μm)

– NO$_2$ (g/s)

– SO$_2$ (g/s)

– Rsmog (g/s), a reactivity coefficient multiplied by concentration of Volatile Organic Compounds (that is, hydrocarbons) (refer to Hurley *et al* (2005b)).

Table 8-2 Emission parameters for existing facilities

Source	Location		Height	Radius	Ex. Vel	Temp	PM₁₀	NO₂	SO₂	Rsmog
	(east)	(north)	(m)	(m)	(m/s)	(K)	(g/s)	(g/s)	(g/s)	(g/s)
ConocoPhillips										
Incinerator #1	702955	8615220	13.7	0.42	13.2	962	0.02	0.25	2.22	0
Comp. Turbine Driver 1	702816	8615047	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 2	702825	8615055	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 3	702833	8615064	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 4	702842	8615073	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 5	702852	8615082	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 6	702861	8615091	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 7	702870	8615100	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 8	702879	8615109	12.2	1.75	27	783	1.1	12.6	0	0
GTG Turbine Driver 1	703128	8615065	24	0.915	31	815	0.07	0.87	0	0
GTG Turbine Driver 2	703136	8615074	24	0.915	31	815	0.07	0.87	0	0
GTG Turbine Driver 3	703145	8615082	24	0.915	31	815	0.07	0.87	0	0
GTG Turbine Driver 4	703155	8615090	24	0.915	31	815	0.07	0.87	0	0
Incinerator #2	702955	8615240	13.7	0.42	13.2	962	0.02	0.25	2.22	0
Comp. Turbine Driver 1	703029	8615260	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 2	703038	8615268	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 3	703046	8615277	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 4	703055	8615286	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 5	703065	8615295	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 6	703074	8615304	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 7	703083	8615313	12.2	1.75	27	783	1.1	12.6	0	0
Comp. Turbine Driver 8	703092	8615322	12.2	1.75	27	783	1.1	12.6	0	0
GTG Turbine Driver 1	703341	8615278	24	0.915	31	815	0.07	0.87	0	0
GTG Turbine Driver 2	703349	8615287	24	0.915	31	815	0.07	0.87	0	0
GTG Turbine Driver 3	703358	8615295	24	0.915	31	815	0.07	0.87	0	0
Inlet Gas Heater 1	703721	8614758	13.7	0.45	10	519	0.04	0.54	0.003	0.002
Inlet Gas Heater 2	703721	8614778	13.7	0.45	10	519	0.04	0.54	0.003	0.002
Marine Flare	702250	8614747	13	1.98	20	1273	0	20.02	0	0.002
Wet Flare1	703240	8615390	3	7.9	20	1273	0	13.35	0.1	0.001
Wet Flare2	703270	8615390	3	7.9	20	1273	0	13.35	0.1	0.001
Wet Flare3	703300	8615390	3	7.9	20	1273	0	13.35	0.1	0.001
Wet Flare4	703330	8615390	3	7.9	20	1273	0	13.35	0.1	0.001
Wet Flare5	703360	8615390	3	7.9	20	1273	0	13.35	0.1	0.001
Wet Flare6	703400	8615390	3	7.9	20	1273	0	13.35	0.1	0.001
Dry Flare1	703240	8615390	3	7.9	20	1273	0	11.2	0	0.001
Dry Flare2	703270	8615390	3	7.9	20	1273	0	11.2	0	0.001
Dry Flare3	703300	8615390	3	7.9	20	1273	0	11.2	0	0.001
Dry Flare4	703330	8615390	3	7.9	20	1273	0	11.2	0	0.001

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Source	Location		Height	Radius	Ex. Vel	Temp	PM$_{10}$	NO$_2$	SO$_2$	Rsmog
	(east)	(north)	(m)	(m)	(m/s)	(K)	(g/s)	(g/s)	(g/s)	(g/s)
Dry Flare5	703360	8615390	3	7.9	20	1273	0	11.2	0	0.001
Dry Flare6	703400	8615390	3	7.9	20	1273	0	11.2	0	0.001
Channel Island Power Station										
Gas Turbine #1	702745	8611360	33	1.93	26	540	0.23	14.59	0.02	0.001
Gas Turbine #2	702765	8611365	33	1.93	26	540	0.23	14.59	0.02	0.001
Gas Turbine #3	702780	8611370	33	1.93	26	540	0.23	14.59	0.02	0.001
Gas Turbine #4	702800	8611380	33	1.93	26	423	0.23	14.59	0.02	0.001
Gas Turbine #5	702820	8611385	33	1.93	26	423	0.23	14.59	0.02	0.001
Gas Turbine #6	702845	8611395	13.72	1.93	26	450	0.23	14.59	0.02	0.001
Weddel River Power Station										
Gas Turbine #1	711760	8608845	15	1.8	17.5	450	0	1.84	0	0
Shipping										
Ship 1	704135	8618670	37.6	2	25.8	495	0	1.63	0.77	0.00071
Ship 2	704367	8618500	37.6	2	25.8	495	0	1.63	0.77	0.00071
Ship 3	704540	8618365	37.6	2	25.8	495	0	1.63	0.77	0.00071
Ship 4	700960	8614716	37.6	2	25.8	495	0	1.63	0.77	0.00071
Ship 5	701090	8620740	37.6	2	25.8	495	0	1.63	0.77	0.00071

8.5.   Normal Operating Condition

INPEX propose to build a gas processing facility on Blaydin Point, comprising two trains each with a nominal capacity of 4.2 (±10%) million tonnes per annum of liquefied natural gas. Key characteristics for each train used for this air quality assessment include:

- electrical power requirements for each train supplied by 4 x Frame 6 gas turbine generators equipped with DLN burners
- process refrigeration for each train powered by 2 x Frame 7 gas turbines with DLN
- 1 x incinerator
- 1 x hot oil furnace

Emissions characteristics for normal routine operations are summarised in **Table 8-3**.

- **Table 8-3 Emission parameters for proposed facility – routine operations**

Source	Location		Height	Radius	Ex. Vel	Temp	PM$_{10}$	NO$_2$	SO$_2$	Rsmog
	(east)	(north)	(m)	(m)	(m/s)	(K)	(g/s)	(g/s)	(g/s)	(g/s)
Compressor turbine WHR West 1 (frame 7)	708479	8615558	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR West 2 (frame 7)	708618	8615297	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR East 1 (frame 7)	708704	8615678	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR East 2 (frame 7)	708843	8615417	65	2.85	13.4	463	0.6	26	0	0.007
Power generation turbine 1 (frame 6)	708715	8614984	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 2 (frame 6)	708767	8615012	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 3 (frame 6)	708789	8615023	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 4 (frame 6)	708841	8615051	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 5 (frame 6)	708863	8615063	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 6 (frame 6)	708916	8615091	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 7 (frame 6)	708937	8615102	40	1.44	20	473	5.6	17	0	0.002
Power generation turbine 8 (frame 6)	708990	8615130	40	1.44	20	473	5.6	17	0	0.002
Power generation turbine 9 (frame 6)	708943	8615158	40	1.44	0	298	0	0	0	0
Incinerator 1	708711	8615384	30	2.25	8.7	847	0	11	16	0
Incinerator 2	708936	8615504	30	2.25	8.7	847	0	11	16	0
Hot oil furnace 1	708855	8615122	50	1.55	0	298	0	0	0	0
Hot oil furnace 2	708872	8615132	50	1.55	0	298	0	0	0	0
Ground flare 5 (Warm)	708317	8614995	4	47	10	773	0.1	0.8	0	0.005
Ground flare 2 (Cold)	708506	8614639	4	52	10	773	0.1	0.8	0	0.005
Ground flare 1 (Spare)	708557	8614543	4	20	10	773	0.1	0.8	0	0.005
Tank Flare 1	707795	8615348	33	19	10	773	0.1	0.5	0	0.002
Tank Flare 2	707809	8615321	33	19	0	298	0	0	0	0
Ground Flare 3	708444	8614757	4	52	10	773	0.1	0.8	0	0.0056
Ground Flare 4	708378	8614880	4	56	0	298	0	0	0	0
Off spec condensate flare 1	707825	8615291	28	16	0	298	0	0	0	0
Off spec condensate flare 2	707839	8615265	28	16	0	298	0	0	0	0

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8.6. Upset Conditions

8.6.1. Overview

Non-routine plant operations include start-up and shut-down. Plant de-inventory may also occur during an emergency event. A non-routine operation may last for several hours to days, with the plant operating under reduced throughput conditions and including the flaring of gas. The plant throughput can vary from 15% to 50% depending on the stage of the start-up/shut-down process in place.

In upset condition scenarios, the flares can become a more significant air emissions source than gas turbines. For example, all the gas turbines could be shut down while the flares are operating to full capacity.

Two upset conditions scenarios have been identified for the purposes of this assessment, representing reasonable worst cases. These are associated with a blocked MR Compressor outlet, and with the complete shutdown of one gas train for maintenance. The following sub-sections detail the emissions characteristics for these scenarios.

8.6.2. Upset Condition 1: Blocked MR compressor

The "worst credible case" flaring emissions scenario results from a blocked MR (mixed refrigerant) compressor outlet, leading to flaring from the assumed Cold-Dry Flare. The duration of emergency flaring for this case is expected to be 15 minutes. During this time, the MR compressor turbine would be operational, and all other plant emissions would continue.

Emissions characteristics for the first upset condition are summarised in **Table 8-4**.

■ **Table 8-4 Upset Condition 1 Emissions Data**

Source	Location		Height	Radius	Ex. Vel	Temp	PM$_{10}$	NO$_2$	SO$_2$	Rsmog
	(east)	(north)	(m)	(m)	(m/s)	(K)	(g/s)	(g/s)	(g/s)	(g/s)
Compressor turbine WHR West 1 (frame 7)	708479	8615558	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR West 2 (frame 7)	708618	8615297	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR East 1 (frame 7)	708704	8615678	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR East 2 (frame 7)	708843	8615417	65	2.85	13.4	463	0.6	26	0	0.007
Power generation turbine 1 (frame 6)	708715	8614984	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 2 (frame 6)	708767	8615012	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 3 (frame 6)	708789	8615023	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 4 (frame 6)	708841	8615051	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 5 (frame 6)	708863	8615063	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 6 (frame 6)	708916	8615091	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 7 (frame 6)	708937	8615102	40	1.44	20	473	5.6	17	0	0.002
Power generation turbine 8 (frame 6)	708990	8615130	40	1.44	20	473	5.6	17	0	0.002
Power generation turbine 9 (frame 6)	708943	8615158	40	1.44	0	298	0	0	0	0
Incinerator 1	708711	8615384	30	2.25	8.7	847	0	11	16	0
Incinerator 2	708936	8615504	30	2.25	8.7	847	0	11	16	0
Hot oil furnace 1	708855	8615122	50	1.55	0	298	0	0	0	0
Hot oil furnace 2	708872	8615132	50	1.55	0	298	0	0	0	0
Ground flare 5 (Warm)	708317	8614995	4	47	10	773	0.1	0.8	0	0.005
Ground flare 2 (Cold)	708506	8614639	4	52	100	773	11	12	0	0.2
Ground flare 1 (Spare)	708557	8614543	4	20	10	773	0.1	0.8	0	0.005
Tank Flare 1	707795	8615348	33	19	10	773	0.1	0.5	0	0.002
Tank Flare 2	707809	8615321	33	19	0	298	0	0	0	0
Ground Flare 3	708444	8614757	4	52	100	773	11	12	0	0.2
Ground Flare 4	708378	8614880	4	56	0	298	0	0	0	0
Off spec condensate flare 1	707825	8615291	28	16	0	298	0	0	0	0
Off spec condensate flare 2	707839	8615265	28	16	0	298	0	0	0	0

8.6.3. Upset Condition 2: Depressurising PR compressor

The second upset conditions scenario is based on depressurising of the propane compressor circuit, resulting in flaring for up to ten hours, but at a much lower rate than the unplanned, emergency, blocked-MR compressor case. During the propane compressor depressurising event, all equipment on one train will be shut-down, while the other train will continue to operate normally.

Emissions characteristics for the second upset condition are summarised in **Table 8-5**.

- **Table 8-5 Upset Condition 2 Emissions Data**

Source	Location		Height	Radius	Ex. Vel	Temp	PM$_{10}$	NO$_2$	SO$_2$	Rsmog
	(east)	(north)	(m)	(m)	(m/s)	(K)	(g/s)	(g/s)	(g/s)	(g/s)
Compressor turbine WHR West 1 (frame 7)	708479	8615558	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR West 2 (frame 7)	708618	8615297	65	2.85	13.4	463	0.6	26	0	0.007
Compressor turbine WHR East 1 (frame 7)	708704	8615678	65	2.85	0	298	0	0	0	0
Compressor turbine WHR East 2 (frame 7)	708843	8615417	65	2.85	0	298	0	0	0	0
Power generation turbine 1 (frame 6)	708715	8614984	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 2 (frame 6)	708767	8615012	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 3 (frame 6)	708789	8615023	40	1.44	20	473	0.5	13	0	0.002
Power generation turbine 4 (frame 6)	708841	8615051	40	1.44	0	473	5.6	17	0	0.002
Power generation turbine 5 (frame 6)	708863	8615063	40	1.44	0	298	0	0	0	0
Power generation turbine 6 (frame 6)	708916	8615091	40	1.44	20	298	0	0	0	0
Power generation turbine 7 (frame 6)	708937	8615102	40	1.44	0	298	0	0	0	0
Power generation turbine 8 (frame 6)	708990	8615130	40	1.44	0	298	0	0	0	0
Power generation turbine 9 (frame 6)	708943	8615158	40	1.44	0	298	0	0	0	0
Incinerator 1	708711	8615384	30	2.25	8.7	847	0	11	16	0
Incinerator 2	708936	8615504	30	2.25	0	298	0	0	0	0
Hot oil furnace 1	708855	8615122	50	1.55	0	298	0	0	0	0
Hot oil furnace 2	708872	8615132	50	1.55	0	298	0	0	0	0
Ground flare 5 (Warm)	708317	8614995	4	47	10	773	0.1	0.8	0	0.005
Ground flare 2 (Cold)	708506	8614639	4	52	60	773	8	9	0	0.16
Ground flare 1 (Spare)	708557	8614543	4	20	10	773	0.1	0.8	0	0.005
Tank Flare 1	707795	8615348	33	19	10	773	0.1	0.5	0	0.002
Tank Flare 2	707809	8615321	33	19	0	298	0	0	0	0
Ground Flare 3	708444	8614757	4	52	60	773	8	9	0	0.16

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Source	Location		Height	Radius	Ex. Vel	Temp	PM$_{10}$	NO$_2$	SO$_2$	Rsmog
	(east)	(north)	(m)	(m)	(m/s)	(K)	(g/s)	(g/s)	(g/s)	(g/s)
Ground Flare 4	708378	8614880	4	56	0	298	0	0	0	0
Off spec condensate flare 1	707825	8615291	28	16	0	298	0	0	0	0
Off spec condensate flare 2	707839	8615265	28	16	0	298	0	0	0	0

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9.   Modelling Results

This section presents the results of atmospheric dispersion modelling for the proposed plant under a series of scenarios, including the existing air quality (i.e. existing contribution from non-industrial activities and existing and approved industrial sources) and the cumulative impacts from the combined set of sources. The modelling results are compared to the relevant assessment criteria.

As discussed in **Section 3.2**, 10% of NO_x is NO_2, though for simplicity only NO_2 is presented in the modelling results below but the full NO_x component has been used in the modelling. The maximum pollutant concentrations have been compared to the NEPM criteria that are listed in **Table 4-1**.

9.1.   Existing (Non-Industrial) Air Quality Case

The modelling results for the existing (non-industrial) air quality in the Darwin region are presented and discussed in the following sections. The emissions used to model this scenario include:

- Biogenic VOC from vegetation (**Section 6.2.1**)
- Biogenic NO_2 from soil and water (**Section 6.2.2**)
- VOC, NO_2 and SO_2 from motor vehicles (**Section 6.3**)
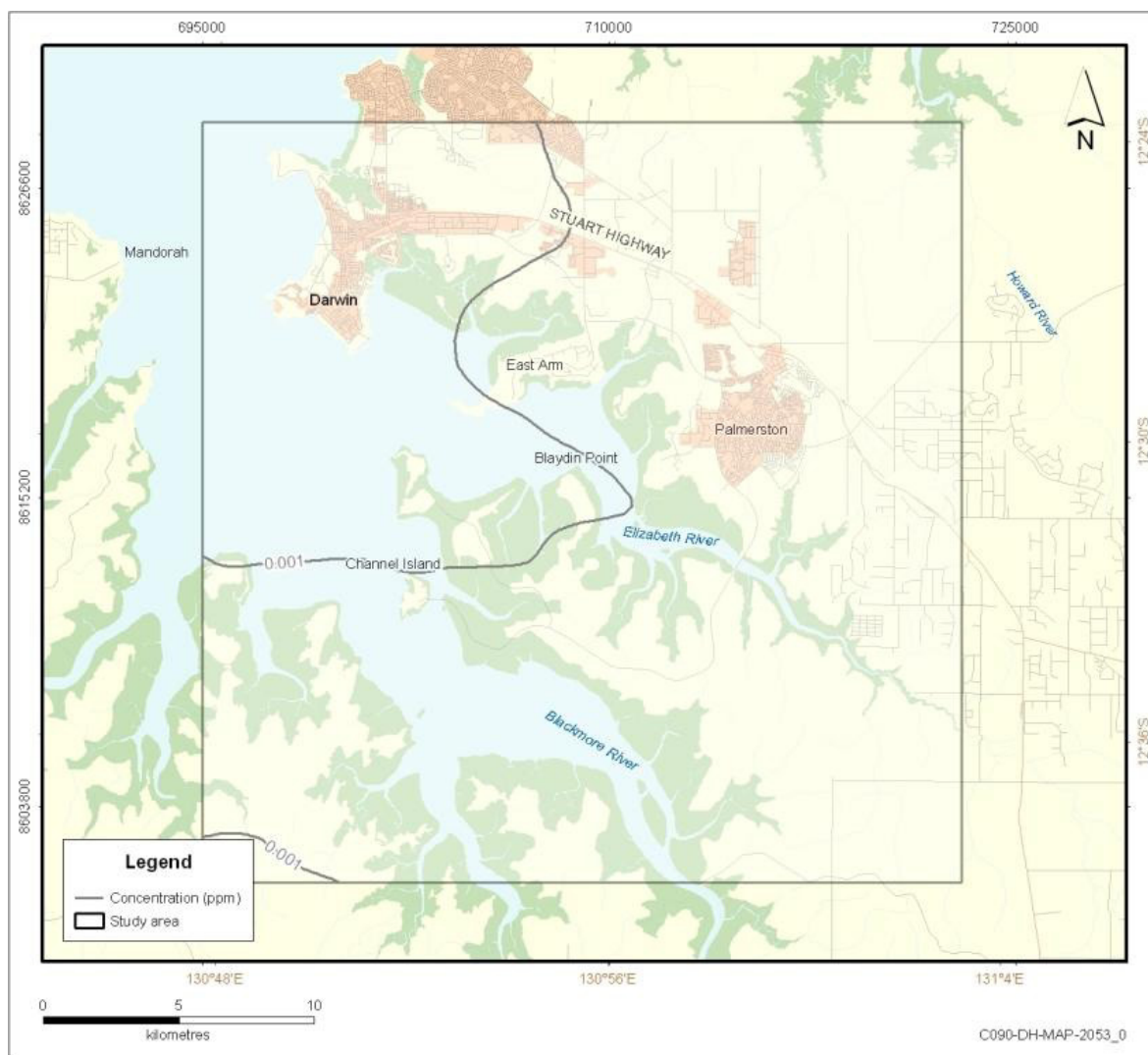
9.1.1.   Nitrogen Dioxide

The maximum predicted 1-hour ground level concentrations of NO_2 from existing (non-industrial) sources are presented in **Figure 19**. This figure shows that the 1-hour predicted ground level concentrations of NO_2 are relatively low. As shown in **Table 9-1**, the predicted 1-hour maximum concentration of NO_2 is 0.01 ppm. This is 10% of the NEPM criteria, indicating a relatively low concentration of NO_2 in the study area.
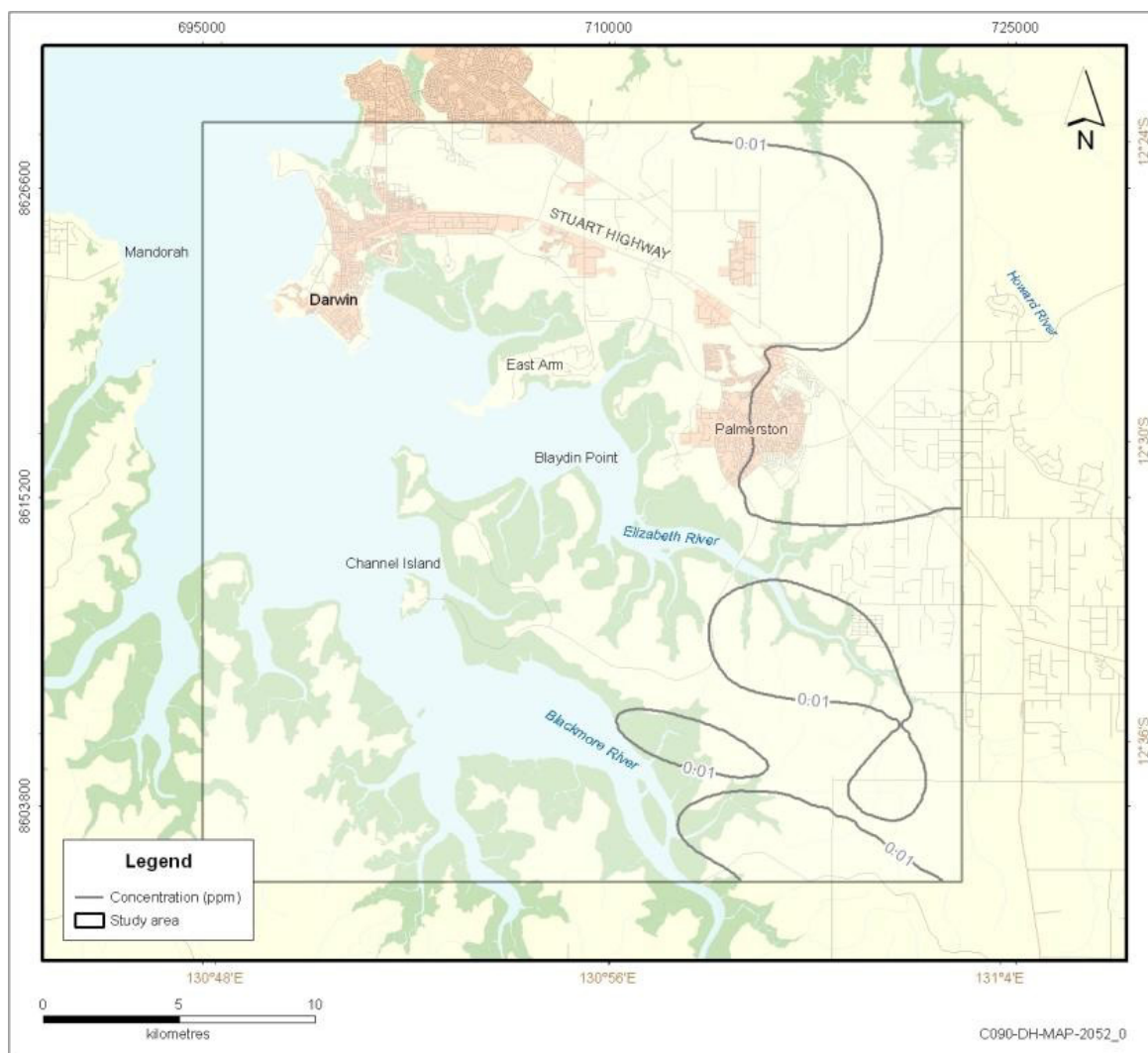
- **Figure 19 Existing (non-industrial) Sources - Maximum 1-hour NO$_2$ concentrations (ppm)**

The predicted annual concentration of NO$_2$ for existing (non-industrial) scenario is presented in **Figure 20**. This figure shows that the annual average concentrations of NO$_2$ are relatively low, with the predicted concentrations spread fairly evenly over the entire grid. As summarised in **Table 9-1**, the predicted maximum annual average concentration of NO$_2$ is 0.001 ppm, which is 4% of the NEPM criteria.

- **Figure 20 Existing (non-industrial) Sources - Annual average NO_2 concentrations (ppm)**

9.1.2. Ozone

The maximum predicted 1-hour ground level ozone concentrations for the existing (non-industrial) case are presented in **Figure 21.** From this figure it can be seen that the maximum concentrations occur to the north west of Darwin, approximately 12 km out to sea. The maximum predicted 1-hour ground level concentration for this scenario is 0.06 ppm, which is 59% of the NEPM criteria.
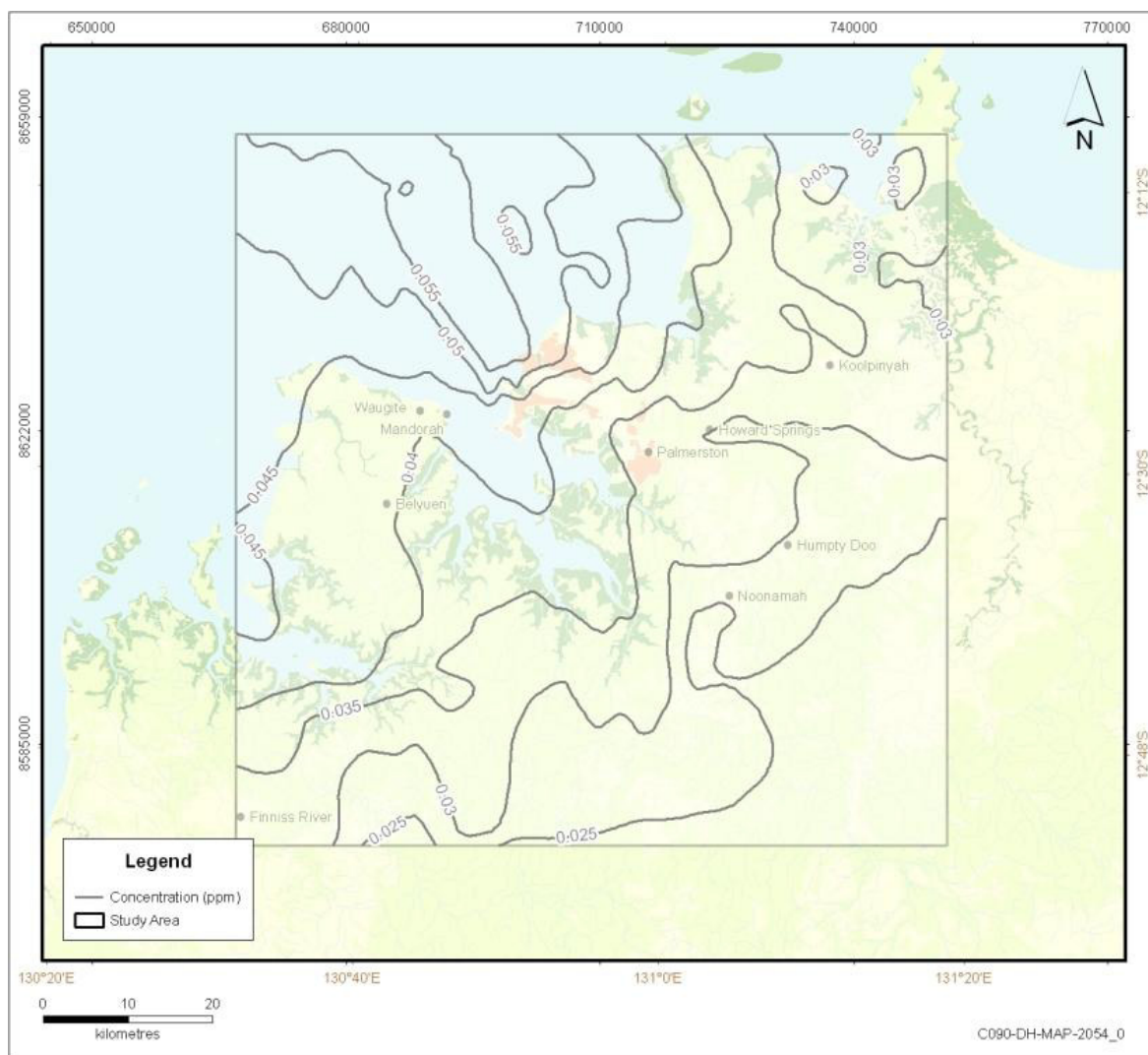
- **Figure 21 Existing (non-industrial) Sources - Maximum 1-hour O$_3$ concentrations (ppm)**

The predicted 4-hour ground level ozone concentrations are presented in **Figure 22**. Maximum concentrations are located in a similar area to those of the 1-hourly ozone concentrations (**Figure 21**). The predicted maximum 4-hourly ground level concentration is 0.05 ppm, which is 67% of the NEPM criteria.
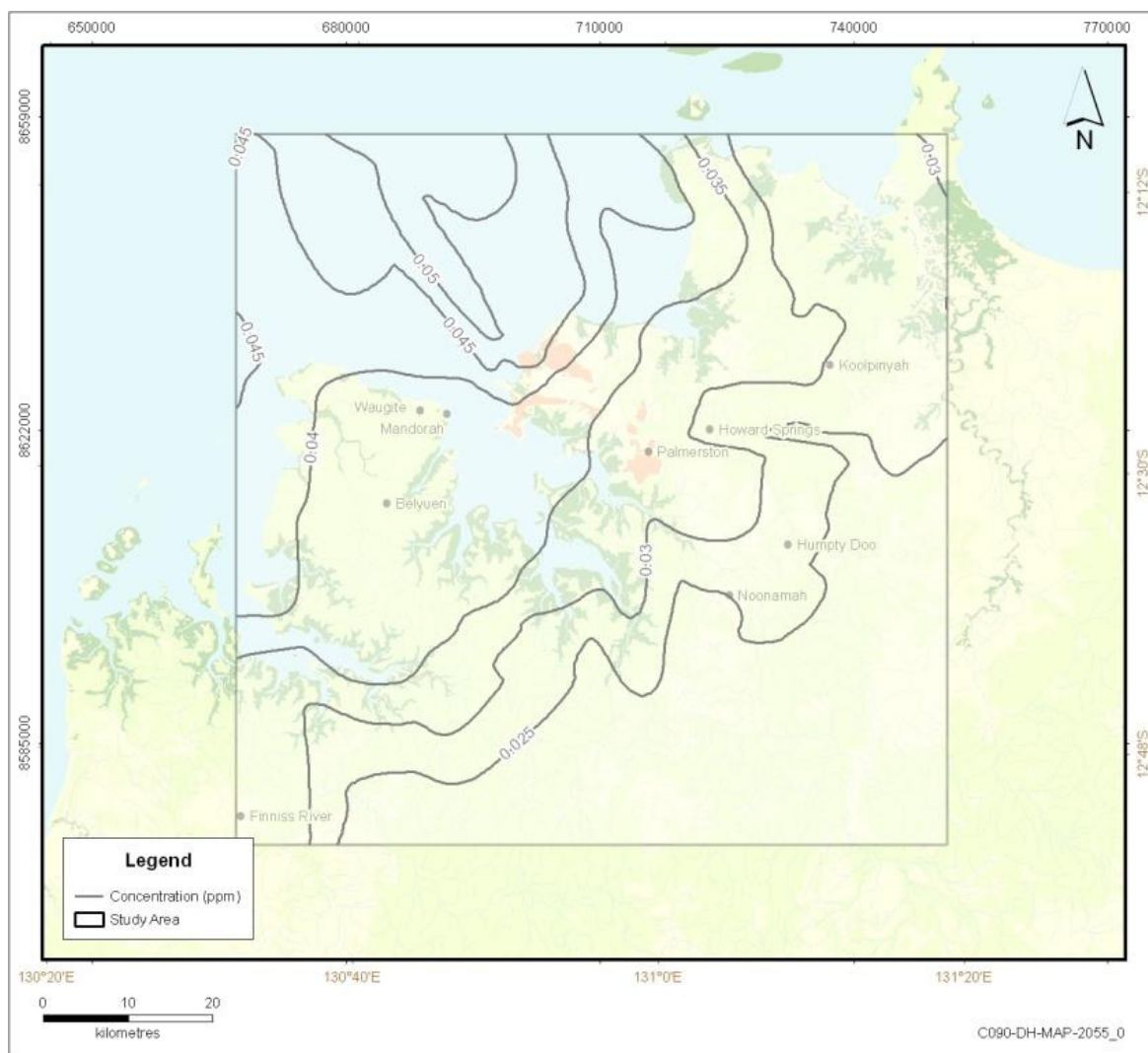
- **Figure 22 Existing (non-industrial) Sources - Maximum 4-hour O_3 concentrations (ppm)**

9.1.3. Sulfur dioxide

SO_2 from vehicles was negligible and has not been reported on.

9.1.4. Particulates (as PM_{10})

PM_{10} from vehicle exhausts was negligible and has not been reported on. Particulates also arise from fires but this has been excluded from this report due to the complexities of modelling short term events that vary spatially.

9.1.5. Maximum on Grid

The maximum predicted ground level concentrations over various averaging times for O_3 and NO_2 are presented in **Table 9-1**. The NEPM criteria are also presented in this table. Comparison between the criteria and the maximum predicted ground level concentrations shows that the predicted NO_2 concentrations are well below the criteria. The maximum predicted concentrations of O_3 are also well below the criteria at 59% and 67% of the applicable NEPM criteria for 1-hour and 4-hour respectively.

- **Table 9-1 Maximum predicted existing (non-industrial) ground level concentration on modelled grid**

Pollutant	Modelled Grid	Averaging Period	Maximum on Grid (ppm)	NEPM Criteria (ppm)	Percentage of Criteria
NO_2	1 km	1-hour	0.01	0.12	10%
		Annual	0.001	0.03	4%
O_3	3 km	1-hour	0.06	0.1	59%
		4-hour	0.05	0.08	67%

Note: The concentrations presented in this table have been rounded to two significant figures

9.2. Existing Air Quality (industrial and non-industrial sources)

The modelling results for the existing air quality in the Darwin region are presented and discussed in the following section. The emissions used to model the background and existing air quality sources include:

- Biogenic VOC from vegetation (**Section 6.2.1**)
- Biogenic NO_2 from soil and water (**Section 6.2.2**)
- VOC, NO_2 and SO_2 from motor vehicles (**Section 6.3**)
- ConocoPhillips gas processing plant including the gas power generation station (**Section 8.4**)
- Channel Island and Weddel River Power Stations (**Section 8.4**)
- Emissions from commercial shipping at Berth (**Section 6.4**)

The pollutants taken into consideration under the existing air quality scenario include NO_2, SO_2 and O_3. The maximum pollutant concentrations have been compared to the NEPM criteria.

9.2.1. Nitrogen Dioxide

The maximum predicted 1-hour ground level concentrations of NO_2 from the existing sources are presented in **Figure 23**. This figure shows that the 1-hour predicted ground level concentrations of NO_2 are relatively low, with the maximum concentrations occurring both to the south east and

northwest of the ConocoPhillips facility. According to **Table 9-2**, the predicted 1-hour maximum concentration of NO_2 is 0.03 ppm and is 23% of the NEPM criteria. This represents an increase above that predicted to occur for the background scenario (**Table 9-1**).
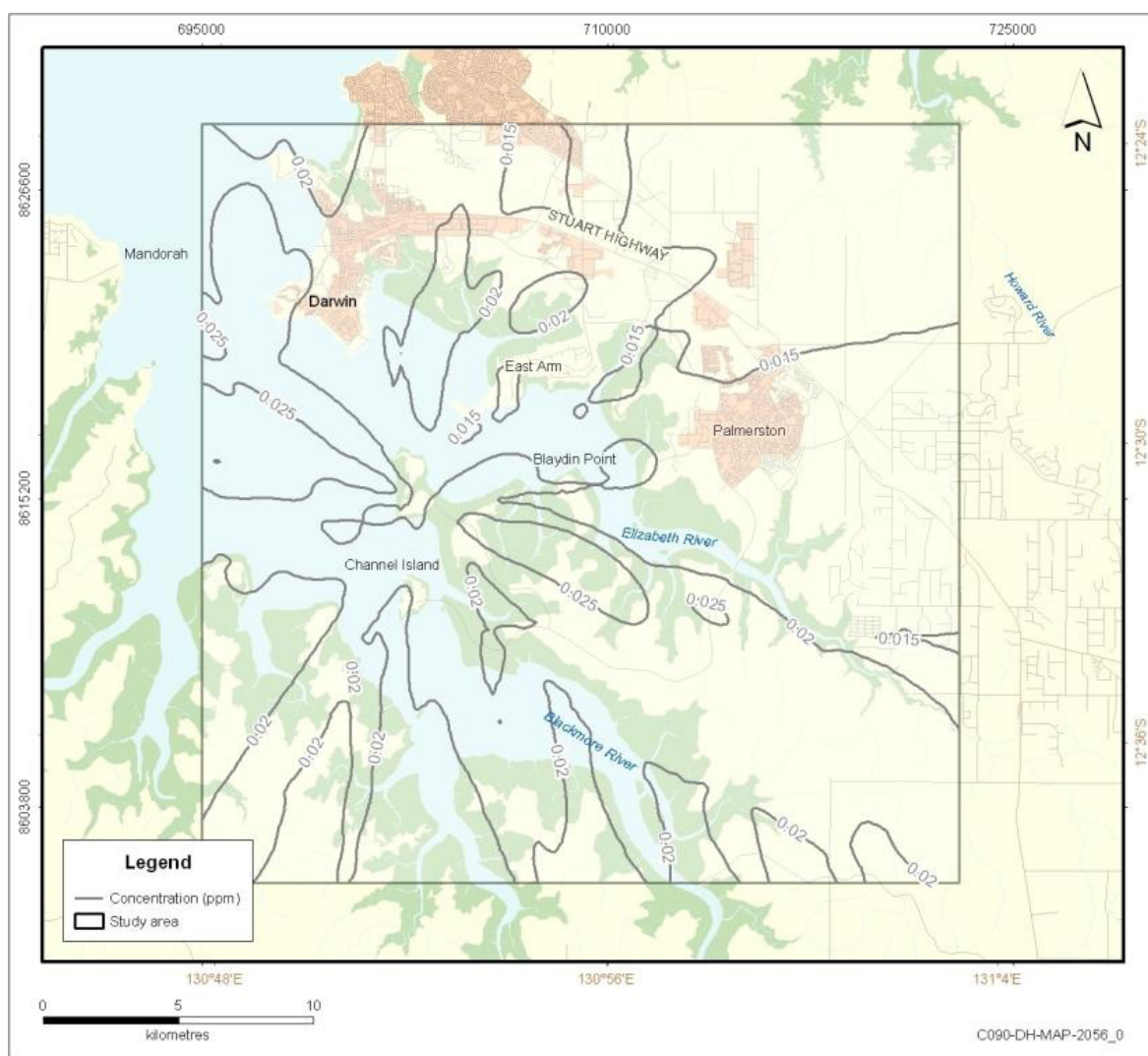
- **Figure 23 Existing Case - Maximum 1-hour NO_2 concentrations (ppm)**

Figure 24 shows that the predicted annual concentration of NO_x occurs immediately to the north west of the ConocoPhillips facility. As summarised in **Table 9-2**, the predicted annual maximum concentration of NO_2 is 0.002 ppm, and is 8% of the NEPM criteria.
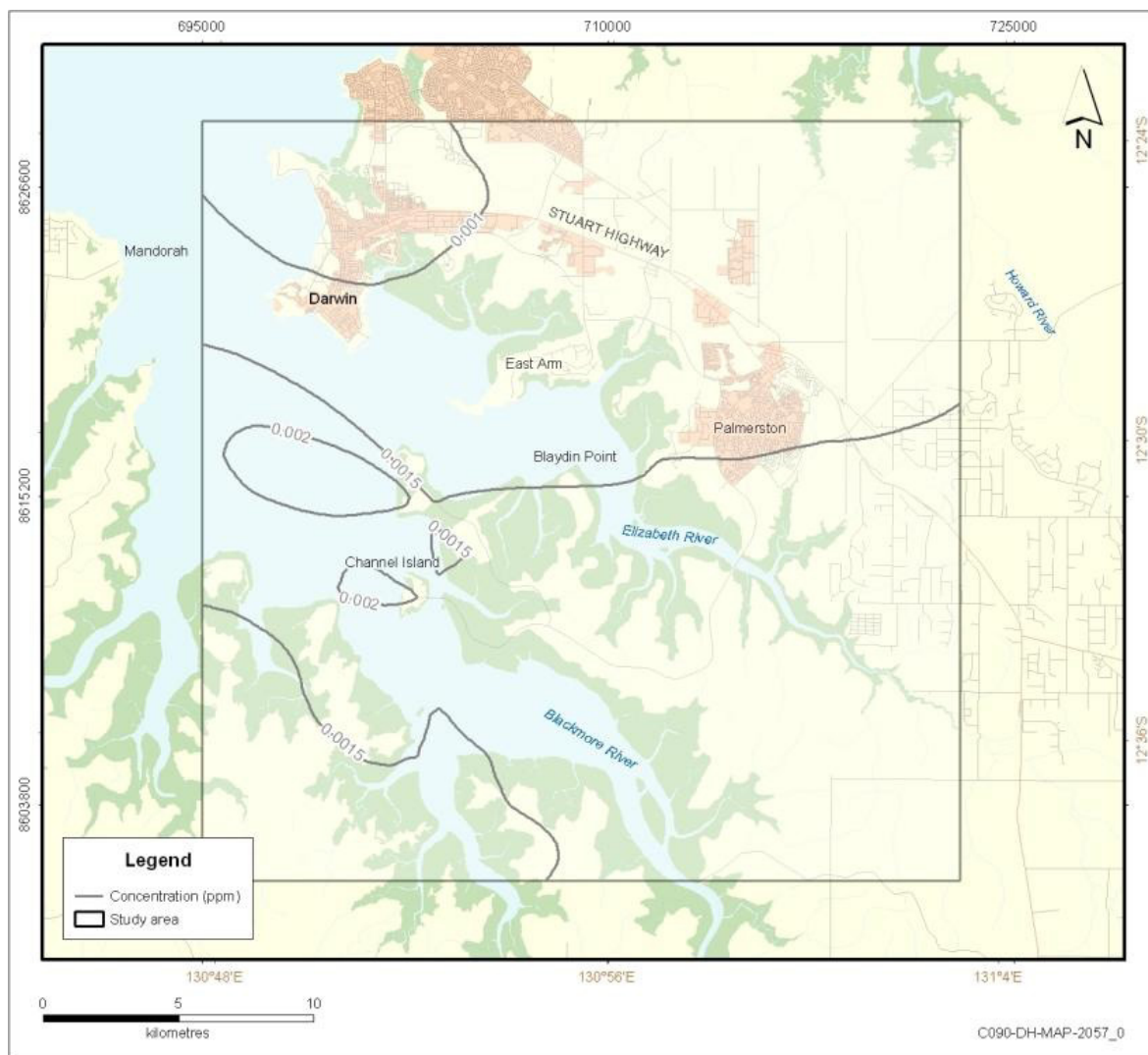
- **Figure 24 Existing Case - Annual average NO$_2$ concentrations (ppm)**

9.2.2. Ozone

The maximum predicted 1-hour ground level ozone concentrations are presented in **Figure 25.** From this figure it can be seen that the maximum concentrations occur approximately 12 km north-west of Darwin over the sea. The maximum predicted 1-hour ground-level concentration for this scenario is 0.06 ppm, and is 59% of the NEPM criteria. The maximum concentration that is predicted to occur within Darwin is 0.05 ppm, representing 50% of the NEPM criteria.
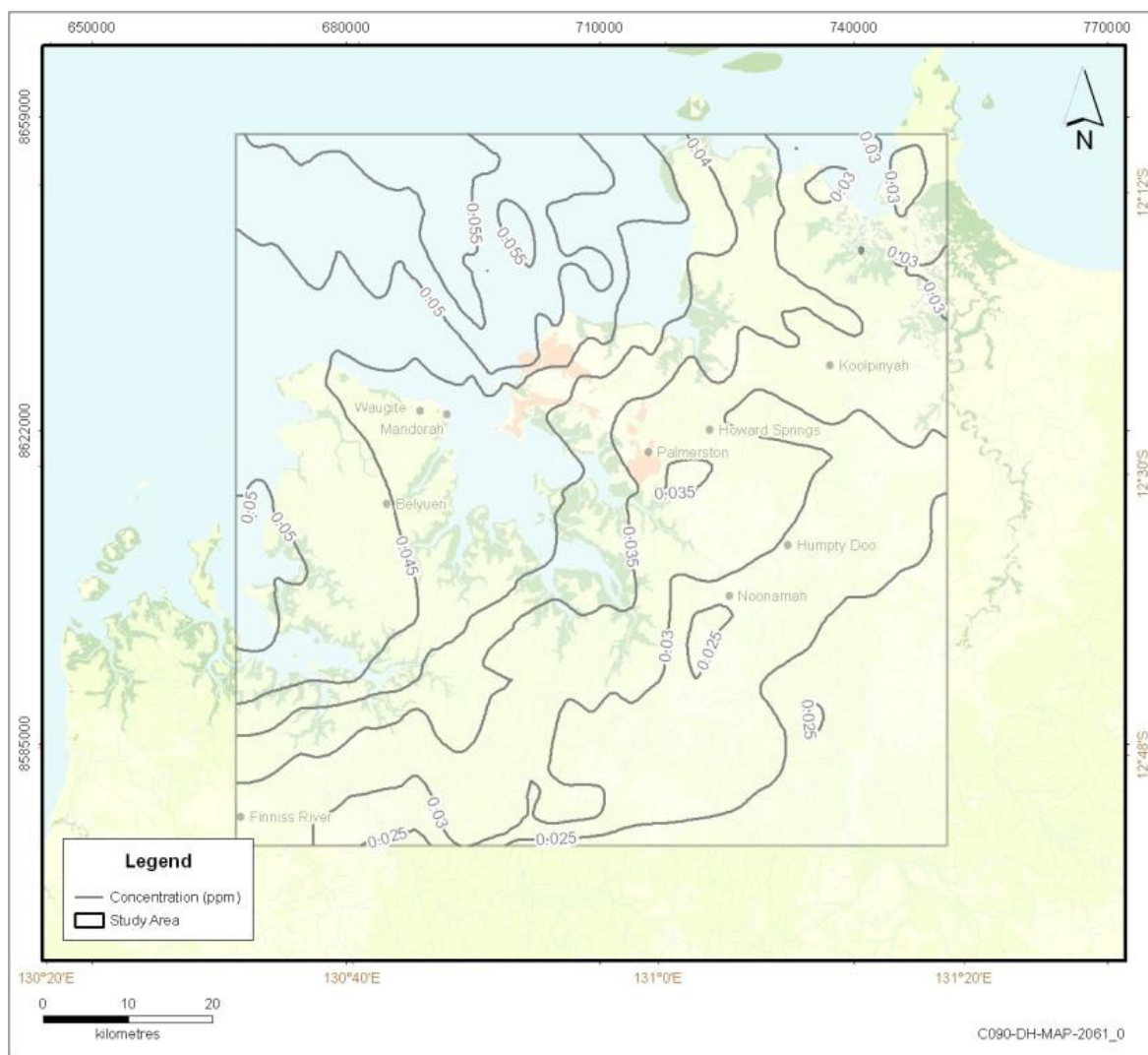
- **Figure 25 Existing Case - Maximum 1-hour Ozone concentrations (ppm)**

The predicted 4-hour ground level ozone concentrations are presented in **Figure 26**. Maximum concentrations are located in a similar area to those of the 1-hourly ozone concentrations (**Figure 25**). The predicted maximum 4-hourly ground level concentration is 0.06 ppm, and is 68% of the NEPM criteria. The maximum concentration that is predicted to occur within Darwin is 0.04 ppm, representing approximately 54% of the NEPM criteria.
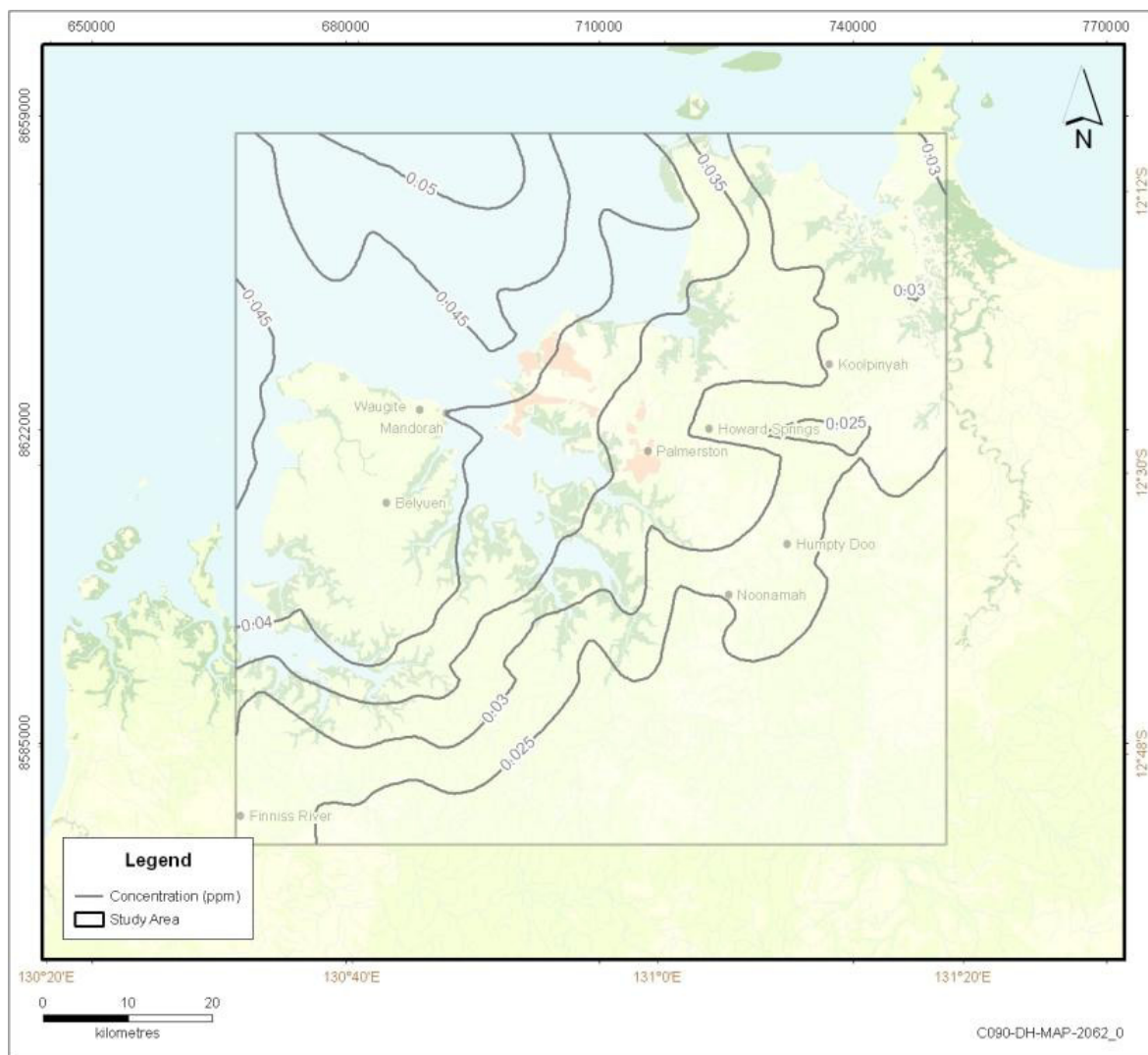
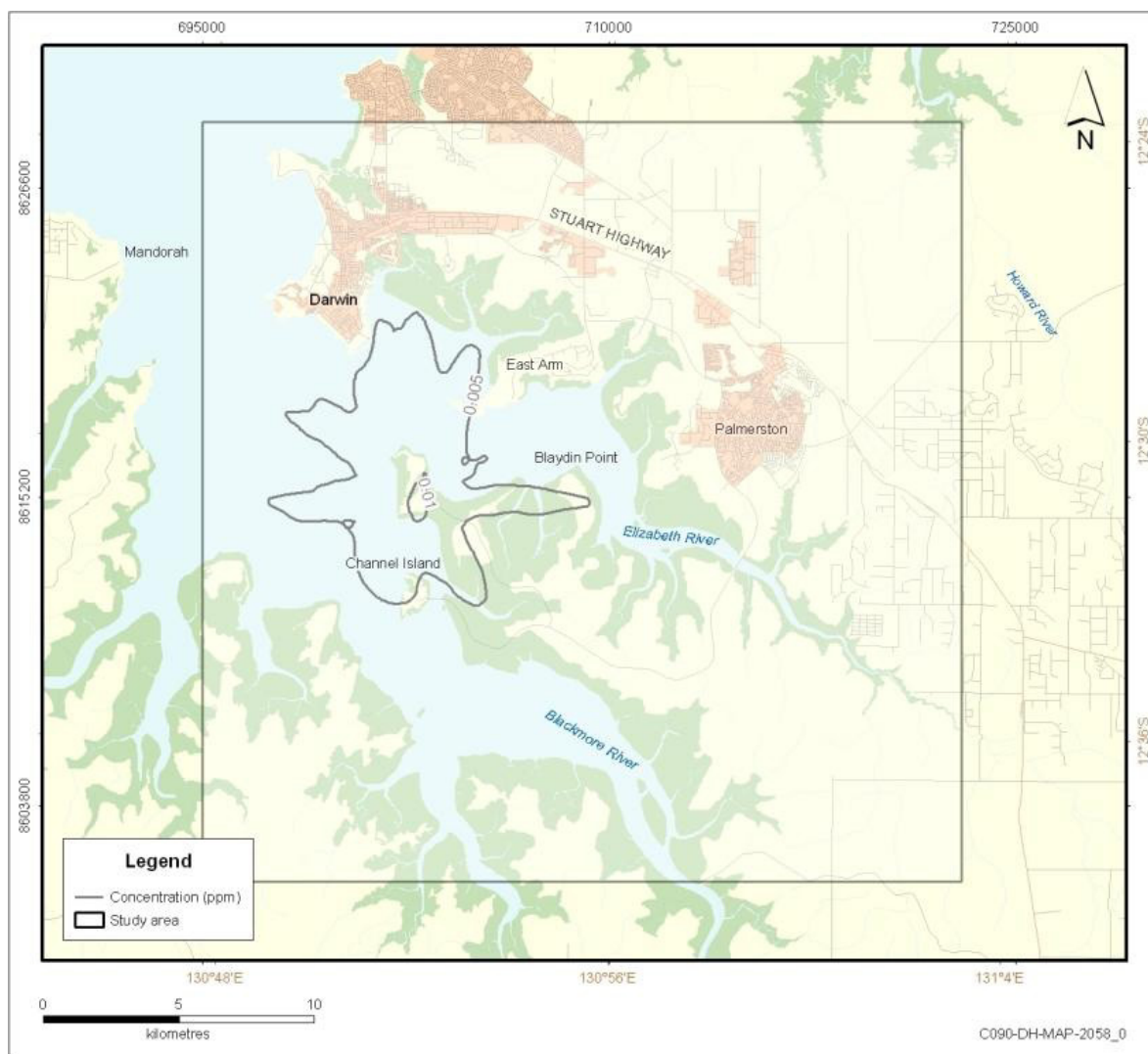■ **Figure 26 Existing Case - Maximum 4-hour Ozone concentrations (ppm)**

9.2.3. Sulfur dioxide

Figure 27 shows the predicted hourly maximum concentration contours for existing SO_2 emissions. This figure shows the highest concentrations are located around the ConocoPhillips facility. The maximum ground level concentration is predicted to be 0.01 ppm and is 7% of the NEPM criteria.

- **Figure 27 Existing Case - Maximum 1-hour SO$_2$ concentrations (ppm)**

The maximum predicted existing 24-hour SO$_2$ concentrations are presented in **Figure 28**. The maximum concentrations occur around the ConocoPhillips facility. The maximum 24-hour ground level concentration predicted is 0.006 ppm, and is well below the NEPM criteria presented in **Table 9-2**.
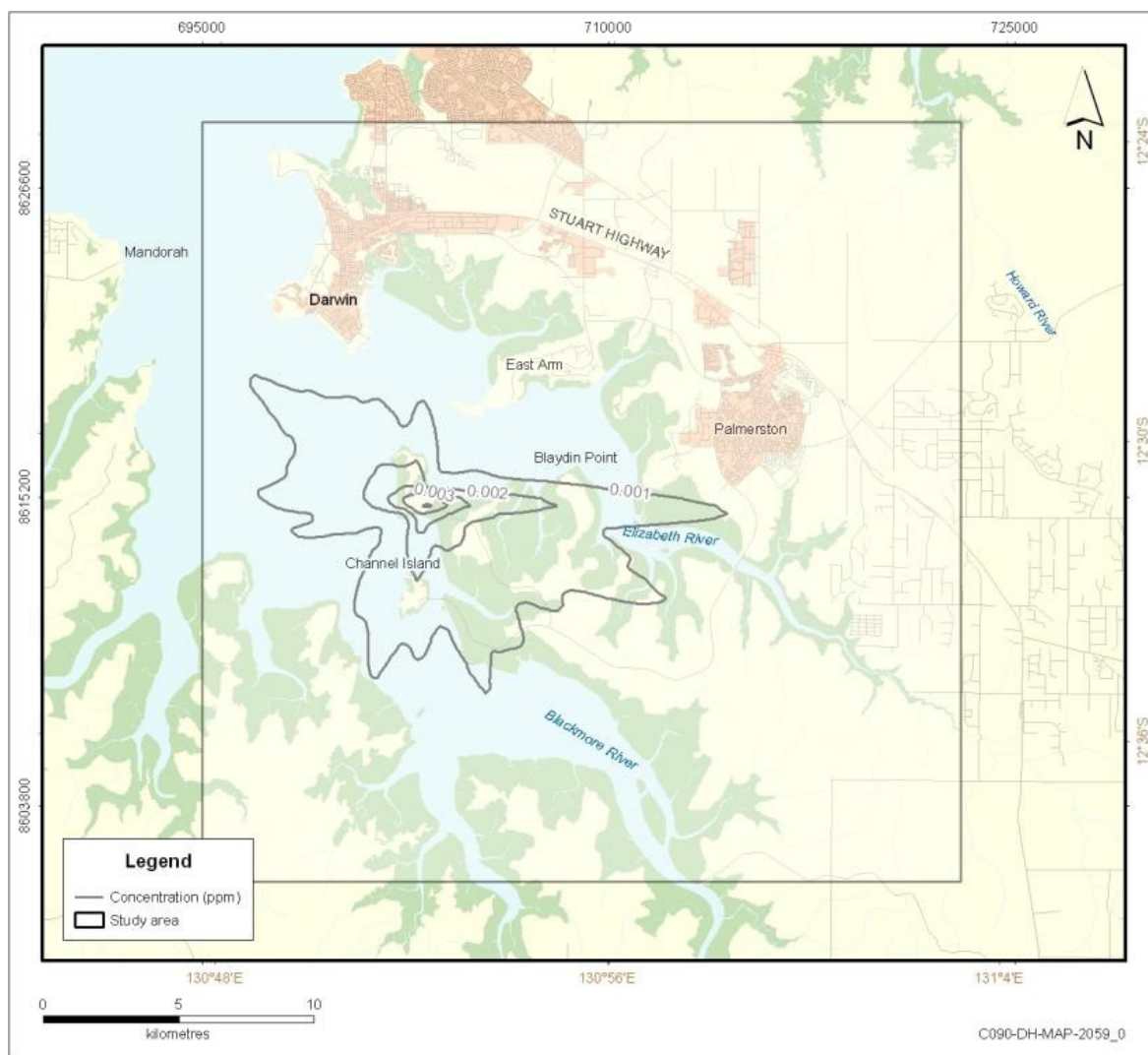
- **Figure 28 Existing Case - Maximum 24-hour SO$_2$ concentrations (ppm)**

The predicted existing annual SO$_2$ concentrations presented in **Figure 29** show a similar trend to that predicted for the 1-hour and 24-hour results in that the predicted concentrations are centred around the ConocoPhillips facility. The maximum predicted annual ground level concentration of SO$_2$ is 0.002 ppm, and is 10% of the NEPM criteria.
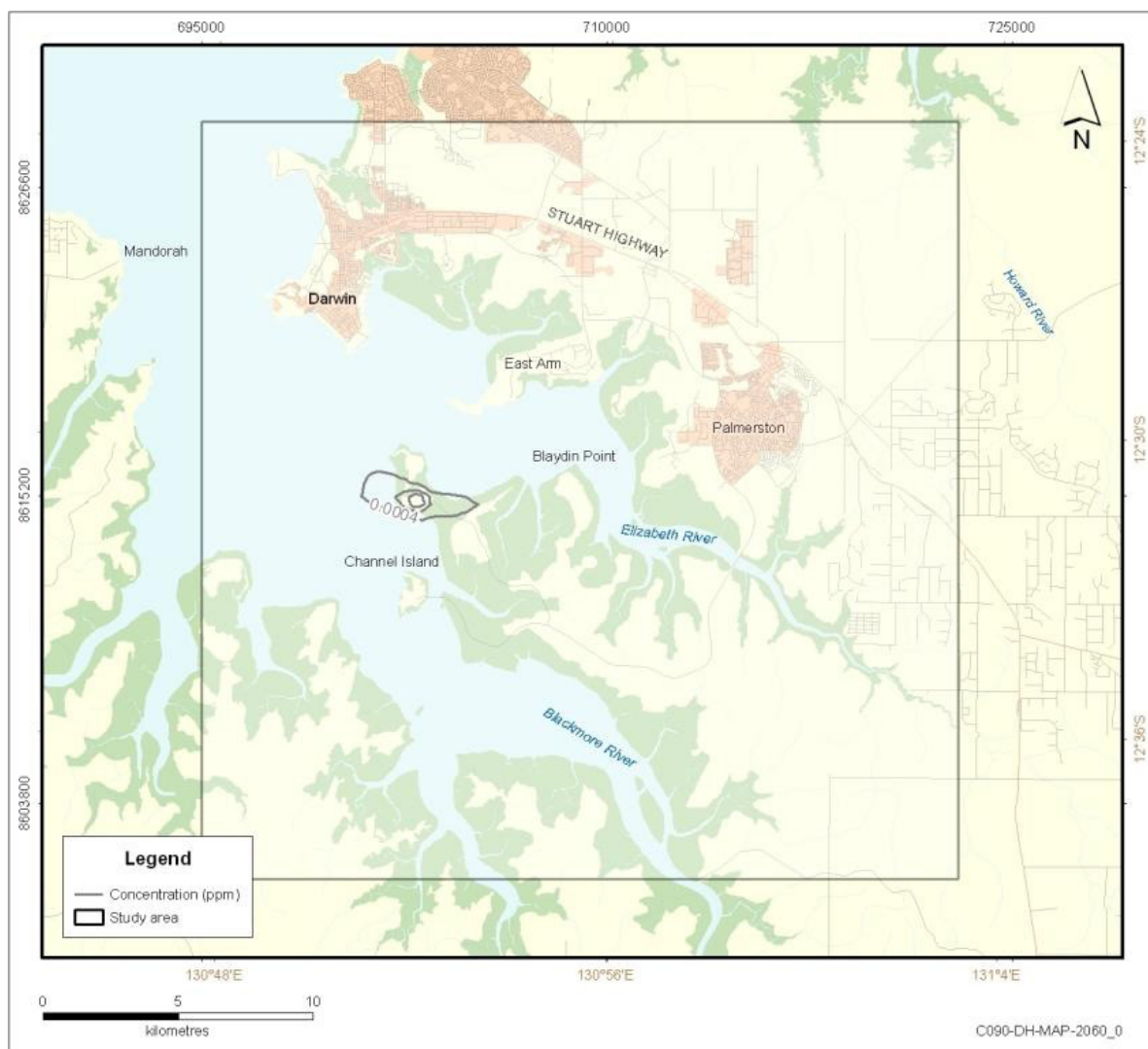
■ **Figure 29 Existing Case - Annual SO$_2$ concentrations (ppm)**

9.2.4. Particulates (as PM$_{10}$)

Ground level concentrations of PM$_{10}$ during this scenario are negligible and have not been reported on.

9.2.5. Maximum on Grid

The maximum predicted ground level concentrations over various averaging times for NO$_2$, SO$_2$ and O$_3$ are presented in **Table 9-2**. The NEPM criterion is also presented in this table. Comparison between the criteria and the maximum predicted ground level concentrations shows that all the predicted concentrations for NO$_2$, O$_3$ and SO$_2$ are below the criterion.

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- **Table 9-2 Existing case - Maximum predicted ground level concentration on modelled grid**

| Pollutant	Modelled Grid	Averaging Period	Maximum on Grid (ppm)	NEPM Criteria (ppm)	Percentage of Criteria
NO_2	1 -km	1-hour	0.03	0.12	23%
		Annual	0.002	0.03	8%
O_3	3 -km	1-hour	0.06	0.1	59%
		4-hour	0.06	0.08	68%
SO_2	1 -km	1-hour	0.01	0.2	7%
		24-hour	0.006	0.08	7%
		Annual	0.002	0.02	10%

Note: The concentrations presented in this table have been rounded to two significant figures

9.3. Future Air Quality – Normal Operations

The modelling for future air quality under normal operating conditions incorporates the emissions used in the existing scenario (**Section 9.2**) plus those expected from the proposed gas processing facility (**Section 8.5**). The pollutants taken into consideration in this section include NO_2, O_3 and SO_2. The maximum ground level concentration of each of these pollutants is compared to the NEPM criteria.

9.3.1. Nitrogen Dioxide

The maximum 1-hour predicted ground level NO_2 concentrations are presented in **Figure 30**. When the results presented in this figure are compared to that for the existing scenario (**Figure 23**) it is apparent that the maximum concentrations are still predicted to occur to the south-east and north-west of both the existing ConocoPhillips facility and the proposed INPEX facility. The maximum predicted ground level concentration is 0.04 ppm, which represents an increase of 0.01 ppm from that predicted for the existing case (**Table 9-2**), and is 34% of the NEPM criteria, shown in **Table 9-3**.
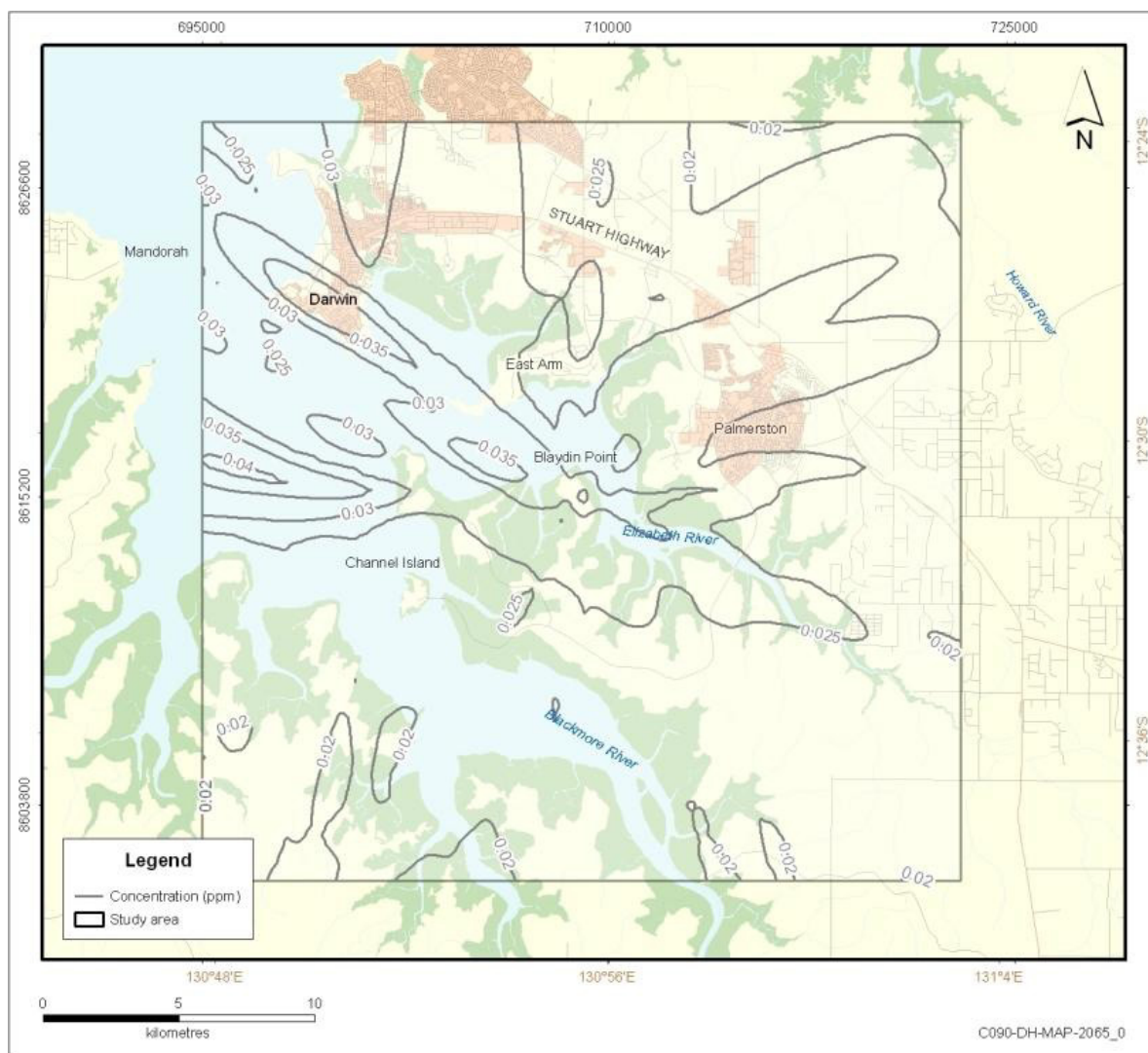
- **Figure 30 Future Case - Maximum 1-hour NO$_2$ concentrations (ppm)**

The predicted annual average ground level NO$_2$ concentrations are presented in **Figure 31**. When the results presented in this figure are compared to that for the existing scenario (**Figure 24**) it is apparent that although the maximum concentrations are still evident to the north west of the ConocoPhillips facility the proposed INPEX facility is contributing to a slight increase in the annual concentrations of NO$_2$. The maximum predicted annual ground level concentration has increased by 0.003 ppm from the existing scenario to 0.005 ppm, and 16% of the NEPM criteria.
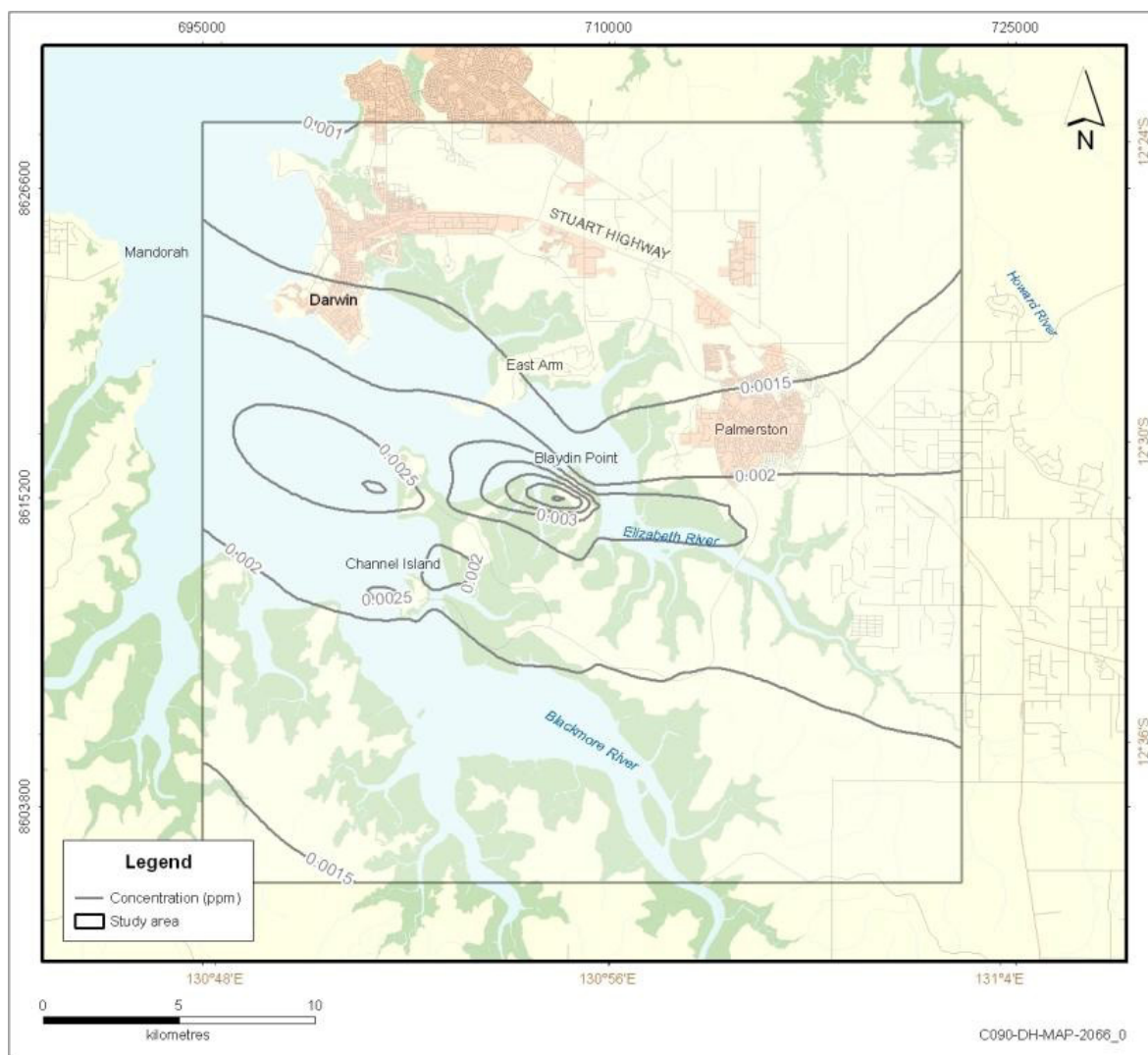
■ **Figure 31 Future Case - Annual average NO$_2$ concentrations (ppm)**

9.3.2. Ozone

The predicted future concentrations of hourly ozone are presented in **Figure 32**. When these concentrations are compared to the existing scenario it is apparent that there is little change in either the maximum predicted concentrations or the location at which they occur. The maximum predicted ground level concentration is 0.06 ppm, and is 59% of the NEPM criteria.

It is important to note that this maximum concentration is predicted to occur approximately 12 km to the north west of Darwin over the sea. The maximum concentration that is predicted to occur within Darwin is 0.05 ppm and represents approximately 48% of the NEPM criteria. O$_3$ is formed

from the photochemical reaction between NO_x (from industry and vehicles) and VOCs (from industry, vehicles and biogenic VOCs). The reaction is non-linear and often low concentrations of reactants can give rise to high O_3 concentrations depending more on the ratio of the two precursors then the actual values of the precursors.
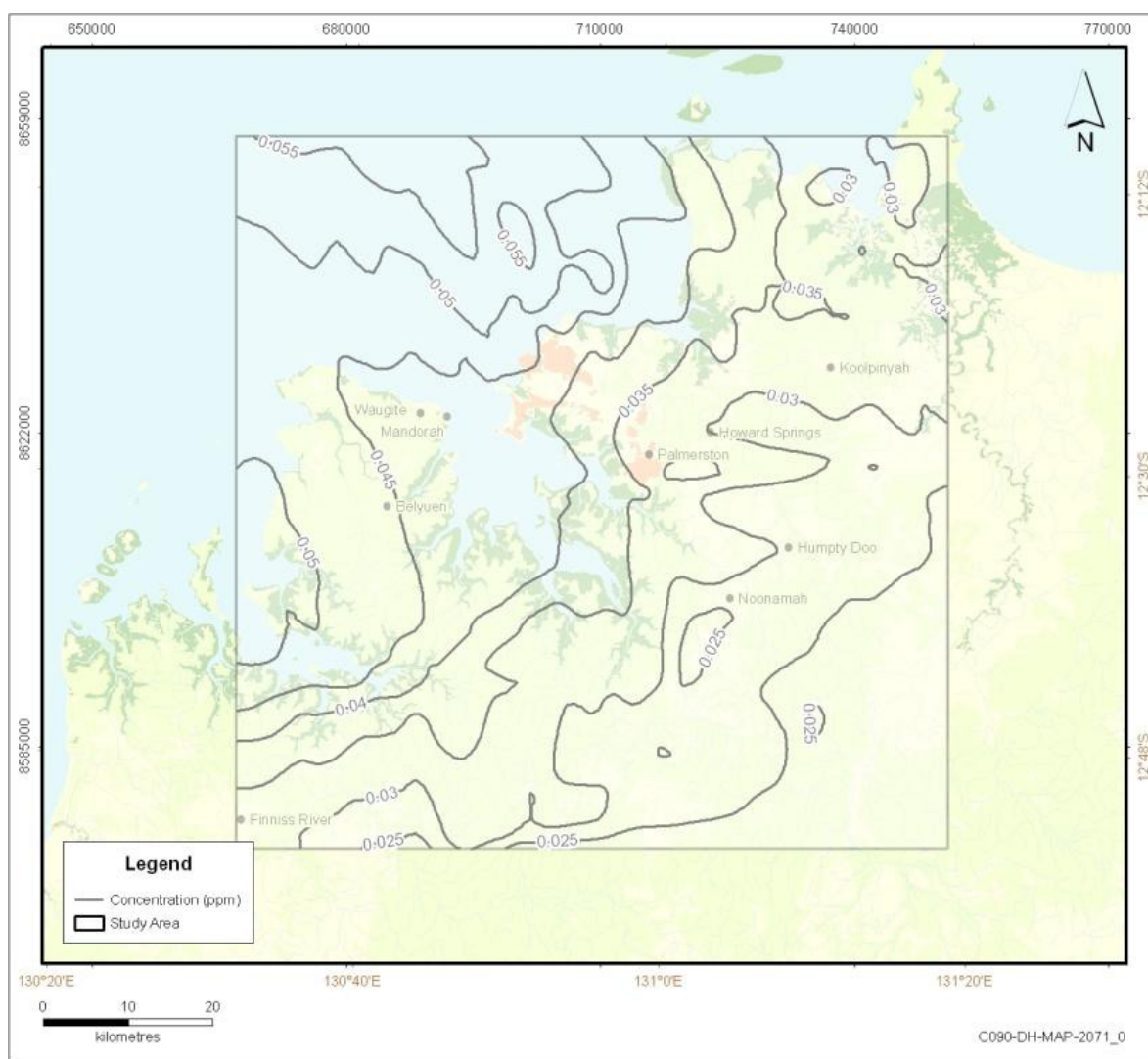
- **Figure 32 Future Case - Maximum 1-hour Ozone concentrations (ppm)**

The predicted future 4-hourly ozone concentrations are presented in **Figure 33**, and as with the 1-hour concentration there is little change in either the maximum predicted concentration or the

location. The maximum predicted 4-hour ground level concentration is 0.05 ppm and is 68% of the NEPM criteria.

It is important to note that this maximum concentration is predicted to occur approximately 12 km to the north west of Darwin over the sea. The maximum concentration that is predicted to occur within Darwin has reduced to 0.04 ppm and represents 54% of the NEPM criteria.

- **Figure 33 Future Case - Maximum 4-hour Ozone concentrations (ppm)**

9.3.3. Sulfur dioxide

Figure 34 shows the predicted hourly maximum concentration contours for future SO_2 emissions. There has been an increase in the predicted ground level concentrations when compared to the existing scenario (**Figure 27**) and the maximum ground level concentration is predicted to be 0.03 ppm and is 12% of the NEPM criteria.
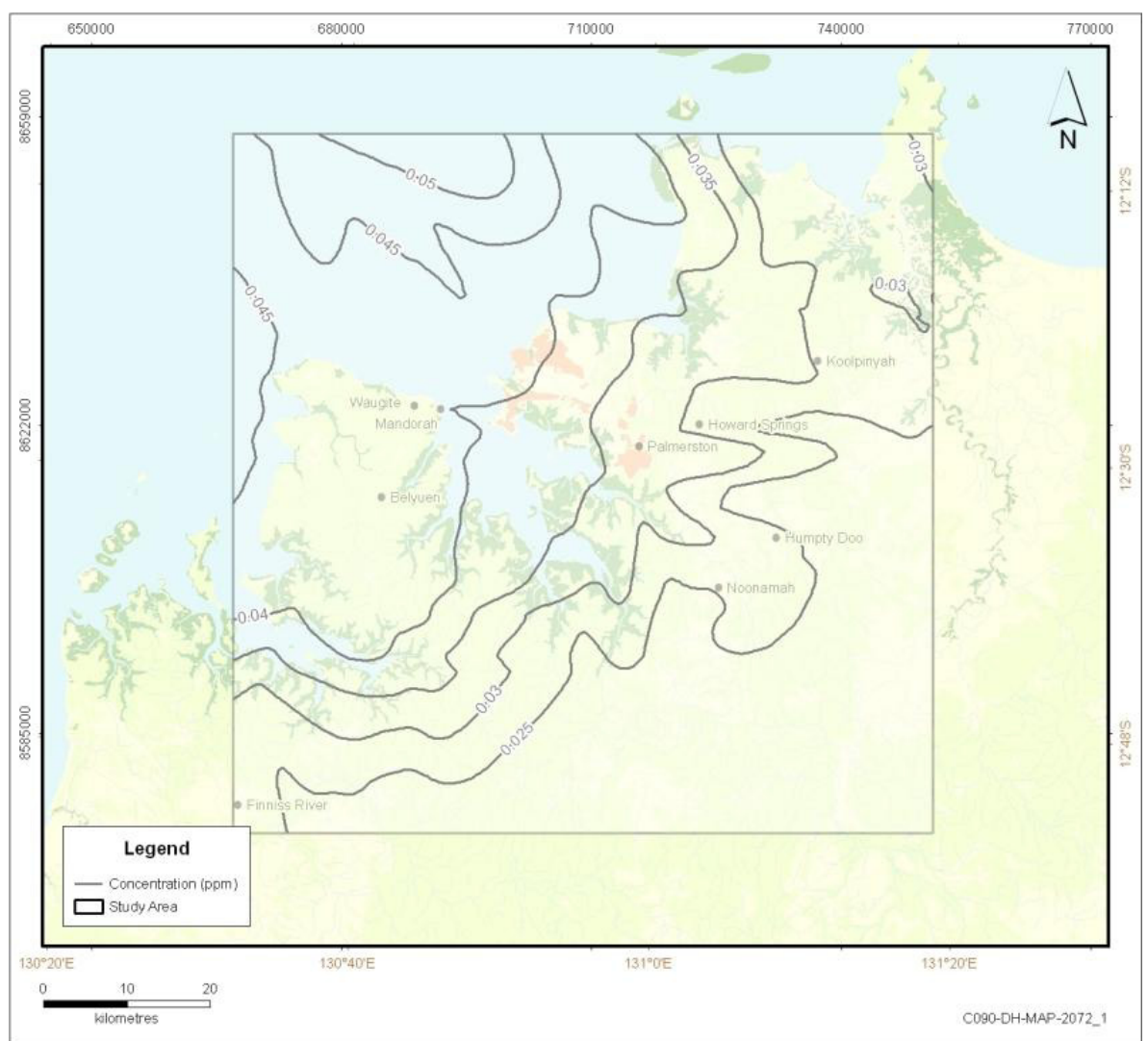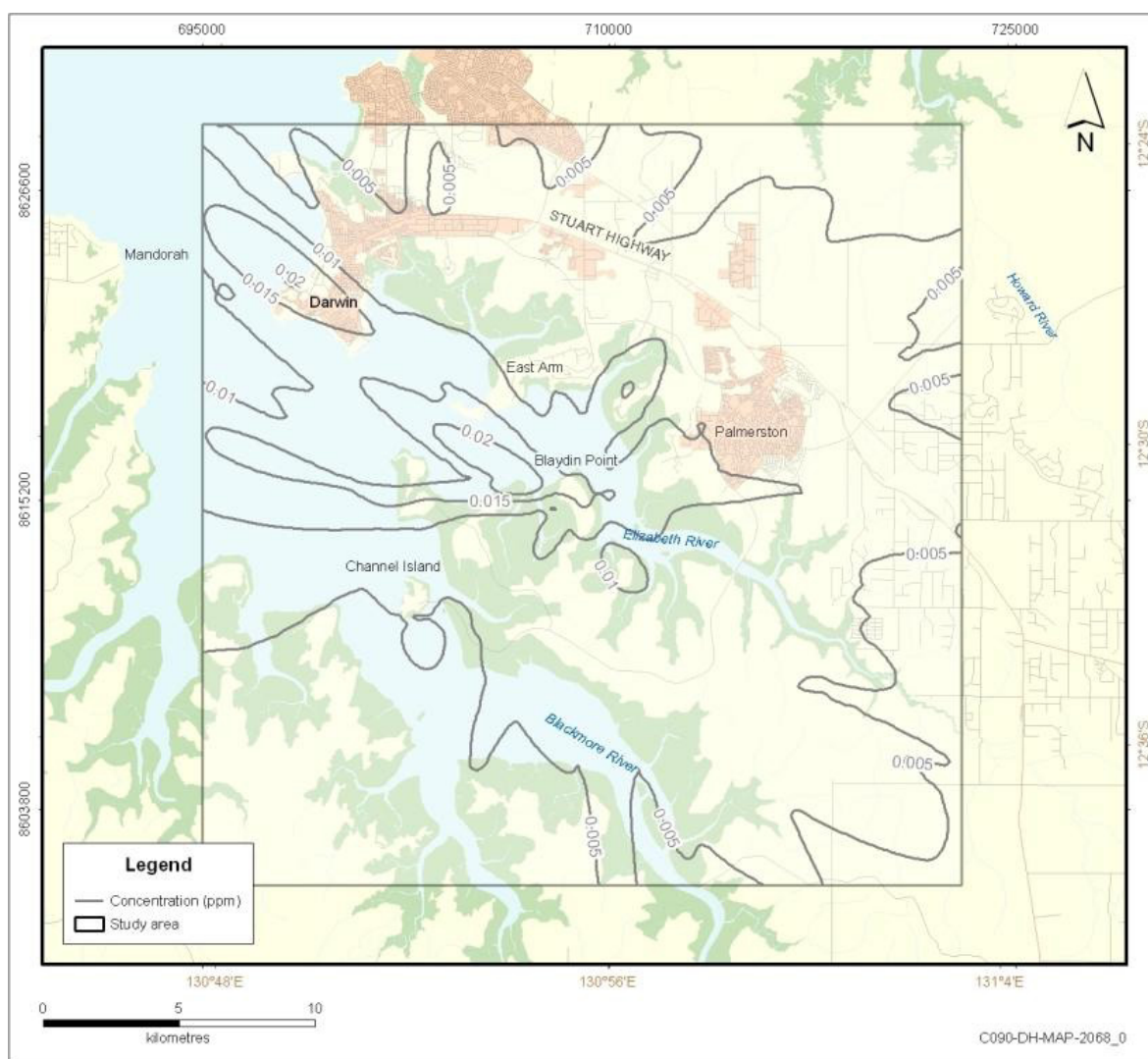

- **Figure 34 Future Case - Maximum 1-hour SO_2 concentrations (ppm)**

The maximum predicted future 24-hour SO_2 concentrations are presented in **Figure 35**. As with the predicted future 1-hour concentrations (**Figure 34**) it appears there has been an increase in the

ground level concentrations of SO_2 however the maximum predicted 24-hour ground level has not changed from the existing scenario, and is well below the NEPM criteria presented in **Table 9-3**.
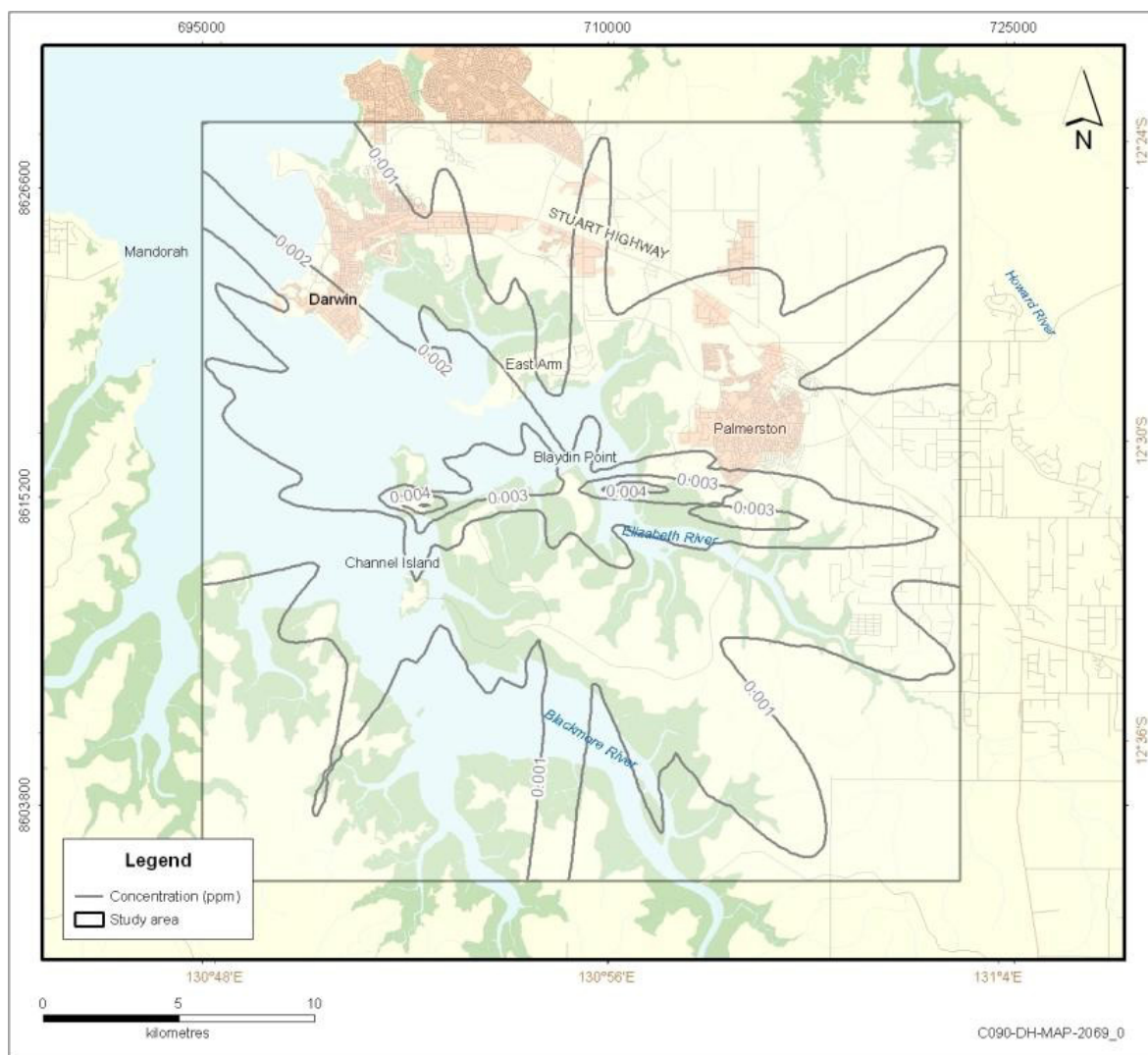
- **Figure 35 Future Case - Maximum 24-hour SO_2 concentrations (ppm)**

The predicted future annual SO_2 concentrations are presented in **Figure 36**. When this figure is compared to that for the existing scenario (**Figure 29**) it is apparent that the proposed INPEX facility will result in a minor increase in the annual SO_2 concentrations in the immediate vicinity of the proposed facility. The maximum predicted annual ground level concentration of SO_2 is 0.002 ppm, and is 10% of the NEPM criteria.

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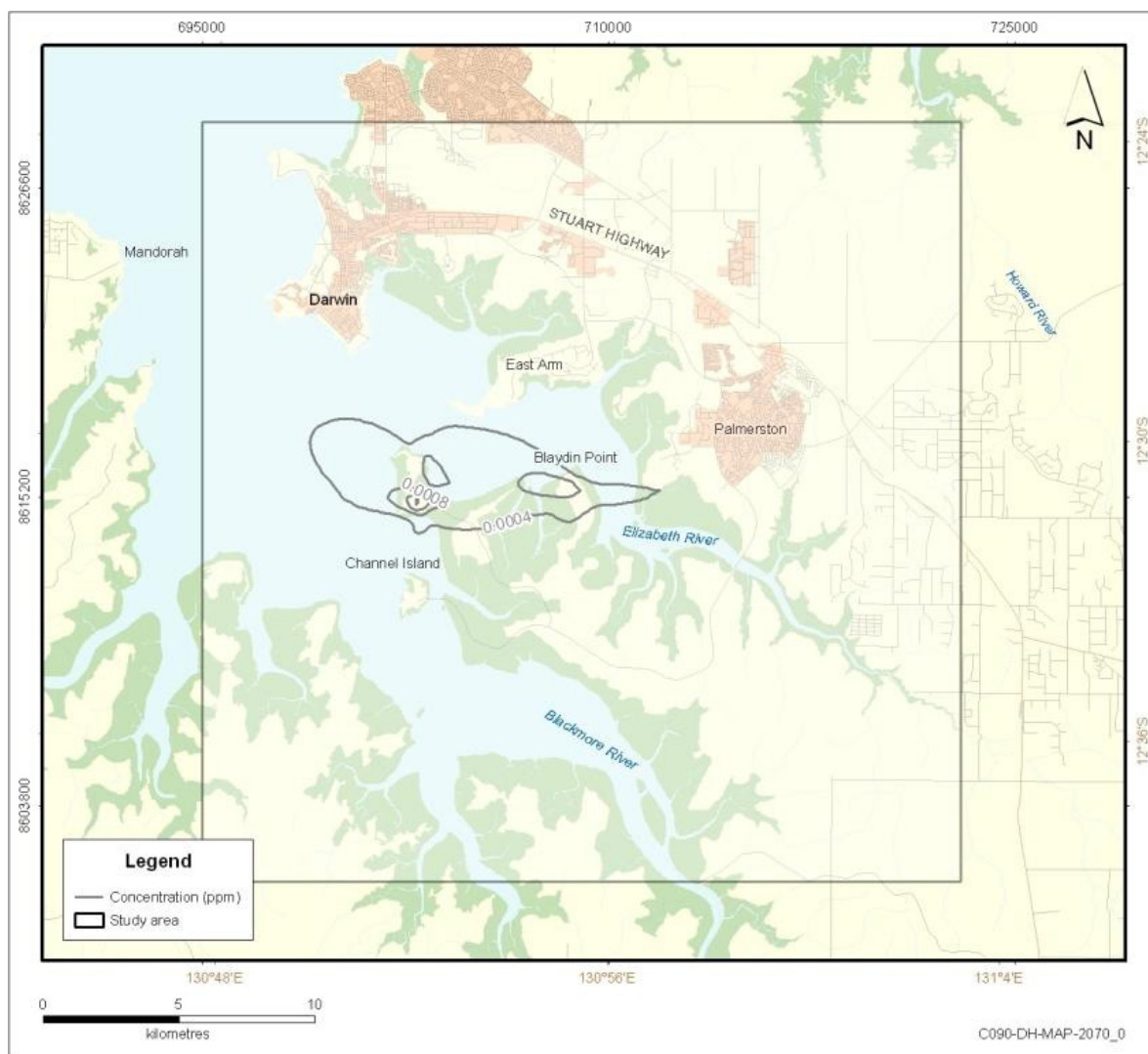
9.3.4.   Particulates (as PM$_{10}$)

The maximum 24-hour predicted ground level PM$_{10}$ concentrations during normal operations are presented in **Figure 37**. The maximum predicted ground level concentration is 10 μg/m^3, which is 21% of the NEPM criteria, shown in **Table 9-3**. When this maximum concentration is compared to that recorded by NRETAS (**Section 6.1**) it is apparent that the particulates emissions from the proposed INPEX facility are insufficient to increase the particulate loading within Darwin to a level that would exceed the NEPM criteria.
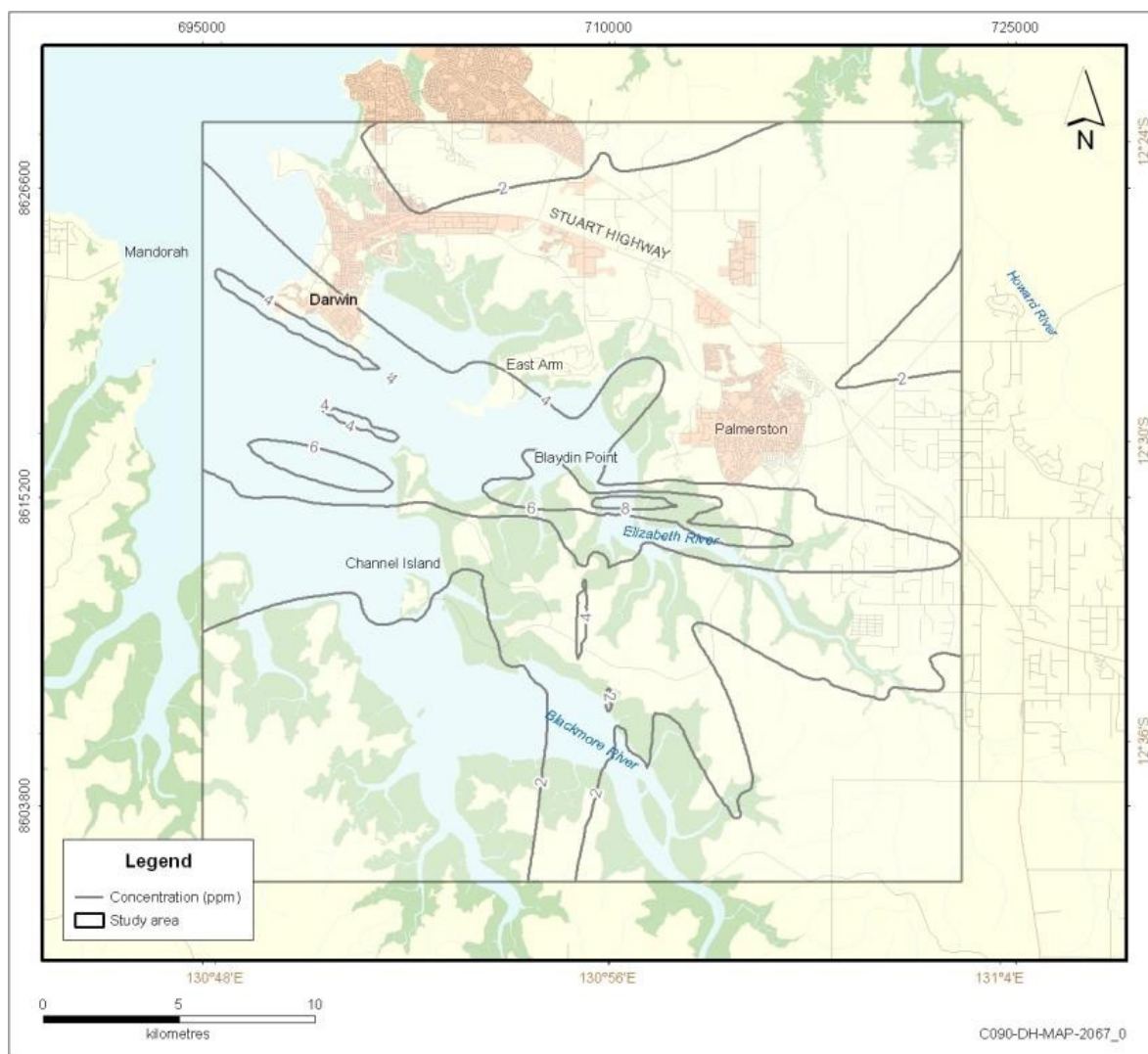
- **Figure 37 Future Case - Maximum 24-hour PM$_{10}$ concentrations (μg/m^3)**

9.3.5. Maximum on Grid

The maximum predicted future ground level concentration for O$_3$, NO$_2$, PM$_{10}$ and SO$_2$ are presented in **Table 9-3** below. A comparison between the criteria and the maximum predicted ground level concentrations shows that all the predicted concentrations for modelled pollutants are below the criterion.

- **Table 9-3 Maximum predicted future ground level concentration under normal operating conditions**

Pollutant	Modelled Grid	Averaging Period	Maximum on Grid (ppm)	NEPM Criteria (ppm)	Percentage of Criteria
NO_2	1 -km	1-hour	0.04	0.12	34%
		Annual	0.005	0.03	16%
O_3	3 -km	1-hour	0.06	0.1	59%
		4-hour	0.05	0.08	68%
SO_2	1 -km	1-hour	0.03	0.2	12%
		24-hour	0.006	0.08	7%
		Annual	0.002	0.02	10%
PM_{10}[1]	1 -km	24-hour	10	50	21%

Notes:
1. Concentrations for Particulates as PM_{10} are in $\mu g/m^3$
2. The concentrations presented in this table have been rounded to two significant figures

9.4. Future Air Quality – Upset Condition 1

As outlined in **Section 8.6.2**, the future TAPM modelling results for the proposed INPEX facility at Blaydin Point under non-routine "Upset 1" conditions are presented here. These are for a short-term flaring event of about 15 minutes duration, caused by a blocked MR (mixed refrigerant) compressor outlet. Given the short duration of this event, results are presented for short-term (1-hour) averages only. The pollutants taken into consideration in this section include NO_2, SO_2, PM_{10} and O_3. The maximum ground level concentration of each of these pollutants is compared to the NEPM criteria.

9.4.1. Nitrogen Dioxide

The maximum 1-hour predicted ground level NO_2 concentrations during upset condition 1 are presented in **Figure 38**. The maximum predicted ground level concentration is 0.04 ppm, which is similar to that predicted to occur during normal operations (**Table 9-3**) and is 34% of the NEPM criteria, as shown in **Table 9-4**.

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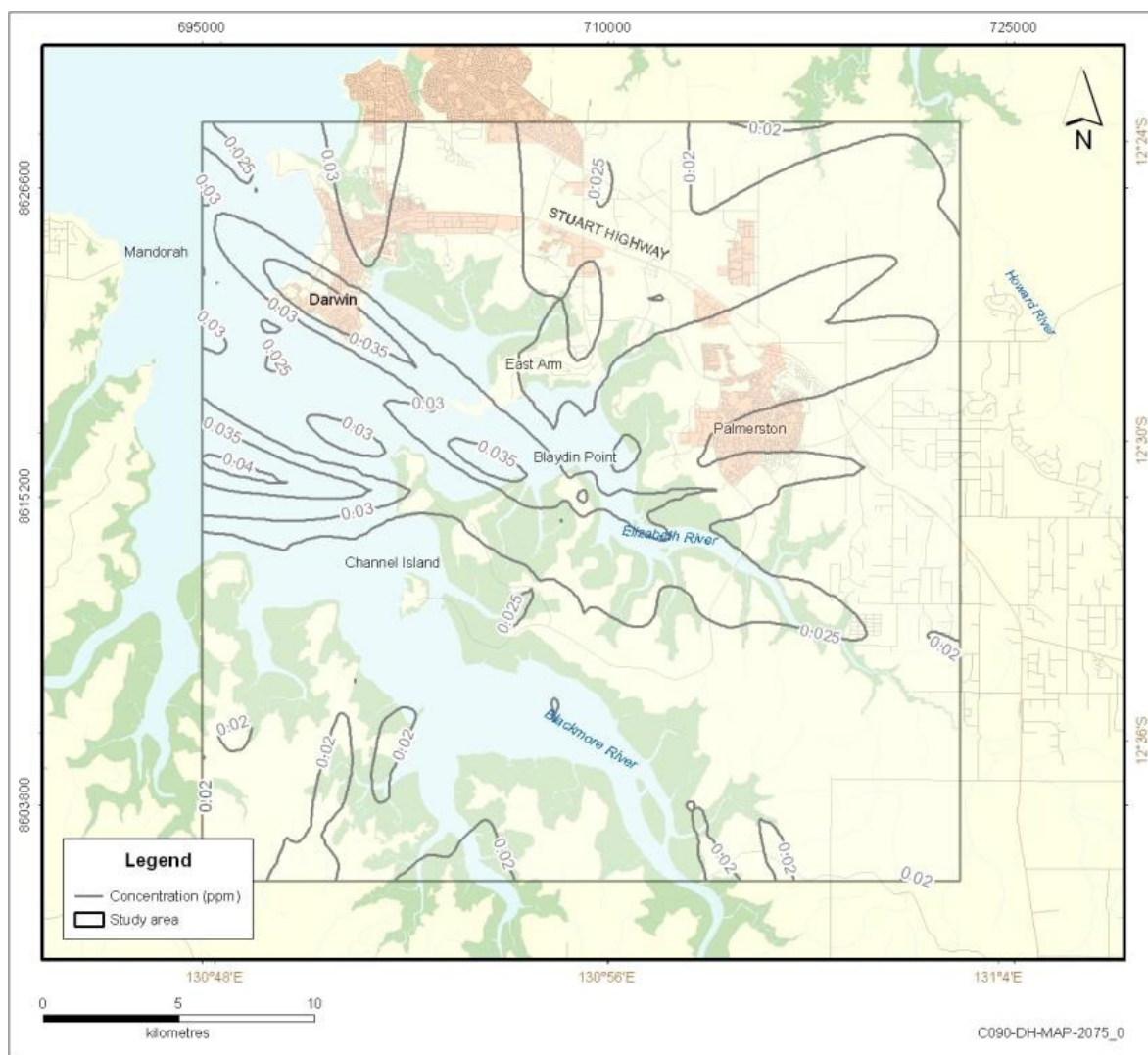
- **Figure 38 Future Case - Maximum 1-hour ground level concentrations of NO$_2$ during Upset Condition 1 (ppm)**

9.4.2. Ozone

The maximum 1-hour predicted ground level O$_3$ concentrations during upset condition 1 are presented in **Figure 39**. The maximum predicted ground level concentration is 0.06 ppm, and is the same as that predicted to occur during normal operations (**Table 9-3**).

- **Figure 39 Future Case - Maximum 1-hour ground level concentrations of O_3 during Upset Condition 1 (ppm)**

9.4.3. Sulfur Dioxide

The maximum 1-hour predicted ground level SO_2 concentrations during upset condition 1 are presented in **Figure 40**. The maximum predicted ground level concentration is 0.03 ppm, and is the same as predicted to occur during normal operations (**Table 9-3**). This is not unusual as it is expected that there will be no increase in SO_2 emissions during such an event.

- **Figure 40 Future Case - Maximum 1-hour ground level concentrations of SO$_2$ during Upset Condition 1 (ppm)**
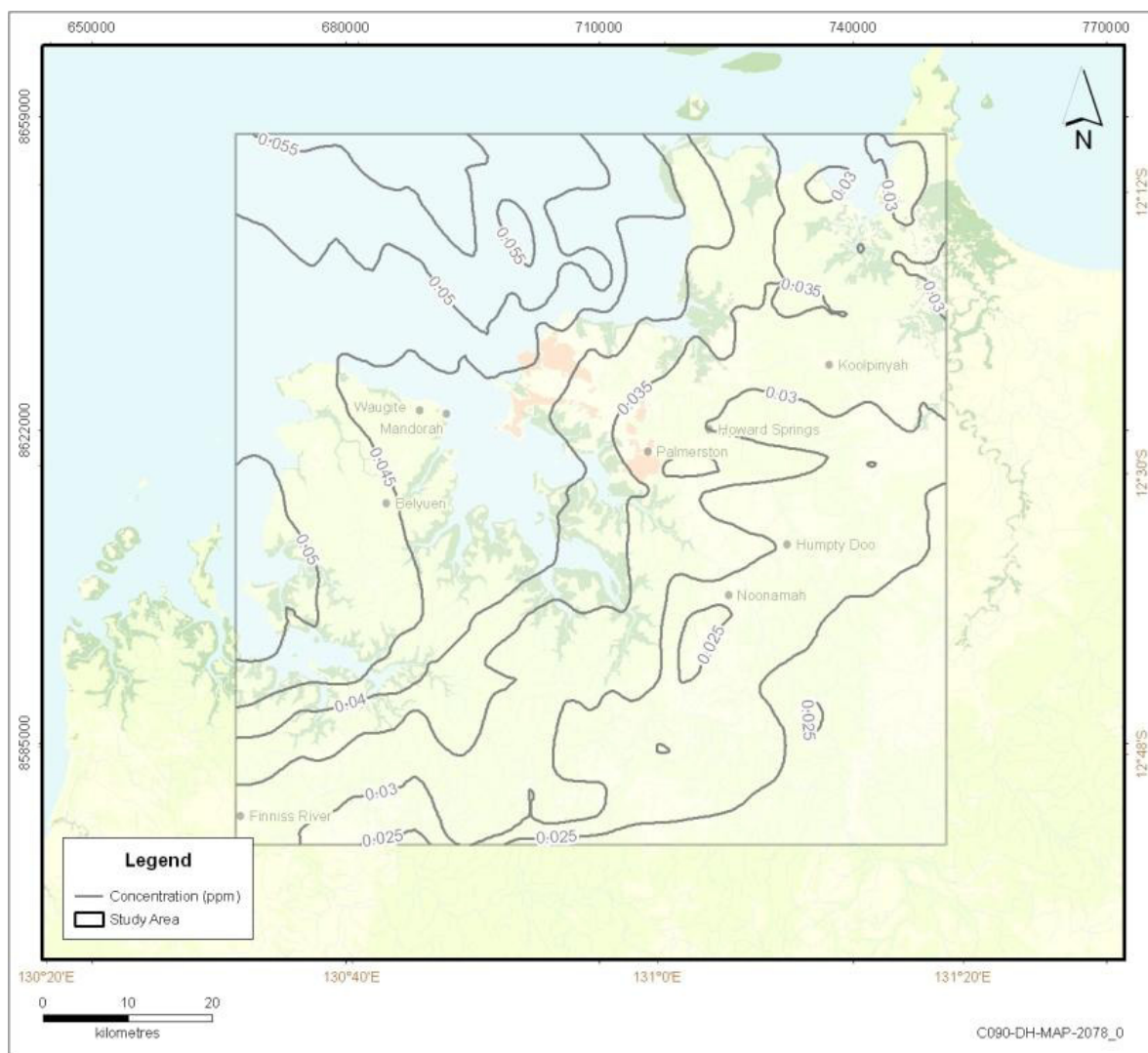
9.4.4. Particulates

The maximum 24-hour predicted ground level PM$_{10}$ concentrations during upset condition 1 are presented in **Figure 41**. The maximum predicted ground level concentration is 17 µg/m^3, which is 35% of the NEPM criteria, shown in **Table 9-4**.

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9.4.5. Maximum on Grid

The maximum predicted future ground level concentrations for O$_3$, NO$_2$, SO$_2$ and PM$_{10}$ during upset condition 1 are presented in **Table 9-4** below. A comparison has been made between the maximum predicted future ground level concentrations and the NEPM criteria, which is also displayed in this table. This table demonstrates that the predicted concentrations for all modelled pollutants are below the assessment criteria.

- **Table 9-4 Future Case - maximum predicted ground level concentration under Upset Condition 1**

Pollutant	Modelled Grid	Averaging Period	Maximum on Grid (ppm)	NEPM Criteria (ppm)	Percentage of Criteria
NO_2	1 -km	1-hour	0.04	0.12	34%
O_3	3 -km	1-hour	0.06	0.1	59%
SO_2	1 -km	1-hour	0.03	0.2	12%
PM_{10}	1 -km	24-hour	17[1]	50[1]	35%

Notes:

1. Concentrations for Particulates as PM_{10} are in $\mu g/m^3$

9.5. Future Air Quality – Upset Condition 2

As outlined in **Section 8.6.3** the TAPM modelling results for existing air emissions and the proposed INPEX facility at Blaydin Point under non-routine "Upset 2" conditions are presented here. This scenario is based on the assumed depressurising of the propane compressor circuit, resulting in flaring for up to ten hours. During this type of event, all equipment on one train will be shutdown, while the other train will continue to operate normally.
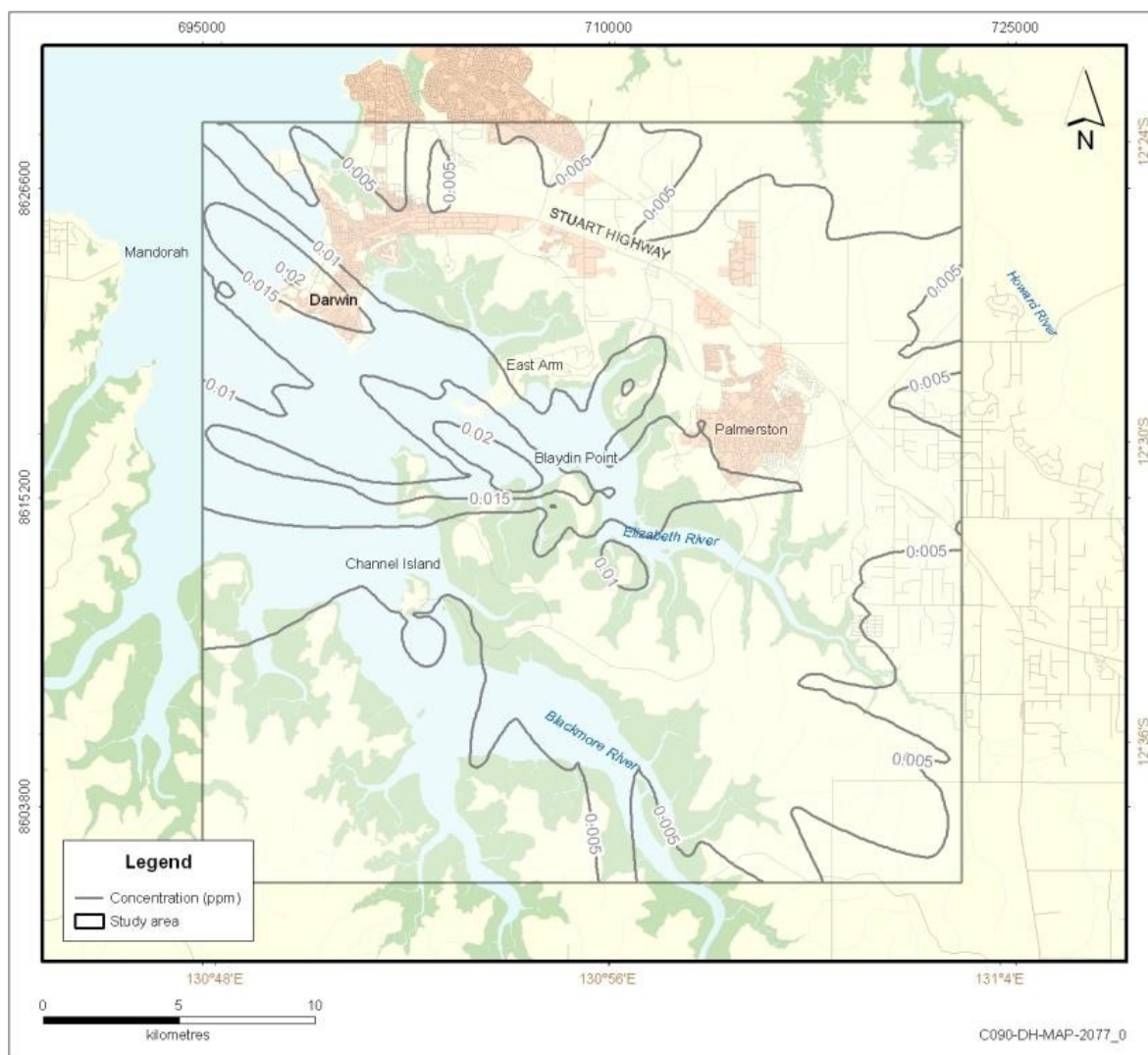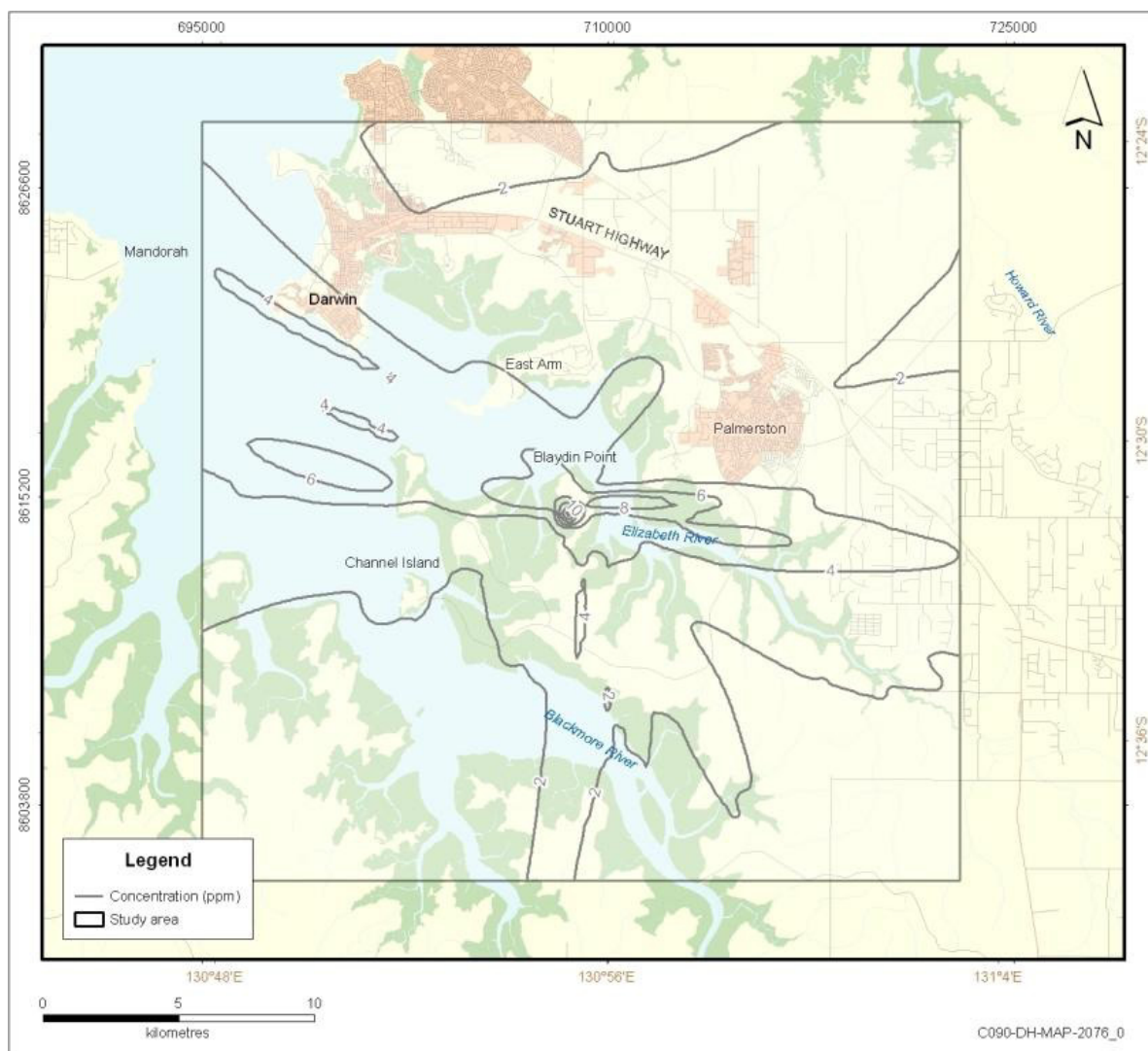
9.5.1. Nitrogen Dioxide

The maximum 1-hour predicted ground level NO_2 concentrations during upset condition 2 are presented in **Figure 42**. The maximum predicted ground level concentration is 0.03 ppm, and represents a decrease when compared to that predicted to occur during normal operations (**Table 9-3**). This predicted maximum concentration is 28% of the NEPM criteria, as shown in **Table 9-5**.
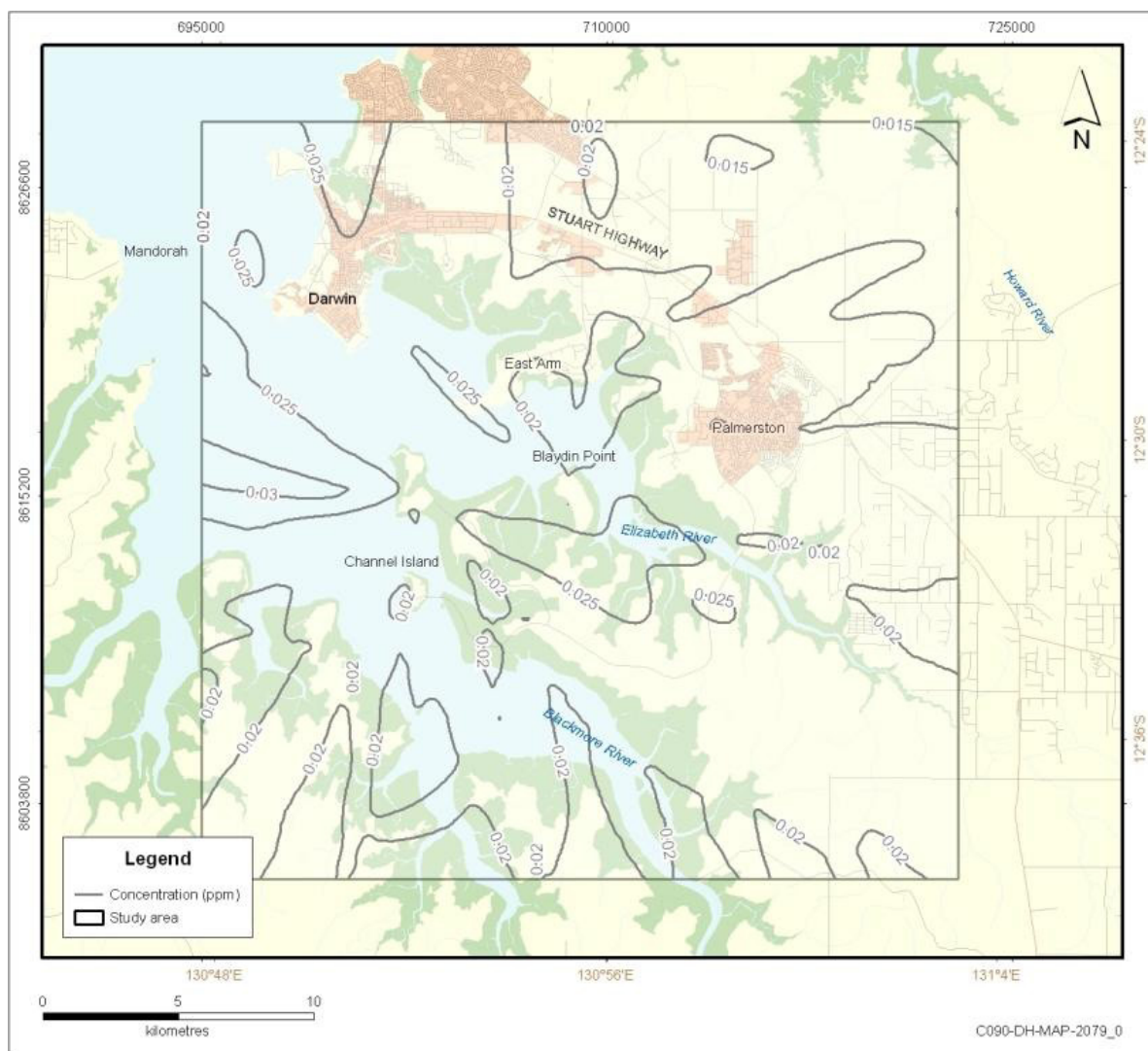
■ **Figure 42 Future Case - Maximum 1-hour ground level concentrations of NO$_2$ during Upset Condition 2 (ppm)**

9.5.2. Ozone

The maximum 1-hour predicted ground level O$_3$ concentrations during upset condition 2 are presented in **Figure 43**. The maximum predicted ground level concentration is 0.06 ppm, and is similar to that predicted to occur during normal operations (**Table 9-3**). As with the predict concentrations during normal operations, the maximum concentration during upset condition 2 are predicted to occur approximately 12 km to the north west of Darwin over the sea.

- **Figure 43 Future Case - Maximum 1-hour ground level concentrations of O_3 during Upset Condition 2 (ppm)**

9.5.3. Sulfur Dioxide

The maximum 1-hour predicted ground level SO_2 concentrations during upset condition 2 are presented in **Figure 44**. This figure shows that higher SO_2 concentrations occur to the east and west of the development. The maximum predicted ground level concentration is 0.01 ppm, and is half that predicted to occur during normal operations (**Table 9-3**). This can be attributed to one train being shut down.
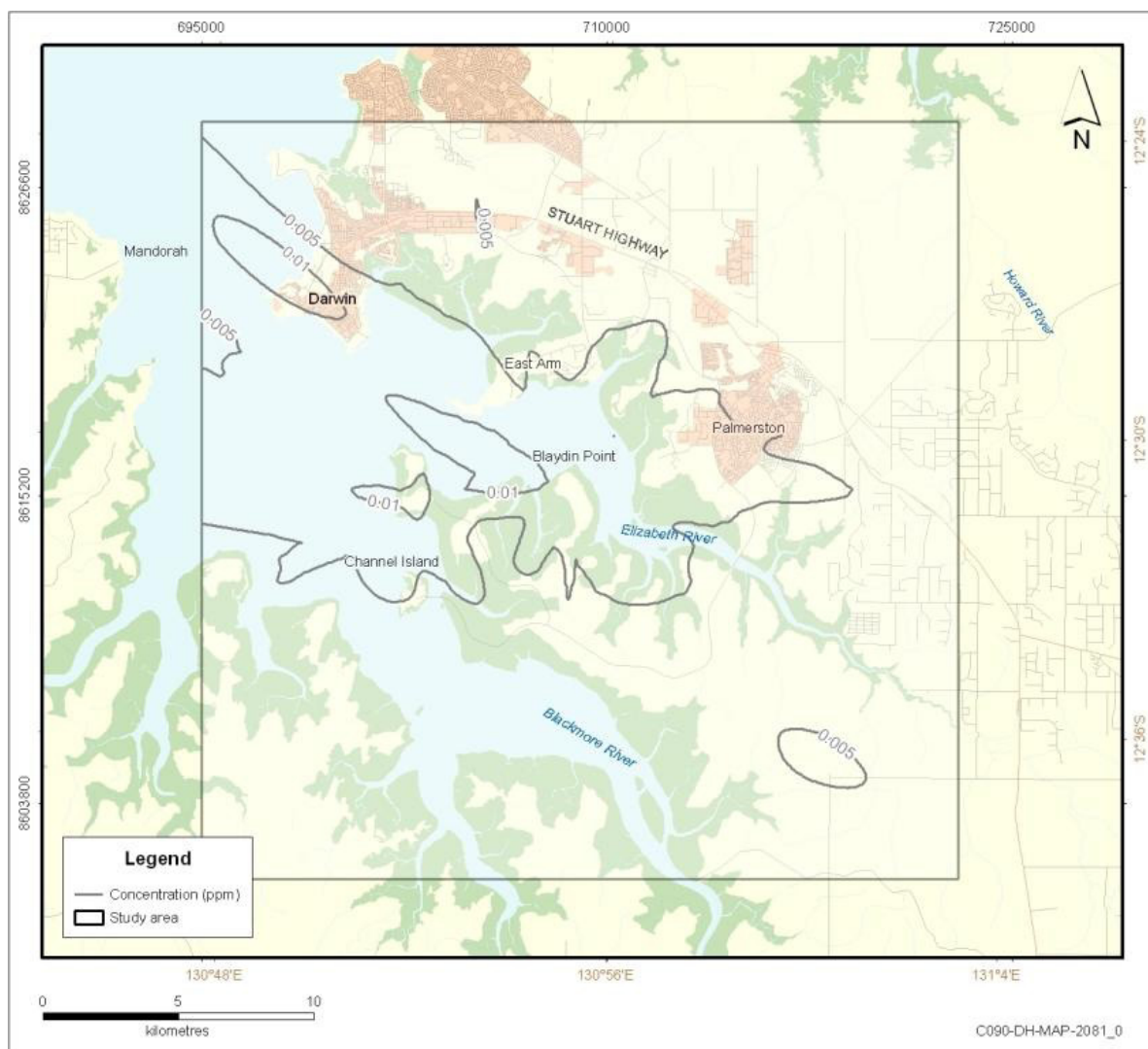
- **Figure 44 Future Case - Maximum 1-hour ground level concentrations of SO_2 during Upset Condition 2 (ppm)**
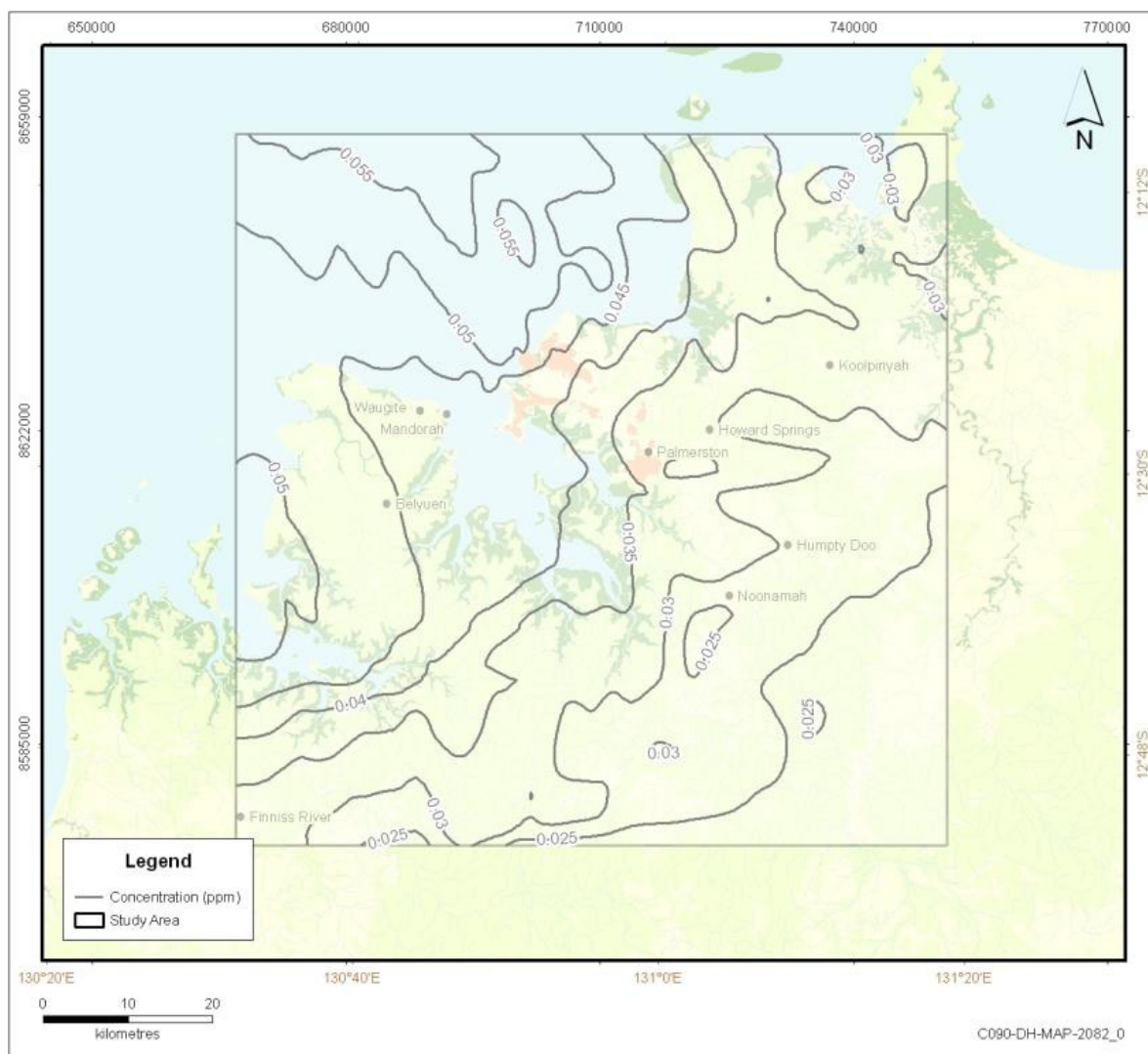
9.5.4. Particulates

The maximum 24-hour predicted ground level PM_{10} concentrations during upset condition 2 are presented in **Figure 45**. The maximum predicted ground level concentration is 6 µg/m^3. This represents a slight decrease from that predicted to occur during normal operations (**Table 9-3**) and is 12% of the NEPM criteria, shown in **Table 9-5**.
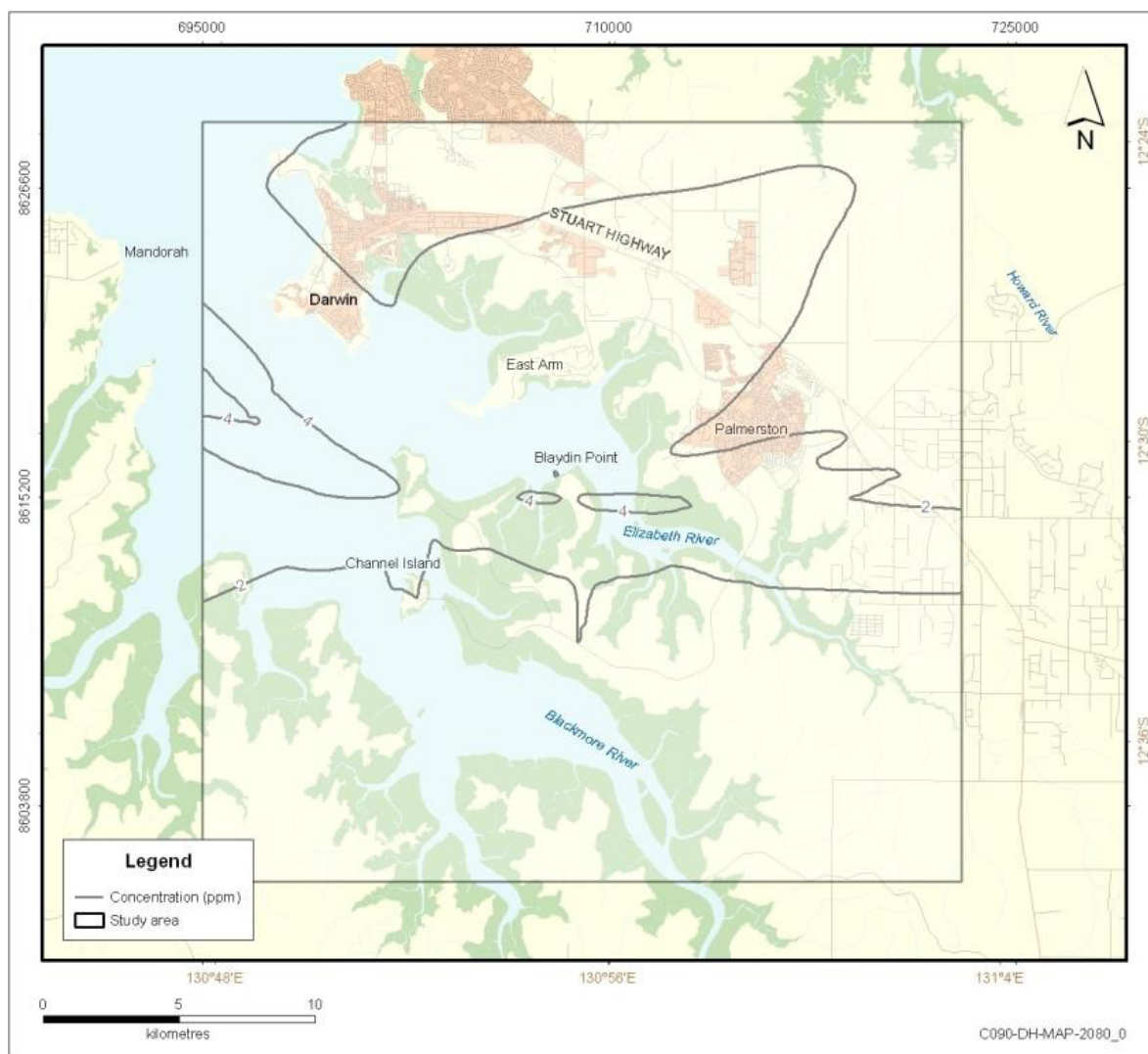
- **Figure 45 Future Case - Maximum 24-hour ground level concentrations of PM$_{10}$ during Upset Condition 2**

9.5.5. Maximum on Grid

The maximum predicted future ground level concentrations for O$_3$, NO$_2$, SO$_2$ and PM$_{10}$ during upset condition 2 are presented in **Table 9-5** below. A comparison has been made between the maximum predicted future ground level concentrations and the NEPM criteria, which is also displayed in this table. This table demonstrates that the predicted concentrations for all modelled pollutants are below the assessment criteria.

- **Table 9-5 Future Case - maximum predicted future ground level concentration under Upset Condition 2**

Pollutant	Modelled Grid	Averaging Period	Maximum on Grid (ppm)	NEPM Criteria (ppm)	Percentage of Criteria
NO_2	1 -km	1-hour	0.03	0.12	28%
O_3	3 -km	1-hour	0.06	0.1	59%
SO_2	1 -km	1-hour	0.01	0.2	7%
PM_{10}[1]	1 -km	24-hour	6	50	12%

Notes:

1. Concentrations for Particulates as PM_{10} are in $\mu g/m^3$

9.6. Impact on Vegetation - Dry Deposition of Nitrogen and Sulfur Dioxide

Acid deposition occurs when SO_2 and NO_2 react with water, oxygen and other oxidants in the atmosphere to form acidic compounds. These acid compounds precipitate in rain, snow and fog, or in dry form as gases and particles. The SO_2 and NO_2 gases and their particulate matter derivatives and sulfate and nitrate aerosols may contribute to air quality impacts, for example, by the acidification of lakes and streams, damage to forest ecosystems and acceleration of the decay of building materials (USEPA 2007). The deposition quantities provided in this assessment are considered indicative of what may occur.

9.6.1. Sulfur Dioxide Deposition

The TAPM predictions for SO_2 deposition (kg/ha/annum) for the existing sources described in **Section 8.4** (together with the area emissions as outlined in **Section 6**) are provided in **Figure 46**. From this figure it can be seen that the majority of the deposition occurs around the existing ConocoPhillips facility with the higher depositions occurring over the sea, due to the high solubility of SO_2. The predicted deposition of SO_2 reaches a maximum of 4 kg/ha/annum, which is well within the WHO guidelines for vegetation.
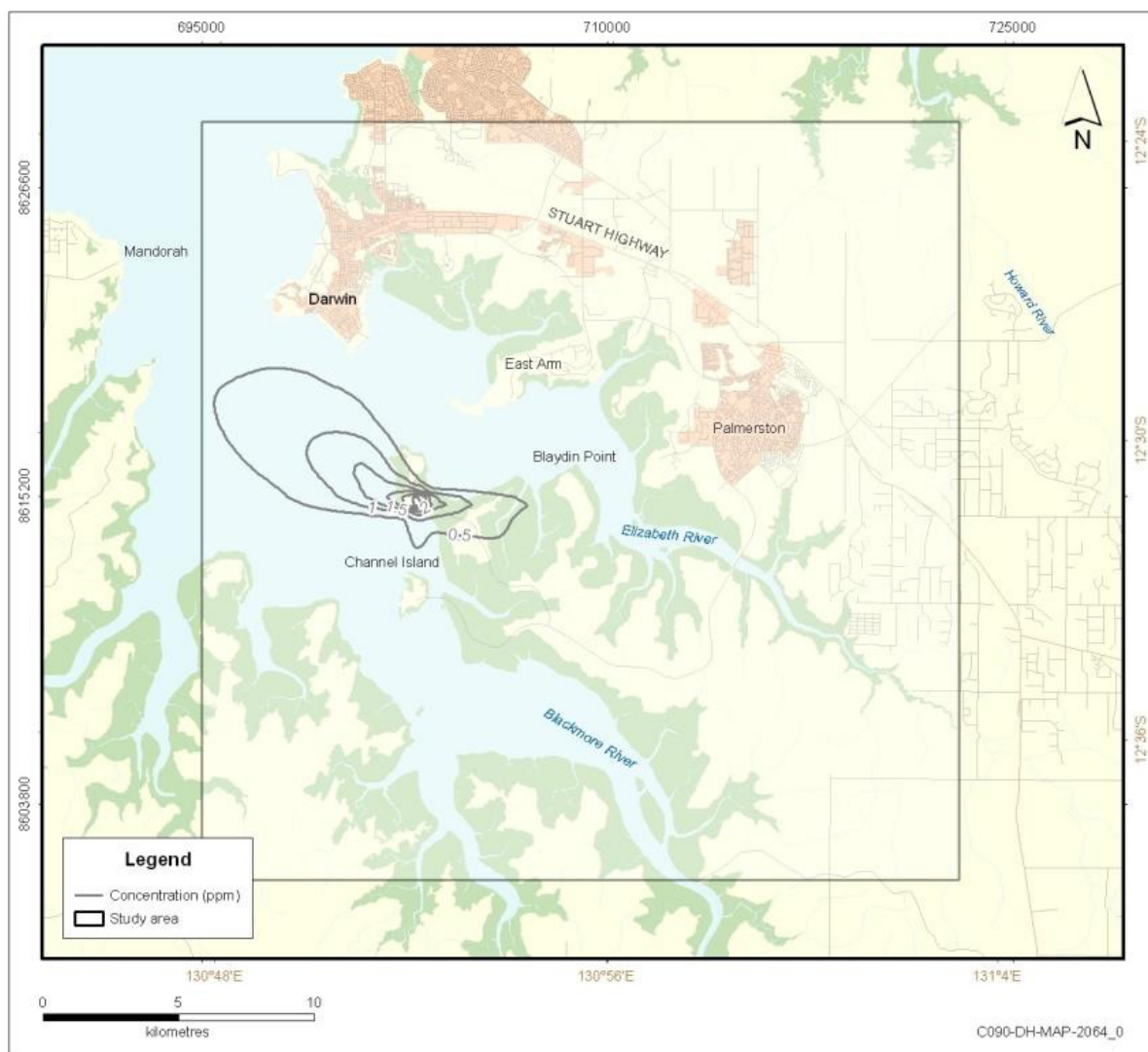
■ **Figure 46 Existing Case - Predicted Annual SO₂ Deposition (kg/ha/annum)**

The TAPM predictions for SO$_2$ deposition (kg/ha/annum) for the existing sources (**Section 8.4**) and the proposed INPEX facility (**Section 8.5**) (together with the area emissions as outlined in **Section 6**) are provided in **Figure 47**. When this figure is compared to the predicted deposition rate for the existing scenario it is apparent that the proposed INPEX facility will have a minimal impact in the region. The predicted deposition of SO$_2$ reaches a maximum of 4 kg/ha/annum, which is a similar to that predicted to occur for the existing scenario and well within the WHO guidelines for vegetation.

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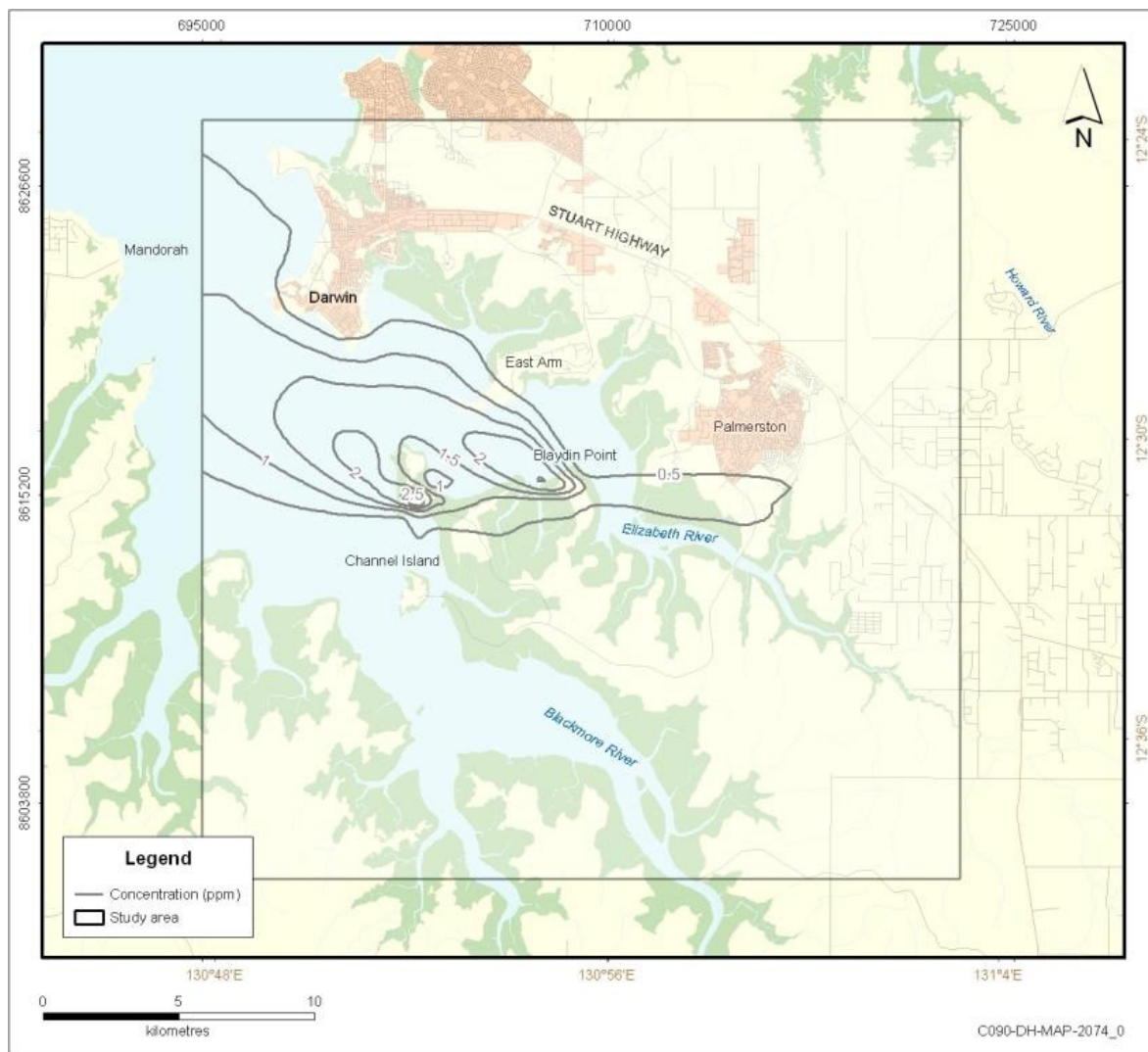
■ **Figure 47 Future Case - Predicted Annual SO$_2$ Deposition (kg/ha/annum)**

9.6.2. Nitrogen Deposition

The TAPM predictions for the existing NO$_2$ deposition (kg/ha/annum) results are provided in **Figure 48**. The highest NO$_2$ deposition rate of 2 kg/ha/annum is predicted to occur adjacent to the existing ConocoPhillips facility. It must be noted that the results are strongly dependent on the NO$_2$ solubility used in the calculations.
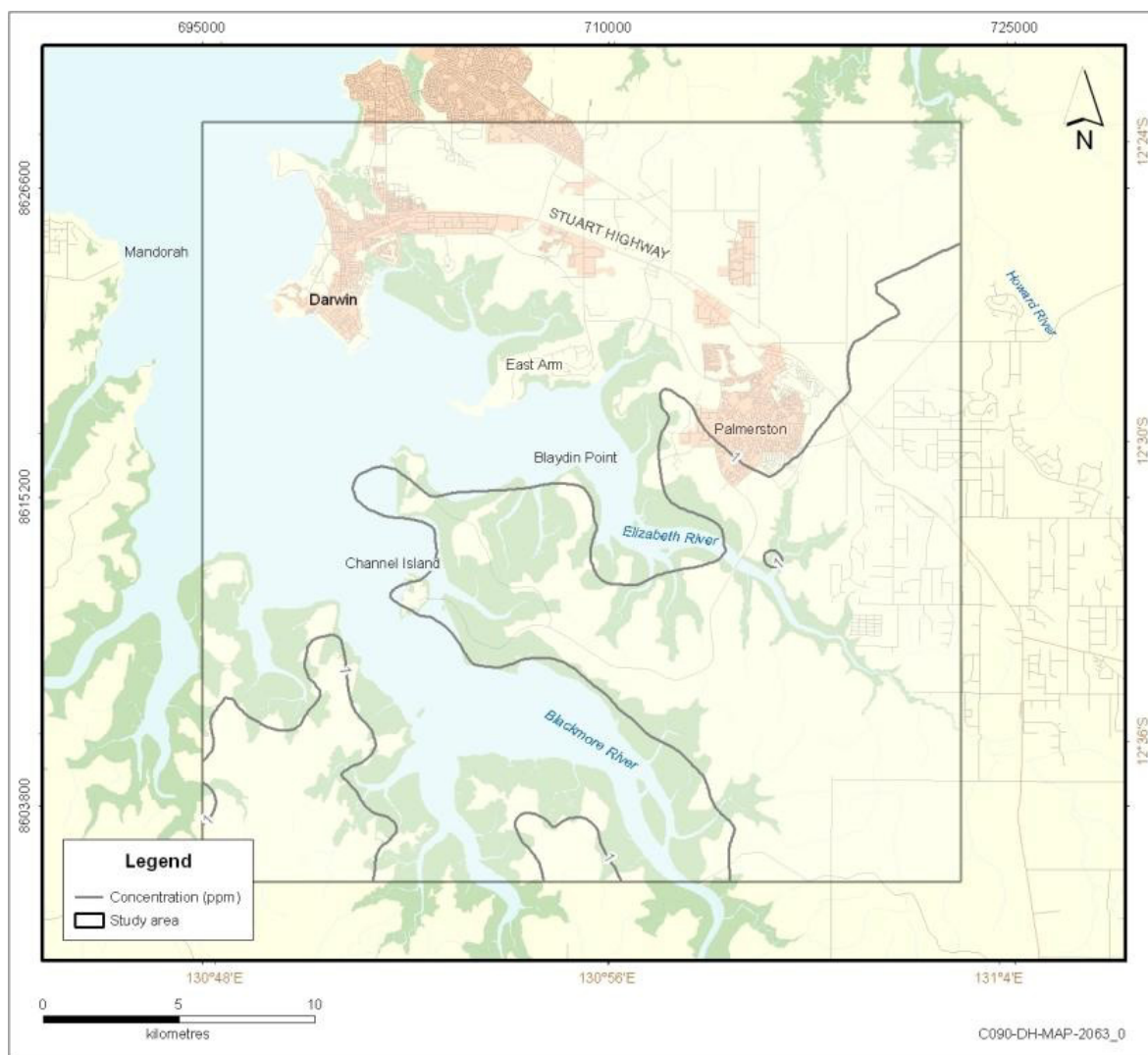
- **Figure 48 Existing Case - Predicted Annual NO$_2$ Deposition (kg/ha/annum)**

The TAPM predictions for the future NO$_2$ deposition (kg/ha/annum) results are provided in **Figure 49**. The highest NO$_2$ deposition rate of 6 kg/ha/annum is predicted to occur adjacent to the proposed INPEX facility on Blaydin Point. This deposition rate is well within the WHO guidelines and as such NO$_2$ deposition from the proposed gas processing facility can be considered to be insignificant.
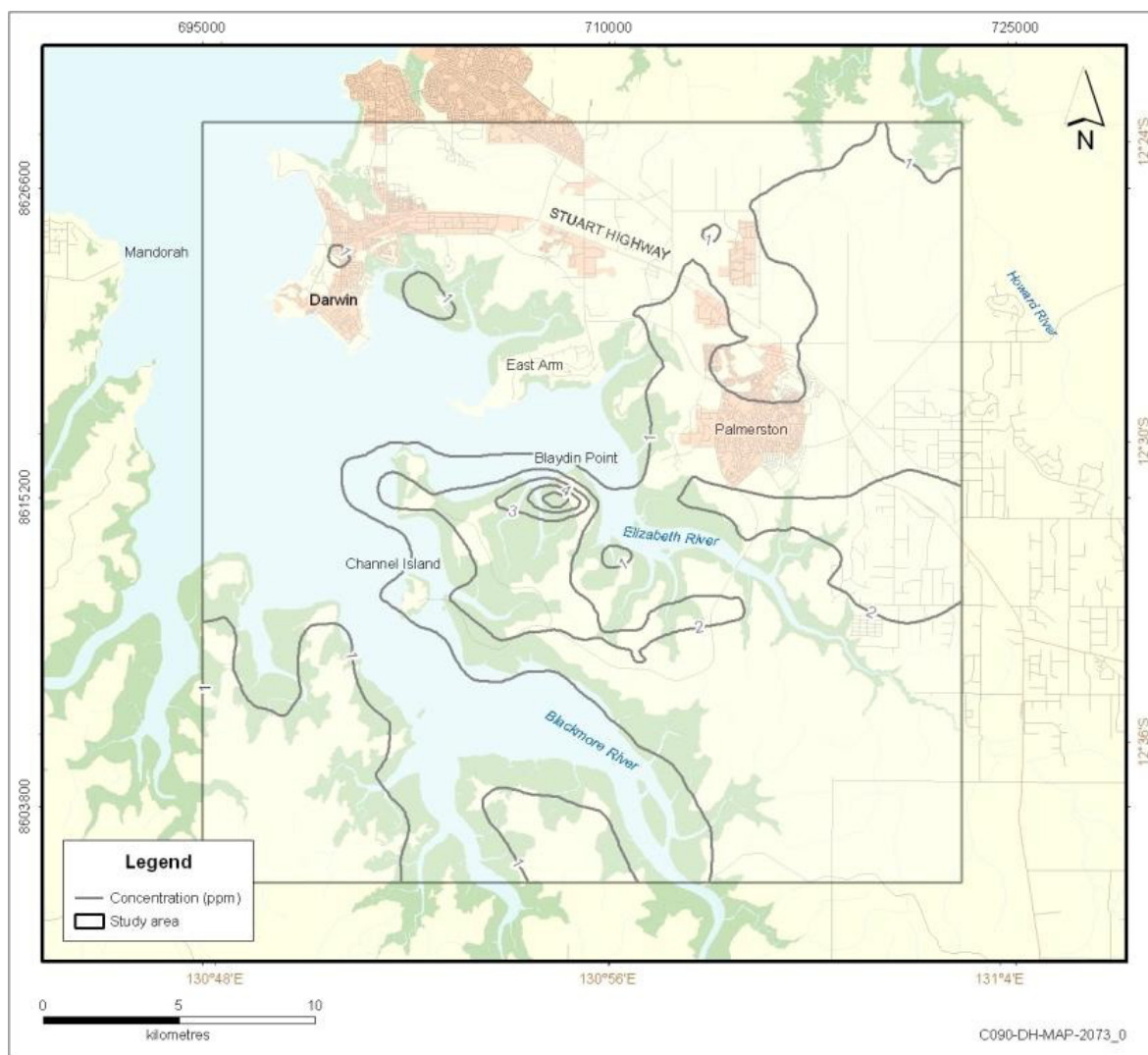
- **Figure 49 Future Case - Predicted Annual NO$_2$ Deposition (kg/ha/annum)**

9.7. Summary of results

9.7.1. Potential Impact on Human Health

The highest risk NEPM 'criteria air pollutants' identified for detailed examination in this assessment are NO$_2$, O$_3$, PM$_{10}$ and SO$_2$.

Existing (non-industrial) Air Quality Case

Existing (non-industrial) air quality, that is the contribution of emissions from biogenic sources and vehicle emissions in the region, is shown to be well below the NEPM criteria for both the predicted

1-hour and 4-hour ground level ozone concentrations. Maximum concentrations occur approximately 12 km out to sea. Predicted maximum concentrations in Darwin are around 15% lower. The 1-hour and annual ground level concentrations of NO_2 are also influenced by the non-industrial sources but to a lesser degree (less than 10% of the NEPM criteria).

Existing (industrial and non-industrial) Air Quality

Atmospheric emissions from the existing industrial operations (and non-industrial emissions) in the region are having an influence on predicted existing air quality. The 1-hour and annual predicted concentrations for NO_2 are higher than those predicted in the background but remain well within the NEPM criteria. The 1-hour and annual predicted concentrations for SO_2 are also well within the NEPM criteria. The predicted maximum concentrations for both the 1-hour and 4-hour ground level ozone concentrations are similar to that predicted for the existing (non-industrial) scenario. This again occurs out to sea. The maximum predicted concentrations in Darwin are lower and are well within the NEPM criteria.

Future air quality – normal operations

Atmospheric emissions from the proposed INPEX facilities will contribute to a relatively small increase in predicted ground level concentrations of O_3, NO_2 and SO_2. Particulate concentrations remain well within the NEPM criteria as well.

This assessment has shown that for NO_2, O_3, SO_2 and PM_{10} that no exceedences of the relevant assessment criteria are expected as a result of operating the proposed facility. This is the case during both normal and specified upset conditions of the plant. The highest predicted concentration within Darwin, for any pollutant, represented 54% of the NEPM criteria (for the 4-hour ozone concentration under normal future operations).

9.7.2. Potential Impact on Vegetation from deposition

This assessment of deposition of SO_2 and NO_2 for the region surrounding the proposed INPEX facility on Blaydin Point, incorporating all emissions associated with existing sources and the proposed gas processing facility indicates that 'typical high' SO_2 and NO_2 deposition in the region around Darwin are 4 kg/ha/annum and 6 kg/ha/annum respectively. These levels are well under WHO (2000) guidelines for assessing the risks of impacts on vegetation; that is, WHO guidelines 8 to16 kg/ha/annum (SO_2) and 49 to 66 kg/ha/annum (NO_2).

10. Conclusions and Recommendations

10.1. Overview

As part of the environmental approvals for the onshore development of the Ichthys Project, this study details the air quality assessment undertaken to determine the predicted air quality impacts from the construction and operation of the development.

The assessment included analysis and description of background and existing ambient air quality in the region, and estimation of emissions of NO_2, O_3, SO_2 and PM_{10} from the proposed development at its maximum expected level of operations and during two sets of upset conditions.

10.2. Existing Sources Air Quality Impacts

There is some direct information available on the local ambient air quality experienced in Darwin, but this data set is not comprehensive. Based on the regional setting and two neighbouring industrial emissions sources, ambient air quality is also expected to be influenced by ocean sources, regional smoke from wild fires and prescribed burning activities.

Dispersion modelling predicts that levels for NO_2, O_3, SO_2 and PM_{10}, will be within the NEPM criteria.

10.3. Cumulative Air Quality Impacts

This air quality assessment has shown that the highest concentrations of air pollutant species due to emissions from the Ichthys Development are NO_2 and O_3. This is consistent with prior studies on other similar developments by CSIRO (Hurley *et al* 2003a and 2003b) and others. The dispersion modelling shows that normal operations and prescribed upset conditions for the Development are not expected to cause any exceedences of the NEPM standards.

The dispersion modelling shows that emissions of all pollutants are expected to increase under normal plant operating conditions. The scale of increase predicted is not significant

For the two upset conditions the modelling suggests an increase will occur only in NO_2 concentrations over those predicted under normal conditions. Again increases predicted are not significant.

10.4. Conclusions

This air quality assessment concludes with the following key findings:

■ Normal and non-routine onshore Ichthys Gas Field Development operations are not expected to cause any significant air quality impacts within the study area.

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- Throughout the year, no exceedences of the relevant air quality standards are expected for any of the pollutants studied.

This assessment provides the following conclusions on predicted air quality impacts from the depositions of SO_2 and NO_2 due to emissions from the proposed INPEX facility:

- NO_2 depositions due to emissions from the proposed gas processing facility on Blaydin Point would be insignificant.
- The very low sulfur emissions from the proposed development would contribute an insignificantly small amount to SO_2 deposition in the region surrounding Blaydin Point.

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12. Abbreviations and Acronyms

ACGIH – American Conference of Governmental Industrial Hygienists

AEC – Australian Environment Council

ANZSIC – Australia New Zealand Standard Industrial Classification

BoM – Bureau of Meteorology

BTEX – Benzene, toluene, ethyl-benzene and xylenes

CAO –Civil Aviation Organisation

CO – Carbon monoxide

CO_2 – Carbon dioxide

DEC – Department of Environment and Conservation (DEC)

DEH – Department of Environment and Heritage

DEWR – Department of Environment and Water Resources

EA – Environment Australia

EPA – Environmental Protection Authority (Western Australia)

EPP – Environment Protection Policy

MOF – Module offloading facilities

NEPC – National Environment Protection Council

NEPM – National Environment Protection Measure

NHMRC – National Health and Medical Research Council

NO_2 – Nitrogen dioxide

NO_3 – Nitrate

NO_x – Oxides of nitrogen

NOHSC – National Occupational Health and Safety Commission

NPI – National Pollutant Inventory

NRETAS – Natural Resources, Environment, The Art and Sport

O_2 – Oxygen

O_3 – Ozone

OSHA – Occupational Safety and Health Administration (US)

PAH – Polycyclic aromatic hydrocarbons

PEL – Permissible Exposure Limit

PM – Particulate matter

$PM_{2.5}$ – Particulate matter less than 2.5 microns in aerodynamic diameter

PM_{10} – Particulate matter less than 10 microns in aerodynamic diameter

POJ – Product offloading jetty

SKM – Sinclair Knight Merz

SO_2 – Sulfur dioxide

SO_x – Oxides of sulfur

STEL – Short term exposure limit

TRC – TRC Companies, Inc

TWA – Time Weighted Average

USEPA – United States Environment Protection Agency

VOC – Volatile organic Compound

WHO – World Health Organisation

Appendix A   Spatial Distribution of Vegetation Types
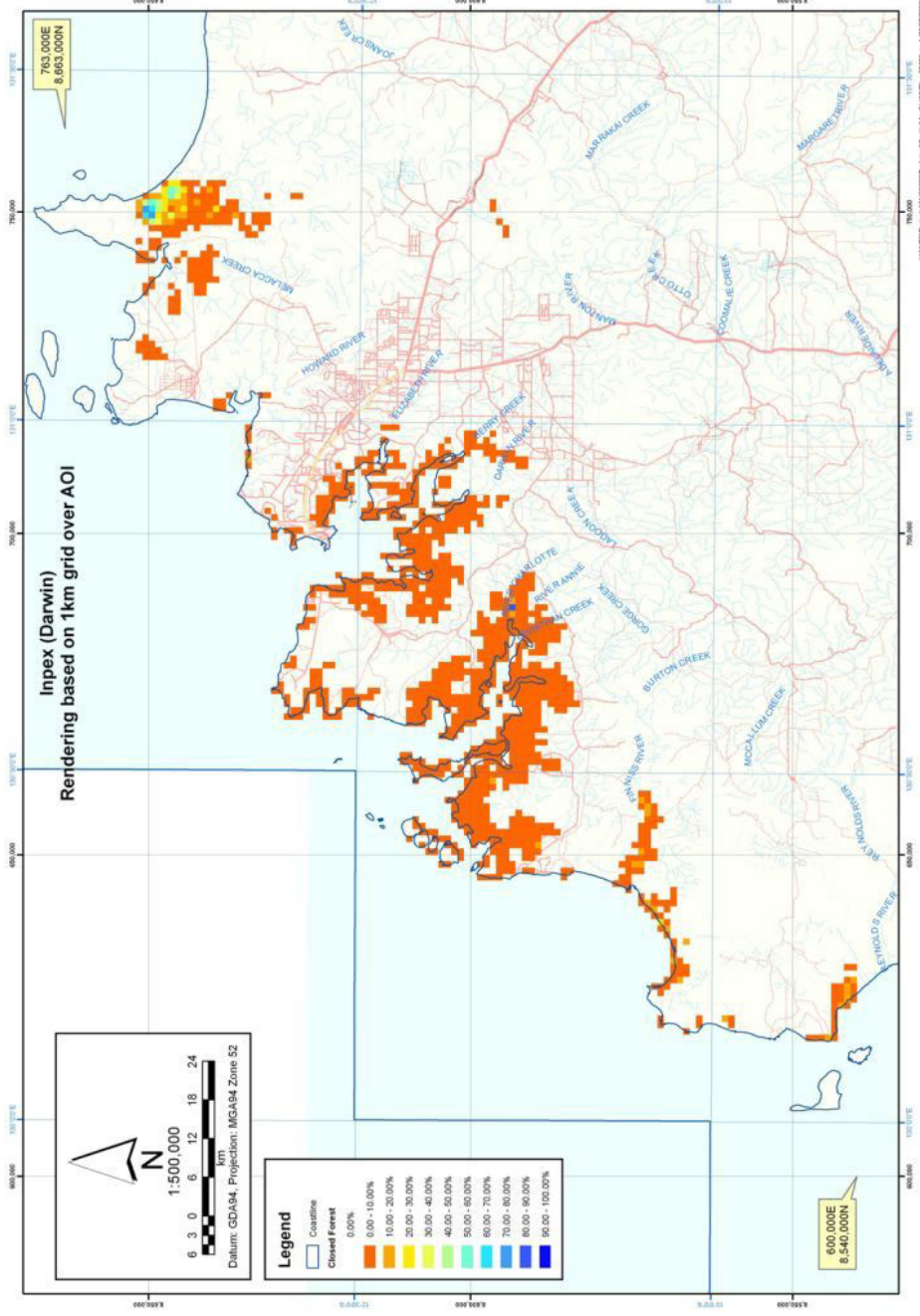
■ **Figure 50 Vegetation density of closed forest in the Darwin study region**
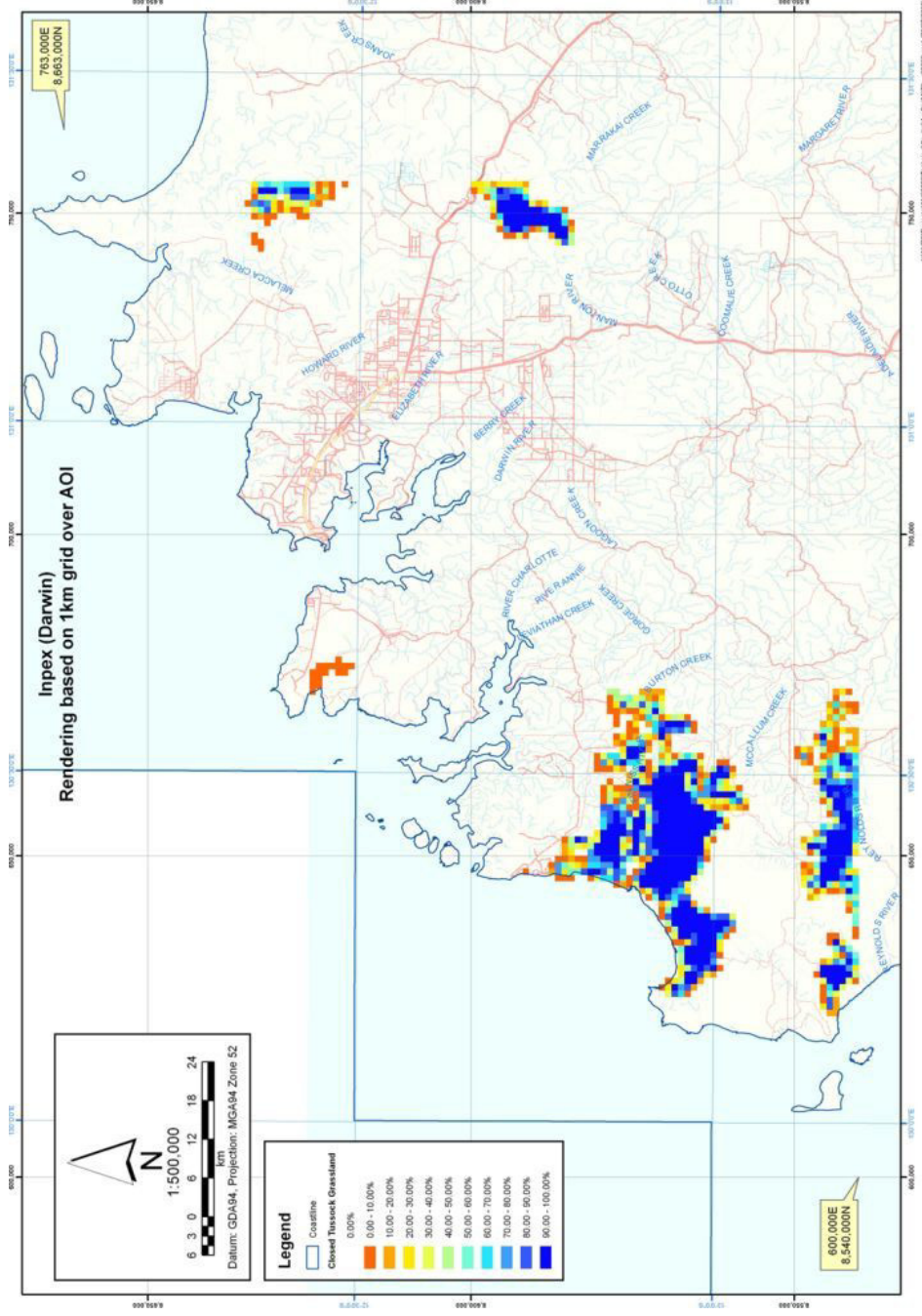
■ **Figure 51 Vegetation density of closed tussock grassland in the Darwin study region**

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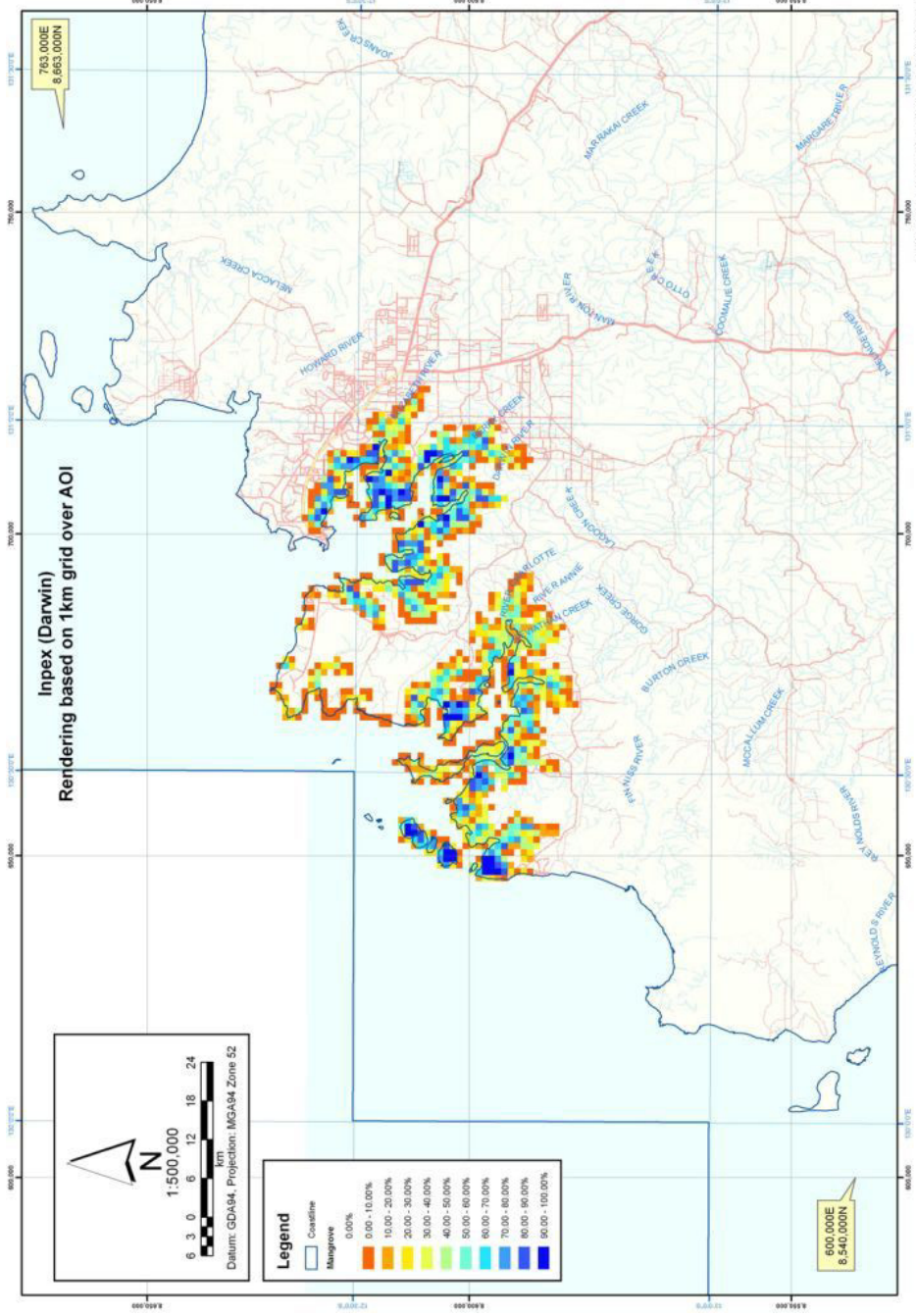
- **Figure 52 Vegetation density of Mangroves in the Darwin study region**

SINCLAIR KNIGHT MERZ
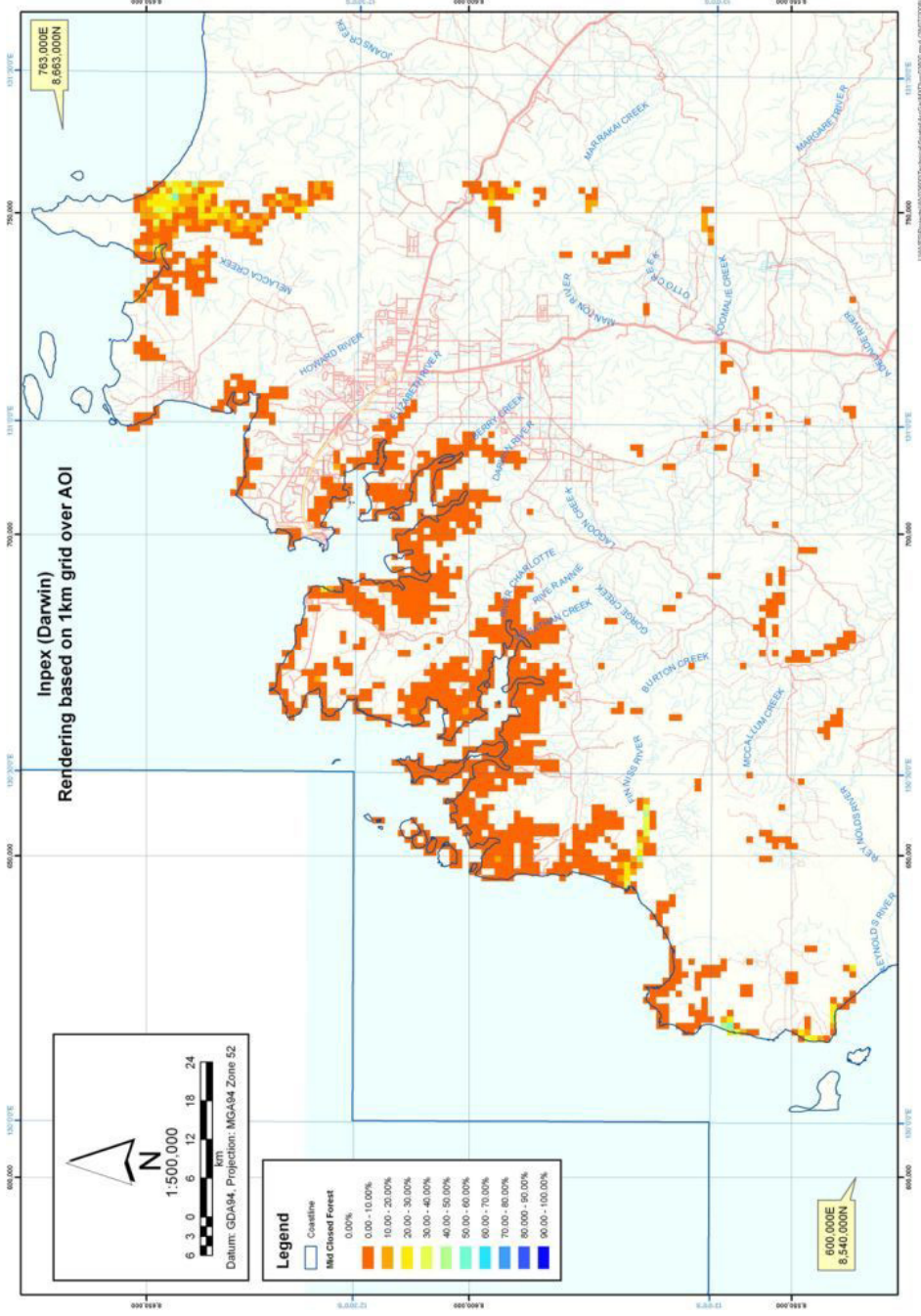
Figure 53 Vegetation density of mid closed forest in the Darwin study region

SINCLAIR KNIGHT MERZ
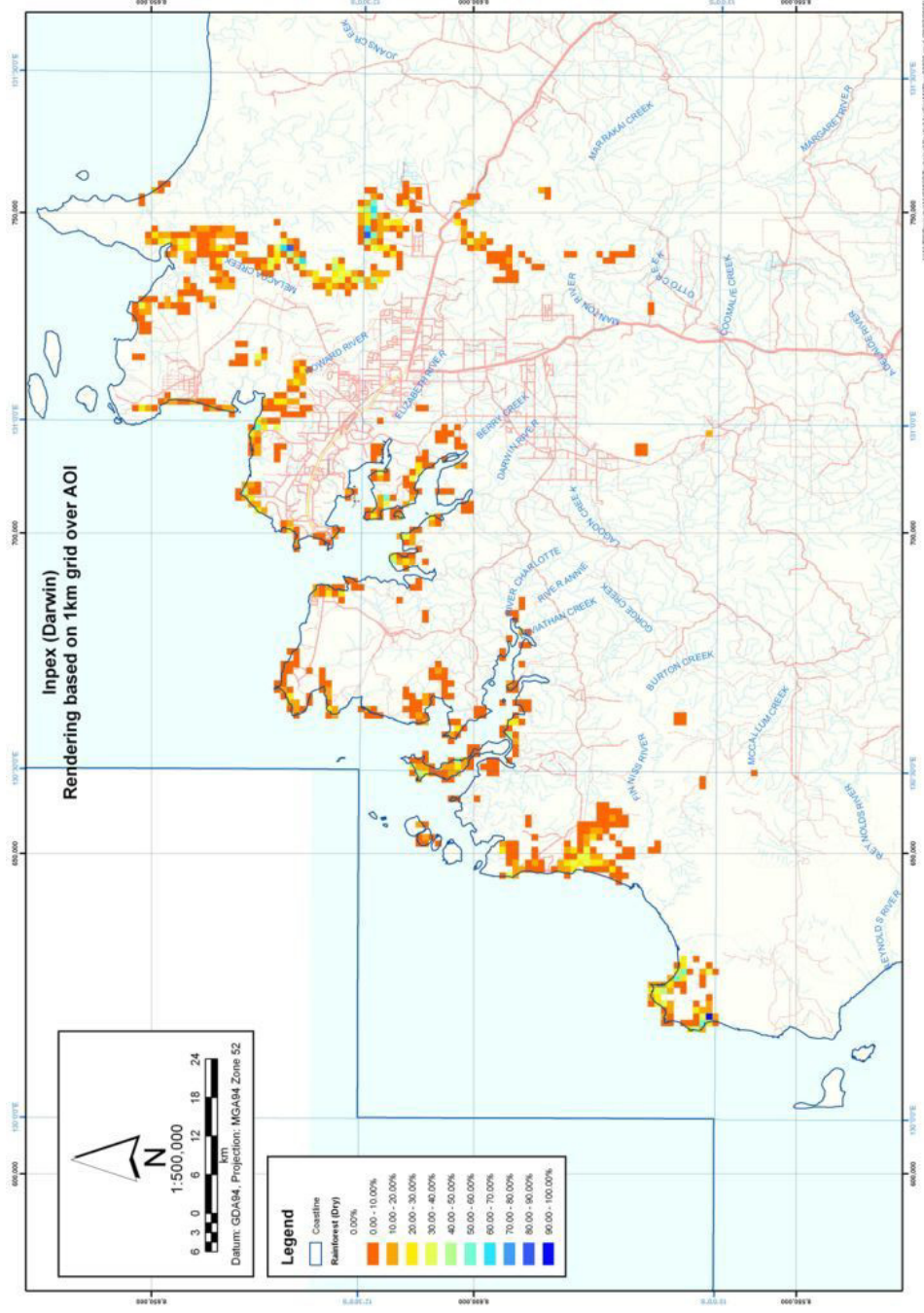
■ **Figure 54 Vegetation density of dry rainforest in the Darwin study region**

SINCLAIR KNIGHT MERZ
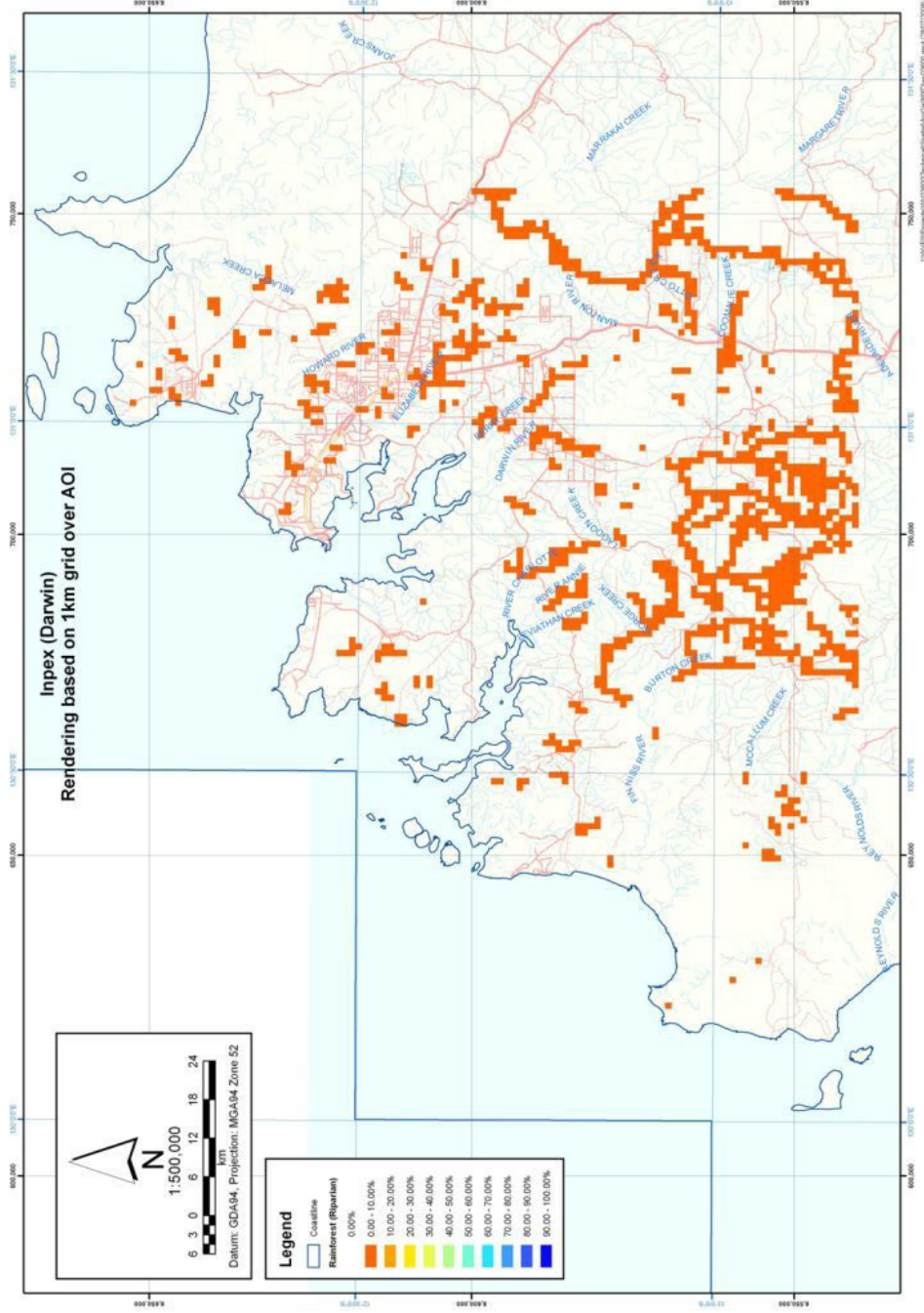
Figure 55 Vegetation density of riparian rainforest in the Darwin study region

SINCLAIR KNIGHT MERZ
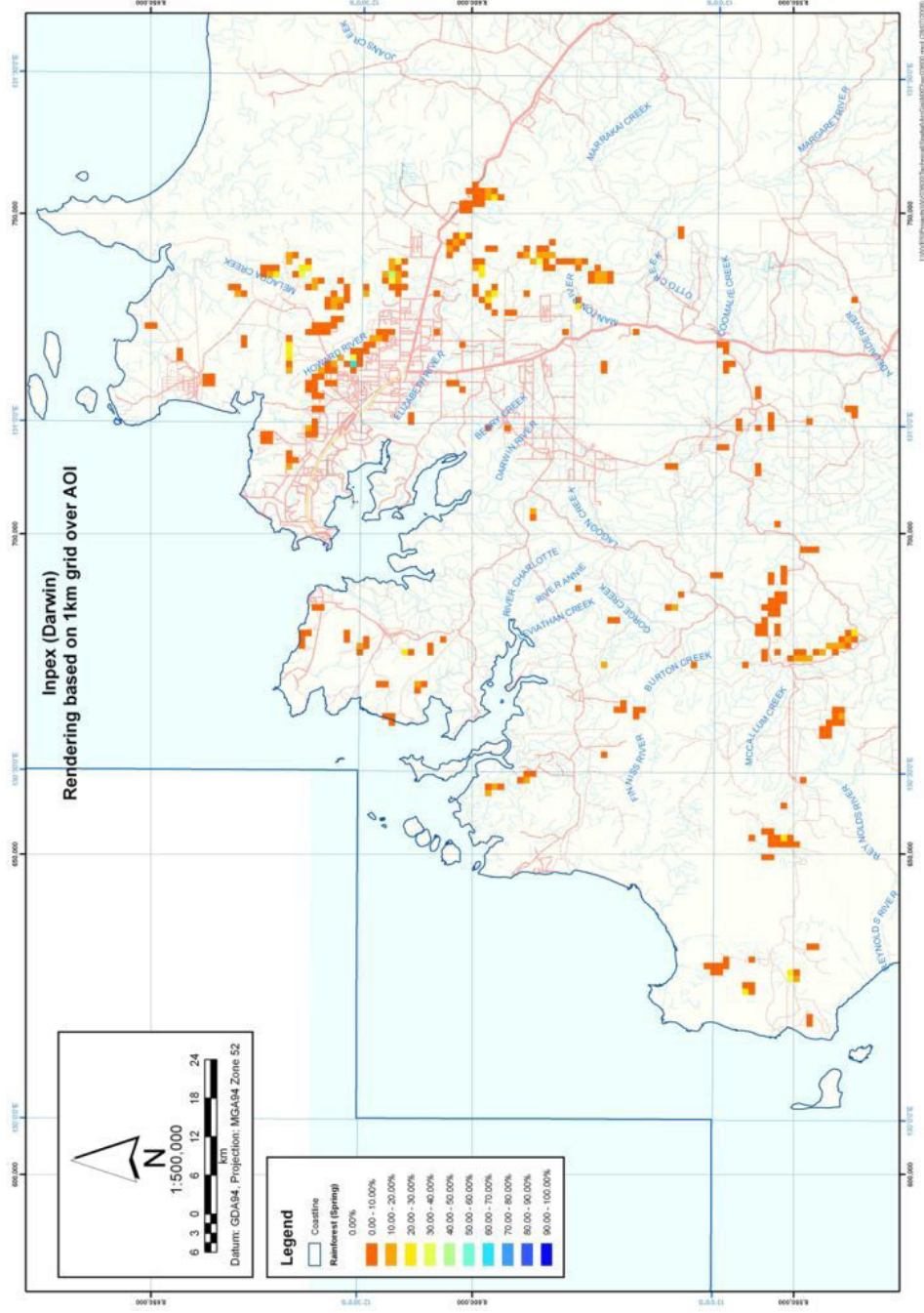
Figure 56 Vegetation density of spring rainforest in the Darwin study region

SINCLAIR KNIGHT MERZ
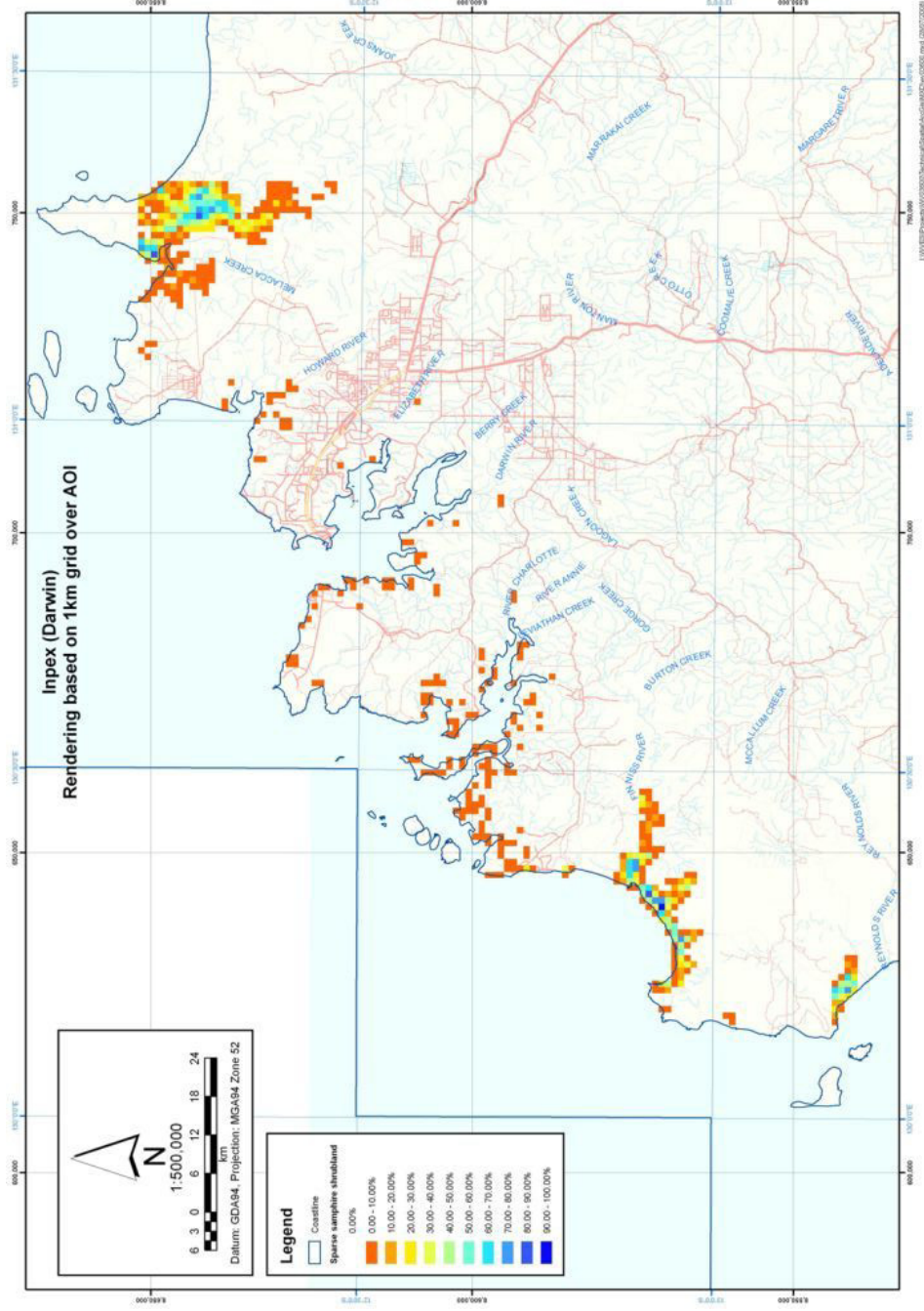
■ **Figure 57 Vegetation density of sparse samphire shrubland in the Darwin study region**

SINCLAIR KNIGHT MERZ
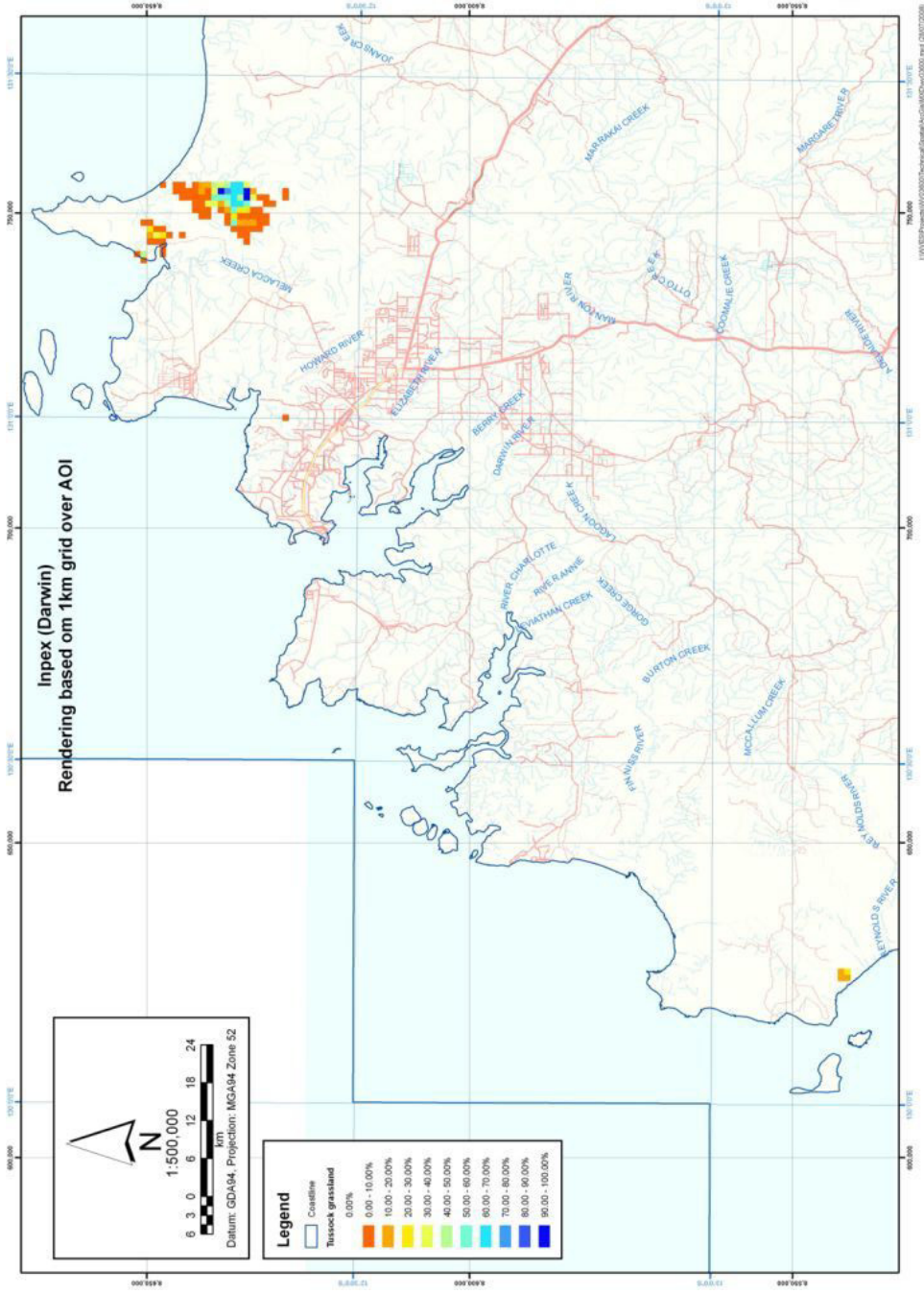
▪ **Figure 58 Vegetation density of tussock grassland in the Darwin study region**

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Appendix B   TAPM *.lis File

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|-----------------------------------|
| THE AIR POLLUTION MODEL (TAPM V3.0.7). |
| Copyright (C) CSIRO Australia.         |
| All Rights Reserved.                   |
|----------------------------------------|

 ----------------
 RUN INFORMATION:
 ----------------
 NUMBER OF GRIDS=                4
 GRID CENTRE (longitude,latitude)=(   130.9250      ,  -12.51667      )
 GRID CENTRE (cx,cy)=(       708990 ,     8615020 ) (m)
 GRID DIMENSIONS (nx,ny,nz)=(           31 ,          31 ,         25 )
 NUMBER OF VERTICAL LEVELS OUTPUT =          20
 DATES (START,END)=(    20050122 ,    20050331 )
 DATE FROM WHICH OUTPUT BEGINS =    20050124
 LOCAL HOUR IS GMT+  8.700000
 SYNOPTIC WIND SPEED MAXIMUM =          30 (m/s)
 SYNOPTIC PRESSURE-GRADIENT SCALING FACTOR =   1.000000
 SYNOPTIC PRESSURE-GRADIENT FILTERING FACTOR =   1.000000
 VARY SYNOPTIC WITH 3-D SPACE AND TIME
 INCLUDE VEGETATION
 EXCLUDE NON-HYDROSTATIC EFFECTS
 INCLUDE PROGNOSTIC RAIN EQUATION
 EXCLUDE PROGNOSTIC SNOW EQUATION
 INCLUDE PROGNOSTIC EDDY DISSIPATION RATE EQUATION
 POLLUTION : CHEMISTRY (APM,NOX,NO2,O3,SO2,FPM)
 EXCLUDE POLLUTANT CROSS-CORRELATION EQUATION
 EXCLUDE POLLUTANT VARIANCE EQUATION
 EXCLUDE 3-D POLLUTION OUTPUT (*.C3D)
 POLLUTANT GRID DIMENSIONS (nxf,nyf)=(           57 ,          57 )
 BACKGROUND APM   =  0.0000000E+00 (ug/m3)
 BACKGROUND NOX&NO2=  0.0000000E+00 (ppb)
 BACKGROUND O3    =   20.00000     (ppb)
 BACKGROUND Rsmog =  0.0000000E+00 (ppb)
 BACKGROUND SO2   =  0.0000000E+00 (ppb)
 BACKGROUND FPM   =  0.0000000E+00 (ug/m3)
 pH of liquid water=  4.500000

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 START GRID           1 D:\TAPM_Run\INPEX\Darwin\RoutineA_23Sep09\InDarA300a
 METEOROLOGY IS BEING INPUT FROM *.M3D FILES
 GRID SPACING (delx,dely)=(        30000 ,        30000 ) (m)
 POLLUTANT GRID SPACING (delxf,delyf)=(        15000 ,        15000 ) (m)
 NO CONCENTRATION BACKGROUND FILE AVAILABLE
 NO BUILDING FILE AVAILABLE
 NUMBER OF pse SOURCES=           80
 NO lse EMISSION FILE AVAILABLE
 NO ase EMISSION FILE AVAILABLE
 USING gse EMISSIONS AND MIXING THEM OVER FIRST           1 LEVEL(S)
 NO bse EMISSION FILE AVAILABLE
 NO whe EMISSION FILE AVAILABLE
 USING vpx EMISSIONS AND MIXING THEM OVER FIRST           1 LEVEL(S)
 USING vdx EMISSIONS AND MIXING THEM OVER FIRST           1 LEVEL(S)
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SINCLAIR KNIGHT MERZ

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USING vlx EMISSIONS AND MIXING THEM OVER FIRST           1 LEVEL(S)
USING vpv EMISSIONS AND MIXING THEM OVER FIRST           1 LEVEL(S)
INITIALISE
LARGE TIMESTEP =   300.0000
METEOROLOGICAL ADVECTION TIMESTEP =   300.0000      (s)
 Deep Soil Moisture Content (kg/kg)=  0.1500000
 Deep Soil & Sea Temperatures (K)  =   301.0000        301.0000
POLLUTION ADVECTION TIMESTEP =   300.0000     (s)
pse KEY :
is    = Source Number
ls    = Source Switch (-1=Off,0=EGM,1=EGM+LPM)
xs,ys = Source Position (m)
hs    = Source Height (m)
rs    = Source Radius (m)
es    = Buoyancy Enhancement Factor
fs_no = Fraction of NOX Emitted as NO
fs_fpm= Fraction of APM Emitted as FPM
INIT_pse
  is, ls,        xs,        ys,        hs,        rs,        es,      fs_no,      fs_fpm
   1,  0,  702955., 8615220.,   13.70,      0.42,      1.80,      0.90,      0.50,
   2,  0,  702816., 8615047.,   12.20,      1.75,      2.00,      0.90,      0.50,
   3,  0,  702825., 8615055.,   12.20,      1.75,      2.00,      0.90,      0.50,
   4,  0,  702833., 8615064.,   12.20,      1.75,      2.00,      0.90,      0.50,
   5,  0,  702842., 8615073.,   12.20,      1.75,      2.00,      0.90,      0.50,
   6,  0,  702852., 8615082.,   12.20,      1.75,      2.00,      0.90,      0.50,
   7,  0,  702861., 8615091.,   12.20,      1.75,      2.00,      0.90,      0.50,
   8,  0,  702870., 8615100.,   12.20,      1.75,      2.00,      0.90,      0.50,
   9,  0,  702879., 8615109.,   12.20,      1.75,      2.00,      0.90,      0.50,
  10,  0,  703128., 8615065.,   24.00,      0.92,      2.50,      0.90,      0.50,
  11,  0,  703136., 8615074.,   24.00,      0.92,      2.50,      0.90,      0.50,
  12,  0,  703145., 8615082.,   24.00,      0.92,      2.50,      0.90,      0.50,
  13,  0,  703155., 8615090.,   24.00,      0.92,      2.50,      0.90,      0.50,
  14,  0,  702955., 8615240.,   13.70,      0.42,      1.80,      0.90,      0.50,
  15,  0,  703029., 8615260.,   12.20,      1.75,      2.00,      0.90,      0.50,
  16,  0,  703038., 8615268.,   12.20,      1.75,      2.00,      0.90,      0.50,
  17,  0,  703046., 8615277.,   12.20,      1.75,      2.00,      0.90,      0.50,
  18,  0,  703055., 8615286.,   12.20,      1.75,      2.00,      0.90,      0.50,
  19,  0,  703065., 8615295.,   12.20,      1.75,      2.00,      0.90,      0.50,
  20,  0,  703074., 8615304.,   12.20,      1.75,      2.00,      0.90,      0.50,
  21,  0,  703083., 8615313.,   12.20,      1.75,      2.00,      0.90,      0.50,
  22,  0,  703092., 8615322.,   12.20,      1.75,      2.00,      0.90,      0.50,
  23,  0,  703341., 8615278.,   24.00,      0.92,      2.50,      0.90,      0.50,
  24,  0,  703349., 8615287.,   24.00,      0.92,      2.50,      0.90,      0.50,
  25,  0,  703358., 8615295.,   24.00,      0.92,      2.50,      0.90,      0.50,
  26,  0,  703721., 8614758.,   13.70,      0.45,      2.00,      0.90,      0.50,
  27,  0,  703721., 8614778.,   13.70,      0.45,      2.00,      0.90,      0.50,
  28,  0,  702250., 8614747.,   13.00,      1.98,      1.00,      0.90,      0.50,
  29,  0,  703240., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  30,  0,  703270., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  31,  0,  703300., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  32,  0,  703330., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  33,  0,  703360., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  34,  0,  703400., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  35,  0,  703240., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  36,  0,  703270., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  37,  0,  703300., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  38,  0,  703330., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  39,  0,  703360., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  40,  0,  703400., 8615390.,    3.00,      7.90,      1.00,      0.90,      0.50,
  41,  0,  702745., 8611360.,   33.00,      1.93,      2.50,      0.90,      0.50,
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42,    0,   702765., 8611365.,    33.00,     1.93,     2.50,     0.90,     0.50,
43,    0,   702780., 8611370.,    33.00,     1.93,     2.50,     0.90,     0.50,
44,    0,   702800., 8611380.,    33.00,     1.93,     2.50,     0.90,     0.50,
45,    0,   702820., 8611385.,    33.00,     1.93,     2.50,     0.90,     0.50,
46,    0,   702845., 8611395.,    13.72,     1.93,     1.00,     0.90,     0.50,
47,    0,   711760., 8608845.,    15.00,     1.80,     1.00,     0.90,     0.50,
48,    0,   704135., 8618670.,    37.60,     2.00,     1.00,     0.90,     0.50,
49,    0,   704367., 8618500.,    37.60,     2.00,     1.00,     0.90,     0.50,
50,    0,   704540., 8618365.,    37.60,     2.00,     1.00,     0.90,     0.50,
51,    0,   700960., 8614716.,    37.60,     2.00,     1.00,     0.90,     0.50,
52,    0,   701090., 8620740.,    37.60,     2.00,     1.00,     0.90,     0.50,
53,    0,   708479., 8615558.,    65.00,     2.85,     1.00,     0.90,     0.50,
54,    0,   708618., 8615297.,    65.00,     2.85,     1.00,     0.90,     0.50,
55,    0,   708704., 8615678.,    65.00,     2.85,     1.00,     0.90,     0.50,
56,    0,   708843., 8615417.,    65.00,     2.85,     1.00,     0.90,     0.50,
57,    0,   708715., 8614984.,    40.00,     1.44,     1.00,     0.90,     0.50,
58,    0,   708767., 8615012.,    40.00,     1.44,     1.00,     0.90,     0.50,
59,    0,   708789., 8615023.,    40.00,     1.44,     1.00,     0.90,     0.50,
60,    0,   708841., 8615051.,    40.00,     1.44,     1.00,     0.90,     0.50,
61,    0,   708863., 8615063.,    40.00,     1.44,     1.00,     0.90,     0.50,
62,    0,   708916., 8615091.,    40.00,     1.44,     1.00,     0.90,     0.50,
63,    0,   708937., 8615102.,    40.00,     1.44,     1.00,     0.90,     0.50,
64,    0,   708990., 8615130.,    40.00,     1.44,     1.00,     0.90,     0.50,
65,    0,   708943., 8615158.,    40.00,     1.44,     1.00,     0.90,     0.50,
66,    0,   708711., 8615384.,    30.00,     2.25,     1.00,     0.90,     0.50,
67,    0,   708936., 8615504.,    30.00,     2.25,     1.00,     0.90,     0.50,
68,    0,   708855., 8615122.,    50.00,     1.55,     1.00,     0.90,     0.50,
69,    0,   708872., 8615132.,    50.00,     1.55,     1.00,     0.90,     0.50,
70,    0,   708317., 8614995.,     4.00,    47.00,     1.00,     0.90,     0.50,
71,    0,   708506., 8614639.,     4.00,    52.00,     1.00,     0.90,     0.50,
72,    0,   708557., 8614543.,     4.00,    20.00,     1.00,     0.90,     0.50,
73,    0,   707795., 8615348.,    33.00,    19.00,     1.00,     0.90,     0.50,
74,    0,   707809., 8615321.,    33.00,    19.00,     1.00,     0.90,     0.50,
75,    0,   708778., 8615073.,    40.00,     1.25,     1.00,     0.90,     0.50,
76,    0,   708795., 8615083.,    40.00,     1.25,     1.00,     0.90,     0.50,
77,    0,   708444., 8614757.,     4.00,    52.00,     1.00,     0.90,     0.50,
78,    0,   708378., 8614880.,     4.00,    56.00,     1.00,     0.90,     0.50,
79,    0,   707825., 8615291.,    28.00,    16.00,     1.00,     0.90,     0.50,
80,    0,   707839., 8615265.,    28.00,    16.00,     1.00,     0.90,     0.50,
LAGRANGIAN (LPM) MODE IS OFF FOR THIS GRID
IN_pse
IN_gse
IN_vpx
IN_vdx
IN_vlx
IN_vpv
DATE=20050122,HOUR= 1
IN_pse
REWIND_pse
IN_gse
REWIND_gse
IN_gse
IN_vpx
REWIND_vpx
IN_vpx
IN_vdx
REWIND_vdx
IN_vdx
IN_vlx
REWIND_vlx
```

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 IN_vlx
 IN_vpv
 REWIND_vpv
IN_vpv
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