Pluto LNG Air Quality Management Plan

December 2019

Revision 4

TABLE OF CONTENTS

Acronyms and Abbreviations

Acronym / Abbreviation	Definition
AGRU	Acid Gas Removal Unit
aMDEA	Activated methyl diethanolamine
BAAMP	Burrup Ambient Air Monitoring Program
BTX	Benzene, Toluene, Xylene
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide equivalent
CSU	Commissioning and Start-up
DLN	Dry Low NOx
DWER	Department of Water and Environmental Regulation
EAR	Environmental Assessment Report
EPA	Environment Protection Authority
GHG	Greenhouse Gases
GLCs	Ground Level Concentrations
GTC	Gas Turbine Compressors
GTG	Gas Turbine Generator
LNG	Liquified Natural Gas
MGA	Map Grid Australia
MS 757	Ministerial Statement 757
N_2	Nitrogen
NEPM	National Environment Protection Measure
NO	Nitrous Oxide
NO_X	Oxides of Nitrogen
NPI	National Pollutant Inventory
NSW	New South Wales
O_2	Oxygen
O_3	Ozone
PER	Public Environmental Review
PM_{10}	Particulate Matter 10 micrometres or less in diameter
$PM_{2.5}$	Particulate Matter 2.5 micrometres or less in diameter
RTO	Regenerative Thermal Oxidiser
RcTO	Recuperative Thermal Oxidiser

Acronym / Abbreviation	Definition
SO_X	Oxides of Sulfur
SO_2	Sulfur Dioxide
TAPM	"The Air Pollution Model"
VOCs	Volatile Organic Compounds
WA	Western Australia
WBPL	Woodside Burrup Pty Ltd
WEL	Woodside Energy Limited

1. Introduction

This plan outlines how air emissions will be managed and monitored for the Pluto Liquefied Natural Gas (LNG) facility and provides an Air Quality Management Plan required for the operations phase of the plant, post approval of the plan by the Office of the Environmental Protection Authority (EPA).

Woodside was granted approval by the Western Australian (WA) Minister for the Environment to implement the proposed Pluto LNG, contingent on meeting the conditions contained in the Ministerial Statement 757 (MS 757) [20] and amendment MS850. Condition 11 relates specifically to air quality management during the operations phase of the development, now called Pluto LNG. Construction of the first of two LNG trains permitted by the approval commenced in 2007, with commissioning occurring over the period 2010 to 2013. Routine operation of the Pluto LNG facility commenced April 2012, with Operational Licence L8752/2013/1 [21] issued in July 2013.

On 1 July 2019, the Minister approved a section 45C to implement changes to the Pluto Liquefied Natural Gas Development (Site B Option) as approved under MS 757 (*Pluto LNG Gas Development: Application under section 45C of the Environmental Protection Act 1986 (WA) – Pluto Expansion. Document number: SA0006AH0000001*) [20].

The following minor changes were approved by the section 45C:

- Deletion of the described gas field from the Proposal preamble, to clarify that gas from other fields can be processed at Pluto LNG (as per the Public Environmental Review);
- Deletion of the described gas turbine types used to drive the liquefaction compressors and for power generation from Schedule 1, to allow for greater flexibility in turbine design;
- Inclusion of gas export via shipping, trucking or piping to Schedule 1, to reflect the existence of the Pluto LNG trucking facility and proposed Pluto-North West Shelf Interconnector.

As part of commencing design and construction activities associated with Pluto Train 2 under the existing approval, this revised Air Quality Management Plan has been prepared to meet the requirements of Condition 11 of MS 757 and amendment MS 850.

Independent reviews of the previous air quality modelling have demonstrated consistency between modelling and subsequent operational air quality monitoring programs. Modelling investigations focussed on human health and vegetation impacts as well as potential emission deposition impacts on rock art across the Burrup Peninsula. Further refinements of the modelling supporting this plan show that Pluto Train 2 air emissions and impacts remain within the existing MS 757 approval.

The modelling shows there is minimal difference between existing NO_2 deposition rates and the modelled future state with Pluto Train 2 in operation, both of which are within the Pluto Public Environment Review deposition monitoring projections.

1.1 Scope

This Air Quality Management Plan has been developed to fulfil the requirements of MS 757 (and amendment MS 850) Condition 11-2 (Refer to Box 1).

This Plan provides a framework for management of emissions to air, founded on a risk-based approach. Implementation of this Plan will follow its approval by the EPA.

Management of greenhouse gases is outside the scope of this Plan and is detailed in the Pluto Greenhouse Gas Abatement Program [32] submitted to fulfil Condition 12 of MS 757

[20] and approved in October 2007. The Pluto Greenhouse Gas Abatement Program [32] will be amended to account for Pluto Train 2.

Revision 1 of the Pluto - Air Quality Management Plan [29] was approved by Office of the EPA (EPA) on 10 November 2011 with a subsequent addendum approved in 2017. Revision 1 of the Pluto - Air Quality Management Plan detailed the following items:

- Outcomes of cumulative air quality modelling and emissions assessments
- Proposed targets and standards for air emissions from the operating facilities
- An air emissions monitoring program
- An ambient air and nitrogen deposition monitoring program
- Management of change
- An annual reporting regime.

Revision 2 of this Plan was provided for information in 2011 detailing the Pluto Nitrogen Deposition Program (Section 9).

This revision (Revision 4) of the plan reflects updates to support the construction and operation of Train 2 of the Pluto LNG facility, and to ensure that additional emissions of odorous substances and substances with the potential to impact human health from the operation of the second train are managed appropriately.

1.2 Description of Operator

Woodside Burrup Pty Ltd, a wholly owned subsidiary of Woodside Energy Limited (WEL), is operator of Pluto LNG. References in this plan to “Woodside” may be references to Woodside Petroleum Ltd or its applicable subsidiaries.

Based in Perth, Western Australia (WA), Woodside has major operational assets and exploration and development interests in six continents including Australia and the United States. In 60 years, Woodside has grown from a pioneer oil and gas explorer to Australia’s largest independent oil and gas company.

Woodside has been operating one of Australia’s largest resources projects, the North West Shelf Project in WA, since 1984. With the successful start-up of the Pluto LNG facility in 2012, Woodside now operates six LNG processing trains in Australia. Woodside also operates four oil floating production storage and offloading vessels in the Carnarvon Basin, North West Shelf and Timor Sea.

Woodside Burrup Pty. Ltd. is the proponent for Pluto LNG and is also operator, on behalf of itself and joint venture partners Tokyo Gas and Kansai Electric.

Further information about Woodside and Pluto LNG can be found on http://www.woodside.com.au.

1.3 Project Background

The Pluto gas field was discovered in April 2005 and is located on the North West Shelf of Western Australia, approximately 190 km north-west of Dampier.

Woodside currently operates Production Licence WA-34-L which incorporates the Pluto gas field and has developed the field through an offshore subsea gathering system connected to an offshore riser platform. Gas and liquids are then exported to shore via a trunkline for processing.

MS 757 was granted for two trains to a capacity of 12 million tonnes per annum (Mtpa). Pluto LNG is currently a 4.9 Mtpa loadable capacity single-train LNG plant with the first cargo shipped in 2012.

Woodside is proposing a brownfield expansion of Pluto LNG through the construction of a second gas processing train. A final investment decision is targeted for 2020 and ready for start-up is targeted for 2024.

1.4 Context

The sources, characteristics, impacts and management of air emissions generated for Pluto LNG have been discussed in detail in the Public Environmental Review (PER) [22] and Supplement and Response to Submissions [23]. Since the publication of the PER and Response to Submissions, further assessments have been undertaken in order to address recommendations made by the Department of Water and Environment Regulation (DWER) and EPA, as well as meet Ministerial Conditions.

This revision of the existing Air Quality Management Plan addresses the requirements of MS 757 (and amendment 850) (Refer to Box 1) relating to control of air emissions and air quality management from Pluto LNG (Condition 11-2).

Box 1 – Extract from Ministerial Statement MS 757 (2007) [20]

11 Air Emissions

11-1 Prior to submitting a Works Approval application for the plant, the proponent shall submit a detailed Front End Engineering Design Report demonstrating that the proposed works adopt best practice pollution control measures to minimise emissions from the plant, to the requirements of the Minister for the Environment on advice of the Environmental Protection Authority.

This Report shall:

- *set out the base emission rates for major sources for the plant and the design emission targets; and*
- *address normal operations, shut-down, and start-up, and equipment failure conditions*

11-2 At least three months prior to commencement of operations, the proponent shall prepare an Air Quality Management Plan to the requirements of the Minister for the Environment.

The objective of this Plan is to ensure that best available practicable and efficient technologies are used to minimise and monitor air emissions from the plant.

This Plan shall include:

1. *cumulative air quality modelling which uses data from the Front End Engineering Design Report and includes emissions from approved industrial sources at Cape Preston and Barrow Island;*
2. *proposed targets and standards;*
3. *an emissions monitoring programme, which includes nitrogen compounds, butene, toluene, ethylene, xylene, ozone, acrylene and hydrogen sulphide emissions from the plant;*
4. *an ambient air monitoring programme and a nitrogen deposition monitoring programme; and*
5. *annual reporting.*

11-3 The proponent shall implement the Air Quality Management Plan required by Condition 11-2.

11-4 The proponent shall make the Air Quality Management Plan required by condition 11-2 publicly available in a manner approved by the CEO.

Since MS 757 was released, Woodside has prepared and submitted a Best Practice Air Emissions Report [24] (as required by Condition 11-1) which describes several design and operational measures taken to mitigate and minimise potential environmental impacts arising from emissions. This report addresses in detail, the expected performance of the facility and relates to potential worst-case impacts at sensitive receptors, identified through cumulative ambient air quality modelling. This was accepted by the Minister for the Environment in November 2008.

Air emissions were further assessed as part of the Works Approval for the first LNG train and associated facilities, which was granted in August 2008 (WA4444/2008/1, [27]). This assessment considered additional information available following detailed plant design that had taken place since the issue of the Pluto LNG Development Draft PER in 2006 [22].

To fulfil requirements of Condition 5(ii) of the LNG facilities Works Approval, Woodside implemented an Emission Test Plan to support validation of the performance of the plant for Pluto LNG. Stack testing for verification and validation of Pluto's emission continued in line with testing detailed in the Pluto Licence L8752-2013-2 [21], with compliance documentation submitted to DWER.

An update of the Best Practice Air Emissions Report was prepared for the proposed Pluto Train 2 and was submitted in July 2019 to the EPA for assessment [31]. This 2019 update of the Air Quality Management Plan incorporates the air quality management aspects associated with the proposed Pluto Train 2.

2. Emissions Identification and Assessment

The most significant sources of air emissions for Trains 1 and 2 include:

- Gas turbine generators for electrical power and gas turbine compressors
- A regenerative thermal oxidiser (Pluto LNG (Train 1))
- Two recuperative thermal oxidisers (Pluto Train 2)
- Flares.

Primary air emissions from these sources include CO_2, CO, NO_X, particulate matter (as PM_{10}), SO_X, VOCs (including BTEX), O_2 and H_2O.

Management of air pollutants from Project sources during the initial operating phase of the project focused on the key emissions of oxides of nitrogen, with monitoring of other pollutants including benzene, toluene and isomers of xylene (BTX), carbon monoxide, oxides of sulfur and hydrogen sulfide also occurring. Pollutants which are not produced or emitted from the Pluto LNG processing system (butene, ethylene, acrylene) have not been monitored (as detailed in Revision 2).

In line with Revisions 1 and 2 of this Plan, independent review of the Ambient Air Quality Monitoring Program and the Nitrogen Deposition Monitoring Program was conducted by Golder Associates and submitted to the EPA [15 and 16]. In a letter from the EPA dated 2 July 2015, the EPA reduced the risk assessment of NO_X and O_3 to “low” based on the findings of the independent review. Therefore prior to the Senate inquiry into the protection of Aboriginal rock art of the Burrup Peninsula, all emissions to air from the Pluto LNG facility have been risk assessed as “Low” by the EPA. It is acknowledged that this assessment aligned then with studies and findings as part of historical CSIRO colour change and deposition monitoring. These studies related to a critical load (nitrogen and sulphur deposition flux) assessment sensitivity class of at least 200 $mEq/m^2/year$). This is further described in Sections 4.3 and 4.4.

2.1 Existing Air Quality

Woodside established the Burrup Ambient Air Monitoring Program (BAAMP) in 2008, which continued to 2011. As part of Pluto LNG operations, Woodside continued the monitoring program to the end of 2015 at a number of locations on the Burrup, at Dampier and Karratha. Prior to the more recent monitoring programs, the Pilbara Air Quality Study (PAQS) was undertaken by the Government of Western Australia in the early 2000s including investigations of monitoring data [18].

2.1.1 Air Quality Effects from Fires

There are a number of air quality reports that suggest bush fires noticeably impact the air quality in the Pilbara region. Air pollutant levels typically affected by bush fires are reported to be O_3, PM_{10}, carbon monoxide (CO), NO_X and NO_2. One source suggested that the highest O_3 levels detected at Karratha in 2012 may have been caused by fires rather than industrial sources [16 and 18].

2.1.2 Nitrogen dioxide and Ozone

NO_x (as an expression of the total amount of nitrogen dioxide (NO_2) and nitric oxide (NO)) and O_3 are key pollutants associated with Pluto LNG. Whilst NO_x is currently emitted, O_3 is a more complex process. In general, O_3 is not emitted directly from combustion and can be generated from NO_x and other pollutants such as VOCs and CO through a photochemical reaction that occurs in the presence of ultraviolet light [18].

The BAAMP results confirmed what was found in previous reviews; that NO_2 is typically observed well below the relevant NEPM (Ambient Air Quality) standard for NO_2 [3]. There is no ambient air quality standard for NO.

The monitoring results showed higher O_3 concentrations in Dampier and Karratha in comparison with NO_2. The opposite was the case for monitoring located closer to the sources on the Burrup Peninsula. An interpretation is NO_X, from industrial sources, was dispersed to lower concentrations by the time it reached the townships of Dampier and Karratha. Therefore, there was less NO_X in the townships to destroy the O_3 that built up to higher concentrations there.

Elevated ozone levels identified as short period anomalies in the Karratha 2012 were analysed as likely due to external sources, and not resulting from Pluto LNG emissions [16].

2.1.3 Benzene, Toluene and Xylene

Maximum hourly average concentrations of benzene measured at Dampier and Karratha over 2008-2010 never exceeded 3 ppb. The measured 90th percentile hourly average benzene concentrations at both locations was 0.1 ppb only.

The NEPM (Air Toxics) Monitoring Investigation Level (MIL) for benzene is 3 ppb as an annual average [4]. The ambient monitoring results reported the annual average concentration of benzene is typically less than 0.1 ppb.

From a review of all ambient air quality monitoring results over 2008-2015 for all monitoring locations, toluene and isomers of xylene were found to be lower levels than benzene [18].

Levels of benzene, toluene and isomers of xylene (BTX) during the monitoring program were typical of background levels.

2.1.4 $PM_{2.5}$ and PM_{10}

The existing environment is characterised by high levels of PM which is relevant to providing context of the existing air quality.

A review of 30 days of PM_{10} data for Karratha (10 April to 10 May 2019) indicates the 'clean air background' PM_{10} levels are approximately 10 µg/m^3, with a median or average closer to approximately 20 µg/m^3. These values are typical of PM_{10} concentrations measured in other parts of Australia [18].

Assessment of longer term PM_{10} data a Dampier indicates that PM_{10} concentrations peaked during higher wind speeds in January, with typical daily concentrations ranging between 30-40 µg/m^3. Exceedances of the NEPM (Ambient Air Quality) standard of 50 µg/m^3 were in the range of approximately 5-10 exceedances per year. Mid-year, during the dry season with corresponding lower wind speeds, typical daily concentrations varied between 10-20 µg/m^3 [18].

The review by Air Assessments (2010) indicated that measurements of PM_{10} at Dampier tend to be high, and "exceed the NEPM (Ambient Air Quality) standard" [3]. Air Assessments (2010) indicated the major sources of particulate matter in the Burrup region are:

- smoke from fires
- dust from wind storms
- iron ore stockpiling and ship-loading operations at the ports of Dampier and Cape Lambert.

Emissions of particulate matter from the on- shore gas plants were recognised as small and of little relevance in comparison with these other sources [18].

Golder [15, 16] reviewed $PM_{2.5}$ monitoring results acquired at Karratha, Dampier and Burrup monitoring stations from December 2011 to December 2012. Although a number of exceedances of NEPM standards for $PM_{2.5}$ were recorded at the three locations: based on back-trajectory analysis, flare rate, black smoke and $PM_{2.5}$ concentrations, Golder [15] concluded there was sufficient evidence to suggest that air emissions from the Pluto LNG Project were not associated with the exceedances. Also, iron ore handling was stated as a probable cause of exceedances of $PM_{2.5}$ standards detected at Dampier monitoring station.

2.1.5 Sulfur Dioxide

A review of SO_2 monitoring results on Burrup Peninsula utilising conservative assumptions were applied for a number of fixed industrial emissions sources, noting very low sulfur in fuel concentrations [18]. For this reason, estimates for exhaust SO_2 for most sources are at or near the limit of detection, thus a reasonable estimate for an annual average would be 0.1 ppb (the NEPM (Ambient Air Quality) standard for annual SO_2 is 20 ppb [3]).

Maximum hourly average concentrations would not be expected to exceed 10 ppb for most locations away from the most significant sources in the region, which are engine exhausts on ships. The comparable maximum hourly average NEPM (Ambient Air Quality) standard is 200 ppb [3].

2.1.6 Deposition of Nitrogen and Sulfur

On the Burrup Peninsula, Gillett (2008) determined total deposition flux of nitrogen and sulfur at a number of measurement sites in 2004/2005 and 2007/2008 by calculating the wet and dry deposition of all nitrogen and sulfur species in the gas and aqueous (rainwater) phases [13]. This included NO_2, SO_2, nitric acid and ammonia gases, and some other species in rainwater. The study showed that the total (wet and dry) deposition flux of nitrogen and sulfur ranged from 19.8-31.6 milliequivalents per square metre per year (mEq/m^2/year) over the two monitoring periods from 2004 to 2008. Units of 'mEq/m^2/year' were used to enable comparisons with previous monitoring results [14].

Dry deposition of NO_2 was estimated to contribute to between 16% and 36% of total deposition flux in the region (Gillett, 2008), and SO_2 6% to 8% based on 2004/2005 data. The 2007/2008 data ranged from 12% to 20% NO_2 contribution to total deposition flux, and from 4% to 7% for SO_2 (Gillett, 2008) [13].

Woodside engaged the CSIRO to determine nitrogen deposition flux on and around the Burrup Peninsula between February 2012 and June 2014; i.e., covering the periods before and after the commissioning of Pluto LNG (Gillett, 2014) [14]. A summary of results for the ranges of total measured nitrogen (N) and sulfur (S) fluxes is provided in Table 1. Dry NO_2 deposition is a sub-component of total measured deposition flux, and percent contribution is provided for comparative assessment with NO_2 deposition modelling outcomes - noting variations and uncertainties in both monitoring and modelling techniques.

Inspection of these results shows they have been reasonably consistent over a long period of sampling.

Table 1 - Summary of results for Burrup Nitrogen and Sulfur Deposition Monitoring Programs

Monitoring Program	Analytes	Range of Deposition (excluding background sites)	Dry Deposition NO_2 Fraction
2004–2005 and 2007–2008	Total nitrogen and sulfur	19.8 – 31.6 mEq/m^2/year	16%-36% of total N & S

2008–2009	Total nitrogen	18.4 – 32.9 mEq/m^2/year	19%-29% of total N only
2012–2014	Total nitrogen	17.1 – 28.8 mEq/m^2/year	17%-34% of total N only

2.2 Risk Assessment

Following approval and commissioning of Pluto LNG, an independent review of the Ambient Air Quality Monitoring Program and the Nitrogen Deposition Monitoring Program was conducted by Golder Associates [15 and 16], using monitoring data gathered by Woodside.

The Golder reviews concluded that the predicted emissions used during the development of the PER and Works Approval processes were consistent with the data obtained from the monitoring program implemented by Woodside following commissioning of Pluto LNG. As described above, the Golder reviews indicated that the environmental risk ratings of all emissions to air from the Pluto LNG facility were low.

To support the development of Pluto Train 2, the Pluto LNG Expansion Air Quality Impact Assessment [18] presents a screening method for relative risk assessment from Pluto LNG, calculated by the ratios between NPI emissions amounts (kg/annum), and a consistent set of air quality standards. The secondary pollutant ozone (O_3) is considered to present the highest risk of adverse air quality impact (in terms of potential impact to human health). The NSW EPA hourly assessment criteria (mg/m^3), was used for risk assessment purposes; noting: NO_2 risk was based on a 30% NO_2/NO_X ratio by mass; and O_3 risk was based on 70% of NO_X emission by mass (NWS EPA, 2016) [18].

It was noted by Jacobs (2019) [18] that benzene, although not listed as the highest potential risk VOC, is considered a 'trigger' emission that is representative of all other VOCs. Ambient air quality monitoring (Section 8) has indicated that benzene is consistently well below relevant standards and as such does not pose a credible human health risk.

CO concentrations from point source emissions are readily dispersed from exhaust stacks and are typically mixed well below criteria concentration within exhaust plumes. The results of previous air quality studies for CO [22] identified that all scenarios were less than 1% of the NEPM assessment criteria. Assessment indicates that there is only a very low risk of impacts on ambient air quality. As such these were excluded from additional modelling and ambient monitoring programs.

Jacobs also noted that H_2S could be considered a high-risk pollutant due to its very low odour threshold. However, given the feed gas has a very low content of sulfur, and the Burrup Peninsula has no known history of H_2S odour complaints, (essentially a null observation result), and H_2S was not identified as a key pollutant by any previous air quality studies, H_2S was not considered an emission of interest [18].

As a result of the risk assessments considered, the key parameters considered in the remainder of this document are shown in Table 2.

Table 2 – Major Equipment Emission Sources and Key Parameters

Emissions Source	Key Parameter	Marginal Contributor
Refrigeration Compressor Gas Turbines	NO_x, CO, CO_2, O_3 (secondary pollutant)	PM, VOCs, SO_2, N_2O
Power Generation Turbines	NO_x, CO, CO_2, O_3 (secondary pollutant)	PM, VOCs, SO_2, N_2O
Acid Gas Thermal Oxidisers	NO_x, CO, CO_2	PM, VOCs, SO_2, H_2S

Emissions Source	Key Parameter	Marginal Contributor
Nitrogen Rejection Unit Recuperative Thermal Oxidiser	NO_x, CO, CO_2	PM, VOCs
Flares	NO_x, CO, CO_2	PM, VOCs

Another identified key issue is the potential accelerated weathering of Aboriginal rock art prevalent across the Burrup Peninsula due to possible chemical interactions from the deposition of acidic compounds derived from airborne pollutants within the airshed. A CSIRO study assessing air pollution on the Burrup Peninsula in 2006 (22 years since the NWS Project facilities commenced operation) stated that while acid deposition fluxes were observed they were not considered to exceed a threshold that would be likely to adversely affect rock art (CSIRO, 2006) [6]. Subsequently, the Senate Environment and Communications References Committee's Report into the Protection of Aboriginal rock art of the Burrup Peninsula has highlighted that a suitable threshold is yet to be determined (Commonwealth of Australia, 2018) [5].

The 2017 CSIRO report assessed potential colour change across various petroglyph sites on the Burrup Peninsula using a standardised technique for recording colour. Analysis of the results has shown that while there has been some change, it is not occurring uniformly as would be expected if actual colour change associated with the petroglyphs was occurring (Duffy et al, 2017) [9].

The report indicates that there are no sites where the lightness of the engraving or background of the petroglyph has consistently increased or decreased; rather the lightness has done both over time at least twice, and not consistently across sites. The report also notes that there were no significant trends associated with a rate of colour change between control sites and sites closer to industrial activity (Duffy et al, 2017) [9].

There have been criticisms of methodology and interpretation of findings from some of the research studies and monitoring undertaken associated with rock art and relationship with anthropogenic emissions [7]. Consequently, the current position of DWER is that 'the weathering, alteration, or degradation of the rock art is currently not sufficiently well understood to enable unequivocal identification and quantification of changes to the integrity or condition of the rock art in response to changes in atmospheric emission, atmospheric deposition and contaminants interaction' [8]. As a result, no limits of 'acceptable' change have been established, nor any guideline 'trigger values' defined to inform proponents on the levels of NOx and SOx emissions that may result in impact to the rock art [7].

3. Summary of Controls and Management for Minimising Air Emissions

3.1 Pluto LNG Assessment of Best Practice

Prior to the commencement of construction at Pluto LNG (Train 1), Woodside prepared the "*Assessment of Best Practice for Minimising Emissions to Air from Major Plant*" [24] to meet the requirements of Condition 11-1 of MS757.

The assessment identified the following key emissions sources for Pluto LNG:

- Gas turbines for electrical power and compression driver
- Acid gas removal unit / regenerative thermal oxidiser
- Flaring

Measures to minimise emissions from Pluto LNG (Train 1) are summarised in "*Assessment of Best Practice for Minimising Emissions to Air from Major Plant*" [24]. Key technologies implemented in Pluto LNG (Train 1) design and operation include:

- DLN emissions control systems on gas turbines
- Specification of aMDEA in the acid gas removal system to reduce co-absorption of BTX and other hydrocarbons.
- Installation of a regenerative thermal oxidiser on the acid gas removal unit.
- Flare design integrated smokeless flaring technologies implemented for the storage and loading flare system, Cold dry flare, warm wet flare and common spare flare

3.2 Pluto Train 2 Assessment of Best Practice

An assessment of best practice has been undertaken by Woodside for Pluto Train 2 and is outlined in the report *"Assessment of Best Practice for Minimising Emissions to Air from Major Plant*" (Woodside, 2019) [31].

The assessment identified the gas turbines for electrical power and compression drivers, the acid gas removal units, the recuperative thermal oxidisers (RcTO) and flaring as the most significant sources of air emissions for the Pluto Train 2. The assessment includes an overview of the various definitions of best practice, a review of the best practice techniques for the minimisation of atmospheric emissions (in the context of gas turbines, thermal oxidisers and flares), and a discussion of the rationale behind technology selection for the Project.

Mitigation measures incorporated into the Pluto Train 2 design, as well as operational controls, for minimising air emissions are documented in detail in the "*Assessment of Best Practice for Minimising Emissions to Air from Major Plant*" [30]. A brief summary of these design and operational controls is provided in the following sections.

3.3 Gas Turbines

GE LM6000PF+ aero-derivative gas turbine with inlet air chilling and DLN emissions control systems have been selected as the driver for the main refrigeration compressors. Aero-derivative drive units have been successfully integrated with the ConocoPhillips Optimized Cascade® Process to be used in Pluto Train 2. They have the lowest NO_X emissions over a wide range of power loads and are considered best practice for this process. Aero-derivative drive units have been integrated in to four of the five most recent LNG developments in Australia.

The aero-derivatives have a higher thermal efficiency, a lower turndown and greater operational flexibility, allowing the process to be optimised to ensure maximum energy efficiency and lower emissions compared to if a carbon copy of Pluto Train 1 was to be adopted using heavy duty industrial frame turbines and scaled up in order to meet the project target LNG production rate for commercial viability.

The use of high efficiency aero-derivative gas turbine compressor drivers, with dry low NOX emissions control systems, combined with unfired waste heat recovery units, meets the criteria for best practice technology for LNG service.

A GE Frame 6B industrial gas turbine was selected to meet the additional power demand associated with Pluto Train 2. The GE Frame 6B industrial gas turbine can be easily integrated into the existing Pluto LNG power system, allowing it to be optimised to ensure maximum energy efficiency and sparing across the facility. It simplifies spares and maintenance and coupled with a proven DLN combustion system, allows for optimal NO_X performance over a wide range of power loads.

As per existing operations, GTG operations have been optimised to a point whereby, in winter one GTG can be switched off. This reduces GHG emissions, whilst maintaining sufficient operational reliability and availability. Post Pluto Train 2 commencing operations and reaching a steady state, best endeavours will be made to optimise the overall plant power to maximise the efficiency, reducing both fuel gas consumption and emissions.

3.4 Acid Gas Removal Unit (AGRU) and Recuperative Thermal Oxidiser

CO_2 is removed from the feed gas in the AGRU by active absorption using activated methyl diethanolamine (aMDEA). Some low levels of hydrocarbons, including BTX, are co-absorbed during the acid gas removal stage. Specification of aMDEA in the acid gas removal system, as opposed to traditional acid gas removal solvents, reduces the co-absorption of BTX and other hydrocarbons by approximately 90%. The thermal oxidisers convert the hydrocarbon fractions into oxidised by-products to minimise environmental impact and protect human health. This has a significant greenhouse saving, as well as occupational health benefits.

Rather than vent the waste gas stream from the AGRU (which consists mainly of CO_2, water and a small component of hydrocarbons, including BTX), waste gases are treated through a regenerative thermal oxidiser (Train 1) and a recuperative thermal oxidiser (Train 2).

Pluto LNG (Train 1) currently has a Regenerative Thermal Oxidizer (RTO) installed for combustion of the waste stream from the AGRU and no NRU thermal oxidizer given the feed gas stream composition.

Pluto Train 2 has selected to use Recuperative Thermal Oxidizer (RcTO) over a RTO for both the AGRU and NRU waste streams since RcTO's are:

- ideal for moderate VOC concentrations
- suitable for Secondary Heat Recovery
- typically, able to achieve destruction efficiency more than 99% of incoming levels compared to the typical destruction efficiency of a regenerative type thermal oxidizer ranging from 95% to 98% (Pollution Systems, 2018) [19].

3.5 Flares

Pluto LNG has minimal continuous flaring with significant flare operation restricted to start-up, shutdown, upset, maintenance and emergency conditions. Flaring may also occur during shipping activities such as, where boil off gas and vapour rates exceed the capacity of available boil off gas compressors.

The frequency of these occasions (i.e. where flaring is required) is expected to be low due to the inclusion of high integrity valves and control systems, gas recovery where practicable, fuel gas balancing and advanced process control. The need to flare due to maintenance activities has been reduced by developing a plant that is reliable and will incorporate appropriate sparing; hence unplanned maintenance is minimised leading to reduced shutdowns. Flaring during plant start up and shutdown will be reduced through operational controls including established plans and procedures.

The flares have also been designed to minimise dark smoke production, as follows:

- Storage and loading flare system (Site A) - single stage flares with air assist
- Cold dry flare (Site B) – single stage flare with sonic flare tip
- Warm wet flare and common spare flare (Site B) – two stage flare with air assist.

Pluto Train 2 will be integrated with the existing Pluto LNG flare system to provide pressure relief and liquids disposal system; no new flare sources will be installed.

Stack heights for the cold dry flare, warm wet flare and spare flare are all located not less than 130 metres above ground level to further limit potential impacts associated with air emissions.

The flaring technologies concentrate on improving air-fuel mixing to ensure sufficient oxygen for complete combustion. Air assist systems achieve better mixing via a forced or natural draft air supply to the flare tip. A multi stage flare allows the fuel flow at each flare tip to be optimised to the size and design of the tip, thus promoting better mixing and combustion. Sonic flare tips generate greater energy at sonic velocities which promotes better mixing (however has the disadvantage of greater noise).

Air emissions from operations have also been reduced via the use of nitrogen to maintain the continuous purge of the flare piping. It is common for flare systems to be continuously purged with small quantities of fuel gas, to prevent explosive air/gas mixtures forming in the flare piping systems. Based on the composition of the feed gas compositions, nitrogen from the reservoir will be produced as a by-product of the LNG process; hence nitrogen will be reclaimed and used to purge the flare systems, resulting in reduced GHG and NO_x emissions. The nitrogen system is designed to supply the maximum requirement of nitrogen continuously to purge the four flare systems on site (Site A: storage and loading flare, Site B: cold-dry flare, warm-wet flare and spare flare). In addition, the spare flare is typically lined up in cold dry service to further smoke optimisation during operations.

4. Cumulative Air Quality Modelling

Cumulative air modelling which include anticipated emissions from Pluto LNG has been undertaken and is documented within the following report:

- Pluto LNG Expansion - Air Quality Impact Assessment (Jacobs, 2019) [18]

The Pluto LNG Expansion Air Quality Impact Assessment was undertaken to understand potential cumulative air quality impacts and how various air emission scenarios would affect air pollutant ground level concentrations (GLC) within and around the Burrup Peninsula. The modelling software used for the assessment was the CSIRO-developed meteorological, air dispersion and photochemical model, 'TAPM-GRS' (The Air Pollution Model – Generic Reaction Set) was selected for modelling for reasons of reliability and efficiency. To confirm that TAPM-GRS performance was fit for purpose, modelled results were compared to measured results from the BAAMP. When compared to ambient air monitoring results for Nitrogen Dioxide (NO_2) and Ozone (O_3) from 2014, modelling results were very close to actual results and the TAPM-GRS model was deemed suitable and accurate [18].

The investigation assessed two fundamental operating types to provide relevant comparisons for scenarios:

- Existing and Expansion – Current 'baseline' existing operating industries associated with the Burrup Strategic Industrial Area (SIA), and Expansion to include Pluto Train 2.
- Future Sensitivity – potential Future Burrup Strategic Industrial Area (FBSIA) air emissions, which include current operating emissions, Pluto Train 2, and indicative representation of potential 'referred' industrial development in the SIA.

Table 3 summarises the industries included in each baseline scenario.

Table 3 - Summary of Emission Sources for Pluto LNG Expansion – Air Quality Impact Assessment (Jacobs, 2019) [18]

Industrial Complex	Existing	Expansion	Future Sensitivity	Emission Sources
Woodside NWS Karratha Gas Plant	✓	✓	✓	44
Woodside Pluto LNG	✓	✓ (2 sources altered)	✓ (2 sources altered)	11
Yara Fertiliser and TAN Plants	✓	✓	✓	4
Pilbara Iron Yurralyi Maya Power Station	✓	✓	✓	5
Santos Devil Creek Gas Plant	✓	✓	✓	7
EDL West Kimberley Power Project	✓	✓	✓	3

Industrial Complex	Existing	Expansion	Future Sensitivity	Emission Sources
ATCO Karratha Power Station	✓	✓	✓	2
General Shipping Berths	✓	✓	✓	18
Woodside Pluto LNG Expansion		✓	✓	9
Indicative Methanol Plant			✓	5
Indicative Urea Plant			✓	5
Total Emission Sources	**94**	**103**	**113**	

Model input emissions inventories were developed based on reasonable and conservative emissions estimates, considering available datasets, design data, monitoring data and for proposed developments preliminary design data based on early 'front end engineering design' concepts. Third party emissions were represented based on consideration of publicly available literature and input following consultation with some parties.

Some regional facilities were excluded from modelling primarily due to their distance from Burrup Peninsula and their size. These sources were either too distant to have a significant effect on the air quality in the Burrup Peninsula area or too small as emitters by mass:

- Chevron Gorgon LNG Development located on Barrow Island approximately 140 km west
- Sino Iron – Port, approximately 60 km WSW, and Sino Iron – Mining, approximately. 80 km SW (sensitivity testing with TAPM eliminated Sino Iron as a significant source for the assessment)
- Port Hedland sources located approximately 190 km ENE
- Cape Lambert / Point Samson approximately 40 km ENE, although shipping at all berths in Cape Lambert was included in the model
- Santos (formerly Quadrant Energy) Devil Creek Power Station
- ATCO Karratha Power Station

Section 5 of the Pluto LNG Expansion - Air Quality Impact Assessment [18] provides further details on the modelling scenarios and key emissions scenarios. A summary is provided in Section 4.2.

4.1 Proportions of Airborne Emissions

The total emissions of the primary airborne pollutants for each industrial complex used in the modelling are listed in Table 4.

Table 4 - Summary of Total Emissions for Pluto LNG Expansion – Air Quality Impact Assessment (Jacobs, 2019) [18]

Industrial Complex	Existing Sources (g/s)			Expansion and Future Sources (g/s)		
	NO_X	SO_2	VOCs	NO_X	SO_2	VOCs
Woodside NWS Karratha Gas Plant	281.1	9.18	147.48	281.1	9.18	147.48
Woodside Pluto LNG	34.1	2.526	3.02	35.58	2.166	3.02
Yara Fertiliser and TAN Plants	30.3	0.36	0.0	30.3	0.36	0.0
Pilbara Iron Yurralyi Maya Power Station	28.2	20	0.2	28.15	20	0.2
Santos Devil Creek Gas Plant	4.5	11	0.035	4.54	11	0.035
EDL West Kimberley Power Project	1.2	0.0018	0.0075	1.155	0.0018	0.0075
ATCO Karratha Power Station	12.0	0.02	0.086	12	0.02	0.086
General Shipping Berths	36.0	36	2.16	36	36	2.16
Expansion: Woodside Pluto LNG Expansion	-	-	-	33.57	0.196	0.09
Future: Indicative Methanol Plant	-	-	-	28.05	0.005	0.05
Future: Indicative Urea Plant	-	-	-	11.18	0.18	0.04
Total Emissions (g/s)	**427.4**	**79.09**	**152.9**	**501.6**	**79.11**	**153.2**

Figure 1 presents the proportional emissions of NO_X from Pluto LNG and Pluto Train 2 versus other industrial complexes in the region for the Baseline Existing Air Emissions and the Future Air Emissions scenarios respectively. Emissions associated with the existing Pluto LNG facility are blue and emissions associated with the proposed Pluto Train 2 are orange.

For the existing emissions, Pluto LNG comprises:

- 8% of total NO_X emissions
- 3% of total SO_2 emissions
- 2% of total VOC emissions.

For the future potential emissions, the combined expanded Pluto LNG facility comprises:

- 14% of total NO_X emissions
- 3% of total SO_2 emissions
- 2% of total VOC emissions.

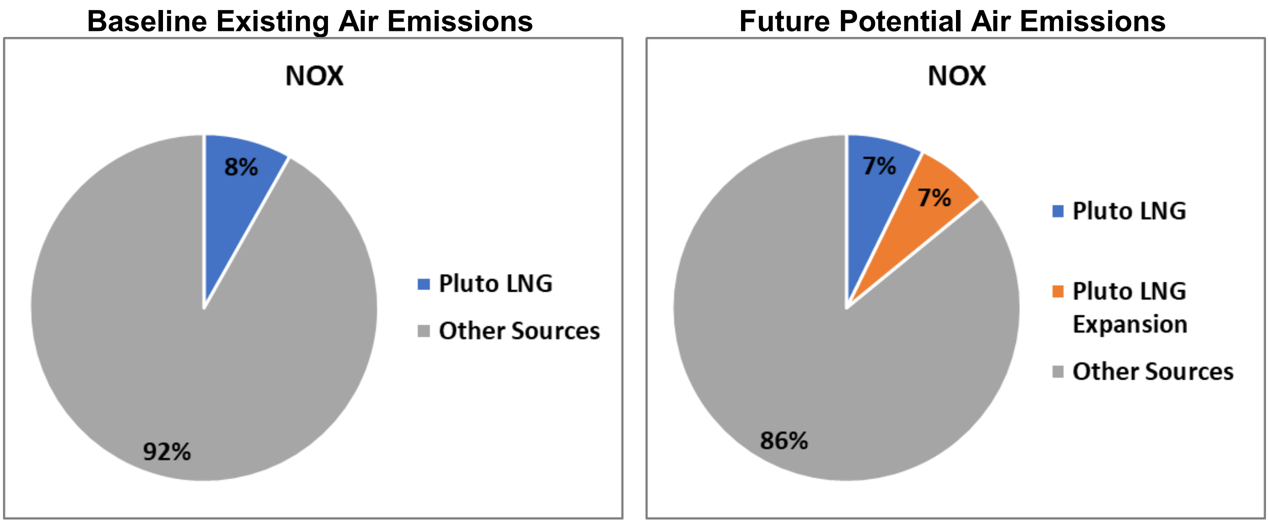

Figure 1 - Distribution of Airborne NO_X Emissions for Pluto LNG Expansion – Air Quality Impact Assessment

4.2 Modelled Scenarios

To assess the impacts on air quality from the proposed Pluto Train 2 across the Burrup region, two primary scenarios were modelled associated with the existing and expansion case (Jacobs, 2019) [18]:

- Current Baseline Model (CBM): representing the existing air emissions scenario mostly applicable to the Burrup Strategic Industrial Area (BSIA) and the region to use as a baseline for assessment.
- Pluto Future State (FPS): CBM plus Expansion – which includes the proposed Pluto Train 2 sources. The purpose of the FPS scenario is to illustrate the potential effects of Pluto LNG Train 2 in the frame of current emissions in the region. The FPS scenario could be described as both a 'best case' and a 'most likely' case.

The comparison between the CBM and the FPS scenarios illustrate the contribution of the Pluto Train 2 to the air quality of the Burrup airshed.

Two future additional sensitivity scenarios were also modelled to ensure the extent of potential other BSIA development outcomes were explored:

- Future Burrup Strategic Industrial Area State (FBSIA): includes all sources in the FPS, plus indicative representation of potential future BSIA proposals such as urea and methanol proposals.
  - The FBSIA represents the best estimate of the future air emissions scenario.

- Pluto Operational Upset Condition (PUC): a worst-case operational upset condition based on the FBSIA scenario with abnormal operations to include concurrent elevated flare operations.
  - The short term (approximately 2 weeks) PUC event scenario represents a 'worst case' scenario for testing.

It is acknowledged that inherent to the modelling method and scenarios, there is a level of conservatism accounted for in the underlying assumptions that feed into the model input information. Thus, the results of the modelling often represent the maximum potential impact of airborne pollutants emanating from the emission sources. Further to this, the results of the Burrup Ambient Air Monitoring Program (BAAMP) that spanned 2008 to 2011 and then continued as part of Pluto LNG to the end of 2015, indicated that the GLCs of pollutants from the modelling have been conservatively estimated historically. The update to the modelled baselines in the Pluto LNG Expansion – Air Quality Impact Assessment is intended to better align the predicted concentrations with the monitored data.

Emission rates used for Pluto Train 2 are based on preliminary Front End Engineering Design data. The conservatism in the model will largely account for any changes in physical design, such as stack heights and minor layout changes, that may take place through Pluto Train 2 detailed design.

The PUC sensitivity scenario is by nature especially conservative. The modelled emission sources are defined as such to identify the worst potential impact(s) accounting for time-varying meteorological conditions.

Appendix A details the predicted air quality in the Burrup Airshed for the modelled scenarios following development of Pluto Train 2.

4.3 Impact Assessment / Modelling Results

4.3.1 Assessment Criteria

The assessment criteria adopted for the investigation are listed in Table 5.

Table 5 - Adopted Assessment Criteria for Investigation (Jacobs, 2019) [18]

Criterion Source	Pollutant	Statistical Parameter	Concentration Value (ppb)	Allowable Exceedances
Human Health Criteria				
NEPM (Ambient Air Quality) (2016) [2]	Nitrogen dioxide (NO_2)	1-hour Average Maximum	120	1 day per year
		Annual Average	30	None
	Ozone (O_3)	1-hour Average Maximum	100	1 day per year
		4-hour Average Maximum	80	1 day per year
		1-hour Average Maximum	200	1 day per year

Criterion Source	Pollutant	Statistical Parameter	Concentration Value (ppb)	Allowable Exceedances
	Sulfur dioxide (SO_2)	24-hour Average Maximum	80	1 day per year
		Annual Average	20	None
Vegetation Protection Criteria				
EU (2008) [12]	SO_2	Annual Average	20 µg/m³ (7.8 ppb @ 30°C)	N/A
	NO_X	Annual Average	30 µg/m³ (16.2 ppb @ 30°C)	N/A
Land Surface Protection Standard: No limits of 'acceptable' change have been established, nor any guideline 'trigger values' defined to inform proponents on the levels of NO_x and SO_x emissions that may result in impact to rock art [7]. Given complexities and uncertainties around potential impacts associated with possible anthropogenic emissions, key pollutants of concern focus on primary emissions have been derived from a literature review. Further work is planned by the Murujuga Rock Art Stakeholder Reference Group to understand the complex system and potentially define key system inputs and dynamic characteristics which may result in accelerated weathering. Deposition modelling discussed in Section 4.3.6 provides for a high level comparative assessment against baseline and historical monitoring results.				

A summary of the modelling results against the assessment criteria is presented in the following sections.

4.3.2 Nitrogen Dioxide (NO_2) Impacts

Ambient concentrations of NO_2 are predicted to be well below their respective NEPM standards, see Table 6.

Table 6 - Summary of Modelled Ambient NO_2 Concentrations at Sensitive Receptors Against Assessment Criteria

Statistical Parameter	Sensitive Receptor	Criteria (ppb)	Ground Level Concentrations (ppb) and Percentage of Assessment Criteria				
			Operating Scenarios			Sensitivity Scenarios	
			CBM	FPS	Differential	FBSIA	PUC
Maximum 1-hour Average	Karratha	120	24.8 (20.7%)	25.9 (21.6%)	+1.1 (+0.9%)	28.3 (23.6%)	27.5 (22.9%)
	Burrup		33.4 (27.8%)	33.8 (28.2%)	+0.4 (0.4%)	34.2 (28.5%)	33.2 (27.7%)

Statistical Parameter	Sensitive Receptor	Criteria (ppb)	Ground Level Concentrations (ppb) and Percentage of Assessment Criteria				
			Operating Scenarios			Sensitivity Scenarios	
			CBM	FPS	Differential	FBSIA	PUC
	Dampier		24.8 (20.7%)	25.8 (21.5%)	+1.0 (+0.8%)	25.8 (21.5%)	24.9 (20.8%)
Annual Average	Karratha	30	0.9 (3.0%)	0.9 (3.0%)	0.0 (0.0%)	1.0 (3.3%)	N/A
	Burrup		3.2 (10.7%)	3.5 (11.7%)	+0.3 (+1.0%)	4.0 (13.3%)	N/A
	Dampier		1.7 (5.7%)	1.7 (5.7%)	0.0 (0.0%)	1.8 (6.0%)	N/A

Ambient ground-level concentrations of NO_2 at the local townships of Dampier and Karratha as well as the Burrup Peninsula monitoring station are all predicted to be well below the NEPM criteria for both 1-hour maximum (short term impacts) and annual average (long term impacts). No annual average values have been calculated for the PUC sensitivity scenario as the event the model simulates is by nature, short term and thus an annual average is not applicable.

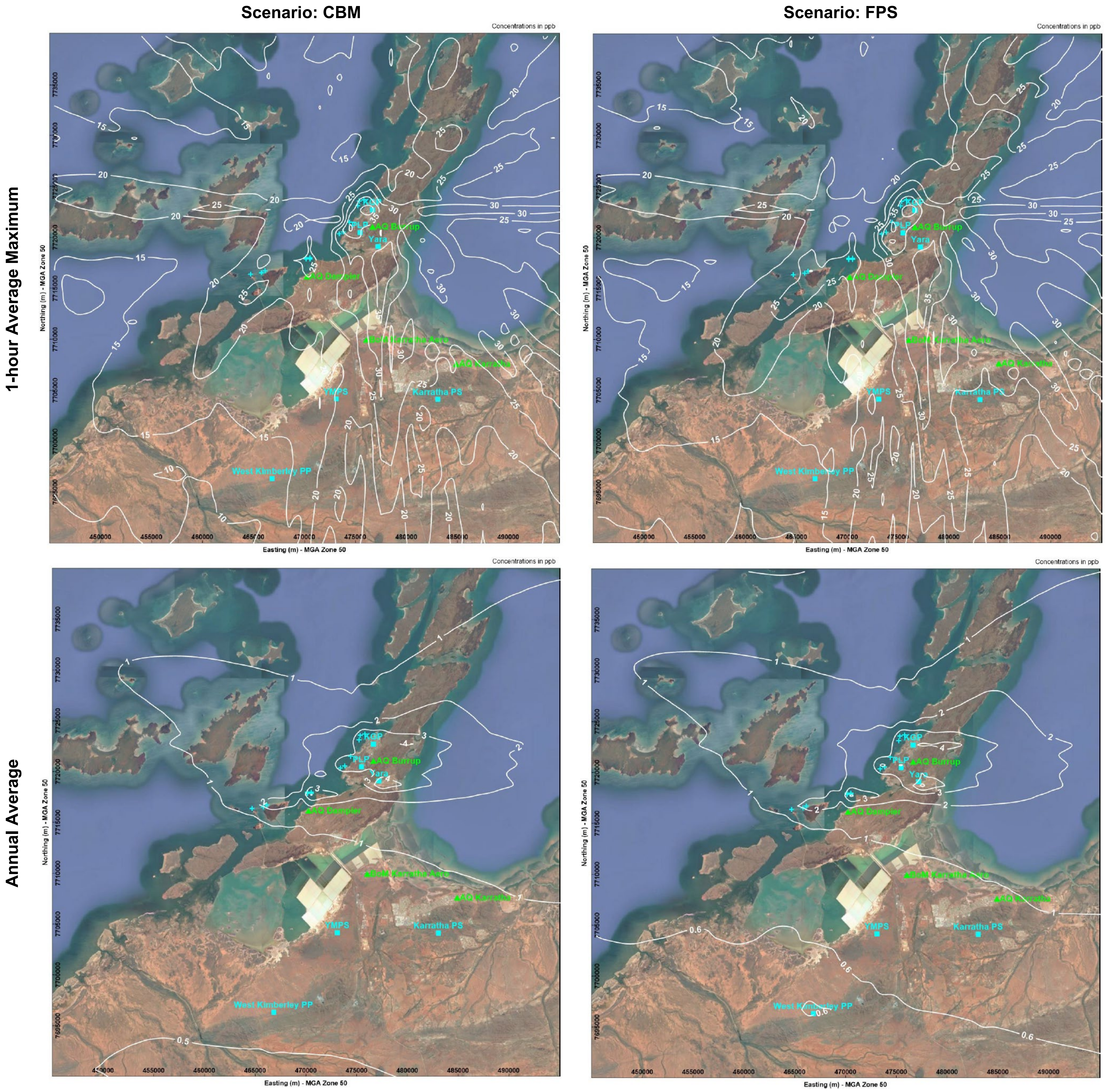

Figure 2 - Summary of NO_2 Ground-level Concentration Isopleth Contour Plots (ppb) for CBM and FPS Scenarios

4.3.3 Ozone (O_3) Impacts

Ambient O_3 concentrations are predicted to be below their respective NEPM standards, see Table 7. Noting that the assumed background concentration of O_3 is 25 ppb. The 4-hour averaged values have been calculated in a step-wise fashion; however, the NEPM standard is defined as a rolling average. In this case, the step-wise average values are a good indicator of compliance against the standard. Figure 3 presents the maximum 1-hour averaged ambient ground-level concentration isopleth contour plots for O_3 (ppb). The 4-hour rolling average contour plots are not presented as they are calculated as step-wise averages and no direct comparison is provided. As can be seen in Figure 3, due to the secondary nature of O_3 as a pollutant, the concentration behaviour does not change significantly between the modelled scenarios.

The predicted ambient ground-level concentrations of O_3 at Karratha and Dampier are well below the maximum 1-hour averaged and maximum 4-hour rolling averaged NEPM criteria.

Table 7 - Summary of Modelled Ambient O_3 Concentrations at Sensitive Receptors Against Assessment Criteria

Statistical Parameter	Sensitive Receptor	Criteria (ppb)	Ground Level Concentrations (ppb) and Percentage of Assessment Criteria				
			Operating Scenarios			Sensitivity Scenarios	
			CBM	FPS	Differential	FBSIA	PUC
Maximum 1-hour Average	Karratha	100	57.9 (57.9%)	59.6 (59.6%)	+1.7 (+1.7%)	61.2 (61.2%)	60.8 (60.8%)
	Burrup		58.7 (58.7%)	59.1 (59.1%)	+0.4 (+0.4%)	58.4 (58.4%)	58.5 (58.5%)
	Dampier		55.4 (55.4%)	55.9 (55.9%)	+0.5 (+0.5%)	56.5 (56.5%)	56.2 (56.2%)
Maximum 4-hour Average (Rolling)	Karratha	80	56.3 (70.4%)	57.8 (72.3%)	+1.5 (+1.9%)	59.1 (73.9%)	58.8 (73.5%)
	Burrup		54.3 (67.9%)	54.1 (67.6%)	-0.2 (-0.3%)	53.7 (67.1%)	53.9 (67.4%)
	Dampier		52.5 (65.6%)	52.9 (66.1%)	+0.4 (+0.5%)	53.6 (67.0%)	53.5 (66.9%)

1-hour Average Maximum

Scenario: CBM | Scenario: FPS

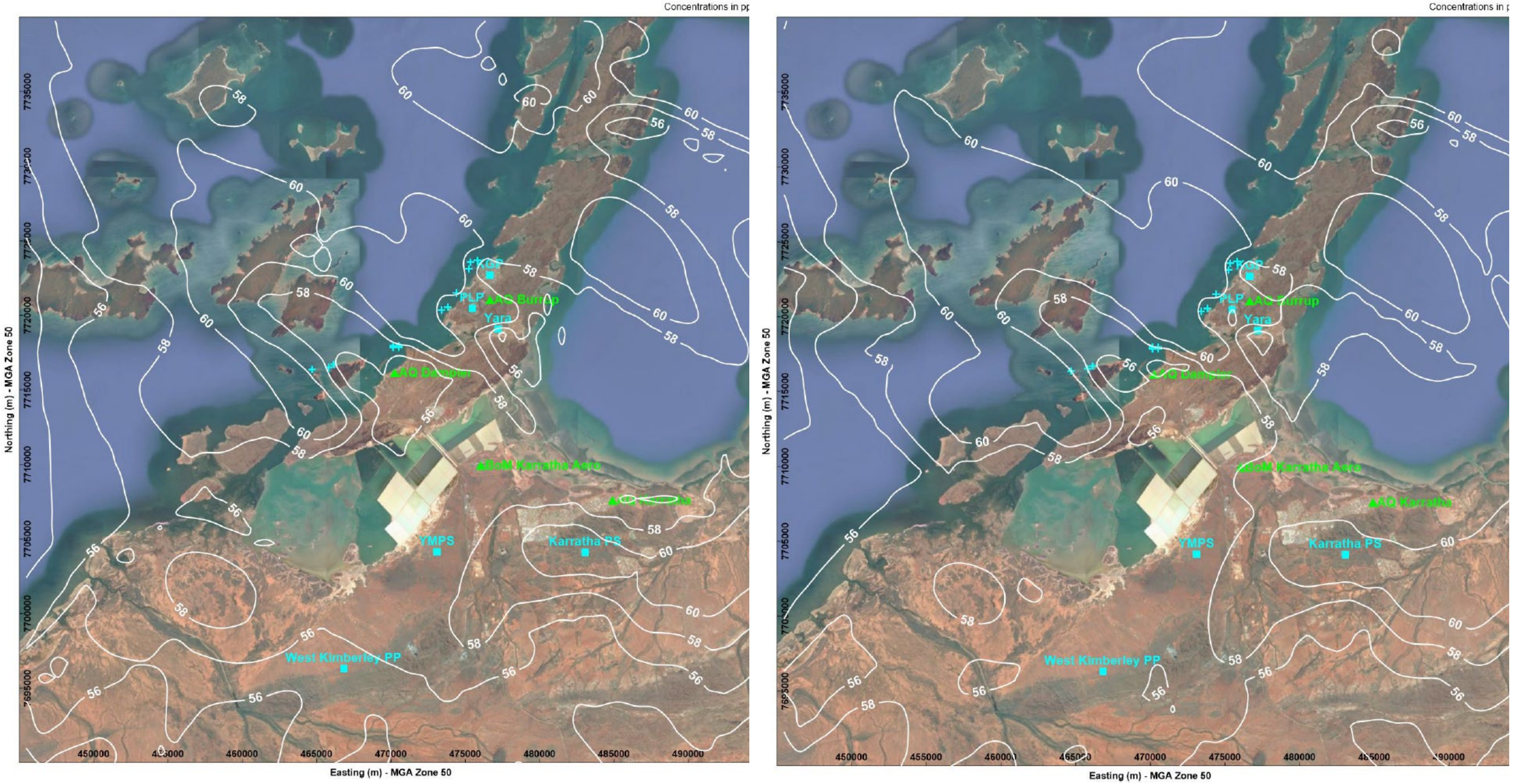

Figure 3 - Summary of O_3 Ground-level Concentration Isopleth Contour Plots (ppb) for CBM and FPS Scenarios

4.3.4 Oxides of Nitrogen (NO_X) Vegetation Impacts

Ambient concentrations of NO_X are predicted to be below 50% of the vegetation criterion for both CBM and FPS scenarios everywhere within the calculation grid, see Table 8. Ground-level concentration isopleth contour plots for both scenarios are presented in Figure 4. It is noted that the maximum point on the calculation grid for each scenario is located to the southeast of Pluto LNG and is not significantly affected by Pluto Train 2 emissions. This localised concentration is influenced by a combination of natural topography, wind direction and point emission sources featuring lower temperature, discharge velocities, height and buoyancy.

Table 8 - Summary of Modelled Ambient NO_X Concentrations for Vegetation Impacts Against Assessment Criteria

Statistical Parameter	Sensitive Receptor	Criteria (ppb)	Ground Level Concentrations (ppb) and Percentage of Assessment Criteria				
			Operating Scenarios			Sensitivity Scenarios	
			CBM	FPS	Differential	FBSIA	PUC
Vegetation Effects							
Annual Average	Maximum Point on Grid	16.2	7.7 (47.5%)	7.9 (48.8%)	+0.2 (+1.3%)	9.0 (56%)	N/A

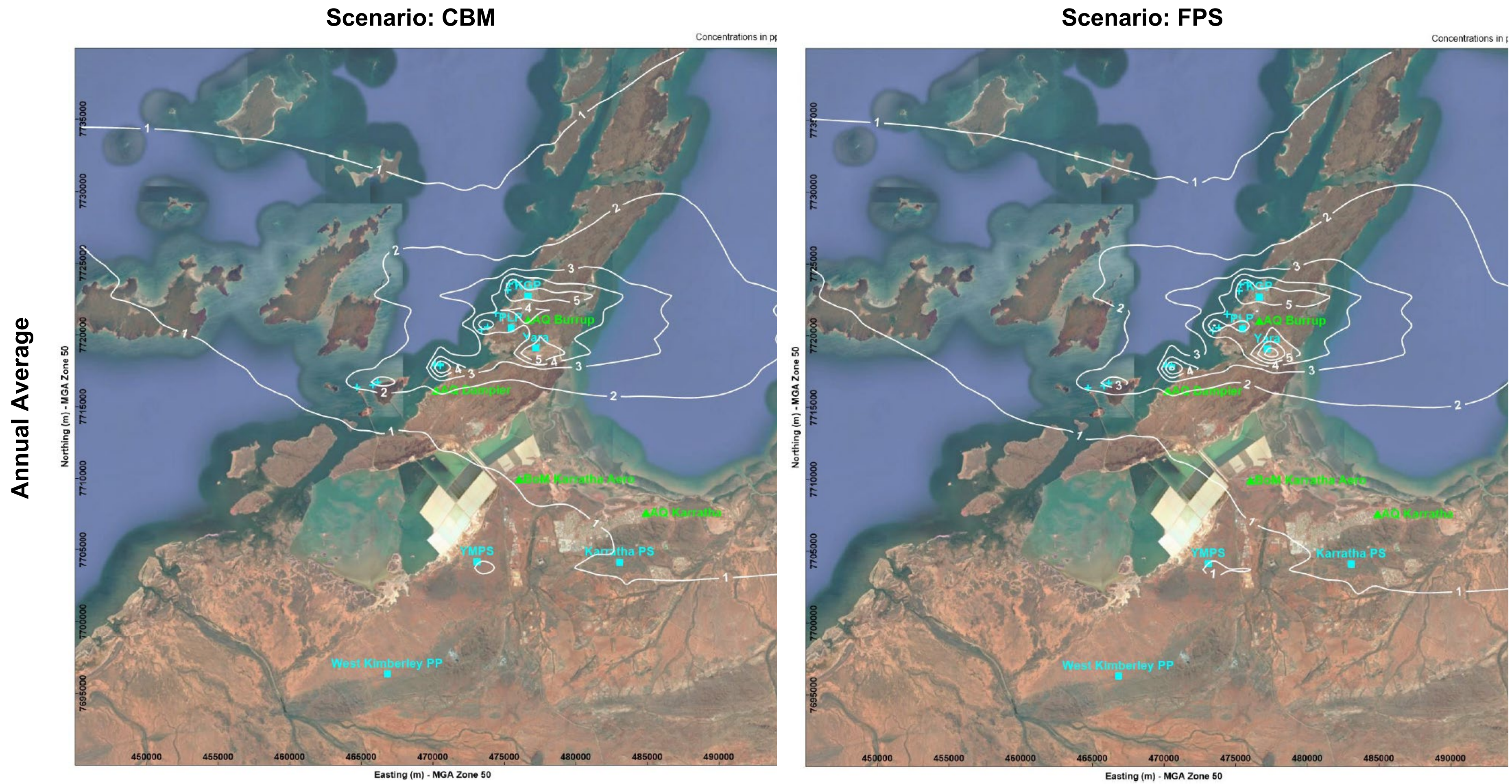

Figure 4 - Summary of NO_X Ground-level Concentration Isopleth Contour Plots (ppb) for CBM and FPS Scenarios

4.3.5 Sulfur Dioxide (SO_2) Impacts

Ambient concentrations of SO_2 are predicted to be well below their respective NEPM standards, see Table 9. No annual average values have been calculated for the PUC sensitivity scenario as the event the model simulates is by nature, short term and thus an annual average is not applicable. Additionally, the vegetation effect standard was not exceeded anywhere within the modelled area. Notably, the maximum point within the calculation grid occurred off the coast from Dampier, correlating with one of the shipping emission sources, not associated with Pluto Train 2.

It is apparent that the various scenarios assessed do not alter the ground-level concentrations significantly, with all values remaining very consistent between scenarios.

Table 9 - Summary of Modelled Ambient SO_2 Concentrations at Sensitive Receptors Against Assessment Criteria

Statistical Parameter	Sensitive Receptor	Criteria (ppb)	Ground Level Concentrations (ppb) and Percentage of Assessment Criteria				
			Operating Scenarios			Sensitivity Scenarios	
			CBM	FPS	Differential	FBSIA	PUC
Human Health							
Maximum 1-hour Average	Karratha	200	3.6 (1.8%)	3.6 (1.8%)	0.0 (0.0%)	3.6 (1.8%)	3.6 (1.8%)
	Burrup		11.3 (5.7%)	11.4 (5.7%)	+0.1 (+0.0%)	11.4 (5.7%)	11.4 (5.7%)
	Dampier		12.9 (6.5%)	12.9 (6.5%)	0.0 (0.0%)	12.9 (6.5%)	12.9 (6.5%)
Maximum 24-hour Average	Karratha	80	1.7 (2.1%)	1.7 (2.1%)	0.0 (0.0%)	1.7 (2.1%)	1.7 (2.1%)
	Burrup		4.7 (5.9%)	4.8 (6.0%)	+0.1 (+0.1%)	4.8 (6.0%)	4.7 (5.9%)
	Dampier		4.6 (5.8%)	4.6 (5.8%)	0.0 (0.0%)	4.6 (5.8%)	4.6 (5.8%)
Annual Average	Karratha	20	0.9 (4.5%)	0.9 (4.5%)	0.0 (0.0%)	0.9 (4.5%)	N/A
	Burrup		2.0 (10.0%)	2.0 (10.0%)	0.0 (0.0%)	2.0 (10.0%)	N/A
	Dampier		1.6 (8.0%)	1.6 (8.0%)	0.0 (0.0%)	1.6 (8.0%)	N/A
Vegetation Effects							
Annual Average	Maximum Point on Grid	7.8	4.5 (57.7%)	4.5 (57.7%)	0.0 (0.0%)	N/A	N/A

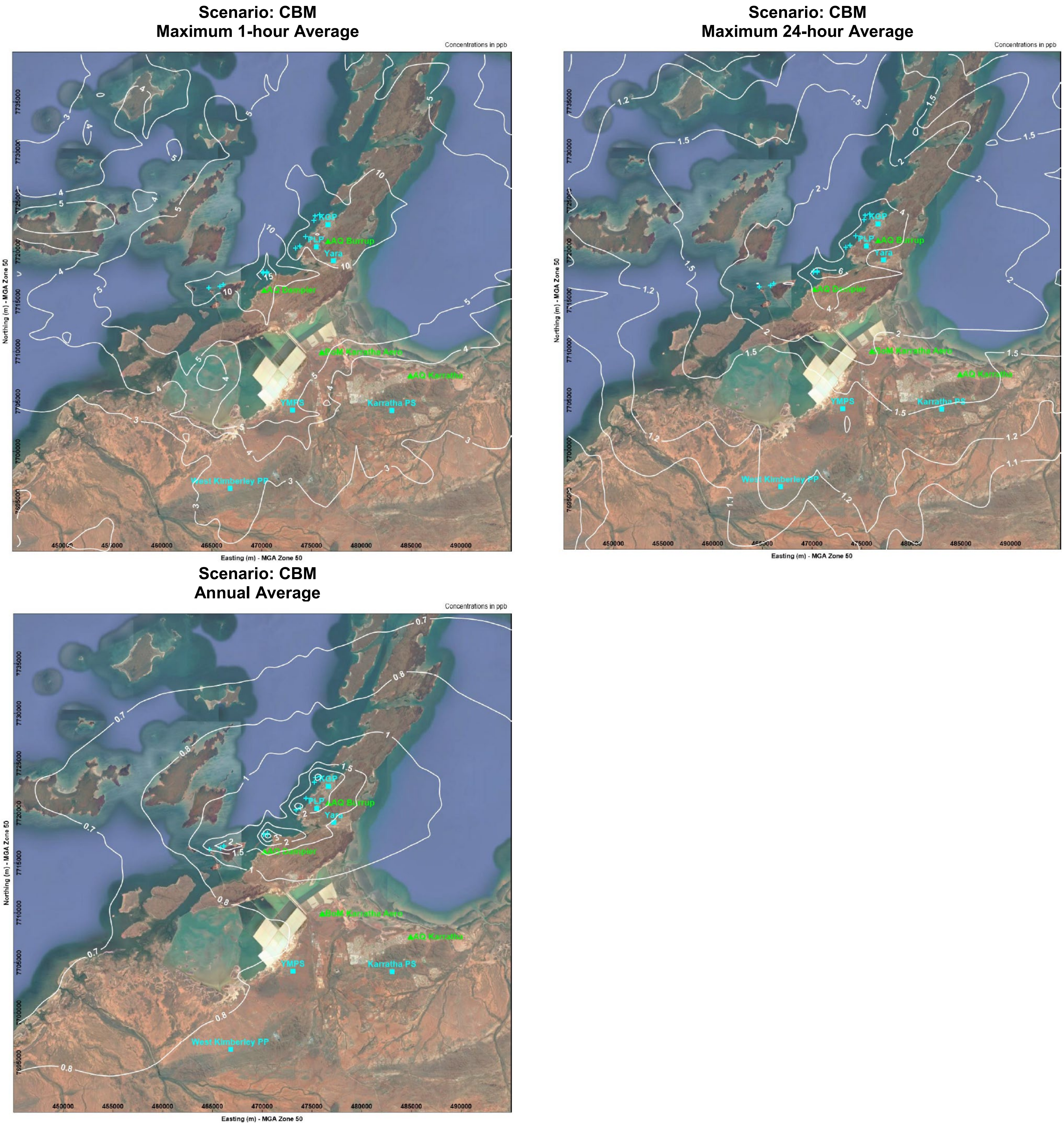

Figure 5 - Summary of SO_2 Ground-level Concentration Isopleth Contour Plots (ppb) for CBM Scenario for Various Averaging Periods

4.3.6 Deposition of NO_2

This section provides a comparative assessment of modelled NO_2 deposition for baseline, expansion and future scenarios against historical monitoring data for the region. Predicted NO_2 deposition rate (as a sub-component of nitrogen and sulphur depositional flux) contour plots are presented in Figure 6 for both units of kg/hectare/year and mEq/m^2/year. A comparative approach is taken as no limits of 'acceptable' change have been established, nor any guideline 'trigger values' defined to inform proponents on the levels of NOx and SOx emissions that may result in impact to the rock art [7].

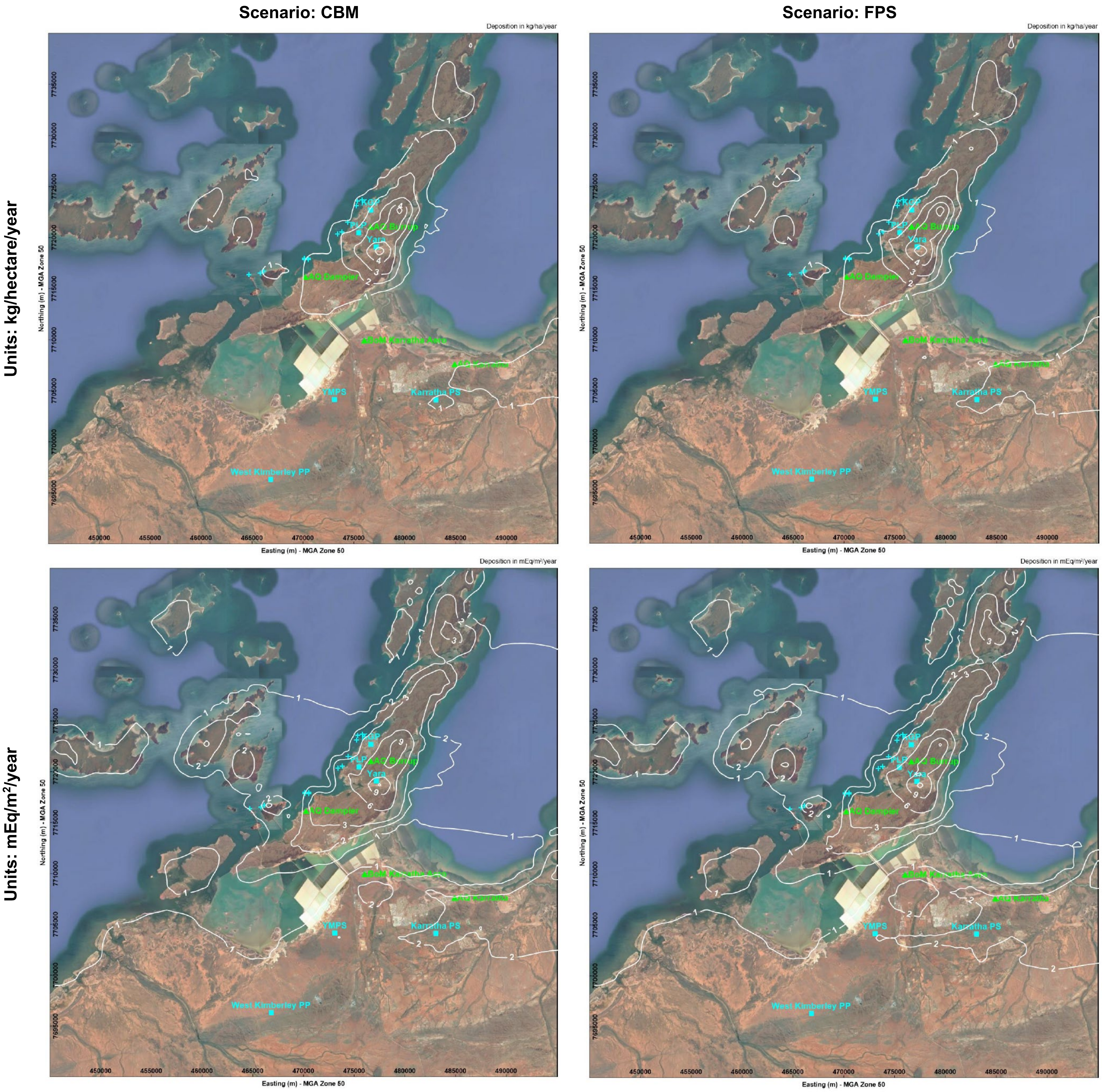

Figure 6 - Summary of NO_2 Deposition Rate Contour Plots for CBM and FPS Scenarios in Various Units

The maximum point within the calculation grid was consistently located to the east of Pluto LNG. This localised concentration is influenced by a combination of natural topography, wind direction and point emission sources featuring lower temperature, discharge velocities, height and buoyancy.

Modelled outputs for NO_2 deposition were compared against the measured NO_2 component of total nitrogen deposition, also measured total nitrogen and sulphur deposition, as an indicator of alignment of the modelling with the measured baseline.

The 2012/2014 monitoring demonstrated the NO_2 (dry gaseous deposition) contribution to the total nitrogen flux ranges between 4.0 and 7.7 mEq/m^2/year (Table 10) [14]. The total nitrogen deposition flux ranged between 17.1 – 28.8 mEq/m^2/year (from Table 1).

Table 10 – Comparisons of model results for CBM and FPS with CSIRO (2014) summary of monitoring (2012/2014 dataset)

	2012/2014 Monitoring [14]		Model results [18]	
Monitoring station [14]	Total Nitrogen Flux (meq/m$_2$/yr)	Dry Deposition NO_2 (meq/m$_2$/yr)	CBM NO_2 Deposition (meq/m$_2$/yr)	FPS NO_2 Deposition (meq/m$_2$/yr)
Gap Ridge (Karratha)	25.5	4.4	1.8	1.9
Fertiliser Plant	23.9	4.0	8.5	9.5
Burrup Materials Facility	28.8	7.7	5.0	5.1
Karratha Gas Plant	17.9	4.4	5.7	6.1
Domgas Station	17.1	5.8	6.2	7.3
Background	9.8	1.3	approx 1.0	approx 1.0

1. Modelled results for background were from southern-most parts of study grid; it is expected these low, but non-zero values were due to modelled biogenic NOx emissions over land (nil emissions modelled over water).

As demonstrated in Figure 6 there is minor change between the CBM and FPS scenarios, this is consistent with results at the six monitoring locations extracted from the model. The comparison of modelling versus monitored results at the six locations shows estimated deposition rates for NO_2 are of a similar order to monitored values, indicating that the modelled values are considered to be credible and therefore comparative interpretation of the modelled values valid for Pluto Train 2.

To aid visual representation of deposition, a data filter was applied to select model values within the National Heritage Listed Area (e.g. to eliminate interpretation influence of 'over-water' or inland deposition data estimates less applicable to potential rock art receptors).Modelling scenario outputs for NO_2 deposition associated with Pluto Train 2 (FPS) were analysed to determine potential variance of overall NO_2 depositions values compared to CBM. Figure 7 represents a strong correlation of NO_2 depositions between the two scenarios.

The majority of NO_2 deposition across the National Heritage Listed Area is in the 1 to 5 mEq/m^2/year range with frequencies of FPS NO_2 deposition between 1 and 3 mEq/m^2/year are estimated to be slightly below that of the CBM. Frequency of FPS NO_2 deposition for the range between 4 and 5 mEq/m^2/year are marginally above the CBM modelled estimates.

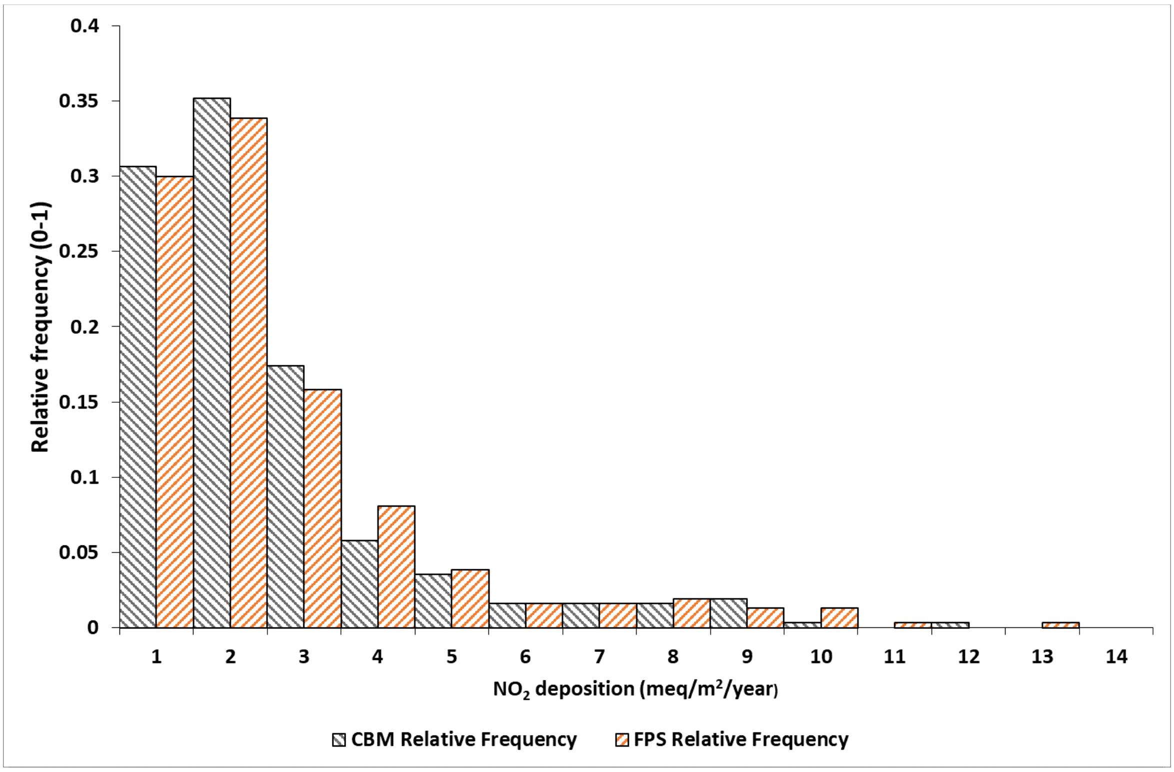

Figure 7 – CBM versus FPS Distribution of NO_2 Deposition over National Heritage Listed Area

Minor change is apparent between the two scenarios, which implies that the addition of Pluto Train 2 emissions does not increase the deposition rate of NO_2 by a material margin and is therefore considered to be a minor contributor to the regional NO_2 deposition rate.

4.3.7 Deposition of SO_2

As anticipated, SO_2 deposition is predicted to be concentrated on the primary sources, being the shipping exhausts from diesel combustion. Deposition of SO_2 decreases further onshore with a minimum contoured level of 2 kg/hectare/year being achieved along the Burrup Peninsula within approximately 1 km of the coastline. The deposition rate decreases to a minimum contoured level of 1 kg/hectare/year on the mainland, also within approximately 1 km of the coastline. Notably, the deposition rate behaviours between the CBM and FPS scenarios are almost identical, indicating that the addition of Pluto Train 2, does not materially affect deposition of SO_2 when compared with existing conditions.

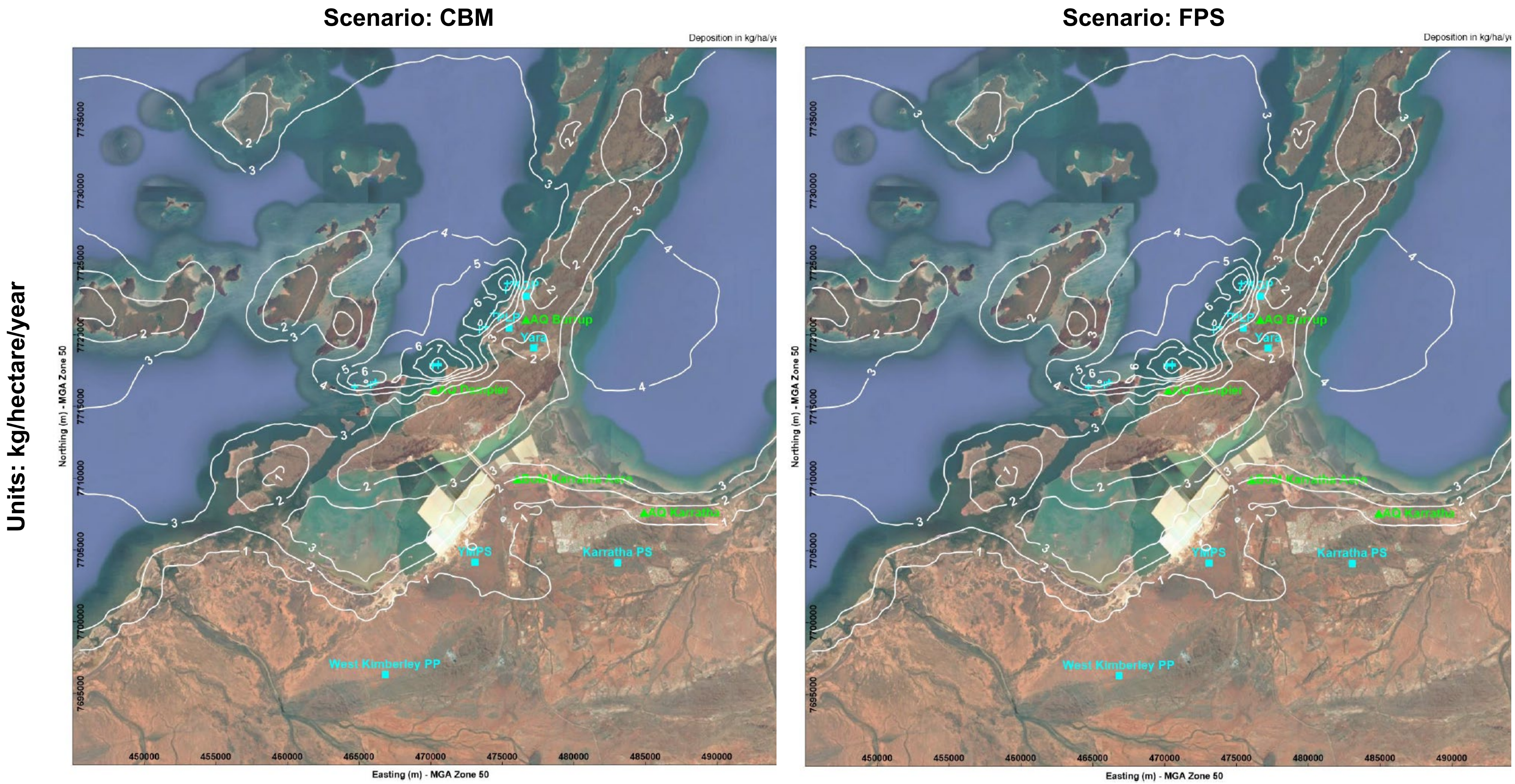

Figure 8 - Summary of SO_2 Deposition Rate Contour Plots (kg/ha/year) for CBM and FPS Scenarios

4.4 Impact Assessment Conclusions

Both the Current Baseline Model (CBM) and the Future Pluto State (FPS) operating scenarios were assessed in detail, with the Future Burrup Strategic Industrial Area State (FBSIA) and Pluto Operational Upset Condition (PUC) sensitivity scenarios investigated to ensure the extent of potential other outcomes were explored. The ambient airborne impacts of primary pollutants: NO_2 and O_3 were the primary focus of the investigation with the impacts of lower risk pollutants: NO_X, SO_2 also explored. Additionally, the impacts of chemical deposition of NO_2 and SO_2 were investigated [18].

Impacts on human health and vegetation were assessed, based on NEPM and EU guidelines [3 and 12]. Predicted impacts from Pluto Train 2 that are considered negligible as:

- Human health impacts from SO_2 ground-level concentrations as ambient concentrations are low, well below criteria, and that primary emission sources are not associated with Pluto LNG
- Emissions of PM from the Development are negligible in relation to natural background, fire and weather induced dust, and other industrial sources in the region
- Sections 2.2 and 8 identify that through ambient air quality monitoring, emissions of VOCs: benzene, toluene and isomers of xylene (BTX) are considered not to present a credible risk to human health, and are controlled through Pluto LNG facility design.
- Vegetation impacts from NO_X and SO_2 ground-level concentrations are below criteria.

Key emission impacts that have been investigated in detail, including source validation and reporting (refer to Section 7) include:

- Human health impacts from NO_2 and O_3
- Deposition impacts of NO_2 and SO_2.

The impact from Pluto LNG on ambient NO_2 ground-level concentrations were determined to be minimal for both short term and long term averaging periods. Given that the ambient ground-level concentrations of NO_2 were less than 30% and 15% of their respective assessment criteria, it was determined that the risk of air quality impact from Pluto LNG is low.

The impact from Pluto Train 2 on ambient O_3 ground-level concentrations were also determined to be minimal. The secondary nature of O_3 concentrations and small quantity of contributing pollutants indicate that Pluto Train 2 does not significantly affect the ambient air quality. Therefore, it was determined that the risk of air quality impact from Pluto Train 2 is low.

Modelled estimates of deposition of NO_2 were compared with on-site data monitored by CSIRO (Gillett, 2014) [14]. A reasonable correlation between predicted and monitored deposition rates was identified and therefore modelled data was considered to be credible and suitable for interpretation. Predicted deposition rates of NO_2 for both the CBM, and FPS scenarios were almost identical between scenarios indicating the Pluto Train 2 did not influence the general NO_2 deposition behaviour significantly.

Deposition of SO_2 was predicted to decrease further onshore to less than 1 - 2 kg/hectare/year within approximately 1 km of the coastline. Deposition was concentrated on the primary emission sources, being shipping exhausts from diesel combustion and were largely uninfluenced by Pluto Train 2.

Hence, Pluto Train 2 is considered to present a low risk of impact and therefore is compliant with the approved PER original 2 train modelling [21], MS757 and amendment 850 [20].

5. Validation of Design Emissions Estimates

Woodside undertakes stack emissions testing as part of its operations of Pluto LNG. The objective of the stack emission testing is to assist in optimising the efficiency of the Pluto facilities; to minimise stack emissions of specific environmentally harmful compounds; to ensure compliance with regulatory performance requirements, and for Woodside to confirm that it is satisfied with the performance of vendor supplied equipment and systems.

5.1 Commissioning and Start-up

Commissioning includes system integrity and function testing. This is the process of initial operation and testing that verifies that the works and all relevant systems, plant, machinery and equipment have been installed and are functional.

Commissioning and start-up phase, which includes the introduction of feed gas and other process fluids required to bring the specific plant systems into an operational state. Start-up leads to performance testing, which is required to verify the system operational parameters against the design, for emissions this is when equipment will be verified that it meets manufacturer specified emission levels and design emission rates. Specific management plans will be developed for each of these phases detailing the activities and associated environmental management requirements as part of the Part V approvals process.

Emissions will be calculated based on fuel usage and emission factors to determine if manufacturer specified emissions performance levels are being achieved. Results from the monitoring will be assessed to determine the need for any refinement or amendments to the regime as required throughout the commissioning of Pluto Train 2. The commission testing program will include emissions, flare and vent and fugitive emissions verification.

5.2 First Year of Steady State Operations

Once steady-state operations have been achieved (post commissioning and start-up phase), it is proposed to monitor all major point sources of air emissions quarterly for important parameters to ensure proper functioning of the equipment for the first year of steady state operations. This is planned to involve quarterly source testing, using Australian Standards and/or using US EPA Methods or equivalent. This is conducted on selected sources during the first year of steady-state operation, to ensure ongoing equipment performance across a range of operational states. When consecutive sets of test during steady state operation are satisfactory with respect to criteria, the source testing frequency will be changed to align with existing annual Pluto LNG operations testing.

Performance testing of the Predictive Emission Monitoring Systems (PEMS) installed on Pluto Train 2 gas turbines will occur during this first year of operations. PEMS is a software-based tool able to provide a reliable and real-time estimation of emission properties (including NOx, CO and CO_2) by means of a model, using process values (temperature, flow, pressure) as input variables [1]. This is a first for Woodside, the PEMS system and associated commissioning and validation requirements will be developed with the vendor during detailed design of Train 2. The performance test for the PEMS is subject to vendor specification, Woodside understand it will be equivalent to that of US EPA requirements which require stack emission test regimes for a period of time to verify performance. This performance testing will be detailed further as part of the Commissioning and Start-up test plan. Stack testing will remain as the primary source of validating stack emissions for reporting purposes, however PEMS will be available to assist with review of stable (non-transient) operations against criteria.

5.3 Operations

Woodside will continue to review the results of stack emissions testing against anticipated emissions performance and compare them with previously completed risk and impact assessments presented in approvals documentation. Results will be provided to DWER within a compliance document and an amendment application for the existing Operating Licence L8752/2013/x [21].

Ongoing annual monitoring and reporting to DWER will be in line with this Plan and the Operating Licence L8752/2013/x [21].

6. Proposed Targets and Standards

Operational limits are set by the existing Operating Licence L8752-2013-2 [21] which specifies limits on the concentration of Oxides of Nitrogen from all Gas Turbine Generators and the regenerative thermal oxidiser. The license distinguishes between the concentration of Oxides of Nitrogen that may be emitted for the optimal "Premix" combustion mode and for the transitional low-power modes. The Licence also includes monitoring and limits for dark smoke production.

For Pluto Train 2, the project design criteria was benchmarked against International Finance Corporation (IFC) Guidelines and New South Wales (NSW) emission standards for equipment. The targets set align with the equipment vendors performance targets and criteria to be verified during commissioning, and recurring monitoring during normal operations. Limits are provided to cover abnormal or upset situations and support typical licensing processes, set to ensure outcomes associated with environmental impact assessment are not exceeded for prolonged periods.

Woodside will continue to manage all atmospheric emissions from the Pluto LNG facility in accordance with good industry practice, to ensure that emissions remain within the predicted range used as the basis for the risk assessment. Management measures include:

- Predictive Emissions Monitoring System (PEMS) and stack sampling ports for Pluto Train 2 Gas Turbines
- Reliability centred maintenance programs for equipment and process systems
- Risk based inspection of equipment and pipework
- Operational fuel gas composition monitoring
- Scheduled turbine maintenance (e.g. water wash, major/minor overhaul)
- Routine inspection of valves and flanges
- Energy efficiency opportunity reviews
- Setting targets for NO_X production lower than the limits specified in the Operating Licence [21], to encourage best practice by Assets.

Point source emissions monitoring (detailed in Section 7.1) will focus on validating emission performance under normal operation against performance targets specified in Table 11. As per existing operations, the targets set the normal operations upper emission limit, any excursions above this will be investigated through normal Woodside Management System investigation practices and actions taken towards rectification back within the emission targets. Target exceedances and responses will be summarised in annual reporting. Limit exceedances are also investigated and expected to be reported as per licensing arrangements for limit exceedances and summarised in annual compliance reports.

Table 11 - Pluto Performance Targets and Air Emission Limits

Performance Criteria	NOx	Target	Limit	Limit (operating in low load)
Train 1				
Train 1 Electrical Power Generation Turbines [GT4001-4004]	NO_X (mg/Nm^3 @ 15% O_2)	50	100	140
Train 1 MR Compression Gas Turbine [1_KT1410]		70	100	N/A
Train 1 PR Compression Gas Turbine [1_KT1430]		70	100	N/A
Train 1 Regenerative Thermal Oxidiser [1_A1251]	NO_X (mg/Nm^3 @ 3% O_2)	70 (NO_X as NO_2)	100 (NO_X as NO_2)	N/A
Train 2				
Train 2 Electrical Power Generation Turbine	NO_X (mg/Nm^3 @ 15% O_2)	50	100	140
Train 2 Main Refrigerant Compressor Turbines		50	100	N/A
Train 2 Recuperative Thermal oxidisers	NO_X (mg/Nm^3 @ 3% O_2)	70 (NO_X as NO_2)	100 (NO_X as NO_2)	N/A

7. Monitoring and Reporting

7.1 Point Source Emissions Monitoring

Monitoring via stack emission tests of NO_X is undertaken for the existing Pluto LNG gas turbines and regenerative thermal oxidiser and will be implemented for Pluto Train 2 point source emission. Ongoing stack emissions testing follows the AN-M-110 methodology or USEPA Method 7E as described in the Operating Licence L8752/2013/x [21]. During stack testing Woodside capture a suite of data (including gas parameters and other analytes (e.g CO and SO_2) following appropriate test methods for ancillary data to inform both operational processes and other regulatory emissions reporting. .

Stack exhaust sampling ports have been installed in accordance with AS4323.1 -1995 (*Stationary source emissions - Selection of sampling points*) on the following equipment to enable point source air emissions monitoring and data collection:

- Mixed refrigerant compressor gas turbine stack: 1A-1410 EXH
- Propane compressor gas turbine stacks 1 and 2: 1A-1430 NTH and 1A-1430 STH
- Power generation gas turbine stacks: A-4001, A-4002, A-4003, A-4004
- Regenerative thermal oxidiser exhaust stack: 1A-1251-B2.

Pluto Train 2 will have stack exhaust sampling ports installed in accordance with AS4323.1 -1995 on the following equipment:

- Methane compressor gas turbine exhaust stacks;
- Ethylene compressor gas turbines exhaust stacks;
- Propane compressor gas turbines exhaust stacks;
- Power generation gas turbine exhaust stack; and
- Recuperative thermal oxidiser vent stacks.

For the first year of stable operations for Pluto Train 2, stack emissions testing will be undertaken quarterly. Following the first year, annual stack emission testing will align with that of existing operations and/or on an as needed basis to ensure ongoing confidence and verification to support operational surveillance monitoring.

A report summarising results of point source emissions from stack sampling points above will be provided as part of annual compliance reporting. This report will be provided concurrently with a Part V Licence annual audit and compliance reporting outlined in Section 10 of this Plan.

7.2 Smoke monitoring

Smoke can be caused during flaring due to incomplete combustion of products. Environmental impacts from smoke emitted from a gas processing plant are considered negligible, however smoke can cause a visual amenity impact. Woodside has focussed on eliminating or significantly reducing the potential for smoke, particularly dark smoke, to be generated from the facility.

The Pluto LNG design has minimal flaring during steady operations, however flaring will occur infrequently during maintenance, shutdowns/restarts and upset conditions. The four flare systems incorporate equipment specifically tailored to minimise the potential for, and/or duration of, dark smoke events from each system. Incorporated equipment includes: liquid knock-out drums and pumps to intercept and recover heavier hydrocarbons from reaching the flare; air blowers and sonic flare tips to assist in achieving complete combustion; and single and multi-stage flares to better match flare flow ranges to the effective operating range of each tip.

Pluto facility smoke monitoring (including colour and duration) occurs for any dark smoke events of a Ringelmann 1 or greater, that continue for a period of 30-minutes or more. The Ringelmann smoke chart is a visual estimation method used to assess smoke density, using the United Kingdom Solid Fuel Technology Institute Ringelmann Charts.

Any expected or actual dark smoke emissions of a shade Ringelmann 3 or greater emitted for a period of 30 minutes or more shall be reported to the DWER as soon as practicable, but no later than 5 pm of the next usual working day. The report will include the date and time the event occurred, the duration of the dark smoke event, Ringelmann number, location and cause of flared gas. Actual and expected flare smoke emissions are reported as part of the Licence (L8752/2013/x) start-up and upset notifications, in case of any limit exceedences, and summarised in the Annual Environmental Report (AER) as outlined in Section 10 of this Plan.

Woodside implements a number of corporate, divisional and facility specific targets, including Pluto LNG specific flaring and fuel intensity reduction targets. Performance against these targets is reported throughout the business and drives proactive operational awareness to support facility optimisation..

7.3 Emissions Reduction Equipment –Thermal Oxidisers

During planned and unplanned outages of the thermal oxidisers (e.g. for planned maintenance or repairs) AGRU waste gas will be vented to a safe location. Operation of the AGRU systems will nominally reduce BTX and other hydrocarbon co-absorption by 90% compared to traditional solvents.

Woodside will notify the DWER regional office of thermal oxidiser outages in a quarterly shutdown report, in accordance with Operating Licence L8752/2013/x [21].

A summary of any notifiable thermal oxidiser outages will be provided to the DWER regional office annually. This report will be provided concurrently with a Part V Licence AER reporting outlined in Section 10 of this Plan.

8. Ambient Air Monitoring and Reporting

Woodside commenced an ambient air monitoring program on the Burrup Peninsula in October 2008 as part of an internal environmental improvement initiative to gain a better understanding of how its operations on the Burrup may affect local air quality. The initial program continued until 2011. Aspects of the program continued to support the Woodside operated Pluto LNG operations from 2011 through to January 2016.

The Ambient Monitoring Program allowed for the comparison of observed ground level concentration air emissions to that of the development air quality modelling and validation of approval process risk assessments. Monitoring was undertaken by specialist consultants in line with relevant monitoring and analysis standards. A number of reviews which have occurred throughout the program were coordinated by Woodside using an independent peer reviewer and review methodology endorsed by the EPA.

As discussed in Section 2.2, the ambient monitoring program confirmed that nitrogen dioxide levels were well below Australian standard levels currently set to protect human health and well-being [3], and are also below the World Health Organisation and USEPA levels designated for protection of vegetation [12]. Independent review also confirmed that the Pluto LNG assessment of risk based on estimated or predicted emissions of nitrogen dioxide and ozone should be “low” as assessed on the framework previously adopted by DWER [15 and 16].

In advance of potential changes to industrial air emissions on the Burrup, Woodside has recommenced ambient air monitoring to further baseline understanding of ambient air quality in the region. The program is expected to further extend the historical dataset and complement air monitoring proposed under the State Murujuga Rock Art Strategy. The Strategy and associated monitoring program tender scope indicates that the WA Government is considering the establishment of a long-term, coordinated and centralised ambient air monitoring network on the Burrup Peninsula.

It is Woodside’s intention to continue the in-place ambient air monitoring program until a coordinated approach established under the State Murujuga Rock Art Strategy is operational. This strategy would achieve a centralised and coordinated monitoring network, that would expand the knowledge base to manage the air quality in the region and result in more informed decision-making.

Historically, Woodside has made a significant financial contribution to a range of scientific studies on the Burrup Peninsula and will continue to contribute to a range of scientific studies on the Burrup Peninsula by providing funds to support the Strategy’s implementation. Woodside will also assist with implementing the Strategy through its role on the Stakeholder Reference Group, which has been established by the Minister for Environment to assist with communication and stakeholder engagement.

In order to ensure that the Pluto MS 757 ambient air monitoring program requirement is met, if the State Murujuga Rock Art Monitoring Program is not operational by Train 2 start-up, a 24-month program will be undertaken, followed by independent review.

Beyond the initial 24-month ambient program to meet MS 757 Condition 11-2(4) post Train 2 start-up, Woodside will continue to undertake annual objective-based ambient monitoring programs (with scope and objectives to be agreed with the EPA), or via appropriate support/contribution to the State Murujuga Rock Art Monitoring Program.

Woodside’s 2019 Ambient Air Monitoring Program (the Monitoring Program) currently uses three powered stations to continuously monitor key pollutant gases and meteorological conditions, such as wind speed and direction. The Monitoring Program design draws from historical experience and review outcomes with consideration of numerous factors when designing the scope and selecting the locations for these monitoring stations (listed in Table 12) which includes balancing:

- objectives of the monitoring campaign
- logistical and environmental issues (e.g. access to electricity; ease of access for routine and non-routine service visits)
- site security
- alignment as far as practical to the following standards (AS 3580.1.1, AS3580.14, AS 3580.5.1, AS 3580.6.1)

The program may be updated from time to time.

Table 12 - Ambient Air Monitoring Locations

Monitoring Station	Location	
	Easting	Northing
Karratha	484,892	7,707,575
Burrup Road	476,665	7,721,038
Dampier	470,239	7,716,142

Locations of the Monitoring Program are shown in Figure 9. Ambient air quality is monitored based on the details in Table 13 and compared to the assessment criteria in Table 14.

Table 13 - Ambient Air Monitoring Parameters

Parameter	Karratha	Dampier	Burrup Road
Oxides of Nitrogen	✓	✓	✓
O_3	✓	✓	-
BTX	-	-	✓
Temperature and RH	✓	✓	✓
Wind speed and direction	✓	✓	✓
Global solar radiation	-	-	✓

Table 14 - Ambient Air Monitoring Criteria

Parameter	Ambient Air Quality NEPM (as amended) Standards[1]		
	Concentration Standard	Averaging Period	Standard
NO_2	120 ppb	1 hour	NEPM (Ambient Air Quality)
	30 ppb	Annual	
O_3	100 ppb	1 hour	NEPM (Ambient Air Quality)
	80 ppb	4 hours	
Benzene	3 ppb	Annual	NEPM (Air Toxics)
Toluene	1000 ppb	24 hours	NEPM (Air Toxics)

	100 ppb	Annual	
Xylene	250 ppb	24 hours	NEPM (Air Toxics)
	200 ppb	Annual	

Note: 1 - The Ambient Air Quality NEPM is currently under review and may be further amended.

Table 15 - Instrumentation and Quality Assurance Requirements

Parameter	Method	Quality Assurance Schedule
Oxides of Nitrogen (NO, NO2, NOx)	• Instrument: Ecotech Serinus 40 • Method: Chemiliminescence	• Daily single point zero / span precision check • Monthly single point zero / span calibration· • Three monthly GPT Converter check· • Six monthly multi-point calibration
Ozone (O_3)	• Instrument: Ecotech Serinus 10 • Method: UV Absorption	• Daily single point zero / span precision check· • Monthly single point zero / span calibration with transfer standard· • Six monthly multi-point calibration
Hydrocarbons (BTX)	• Instrument: Synspec GC955 • Method: Gas Chromatograph with PID detection	• Weekly precision check· • Monthly multipoint calibration
Dilution Calibrator	• Instrument: Ecotech Cal2000 • Method: Gas dilution from certified compressed calibration gas cylinder	• Annual flow audit

Equipment assurance and data management and reporting for the program is managed via specialised contractors for air quality monitoring. A calendar year annual report will be developed summarising the monitoring results and a summary of the ambient air results against criteria will be provided in the MS757 Annual Compliance Report.

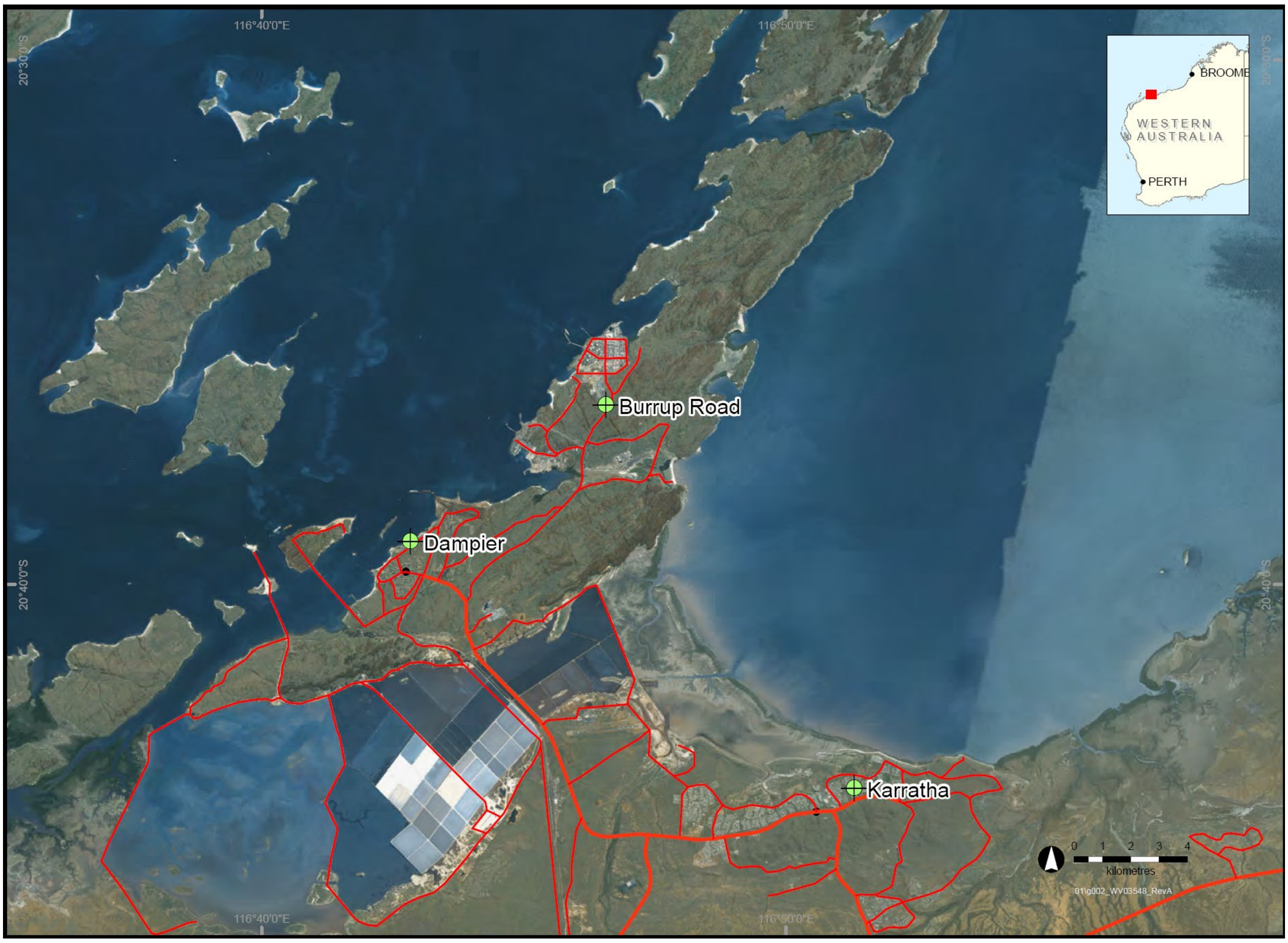

Figure 9 - Monitoring site locations for the Pluto program

9. Deposition Monitoring

Atmospheric deposition monitoring is proposed under the State Murujuga Rock Art Strategy. Woodside support the strategy and will provide input and fund activities as appropriate.

The Strategy [7], and associated monitoring program scope indicates that the WA Government will establish an atmospheric deposition monitoring network to provide data on the composition and concentrations of contaminants that are potentially transferred from the atmosphere to the rock surfaces. The scoping of the network is likely to be informed by historical and present monitoring undertaken on Murujuga. This program includes monitoring to estimate nitrogen deposition, potentially relating to industrial emissions from Woodside operations.

It is Woodside's intention to support the coordinated approach for the atmospheric deposition monitoring program to be established under the State Murujuga Rock Art Strategy.

Should the State Murujuga Rock Art Strategy and proposed Murujuga nitrogen deposition monitoring program not be operational by Train 2 start-up, Woodside in consultation with relevant stakeholders would look to establish a 24-month Pluto Train 2 deposition program to ensure that the requirements of Pluto LNG MS 757 [20] are met. The details of such a program would be developed with stakeholders (e.g Murujuga Rock Art Strategy Reference Group, DWER, and land custodians for station citing) and approved by the relevant authorities (including DWER regarding location, frequency, conditions, methodology and reporting) prior to its commencement. The program would commence in line with Pluto Train 2 operations for a period of 24 months to compare with historical studies. Following the 24-month monitoring period, a review of the data would be conducted. This review would be coordinated by Woodside using an independent peer reviewer to be agreed with EPA. The review process methodology would be agreed upon before the review with the relevant stakeholders.

A decision on the continuation of the nitrogen depositional monitoring program would occur as part of the review process.

10. Scheduled Reporting and Review

Woodside will continue to regularly review results of ongoing emissions monitoring outlined in this document. Results will be compared with previously completed sampling. In accordance with this Plan and Operating Licence L8752/2013/x [21] an Annual Environmental Report (AER) will be prepared and submitted to DWER within 90 days after the end of each annual period. The AER will summarise the results of stack emissions testing and dark smoke monitoring and other Licence notifications and reporting. The AER will be provided to DWER.

Woodside will continue to report emission data from Pluto LNG to the National Pollutant Inventory (NPI) and National Greenhouse and Energy Reporting (NGER) Scheme annually.

Woodside proposes to manage potential impacts to Aboriginal rock art on the Burrup Peninsula in accordance with the Murujuga Rock Art Strategy [7] and as a member of the Murujuga Rock Art Stakeholder Reference Group. The AER will include reporting of Woodside's support and participation in implementation of the DWER Murujuga Rock Art Strategy.

This AQMP plan will be revised as required, for example to reflect a change in any regulatory conditions that apply to Pluto LNG and to ensure the plan remains up-to-date. If there are any significant changes required, a revised plan will be provided to the EPA for review and assessment to advise the Minister. Approval will be obtained from the Minister before the revised plan is implemented and the revised plan will be made publicly available on the Woodside website.

11. Management of Change

It may be necessary to temporarily operate equipment outside of the specific controls and management measures described in this plan from time to time due to maintenance issues, operational vulnerabilities and/or equipment reliability impacts.

Appropriate temporary controls and rectification measures will be identified and implemented as soon as reasonably practicable with the aim of minimising air emissions from the plant and to ensure that material changes to air emissions do not occur. Rectification measures will be designed to re-instate the controls and management measures described in this plan.

12. Stakeholder Consultation and Community Queries

Woodside has well-established relationships with the community, and regularly engages with stakeholders through various forums on a broad range of issues, including potential environmental and social impacts associated with its operations. Key to understanding local issues are mechanisms such as the Karratha Community and Heritage Liaison Group, which meet quarterly. Woodside also has an established office in Karratha, which provides an avenue for locals to discuss any issues in person.

Woodside has in place a process [28] to ensure that any member of the community can easily raise a query or concern with Woodside, which will be addressed promptly.

This process ensures that:

- All interaction, queries, feedback or complaints are efficiently and politely received;
- All necessary information is collected and reported; and
- Appropriate corrective and preventative action are taken, including feedback (if requested or required) to the person raising the query.

Any feedback is logged in a Complaints Query Log Sheet and forwarded to the appropriate area within Woodside for action. [26]

Feedback on Pluto LNG can be lodged with Woodside at any time, via Pluto free call number 1800 634 988 or email KarrathaCommunityRelations@woodside.com.au.

Consultation activities conducted for Pluto Train 2 builds upon Woodside's extensive and ongoing stakeholder consultation for its petroleum activities in the region. Woodside has undertaken consultation with a number of regulators and other stakeholders specific to Pluto Train 2. A summary of relevant consultation is shown in Appendix B.

Further stakeholder consultation associated with Pluto Train 2 will be ongoing and undertaken as required.

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APPENDIX A: Pluto LNG Expansion - Air Quality Impact Assessment Report

Pluto LNG Expansion

Woodside Energy Ltd.

Air Quality Impact Assessment

Final | Revision 5

12 August 2019

Pluto Expansion 2019

Pluto LNG Expansion

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4	22 Jul 2019	For issue to Woodside	M Pickett, A Boyd & J Davies	S Blackford	M Goodwin
5	12 Aug 2019	Final Report	M Pickett, A Boyd & J Davies	S Lakmaker & M Goodwin	M Goodwin

Contents

List of Tables

List of Figures

Executive Summary

This report details the results of the air quality impact assessment that has been undertaken to support the Pluto Expansion Project (Pluto Train 2). To understand potential cumulative air quality impacts and how various air emission scenarios would affect air pollutant ground level concentrations (GLC), current, expansion and sensitivity modelling scenarios were developed for Pluto Train 2. These modelling scenarios were then assessed against the National Environmental Protection (Ambient Air Quality) Measure (NEPM [Ambient Air Quality]) standards, for the protection of human health, and against European Union air quality standards for the protection of vegetation.

The CSIRO meteorological, air dispersion and photochemical model, 'TAPM-GRS' (The Air Pollution Model – Generic Reaction Set) was selected for modelling for reasons of reliability and efficiency. Air emissions inventories for input to modelling were developed in consultation with Woodside, based on reasonable and conservative emissions estimates, considering available datasets, design data, monitoring data and for the proposed development's preliminary design data based on early, 'front end engineering design' concepts. Third party emissions were represented based on consideration of publicly available literature and input from consultation with third parties.To confirm that TAPM-GRS performance was fit for purpose, modelled results were compared to measured results from a Woodside ambient air monitoring program. When compared to ambient air monitoring results for Nitrogen Dioxide (NO_2) and Ozone (O_3) from 2014, which was when the North West Shelf (NWS) Project: Karratha Gas Plant, and Pluto Liquified Natural Gas (LNG) Development were first operating together at or near capacity, modelling results were very close to actual results and the TAPM-GRS model was deemed suitable and accurate.

The scope of this air quality impact assessment included modelling NO_2, O_3, Sulfur Dioxide (SO_2) for assessment against National Environmental Protection (Ambient Air Quality) Measure (NEPM [Ambient Air Quality]), National Environmental Protection (Air Toxics) Measure (NEPM [Air Toxics]) and NSW EPA (2016) assessment criteria for BTX. Results for annual average (airborne) NO_x and SO_2 were obtained for comparison against the European Union (2008) air quality standards for the protection of vegetation. Results for NO_2 and SO_2 deposition modelling were provided to support any future assessment of potential impacts to landforms, including the rock art of the Burrup Peninsula.

Airborne particulate matter (PM) as PM_{10} and $PM_{2.5}$ from the Pluto Expansion Project was not modelled for this study. Although exceedances of ambient air quality standards for these air quality indicators occur on the Burrup Peninsula, they are primarily due to, for example, smoke from bushfires and controlled burns, raised dust, and other industrial sources. Emissions of PM from the Pluto LNG Development and Pluto Expansion Project are negligible in relation to these other sources.

Key results for the Pluto Expansion Project air quality impact assessment are:

- There were no predicted exceedances of NEPM (Ambient Air Quality) standards for NO_2, O_3, and SO_2. All results for these pollutants were well below NEPM (Ambient Air Quality) standards.
- There were no predicted exceedances of European Union (2008) ambient air quality standards for oxides of nitrogen (NO_x) and SO_2 for the protection of vegetation.

In conclusion, there is a low risk of air quality impact on human health and vegetation from the Pluto Expansion Project.

Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to provide air quality assessment services for the Pluto Expansion Project in accordance with the scope of services set out in the contract between Jacobs and the Client, Woodside Energy Ltd.

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

Jacobs derived the data in this report using various information sourced from Woodside Energy Pty Ltd and/or available in the public domain 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. Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, 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, to the extent permitted by law.

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

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Abbreviations and Definitions

Abbreviation	Expansion / Definition
ABS	Australian Bureau of Statistics
AG	Australian Government
AGRU	Acid Gas Removal Unit
BAAMP	Burrup Ambient Air Monitoring Program
BoM	Bureau of Meteorology
CO	Molecular formula for carbon monoxide
CO_2	Molecular formula for carbon dioxide
CRO	Current Routine Operations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DANHP	Dampier Archipelago National Heritage Place
DCGP	Devil Creek Gas Plant
DSMC	Deep soil moisture content
EPA	Environmental Protection Authority (Government of Western Australia)
FBSIA	Future Burrup Strategic Industrial Area
FEED	Front-End Engineering and Design
FRO	Future Routine Operations
GLC	Ground Level Concentration; an output from an air dispersion model commonly used for assessment
GRS	Generic Reaction Set – a photochemical modelling scheme in-built to TAPM; e.g. see Hurley (2008a).
GTC	Gas Turbine Compressor
GTG	Gas Turbine Generator
GWA	Government of Western Australia
IMO	International Maritime Organization
IOA	Index of Agreement
Jacobs	Jacobs Group (Australia) Pty. Limited
KGP	Karratha on-shore Gas Plant
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
$meq/m^2/year$	Milliequivalents per square metre per year – deposition flux units; a milliequivalent is one thousandth of a chemical equivalent. An equivalent of an ion is the mass in grams of the ion divided by its molecular weight and multiplied by the charge on the ion; e.g., Gillett (2014)
Mtpa	Mega (million) tonne per annum
NEPM	National Environment Protection Measure
NH_3	Molecular formula for ammonia
NO	Molecular formula for nitric oxide
NO_2	Molecular formula for nitrogen dioxide
NO_x	Molecular formula for oxides of nitrogen, the sum of NO and NO_2
NPI	National Pollutant Inventory
O_3	Molecular formula for ozone

Abbreviation	Expansion / Definition
PAQS	Pilbara Air Quality Study
PLP	Pluto LNG on-shore Plant
Pluto LNG Development	The Pluto LNG Development as described in the Pluto LND Development Draft Public Environment Report/Public Environmental Review, December 2006.
Pluto LNG Expansion	The current Pluto Train 2 proposal
Pluto Train 2	Pluto LNG Expansion
PM	Particulate Matter (general reference to airborne particulate matter).
$PM_{2.5}$	Particulate Matter 2.5 – mass concentration of particles with aerodynamic diameters less than 2.5 microns.
PM_{10}	Particulate Matter 10 – mass concentration of particles with aerodynamic diameters less than 10 microns.
PUC	Pluto Operational Upset Condition
RMSE	Root mean square error
RTO	Regenerative Thermal Oxidiser
SIA	(Burrup) Strategic Industrial Area
SKM	Sinclair Knight Merz
SO_2	Molecular formula for sulfur dioxide
TAN	Technical Ammonium Nitrate (Yara Pilbara Nitrates)
TAPM	The Air Pollution Model – a meteorological and air dispersion model developed by CSIRO (Hurley, 2008).
Tpd	tonne per day
YMPS	Yurralyi Maya Power Station

1. Introduction

1.1 Overview

Woodside Burrup Pty Ltd, a wholly owned subsidiary of Woodside Energy Ltd (Woodside), is operator of the Pluto LNG Expansion (Pluto Train 2). Woodside proposes a brownfield expansion of the existing Pluto LNG Development within the Burrup Strategic Industrial Area (BSIA), Western Australia (WA). This includes the construction and commissioning of a second LNG processing train, Pluto Train 2.

This air quality impact assessment, based on air pollutant dispersion modelling, was prepared to support applications for environmental approvals and to inform Woodside of the potential impacts to air quality from the operation of the Pluto LNG Development with Pluto Train 2.

1.1.1 Project background

Between 2000 and 2010, the air pollution sources on the Burrup Peninsula and the dispersion of these air pollutants was a focus of intense study including meteorological modelling, air emissions inventory, and air dispersion modelling. These studies included several by the CSIRO Division of Atmospheric Research, SKM (now Jacobs), and other specialist air quality consultants. Commonly, the 'The Air Pollution Model' (TAPM), which was developed by atmospheric scientists of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Hurley, 2008), was used for these modelling studies in the 2000s. Further aspects of these modelling studies are described in Section 6 (Modelling Methodology).

The Pluto LNG Development was referred to the Environmental Protection Authority (EPA) for assessment in April 2006 and the Commonwealth Department of Environment and Energy (then Department of Environment and Heritage) in August 2006. It was determined by both regulators that the Pluto LNG Development needed to be assessed at the Public Environment Report and Public Environment Review level of assessment. Therefore in December 2006 Woodside submitted the Pluto LNG Development Draft Public Environment Report/Public Environmental Review for assessment. To support the assessment of air emissions from the Pluto LNG Development SKM (now Jacobs) was engaged to conduct air quality modelling of the Pluto LNG Development (SKM, 2006).

Following EPA review of the Pluto LNG Development Draft Public Environment Report/Public Environmental Review, SKM conducted further modelling to support cumulative assessment inclusive of the Gorgon Gas Development at Barrow Island and the Austeel Direct Reduced Iron Plant at Cape Preston. The findings of this were included in the Pluto Works Approval Supporting Study: Air Quality Study of Revised Plan dated 19 December 2007.

This air quality impact assessment considers the assessments that have been done historically for the Pluto LNG Development and where appropriate uses similar methodologies and assessment practices.

1.1.2 Scope

This report provides an air quality impact assessment for Pluto Train 2. The following items are within the scope of this report:

- Modelling of predicted air emissions from the operation of Pluto Train 2.
- Demonstration of cumulative air quality impacts associated with the operation of Pluto Train 2, including existing and proposed developments on the Burrup Peninsula.

1.1.3 Geographical Summary

Pluto LNG Development is located on the central Burrup Peninsula on a lease area of approximately 200 hectares. The Burrup Peninsula forms part of the Dampier Archipelago on the Pilbara coast and is a low-lying, rocky peninsula approximately 40 km in length, including Dolphin Island. The highest terrain elevations are between approximately 100–120 metres (m) above sea level.

The towns of Dampier and Karratha are approximately 7 km and 14 km respectively from the Pluto LNG Development.

The Burrup Peninsula has significant cultural heritage value to Aboriginal people, particularly due to the large collection of rock art (in the form of petroglyphs), standing stones and other cultural sites such as foraging areas, ceremonial sites and hunting areas. The area is traditionally referred to as Murujuga and includes areas with protection as a National Heritage Place and National Park.

The location of the Pluto LNG Development in relation to the towns of Dampier and Karratha are shown in Figure 1-1.

Figure 1-1: Pluto LNG Development Location

2. Air Quality Assessment Criteria

2.1 Overview

This section sets out legislation, policy and guidelines applicable to air assessments in WA, and which are relevant to the Pluto Expansion Project.

2.2 Ambient Air Quality Standards – Criteria Pollutants

The WA EPA provides guidance for assessing the potential impacts of a proposal on air quality in the Environmental Factor Guideline: Air Quality, published in 2016 (EPA, 2016); whilst this does not specify air quality standards for assessment it does provide the following considerations:

- Whether numerical modelling and other analyses to predict potential impacts have been undertaken using recognised standards with accepted inputs and assumptions.
- Whether existing background air quality, including natural variations, has been established through monitoring and accepted proxy data.
- Whether analysis of potential health and amenity impacts has been undertaken using recognised criteria and standards, where relevant, informed by Australian and international standards.

In the absence of specific air quality standards from the EPA, it is common practice for the NEPM (Ambient Air Quality) to be adopted for air quality impact assessments in WA. Therefore, to assess potential ground level concentrations (GLC) for the Pluto Expansion Project modelled predictions were assessed against the relevant NEPM (Ambient Air Quality) standards shown in Table 2-1. Section 4 describes the risk assessment undertaken to determine the relevant pollutants.

Table 2-1: NEPM (Ambient Air Quality) Standards relevant to the Pluto Expansion Project[1]

Air pollutant	Averaging period	Maximum concentration standard	Maximum allowable exceedances
Nitrogen dioxide (NO_2)	1 hour	120 parts per billion (ppb)	1 day a year
	1 year	30 ppb	None
Ozone (O_3)	1 hour	100 ppb	1 day a year
	4 hours	80 ppb	1 day a year
Sulfur dioxide (SO_2)	1 hour	200 ppb	1 day a year
	1 day	80 ppb	1 day a year
	1 year	20 ppb	None

1. It is noted that the Commonwealth of Australia has published a Notice of Intention to vary the NEPM (Ambient Air Quality). However, as that amendment has not been formalised this air assessment has only considered the 2015 standards, which were in force at the time of writing this air quality impact assessment.

2.3 Investigation Levels for Hydrocarbons

When assessing BTX as an indicator of VOCs, the National Environment Protection (Air Toxics) Measure 2011 and the New South Wales Environment Protection Authority assessment criteria (NSW EPA, 2016) are two relevant options.

The NEPM (Air Toxics) contains Monitoring Investigation Levels (MILs) that are used in the assessment of ambient hydrocarbon concentrations. The MILs that are relevant to Pluto Train 2 are shown in Table 2-2. The NEPM (Air Toxics) sets out standards for long term (annual) averages because these are more readily related to human health effects than shorter term averages.

The New South Wales (NSW) Environment Protection Authority assessment criteria (NSW EPA, 2016) are relevant as they set out hourly average concentration assessment criteria. Therefore, the NSW EPA assessment criteria were used to assist with interpretation of measured hourly average concentrations.

(Information is lost if only assessing longer term averages). The NSW EPA (2016) assessment criteria relevant to the Pluto Expansion Project are also shown in Table 2-2.

Table 2-2: NEPM (Air Toxics) Monitoring Investigation Levels and NSW EPA Assessment Criteria

Air Pollutant	NEPM (Air Toxics) MIL, averaging period	NSW EPA (2016) assessment criterion, averaging period
Benzene	3 ppb, annual	9 ppb, 1 hour
Toluene	1000 ppb, 24 hours	90 ppb, 1 hour
	100 ppb, annual	
Xylenes	250 ppb, 24 hours	40 ppb, 1 hour
	200 ppb, annual	

2.4 Vegetation Protection Standards

Air quality standards for the protection of vegetation have been set out by the World Health Organization (WHO, 2000), and the European Union (EU, 2008). While these standards were developed for the protection of a variety of vegetation in the European region, such as conifer forests, they have had wider application and have been used for the assessment of proposals in WA previously. SKM (2006) used the WHO (2000) standards. This air quality impact assessment has adopted the EU (2008) standards given they are the most recent; the relevant standards are listed in Table 2-3. To be able to compare the results from the NO_x and SO_2 dispersion modelling the units of the EU (2008) standards were converted to ppb. A temperature of 30 ^oC was used for this conversion, which is a typical ambient temperature relevant to Pluto Train 2. Note that SKM (2006) used zero degrees Celsius for the conversion calculations, which was a low temperature.

Table 2-3: EU (2008) Air Quality Standards for the Protection of Vegetation

Air Pollutant	EU (2008) Air Quality Standard	Standard Adopted for Assessment; Annual Average
SO_2	20 µg/m^3, annual	7.8 ppb at 30 ^oC
NO_x	30 µg/m^3, annual	16.2 ppb at 30 ^oC

Air dispersion models calculate surface deposition for airborne substances using an airborne concentration near ground-level, a deposition velocity for the substance of interest and other parameters (Seinfeld and Pandis (2016)). These parameters are difficult to accurately quantify, and therefore the standards for deposition have greater uncertainties than the standards based on airborne concentrations only.

2.5 Land Surface Protection Standards

There are no accepted or commonly applied standards for assessing deposition of air pollutants on land surfaces, such as Burrup Peninsula rock art, and the Government of WA Murujuga Rock Art Strategy (2019) indicates further research is needed in this area.

While this assessment report provides results for NO_2 and SO_2 deposition, no assessment nor commentary is provided about the potential impacts on rock art. In this case model results for deposition were provided, primarily for comparisons with other results obtained from measurements.

3. Existing Air Quality

3.1 Overview

The purpose of this section is to describe existing air quality in the Burrup Peninsula region, primarily by a review of Woodside ambient air quality monitoring data. To understand the existing meteorology relevant to Pluto Train 2 a review of local meteorology on the Burrup Peninsula is provided in Appendix B.

Woodside established the Burrup Ambient Air Monitoring Program (BAAMP) in 2008, which continued to 2011. As part of the Pluto project, Woodside continued the monitoring program to the end of 2015 (Jacobs, 2016). Prior to the more recent monitoring programs, the Pilbara Air Quality Study (PAQS) was undertaken by the Government of Western Australia in the early 2000s including investigations of monitoring data. The PAQS established important baselines for future assessments (DEP, 2002; DoE, 2004).

Data from the ambient air quality programs and the PAQS has been used to describe the existing air quality relevant to Pluto Train 2.

3.2 Air Quality Effects from Fires

There are a number of air quality reports that suggest bush fires noticeably impact the air quality in the Pilbara region. Air pollutant levels typically affected by bush fires are reported to be O_3, PM_{10}, carbon monoxide (CO), NO_x and NO_2. One source suggested that the highest O_3 levels detected at Karratha in 2012 may have been caused by fires rather than industrial sources (Golder, 2014b).

3.3 Nitrogen Dioxide and Ozone

NO_x and O_3 are key pollutants associated with Pluto Train 2. Whilst NO_x is emitted from the Pluto LNG Development and Pluto Train 2, O_3 is a more complex process. In general, the production of O_3 from emissions of NO_x and other pollutants such as VOCs and CO in the presence of ultraviolet light (Seinfeld and Pandis, 2016).

The entire BAAMP dataset of hourly average NO_x and O_3 acquired from 2008 to 2015 was re-analysed for this project. NO_x is an expression of the total amount of both nitric oxide (NO) and NO_2 in a gas, with the mass of NO_x calculated by assuming that all of the NO has been oxidised to NO_2. Data capture for each pollutant, for each location, was an important consideration in the review. The results confirmed what was found in the previous reviews by Golder (2014b); i.e. that NO_2 is typically observed well below the relevant NEPM (Ambient Air Quality) standard of 120 ppb for NO_2. (There is no ambient air quality standard for NO.) The monitoring results showed that O_3 is a higher risk air pollutant for the Burrup Peninsula based on comparisons with the corresponding NEPM (Ambient Air Quality) standard of 100 ppb.

The monitoring results showed higher O_3 concentrations in Dampier and Karratha in comparison with NO_2. The opposite was the case for the Burrup Road ('Burrup') station, located closer to the sources. An interpretation is NO_x, assumed to be emitted primarily by Woodside sources, was dispersed to lower concentrations by the time it reached the townships of Dampier and Karratha. Therefore, there was less NO_x in the townships to destroy the O_3 that built up to higher concentrations there. A review of ambient monitoring data between 2010-2013 by Golder (Golder, 2014b) identified four small exceedances only of the NEPM (Ambient Air Quality) standard for maximum 4-hourly average O_3 concentration (80 ppb), which all occurred on 24 and 26 October 2012. A detailed analysis by Golder (2014b) could not determine the source of this anomaly.

BAAMP data capture for NO_2 and O_3 for the three monitoring stations is set out in the tables overleaf for 2009-2015. In the tables, data capture less than 80% is indicated in red. Years for which no measurements occurred are indicated by 'ND' (No Data). Annual and campaign data capture results are provided for O_3.

Table 3-1: Karratha Air Quality Monitoring – Data Capture NO_2 and O_3

Substance	2009	2010	2011	2012	2013	2014	2015
NO_2	91.8%	93.1%	92.4%	94.8%	94.4%	91.5%	94.6%
O_3	70.8% (year) 94% (1 April to 31 Dec)	94.3%	90.6%	90.1%	91.3%	89.0%	91.2%

Table 3-2: Dampier Air Quality Monitoring Results – Data Capture NO_2 and O_3

Substance	2009	2010	2011	2012	2013	2014	2015
NO_2	89.2%	86.9%	86.9%	87.4%	92.2%	89.6%	92.4%
O_3	3% (year) 51% (10 Dec to 31 Dec)	90.9%	95.4%	94.5%	95.3%	92.5%	95.9%

Table 3-3: Burrup Road Air Quality Monitoring Results – Data Capture NO_2 and O_3

Substance	2009	2010	2011	2012	2013	2014	2015
NO_2	82.7%	91.5%	84.0%	88.4%	94.7%	92.6%	91.3%
O_3	8.8% (year) 94.3% (24 Oct to 27 Nov.)	ND	ND	ND	ND	ND	ND

Statistical summaries of the BAAMP results for hourly average NO_2 concentrations for the three monitoring locations are illustrated in Figure 3-1 (Karratha), Figure 3-2 (Dampier), and Figure 3-3 (Burrup).

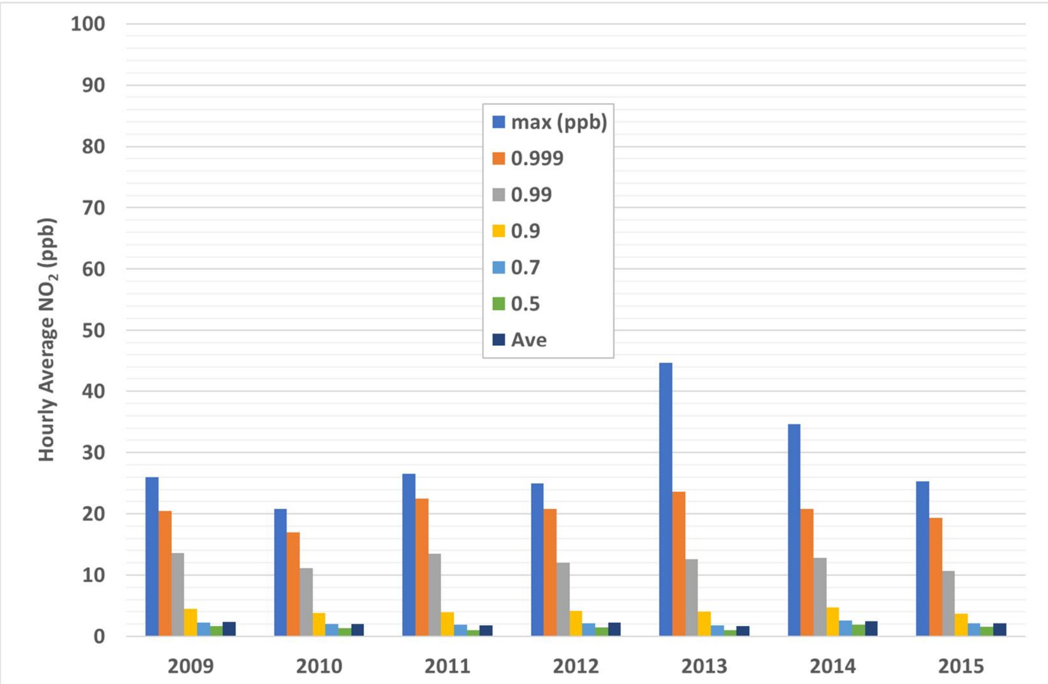

Figure 3-1: Woodside Air Quality Monitoring Results 2009-2015: Karratha NO_2

The NEPM (Ambient Air Quality) maximum hourly average NO_2 standard is 120 ppb, and the annual average standard is 30 ppb. Inspection of the maximum hourly average and annual average NO_2 concentrations (ppb) for the years shown in Figure 3-1 (Karratha), Figure 3-2 (Dampier), and Figure 3-3 (Burrup), demonstrate clearly that there have been no exceedances of any NO_2 standards over the monitoring period of several years. This includes 2014 when Pluto LNG Development LNG Plant (PLP) had ramped up to full production; Karratha Gas Plant (KGP) was operating to capacity in 2014 also.

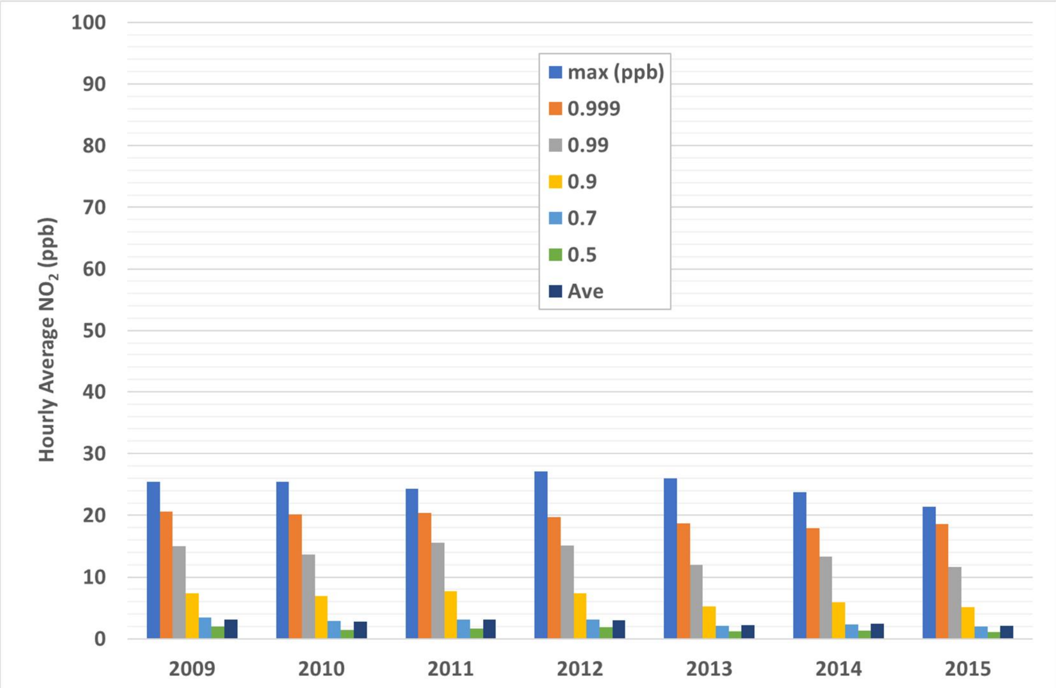

Figure 3-2: Woodside Air Quality Monitoring Results 2009-2015: Dampier NO_2

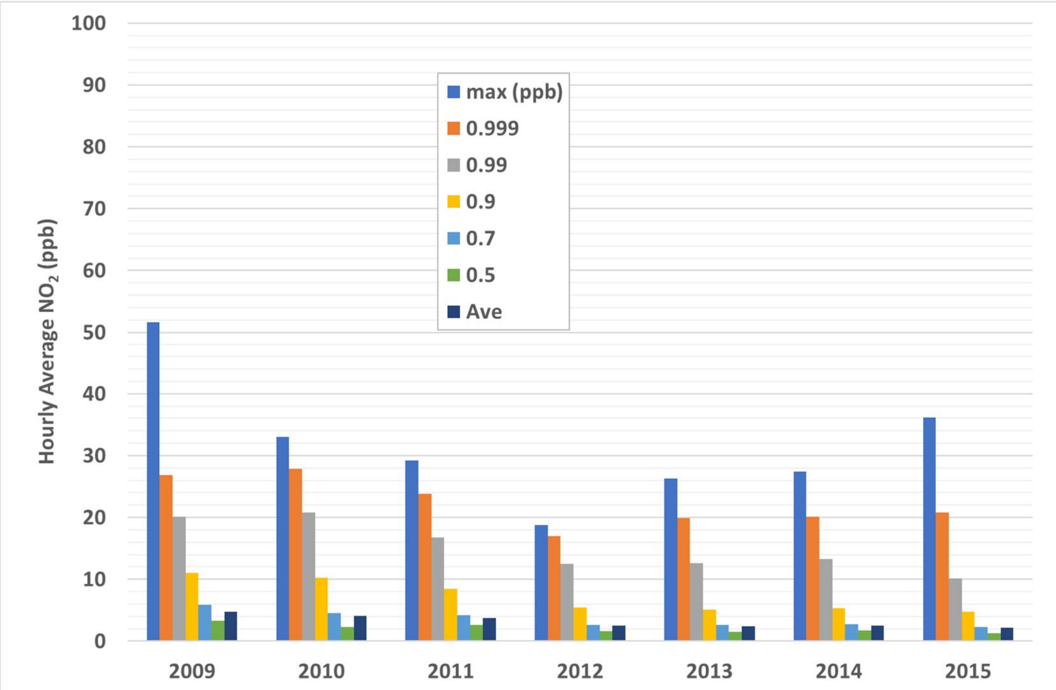

Figure 3-3: Woodside Air Quality Monitoring Results 2009-2015: Burrup NO_2

Statistical summaries of results for hourly average O_3 concentrations are shown for the two monitoring locations where data capture was adequate: Karratha (Figure 3-4) and Dampier (Figure 3-5). The corresponding NEPM (Ambient Air Quality) standard (maximum hourly average, 100 ppb) was not exceeded in any hour measured over 2009-2014.

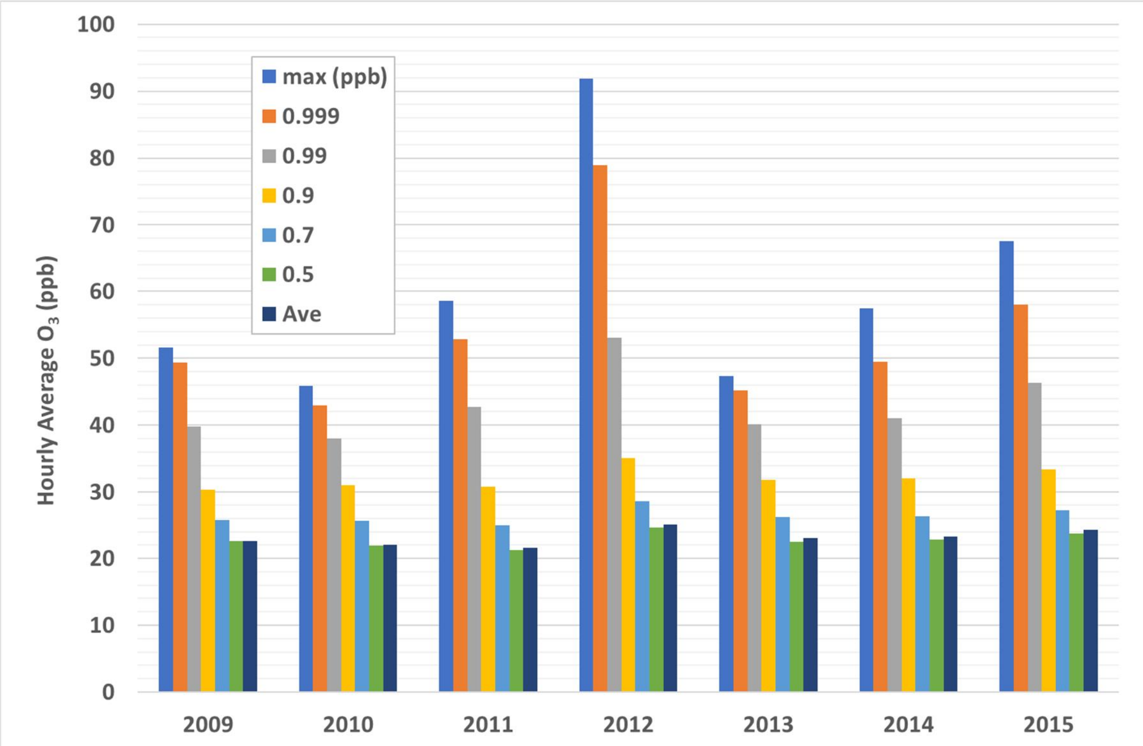

Figure 3-4: Woodside Air Quality Monitoring Results 2009-2015: Karratha O_3

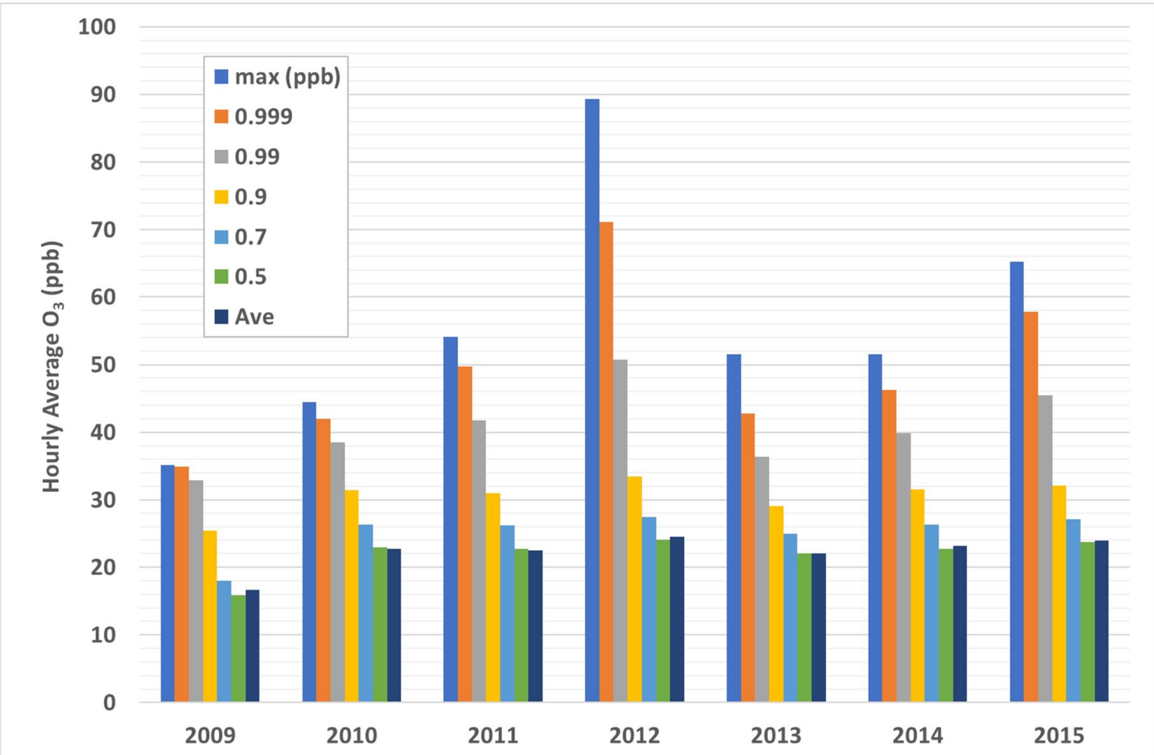

Figure 3-5: Woodside Air Quality Monitoring Results 2009-2015: Dampier O_3

3.4 Hydrocarbons – Benzene Toluene Xylenes

A statistical analysis was undertaken for the whole benzene, toluene and xylene (BTX) ambient air monitoring dataset (hourly averages), which were measured at Burrup ambient air monitoring stations between 2008-2015, and Dampier and Karratha ambient air monitoring stations over 2008-2010. A summary of the key findings is provided in the following paragraphs.

Benzene. Maximum hourly average concentrations measured at Dampier and Karratha over 2008-2010 (approximately 11,000-12,000 hourly averages) never exceeded 3 ppb. For comparison, the corresponding NSW EPA (2016) assessment criterion is 9 ppb (NSW DEC, 2016). The measured 90th percentile hourly average benzene concentrations at both locations was 0.1 ppb only. There were some exceedances of the NSW EPA (2016) assessment criterion for benzene (9 ppb) at the two Burrup monitoring stations: 14 hours at 'Burrup 1' (0.03% of total hours), and 12 hours at 'Burrup 2' (0.04% of total hours). When assessing these exceedances it is relevant to consider that there were very few instances and they are unlikely to impact on sensitive receptors. The NEPM (Air Toxics) MIL for benzene is 3 ppb as an annual average, from the ambient monitoring results the annual average benzene is typically less than 0.1 ppb.

Toluene and Xylenes. From a review of all ambient air quality monitoring results over 2008-2015 for all monitoring locations, toluene and xylenes were found to be lower levels than benzene. This is based on analysis of the concentrations and comparisons with relevant air quality standards. Therefore, benzene could be assigned as a 'trigger pollutant' for the BTX group; i.e. if benzene does not cause air quality impacts then it is unlikely that any other of the BTX components will cause air quality impacts.

The BAAMP results for data capture for BTX are listed in the tables below for: Karratha (Table 3-4), Burrup (Table 3-5), and Dampier (Table 3-6). Years for which no measurements occurred are indicated by 'ND'.

Table 3-4: Karratha Air Quality Monitoring – Data Capture for BTX

Substance	2009	2010	2011
Benzene	91%	32%	ND
Toluene	91%	32%	ND
Xylene	91%	32%	ND

Table 3-5: Burrup Air Quality Monitoring – Data Capture for BTX

Substance	2009	2010	2011	2012	2013	2014	2015
Benzene	90%	89%	72%	75%	75%	77%	73%
Toluene	90%	89%	72%	75%	75%	77%	70%
Xylene	88%	84%	70%	63%	75%	74%	62%
Benzene 2*	ND	57%	81%	76%	76%	73%	78%
Toluene 2*	ND	57%	81%	76%	76%	73%	78%
Xylene 2*	ND	57%	81%	76%	76%	73%	78%

*Duplicate BTX samples undertaken at Burrup Road monitoring station from 2010 onwards; therefore the true data capture is higher than indicated here.

Table 3-6: Dampier Air Quality Monitoring – Data Capture for BTX

Substance	2009	2010	2011
Benzene	91%	35%	ND
Toluene	91%	35%	ND

Substance	2009	2010	2011
Xylene	91%	35%	ND

A statistical summary of the hourly average BTX monitoring results for 2009, the only year where data capture was greater than 75% for each station, is provided in Table 3-7. The statistics listed are maxima, 99.9 percentile hourly average, etc. The results show the BTX concentrations were very low for the great majority of time (99.9% of hours). The summaries are based on data from 2009 until April 2015 (at the time of writing this air quality impact assessment, the data post-April 2015 were unavailable for analysis). In 2015, BTX was measured at Burrup only, with data available for analysis to April 2015 only.

Table 3-7: Air Quality Monitoring 2009 – BTX Statistics at Karratha, Burrup and Dampier

Hydrocarbon	Benzene (ppb)			Toluene (ppb)			Xylenes (ppb)		
Station	Karratha	Burrup	Dampier	Karratha	Burrup	Dampier	Karratha	Burrup	Dampier
Data Capture	91%	90%	91%	91%	90%	91%	91%	88%	91%
Max.	3.45	12.29	0.91	37.44	65.80	0.95	0.93	6.83	0.58
NSW Assessment Criterion	9			90			40		
99.9th percentile 1h avg.	0.37	8.77	0.29	3.88	13.78	0.34	0.51	3.92	0.27
99th percentile 1h avg.	0.19	0.99	0.12	0.75	2.36	0.14	0.21	0.55	0.07
90th percentile 1h avg.	0.07	0.31	0.06	0.13	0.17	0.05	0.07	0.18	0.03
70th percentile 1h avg.	0.04	0.08	0.03	0.05	0.03	0.02	0.05	0.03	0.02

3.5 Airborne Particulate Matter as PM_{10} and $PM_{2.5}$

Although PM is not a high emission from LNG facilities the existing environment is characterised by high levels of PM which is relevant to providing context of the existing air quality.

Rio Tinto conducts PM monitoring at Dampier, Karratha, King Bay, Wickham, Point Samson and Roebourne (Rio Tinto, 2015). Monitoring reports were not available for review at the time of writing. However, recent data are published on a website (http://www.pilbarairon.com/dustmonitoring/, accessed 9 May 2019). For example, on 9 May 2019 very high PM_{10} (particulate matter less than 10 µm in diameter) concentrations were observed at Dampier, Karratha, Wickham, Point Samson, and Roebourne. The good correlation between these measurements by several monitors on this day indicates a dust storm was the probable cause. A review of 30 days of PM_{10} data for Karratha (10 April to 10 May 2019) indicates the 'clean air background' PM_{10} levels are approximately 10 µg/m^3, with a median or average closer to approximately 20 µg/m^3. These values are typical of PM_{10} concentrations measured in other parts of Australia.

SKM (2005) provided a useful time series plot of daily PM_{10} measured at Dampier by Hamersley Iron over 2001-2004. Some broad conclusions about the variations in PM_{10} on the Burrup Peninsula can be drawn by inspection of this relatively long-term record, which provides information about the clean-air background and air quality impacts, the latter probably due to local particulate emissions from bushfires, dust storms, and some industry. The PM_{10} concentrations peaked during higher wind speeds in January, with typical daily concentrations ranging between 30-40 µg/m^3. Exceedances of the NEPM (Ambient Air Quality) standard of

50 µg/m^3 were in the range of approximately 5-10 exceedances per year. Mid-year, during the dry season with corresponding lower wind speeds, typical daily concentrations varied between 10-20 µg/m^3.

The Pluto LNG Development Cumulative Air Quality Study (SKM, 2006) reviewed monitoring results for particulate matter as PM_{10}. The study found that existing industrial activity in the Pilbara air shed mainly contributed to emissions of $PM_{2.5}$ and PM_{10}, with PM exceeding NEPM (Ambient Air Quality) standards. SKM (2006) stated that higher PM_{10} concentrations were observed on days of high wind speeds. On these days the $PM_{2.5}$/PM_{10} fraction was reduced from approximately 50% to approximately 20%, indicating wind-blown dust caused the high PM_{10} concentrations, this is because the small particle fraction is higher in smoke emissions.

The review by Air Assessments (2010) indicated that measurements of PM_{10} at Dampier tend to be high, and "exceed the NEPM (Ambient Air Quality) standard". Air Assessments (2010) indicated the major sources of particulate matter in the Burrup region are: smoke from fires, dust from wind storms and iron ore stockpiling and ship-loading operations at the ports of Dampier and Cape Lambert. Emissions of particulate matter from the on-shore gas plants were recognised as small and of little relevance in comparison with these other sources.

Golder (2014b) reviewed $PM_{2.5}$ monitoring results acquired at Karratha, Dampier and Burrup monitoring stations from December 2011 to December 2012. Although a number of exceedances of NEPM standards for $PM_{2.5}$ were recorded at the three locations, based on back-trajectory analysis, flare rate, black smoke and $PM_{2.5}$ concentrations, Golder (2014b) concluded there was sufficient evidence to suggest that air emissions from the Pluto LNG Project were not associated with the exceedances. Also, iron ore handling was stated as a probable cause of exceedances of $PM_{2.5}$ standards detected at Dampier monitoring station.

3.6 Sulfur Dioxide

A review of SO_2 monitoring results on Burrup Peninsula was undertaken by Air Assessments (2010b). Conservative assumptions were applied for a number of fixed industrial emissions sources, noting very low sulfur in fuel concentrations. For this reason estimates for exhaust SO_2 for most sources are at or near the limit of detection, thus a reasonable estimate for an annual average would be 0.1 ppb (the NEPM (Ambient Air Quality) standard for annual SO_2 is 20 ppb). Maximum hourly average concentrations would not be expected to exceed 10 ppb for most locations away from the most significant sources in the region, which are engine exhausts on ships. The comparable maximum hourly average NEPM (Ambient Air Quality) standard is 200 ppb.

3.7 Deposition Fluxes of Nitrogen and Sulfur

The deposition of NO_2 and SO_2 was modelled to provide information for potential future studies of the total acid deposition flux on land surfaces. On the Burrup Peninsula, Gillett (2008) determined total deposition flux of nitrogen and sulfur at a number of measurement sites in 2004/2005 and 2007/2008 by calculating the wet and dry deposition of all nitrogen and sulfur species in the gas and aqueous (rainwater) phases. This included NO_2, SO_2, nitric acid and ammonia gases, and some other species in rainwater. The study showed that the total (wet and dry) deposition flux of nitrogen and sulfur ranged from 19.8–31.6 milliequivalents per square metre per year (meq.m^{-2}.yr^{-1}) over the two monitoring periods from 2004 to 2008. Units of 'meq/m^2/year' were used to enable comparisons with previous monitoring results. Dry deposition of NO_2 was estimated to contribute to between 16% and 36% of total deposition flux in the region (Gillett, 2008), and SO_2 6% to 8% based on 2004/2005 data. The 2007/2008 data ranged from 12% to 20% NO_2 contribution to total deposition flux, and from 4% to 7% for SO_2 (Gillett, 2008).

Woodside engaged the CSIRO to determine nitrogen deposition flux on and around the Burrup Peninsula between February 2012 and June 2014; i.e., covering the periods before and after the commissioning of the Pluto Liquid Natural Gas (LNG) Plant (Gillett, 2014). A summary of results for the ranges of total measured nitrogen (N) and sulfur (S) fluxes is provided in Table 3-8. Inspection of these results shows they have been reasonably consistent over a long period of sampling.

Table 3-8: Summary of Results for Burrup N and S Deposition Monitoring Programs

Monitoring Program	Analyte	Range of Deposition Excl. Background Sites	Dry Deposition NO_2 Fraction
2004–2005 and 2007–2008	Total nitrogen and sulfur	19.8 – 31.6 meq/m^2/year	16%-36% of total N & S
2008–2009	Total nitrogen	18.4 – 32.9 meq/m^2/year	19%-29% of total N only
2012–2014	Total nitrogen	17.1 – 28.8 meq/m^2/year	17%-34% of total N only

4. Risk Assessment

4.1 Introduction

To determine what the key air emission sources and air pollutants are for Pluto Train 2 a broad-level risk assessment was conducted. The purpose of this assessment was to determine the relative risk of air emission sources and pollutants in proximity to the Pluto LNG Development, with a focus on the BSIA and surrounding region (the region). This assessment was undertaken reviewing previous air assessments and other relevant publicly available information, as a part of validation of the existing air quality environment and model inputs. The outcomes of this risk assessment informed what facilities needed to be included in the modelling and what substances should be modelled.

4.2 Air Pollutant Sources on Burrup Peninsula

4.2.1 Existing Sources

Recent National Pollutant Inventory (NPI) annual reports were analysed as a first-pass screening method to undertake a comparative review of facilities on and nearby the Burrup Peninsula. This review included comparisons of the mass emissions of air pollutants (kg/annum) with a consistent set of ambient air quality criteria. It is noted that NPI reporting methods vary between facilities, operators and analytes, with some analytes approximated at a high level by facility; in general the emissions are determined by an estimate for fuel throughput multiplied by a standard NPI emission factor. Point sources were assumed to be the most relevant sources for the assessment, so the comparative review used the NPI results for the point sources.

A review of NPI reports covering several financial years was undertaken for the many industrial facilities in the Pilbara. The assessment found some facilities could be excluded from further risk assessment and modelling primarily due to their distance from Burrup Peninsula, and their small volumes of emissions.

The following paragraphs contain more detail about the facilities that were considered and the conclusions that were made.

4.2.2 Chevron Gorgon LNG Development, Barrow Island

The Chevron Gorgon LNG Development located on Barrow Island is approximately 140 km west of Burrup Peninsula. Air Assessments (2012) conducted regional scale air quality modelling covering potential emissions from the Gorgon LNG Development, which included modelled emissions sources on the Burrup Peninsula. The results indicated that while there may be some transfer of air pollutants between the two regions, these would be minimal–as expected, given the distance. The Air Assessments (2012) results show clearly that air quality effects on the Burrup Peninsula would be due to, primarily, sources of air emissions on the Burrup Peninsula.

4.2.3 Sino Iron Minerals Processing Plant and Port

A Sino Iron minerals processing plant is located approximately 74 km from Dampier and 77 km from Karratha, and Sino Iron port facility at Cape Preston located approximately 60 km WSW of Dampier. Similar to Gorgon, the location of Sino Iron meant that air pollutant sources were not expected to cause air quality impacts on Burrup Peninsula. However, sensitivity testing by TAPM modelling was undertaken to test this, given they are closer than Gorgon. The Sino Iron minerals processing plant emits more than ten times the NO_x than the Sino Iron port, as such the focus of the sensitivity testing was on the processing plant. The Sino Iron processing plant was modelled as a continuous NO_x source operating at half-production based on recent NPI reports, but with a conservative high 100% NO_x-to-NO_2 conversion ratio.

The modelling sensitivity tests indicated the Sino Iron mineral processing plant has a small effect on air quality in Dampier and Karratha, although this would be on rare occasions. However, any effects that occur in Dampier and Karratha due to Sino Iron sources, which would occur during southwesterly winds, were considered unlikely to occur at the same time as effects due to sources on the Burrup Peninsula, which are north to northwest of those receptors. The estimates for background NO_x and O_3 included in the modelling for the Pluto Expansion

Project were considered to be sufficient to account for the effects from the Sino Iron facilities, and also the effects from other distant or small facilities.

4.2.4 Other Existing Sources

Port Hedland sources located approximately 190 km east-northeast of Burrup Peninsula were considered to be too distant from the Burrup Peninsula air quality study area to have any significant impacts to air quality.

Cape Lambert and Point Samson sources are located approximately 40 km east-northeast of Karratha; most sources were not included in the modelling due to their distance and low emissions quantities as determined from a review of NPI reports. However, shipping emissions from all berths on Cape Lambert were included in the modelling.

TAPM modelling sensitivity tests were undertaken to test the effects of emissions from shipping; this comprised photochemical modelling for December 2012 only, which was one of the worst months for ozone, based on a review of monitoring data. The TAPM results indicated shipping emissions would have a significant effect on ozone levels. As such modelling of shipping emissions was included in the main assessment (Cape Lambert and Burrup Peninsula).

While emissions from the Santos (formerly Quadrant Energy) Devil Creek Power Station, ATCO Karratha Power Station, and EDL West Kimberley Power Project are relatively small, they were included in the modelling for the Project due to their proximity to the Burrup Peninsula.

The two facilities most relevant to be included in the modelling for the Pluto Expansion Project are the existing Woodside operated PLP and KGP facilities. The emissions from the PLP were considered in further detail for the risk assessment, described in the next section.

4.2.5 PLP Emissions

The Australian Government (AG) FY17/18 NPI report for the PLP (AG, 2019) was analysed for the risk assessment. The relative risks were calculated by the ratios between emissions amounts (kg/annum), and a consistent set of air quality standards. The NSW EPA (2016) hourly assessment criteria were used for this purpose. In this simple, first-pass assessment, the NO_2 risk was based on a 30% NO_2/NO_x ratio by mass, and O_3 risk based on 70% of NO_x emission by mass.

The results of analysis of the PLP FY17/18 NPI report clearly showed the key (elevated risk) air pollutants for air quality impact assessment, in terms of the potential impact to human health were NO_2 and O_3, as expected from the string of previous modelling studies; e.g., SKM (2007). Formaldehyde was identified with a higher risk than benzene, but the results for all other VOCs i.e. toluene, xylenes, Polycyclic Aromatic Hydrocarbons (PAHs), and dioxins and furans, all presented with lower risk values than benzene. Formaldehyde was investigated further and found to present with a substantially lower risk than NO_2 and benzene for emissions from the KGP, thereby lowering the overall risk for this substance.

It is noted that H_2S could be an elevated-risk pollutant due to its very low odour threshold (for the human sense of smell). However, given the Burrup Peninsula has no known history of H_2S odour complaints, which is essentially a null observations result, and H_2S was not identified as a key air pollutant by any of the previous air quality studies, H_2S was eliminated as a substance of interest for this assessment.

The particulate matter group $PM_{2.5}$ was also identified from the analysis of the PLP FY17/18 NPI report as an elevated-risk pollutant, but with significantly lower risk than NO_2. As such estimates of $PM_{2.5}$ (and PM_{10}) were included as input to the more detailed modelling assessment. However, it is known that particulate air pollution on the Burrup Peninsula is dominated by bushfires, dust storms, and other dust sources such as iron ore ship-loading (Air Assessments, 2010).

It is emphasised the analysis of NPI data represented a first-pass risk assessment and checks on previous assessment results, to confirm the selection of substances for assessment. Further, more detailed assessment of industrial emissions was addressed by modelling.

4.2.6 Proposed Future Sources

There are a number of third-party developments that are proposed to be developed on the Burrup Peninsula in the foreseeable future. The emission sources and air pollutants from proposed third-party developments are relevant to cumulative impacts, as defined by the EPA. Therefore, these facilities were reviewed in terms of the types and quantities of substances proposed to be emitted, and their proximity to Burrup Peninsula sensitive receptors. Third-party emissions were represented based on consideration of publicly available literature and input following consultation with some proponents. Two proposals were considered to be significant and therefore added to the cumulative air quality impact assessment for the Pluto Expansion Project; these are described briefly in the following paragraphs (detailed emissions estimates are provided in Section 5).

A third-party indicative urea plant with a proposed production capacity of approximately 2 million tonnes per annum (Mtpa) is proposed for Sites C and F within the BSIA (EPA project notice, 3 December 2018); termed Urea Proposal hereafter. The emissions estimate for the 2Mtpa Urea Proposal were provided by the third-party proponent, with the data checked for accuracy by comparisons with two other similar urea proposals for the Burrup Peninsula (Plenty River, 1998; Dampier Nitrogen, 2002).

A third-party indicative methanol plant with a proposed production capacity of approximately 5,000 tpd is proposed for Site E within the BSIA (EPA project notice, 3 December 2018); termed Methanol Proposal hereafter. The emissions estimate for the Methanol Proposal for this Project were based on a review of the data from a previous, similar Methanex proposal described by EPA (2002); Methanex emissions estimates for a production rate of 7,000 tpd were scaled down to a nominal 6,000 tpd (conservative high) for the 2019 Methanol Proposal, for use in the cumulative impact assessment for Pluto Train 2.

4.2.7 Outcomes

The outcomes of the risk assessment described in the sections above are as follows:

- The key substance for assessment was NO_x from which NO_2 and O_3 concentrations can be determined by photochemical modelling.
- The key sources for modelling were the point source (stack) emissions of NO_x, VOCs and other substances from these facilities:
  - Woodside KGP;
  - Woodside PLP;
  - Yara Pilbara Technical Ammonium Nitrate (TAN) plant;
  - Yara Pilbara Fertilisers liquid ammonia (NH_3) plant;
  - Pilbara Iron Yurralyi Maya Power Station;
  - Santos (formerly Quadrant Energy) Devil Creek Power Station;
  - ATCO Karratha Power Station;
  - EDL West Kimberley Power Project; and
  - Emissions from shipping around Burrup Peninsula comprising modelled sources at all berths on Burrup Peninsula and Cape Lambert.
- Air emissions from all other sources (not listed in bullet point 2) were assessed as unlikely to make a significant contribution to the model-predicted GLCs. In any case the air quality effects from smaller or lower risk sources were accounted for to some extent by the inclusion of background air pollutant concentrations in the modelling. The lower risk sources fell into these classes:
  - Too small as emitters by mass.
  - Too distant, i.e. beyond approximately 50 km from Dampier and Karratha, for the dispersed pollutants to make a significant contribution to GLCs around the Burrup Peninsula.
  - Substances emitted not associated with air quality effects caused by emissions from the Pluto processing facilities; e.g. NH_3 and particulate matter from ship-loading.

- Ambient air monitoring data showed that particulate emissions from the PLP are small, and unlikely to cause measurable air quality effects (Golder, 2014b). Potential air quality impacts from airborne PM in the region are caused mostly by smoke from bushfires, raised dust during high winds, and other industrial sources such as iron ore handling. As such, the particulate assessment parameters PM_{10} and $PM_{2.5}$ were excluded from the modelling study.
- Monitoring of BTX undertaken from 2009-2015 showed that emissions of BTX had insignificant air quality effects at the sensitive receptor locations of Dampier and Karratha. Most of the time, BTX concentrations were nil at those locations. It was concluded formaldehyde would have low concentrations approximately the same as benzene. The conclusion for VOCs was that they be excluded from the modelling for the Pluto Expansion Project. It is noted that estimates for total VOC emissions were included in the modelling as a part of the input for the photochemical modelling.
- H_2S was not identified as an elevated-risk pollutant by any of the previous air quality studies so eliminated as a substance of interest for this assessment.

5. Emissions Sources and Estimates

5.1 Overview

This overview provides a brief technical description of the emissions Pluto LNG Development and Pluto Train 2. Emissions inventories were developed in consultation with Woodside, based on reasonable and conservative emissions estimates, considering available datasets, design data, monitoring data and for the Pluto Train 2 preliminary design data. Third-party emissions were represented based on consideration of publicly available literature and input following consultation with some parties. Further details of the air emissions scenarios and input data for modelling are set out in the following sub-sections.

The Pluto LNG Development processes hydrocarbon gas and liquids piped onshore from the offshore Pluto riser platform to produce LNG and condensate. The Pluto LNG Development is approved to process up to 12 Mtpa of LNG, with the current Train 1 operational facility licenced under the *Environmental Protection Act 1986* (WA) to process up to 6 Mtpa of LNG and up to 160 megawatts of electric power generation using natural gas.

A natural gas processing plant such as the Pluto LNG Development uses Gas Turbine Generators (GTGs) for power generation and driving Gas Turbine Compressors (GTCs). The GTGs and GTCs are combustion engines that emit air pollutants such as CO and NO_x. Air emissions from GTGs and GTCs are minimised via the selection of best practicable technology; e.g. Dry Low-NO_x (DLN) emissions control systems. The existing Pluto LNG Development includes a Regenerative Thermal Oxidiser (RTO) used to destroy hydrocarbons such as benzene, and oxidize sulfur compounds from the Acid Gas Removal Unit (AGRU). The purpose of the AGRU is to prevent process blockage (e.g. dry CO_2) and meet sales gas specifications for sulfur and carbon dioxide (CO_2). Removed gaseous species include H_2S and mercaptans (Mokhatah et al, 2015).

The construction of Pluto Train 2 will comprise six GTCs, one GTG, an AGRU and Nitrogen Rejection Unit (NRU) thermal oxidisers.

Air emissions are also reduced through the recovery of waste heat from gas turbine units (Waste Heat Recovery Units). Recovered heat will usually supply all of the heat demand of a gas processing plant, thus enhancing energy efficiency and eliminating the need for further combustion sources and, therefore, additional air emissions. The Pluto LNG Development flare operations were designed to be restricted to start-up, shutdown, upset, maintenance and emergency conditions.

Four air emissions scenarios were tested by modelling to support the Pluto Expansion Project. A summary of these scenarios is provided in Table 5-1, and further details are set out in the following sub-sections.

Table 5-1: Model Scenarios

Modelling Type	Scenario	Description and Emission Sources
Current and Expansion	Current Baseline (CBM)	Representing the existing air emissions scenario mostly applicable to the BSIA and the region to use as a baseline for assessment. · KGP · PLP · Yara Technical Ammonium Nitrate and Liquid Ammonium Plant · Pilbara Iron Yurralyi Maya Power Station · Santos Devil Creek Power Station · ATCO Karratha Power Station · EDL West Kimberley Power Plant · All shipping berths on the Burrup Peninsula

Modelling Type	Scenario	Description and Emission Sources
		· All shipping berths at Cape Lambert
	Pluto Future State (FPS)	Current Baseline plus the proposed future Pluto Expansion Project primarily including the Pluto Train 2 sources. The purpose of the Pluto Future State scenario is to illustrate the potential future effects of the Pluto Expansion Project in the frame of current emissions in the region. The Pluto Future State scenario could be described as both a 'best case' and a 'most likely case' (EPA, 2019).
Sensitivity	Future BSIA (FBSIA)	Includes Current Baseline plus the Pluto Expansion Project, as well as other potential BSIA future proposals such as the Urea and Methanol Proposals. The FBSIA scenario represents the best estimate of the future air quality.
	Pluto Operational Upset Condition (PUC)	A worst-case operational upset condition based on the FBSIA with abnormal operations to include concurrent elevated flare operations. The PUC scenario represents a 'worst case' scenario for testing (EPA, 2019).

5.2 Current and Expanded Operations

5.2.1 Overview of Current Baseline Scenario

The Current Baseline scenario provided the air quality 'baseline' for the assessment, comprising the existing Burrup Peninsula air emissions scenario for modelling and assessment. This was a critical piece of the assessment because the results from the Current Baseline scenario were used for comparisons of air quality modelling results with NO_2 and O_3 measurements obtained at the Burrup, Dampier and Karratha ambient air quality monitoring stations.

The Current Baseline scenario included air emissions estimates for 94 existing air pollutant 'point' (stack) sources on the Burrup Peninsula. A summary of these point sources with total NO_x emissions (g/s) shown for comparison is provided in Table 5-2.

Table 5-2: Summary of Air Emissions Sources

Industrial Facility	Number of Emission Sources	Total NO_x Emission Rate (g/s)
KGP	44	281
PLP	11	34.1
Yara Technical Ammonium Nitrate and Liquid Ammonium Plant	4	30.3
Pilbara Iron Yurralyi Maya Power Station	5	28.2
Santos Devil Creek Power Station	7	4.5
ATCO Karratha Power Station	2	12.0
EDL West Kimberley Power Plant	3	1.2
All shipping berths on the Burrup Peninsula	13	26.0
All shipping berths at Cape Lambert	5	10.0

The emissions parameters used as inputs to the modelling for the Current Baseline are provided in the subsections that follow.

5.2.2 Karratha Gas Plant

The existing KGP air emission sources comprise:

- Four domestic gas (Domgas) GTCs.
- Trains 1, 2 and 3 - each consisting of five GTCs, with one GTC exhaust per train with integrated Acid Gas Removal Unit (AGRU) CO_2 vent stack system.
- Trains 4 and 5 – each consisting of two GTCs, with one machine each including two WHRU exhaust stacks.
- 10 power generation gas turbines, with two providing integrated AGRU CO_2 vent stack systems for LNG Trains 4 and 5.

Air emissions parameters for the KGP air emissions sources are listed in Table 5-3.

Table 5-3: Woodside KGP Air Emissions Parameters – Current Baseline Scenario

Emissions Source	Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Domgas GTC 1	24.0	0.98	42.3	815	3.81	0.12	0.01
Domgas GTC 2	24.0	1.40	43.4	764	12.02	0.25	0.01
Domgas GTC 3	24.0	0.98	42.3	815	3.81	0.12	0.01
Domgas GTC 4	24.0	1.40	43.4	764	12.02	0.25	0.01
TRAIN 1 – GTC 1	40.0	1.94	19.5	777	10.15	0.27	0.01
TRAIN 1 – GTC 2	40.0	1.94	19.5	782	9.68	0.27	0.01
TRAIN 1 – GTC 3	40.0	1.80	22.7	767	9.81	0.27	0.01
TRAIN 1 – GTC 4	40.0	1.80	21.7	771	9.19	0.27	13.5
TRAIN 1 – GTC 5	40.0	1.36	18.9	795	3.55	0.12	0.01
TRAIN 2 – GTC 1	40.0	1.94	19.5	777	10.15	0.27	0.01
TRAIN 2 – GTC 2	40.0	1.94	19.5	782	9.68	0.27	0.01
TRAIN 2 – GTC 3	40.0	1.80	22.7	767	9.81	0.27	0.01
TRAIN 2 – GTC 4	40.0	1.80	21.7	771	9.19	0.27	13.5
TRAIN 2 – GTC 5	40.0	1.36	18.9	795	3.55	0.12	0.01
TRAIN 3 – GTC 1	40.0	1.94	19.5	777	10.15	0.27	0.01
TRAIN 3 – GTC 2	40.0	1.94	19.5	782	9.68	0.27	0.01
TRAIN 3 – GTC 3	40.0	1.80	22.7	767	9.81	0.27	0.01
TRAIN 3 – GTC 4	40.0	1.80	21.7	771	9.19	0.27	13.5
TRAIN 3 – GTC 5	40.0	1.36	18.9	795	3.55	0.12	0.01
TRAIN 4 – GTC 2	40.1	3.00	23.8	811	5.79	0.64	0.01
TRAIN 4 – GTC 1 WHRU1	40.1	1.45	50.9	588	3.13	0.29	0.01
TRAIN 4 – GTC 1 WHRU2	40.1	1.45	50.9	521	3.13	0.29	0.01
TRAIN 5 – GTC 2	40.1	3.01	23.7	811	7.18	0.64	0.01
TRAIN 5 – GTC 1 WHRU 1	40.1	1.45	50.9	523	3.11	0.29	0.01

Emissions Source	Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
TRAIN 5 – GTC 1 WHRU 2	40.1	1.45	50.9	483	3.11	0.29	0.01
Stabiliser 2 Furnace Stack	33.0	0.73	39.2	699	2.56	0.01	0.01
Stabiliser 4 Furnace Stack	33.0	0.73	39.2	668	2.17	0.01	0.01
Stabiliser 5 Furnace Stack	33.0	0.73	39.2	659	2.23	0.01	0.01
Stabiliser 6 Furnace Stack	32.6	0.73	39.2	630	1.98	0.01	0.01
Power Generation GTG 1	40.0	1.98	20.4	681	11.58	0.24	0.01
Power Generation GTG 2	40.0	1.98	21.5	681	12.21	0.24	0.01
Power Generation GTG 3	40.0	1.98	20.4	675	8.63	0.24	0.01
Power Generation GTG 4	40.0	1.98	21.5	681	12.21	0.24	0.01
Power Generation GTG 5	40.0	1.98	20.4	675	8.63	0.24	0.01
Power Generation GTG 6 + AGRU 4 & 5 Vent	40.0	1.98	20.4	675	8.63	0.24	40.6
Power Generation GTG 7	40.0	1.79	22.2	751	3.00	0.22	0.01
Power Generation GTG 8	40.0	1.79	17.7	751	2.66	0.22	40.6
Power Generation GTG 9	40.0	1.79	34.6	751	4.45	0.22	0.01
Power Generation GTG 10	40.0	1.79	31.3	745	3.64	0.22	0.01
Domgas-E Flare	128.5	0.51	20.0	1273	0.28	0.00	0.58
LNG Emergency Flare (representative)	145.3	3.26	20.0	1273	11.32	0.04	23.42
LNG-SL Flare	56.9	0.28	20.0	1273	0.08	0.00	0.17
LPG-SL Flare	56.5	0.21	20.0	1273	0.05	0.00	0.10
Operations Flare	46.8	0.73	20.0	1273	0.56	0.00	1.17

*Power Generation Turbine 6 is modelled together with the AGRU vent systems 4&5 as a single source.

Flares emissions are represented conservatively with elevated rate applied for KGP LNG Emergency Flare as a constant source in the model to reflect potential for frequent intermittent operation across KGP and PLP. Credible baseload flaring is assumed for other flare points.

5.2.3 Pluto onshore LNG Plant

The locations of the current (baseline) and proposed future 'point' (or stack) air emissions sources for the Pluto LNG Development and Pluto Expansion Project are shown in Figure 5-1.

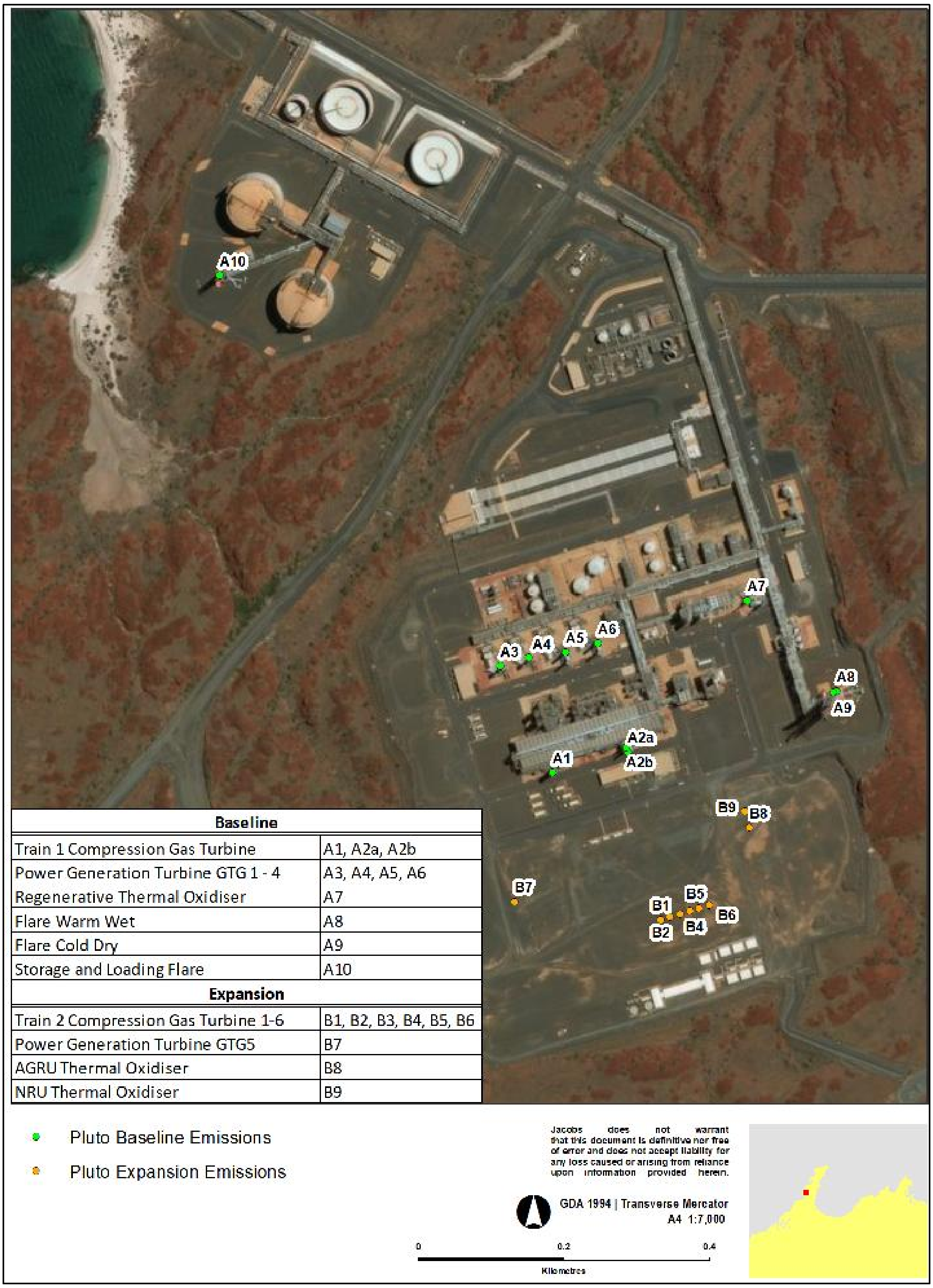

Figure 5-1: Pluto LNG Development and Pluto Expansion Project Air Emissions Point Sources for Modelling

The existing PLP air emissions parameters used as input to the modelling for the Current Baseline scenario are listed in Table 5-4.

Table 5-4: Woodside PLP Air Emissions Parameters – Current Baseline Scenario

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
PLP Train 1 – GTC 1 WHRU 1	40.0	2.90	39.2	531	5.63	0.37	0.01
PLP Train 1 – GTC 1 WHRU 2	40.0	2.90	41.2	527	5.10	0.38	0.01
PLP Train 1 – GTC 2	40.1	6.01	28.0	824	10.20	0.37	0.01
PLP GTG 1	40.0	3.11	28.0	868	3.27	0.25	0.01
PLP GTG 2	40.0	3.86	23.0	874	3.36	0.24	0.01
PLP GTG 3	40.1	2.80	23.8	879	3.22	0.16	0.01
PLP GTG 4	40.1	2.80	22.0	883	1.82	0.33	0.01
PLP Train 1 - Regenerative Thermal Oxidiser	40.0	2.80	17.7	394	0.08	0.42	0.01
Flare Cold Dry	139.5*	1.34	20.0	1273	0.49	0.002	1.01
Flare Warm Wet	139.5*	1.34	20.0	1273	0.49	0.002	1.01
Storage and Loading Flare	64.3*	1.28	20.0	1273	0.45	0.002	0.92

*Calculated 'Effective' stack height for flare sources; USEPA (1992); USEPA (1995).

5.2.4 Yara Pilbara Fertiliser and Technical Ammonium Nitrate Plants

The Yara Pilbara Fertilisers and Yara Pilbara Nitrates Technical Ammonium Nitrate (TAN) air emissions parameters are listed in Table 5-5.

Table 5-5: Yara Pilbara Fertiliser and Yara Pilbara Nitrates TAN Air Emissions Parameters

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
TAN Plant Stack	54	1.4	27.5	423	4.2	0	0
TAN power generation	30	2.6	16.9	450	2.1	0	0
Fertiliser Reformer	35	3.5	15.0	413	17.1	0.23	$2x10^{-5}$
Fertiliser Boiler	30	3.0	4.1	450	6.9	0.13	0

5.2.5 Hamersley Iron Yurralyi Maya Power Station

The Yurralyi Maya Power Station, owned and operated by Hamersley Iron Pty Ltd, is located approximately 17 km south of the Burrup Hub site. Key air emissions sources of the Yurralyi Maya Power Station are the gas turbines; air emissions parameters are listed in Table 5-6.

Table 5-6: Yurralyi Maya Power Station Emissions Data

Emissions Source	Stack Height (m)	Stack Diam. (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	40	3.57	25.7	722	5.63	4.0	0.04
GTG 2	40	3.57	25.7	722	5.63	4.0	0.04
GTG 3	40	3.57	25.7	722	5.63	4.0	0.04
GTG 4	40	3.57	25.7	722	5.63	4.0	0.04
GTG 5	40	3.57	25.7	722	5.63	4.0	0.04

5.2.6 Santos Devil Creek Gas Plant

The Devil Creek Gas Plant, operated by Santos (formerly Quadrant Energy), is located 48 km south west of the Burrup hub site. The Devil Creek Gas Plant equipment identified as key air emissions sources associated with power generation turbines, compression turbines, waste gas incinerator and flares for the Current Baseline scenario were: two Solar Taurus 60 GTGs of nominal 5000 kW capacity providing electrical power requirements; two sales gas compressors power by Solar Taurus 60 gas turbines, fitted with waste heat recovery units; a waste gas incinerator; and an elevated flare and ground flare. The associated air emissions parameters are listed in Table 5-7.

Table 5-7: Devil Creek Gas Plant Air Emissions Parameters

Emissions Source	Stack Height (m)	Stack Diam. (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	13	1.6	23.5	783	0.75	0.0	0.005
GTG 2	13	1.6	23.5	783	0.75	0.0	0.005
GTC 1	13	1.6	16.0	633	0.75	0.0	0.005
GTC 2	13	1.6	16.0	633	0.75	0.0	0.005
Waste Gas Incinerator	21	1.8	14.0	1073	0.0	11.0	0.005
Elevated Flare	48	1.6	20.0	1273	0.77	0.0	0.005
Ground Flare	20	1.6	20.0	1273	0.77	0.0	0.005

5.2.7 EDL Energy West Kimberley Power Project

The West Kimberley Power Project, operated by EDL Energy, is located approximately 25 km south-west of the Burrup Hub site. Air emissions parameters for the gas turbines are listed in Table 5-8.

Table 5-8: West Kimberley Power Project Emissions Data

Emissions Source	Stack Height (m)	Stack Diam. (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	10	1.2	26.5	700	0.385	0.0006	0.0025
GTG 2	10	1.2	26.5	700	0.385	0.0006	0.0025
GTG 3	10	1.2	26.5	700	0.385	0.0006	0.0025

5.2.8 ATCO Karratha Power Station

The ATCO Karratha Power station is located 18 km south-east of the Burrup Hub site. Key air emissions sources identified were two LM6000 DP Sprint gas turbines; the air emissions parameters are listed in Table 5-9.

Table 5-9: Karratha Power Station Emissions Data

Emissions Source	Stack Height (m)	Stack Diam. (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	18.2	3.57	26.0	723	6.0	0.01	0.043
GTG 2	18.2	3.57	26.0	723	6.0	0.01	0.043

5.2.9 Shipping and Berths

Emissions from shipping were modelled for all (13) berths on the Burrup Peninsula and five berths at Cape Lambert. A ship was assumed to be docked at each of these berths with ancillary engines running continuously; i.e. 24 hours per day, every day of the year. The air emissions parameters assigned to each of the total of 18 berth locations are listed in Table 5-10.

Table 5-10: Air Emissions Data for Shipping

Stack Height (m)	Stack Diameter (m)	EV (m/s)	Temp. (K)	NO_x (g/s)	CO (g/s)	SO_2 (g/s)	VOC (g/s)
35	0.5	11.9	673	2.0	0.33	2.0	0.12

5.2.10 Pluto Future State Scenario

The purpose of the Pluto Future State scenario is to illustrate the potential future effects of the Pluto Expansion Project in the frame of current emissions in the region. The Pluto Future State emissions parameters are based on CBM, with addition of Train 2 emissions and minor changes to Train 1 GTG parameters (Table 5-11).

Table 5-11: Pluto Train 2 Air Emissions Parameters[1]

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Train 1 – GTG 3	40.1	1.40	29.1	821	2.98	0.07	0.01
Train 1 – GTG 4	40.1	1.40	29.5	823	3.53	0.06	0.01
Train 2 – GTC 1	50.7	3.06	29.6	741	4.55	0.002	0.01
Train 2 – GTC 2	50.7	3.06	29.6	741	4.55	0.002	0.01
Train 2 – GTC 3	50.7	3.6	2.4	741	4.55	0.002	0.01
Train 2 – GTC 4	50.7	3.06	29.6	584	4.55	0.002	0.01
Train 2 – GTC 5	50.7	3.6	2.4	741	4.55	0.002	0.01
Train 2 – GTC 6	50.7	3.06	29.6	584	4.55	0.002	0.01
PLP GTG 5	30.0	5.7	38.3	787	4.88	0.003	0.01
PLP Train 2 - AGRU Thermal Oxidiser	16.0	0.84	13.2	962	0.69	0.141	0.01
PLP Train 2 - NRU Thermal Oxidiser	30.5	1.07	31.0	700	0.70	0.040	0.01

1. Pluto Train 2 emissions characteristics are modelled based on early FEED concept reports, and are subject to change as design matures.

5.3 Sensitivity Modelling

5.3.1 Overview

The purpose of the sensitivity modelling scenarios is to show possible projections that account for referred BSIA proposals. The FBSIA and Pluto Operational Upset Condition scenarios build on the Pluto Future State scenario and include possible emissions from the Urea and Methanol Proposals (FBSIA scenario) and an upset operational condition at Pluto (Pluto Operational Upset Condition).

Air emissions parameters used in the modelling for the Urea Proposal are set out in Table 5-12, and for the Methanol Proposal in Table 5-13.

Table 5-12: Air Emissions Data for Urea Proposal

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Fired Heater H201	75	2.5	15.3	423	6.68	0.04	0.02
GTG 1	30	3.0	20.8	378	2.25	0.07	0.01
Urea Train 1 Absorber vent	40	6.5	19.6	320	0	0	0
Urea Train 2 Absorber vent	40	6.5	19.6	320	0	0	0

Table 5-13: Air Emissions Data for Methanol Proposal

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Flue Gas Stack	35	3.7	20.0	433	20.8	0.001	0.01
Process Condensate Stripper	8.3	0.5	20.0	343	0	0.001	0.01
Flare Stack	35	1.4*	20.0	1273	0.028	0.001	0.01
Gas Turbine Stack	20	3	8.0	753	0.83	0.001	0.01
Auxiliary Boiler Stack	30	3.7	6.0	463	6.39	0.001	0.01

5.3.2 FBSIA Scenario

The FBSIA scenario includes Woodside sources associated with the Pluto Expansion Project and the Urea and Methanol Proposals, and represents the best estimate of the future BSIA air emissions including the Pluto Expansion Project.

The FBSIA scenario comprises Pluto Train 2 in operation, while operating changes are made to PLP Train 1 GTG 3 and GTG 4 associated with integrated power supply. The air emissions parameters for the FBSIA scenario are listed in Table 5-11.

5.3.3 Pluto Operational Upset Condition

The Pluto Operational Upset Condition scenario replicates the FBSIA scenario then simulates the flaring of the PLP that may occur over a period of several days or weeks. The model scenario assumed that these emissions were continuous for the whole simulated meteorological year, and therefore represented a conservative step in the assessment. This is a highly unlikely and therefore conservative scenario.

Under the PUC scenario flaring occurs at the ‘Cold Dry Flare’ stack, while the GTC-1 and 2 are not in operation. Emissions are otherwise modelled as for the FBSIA scenario.

Table 5-14: Pluto Operational Upset Condition Air Emissions Parameters

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Flare Cold Dry – Upset Case	177.65*	7.09*	20	1273	54.75	0.21	113.29
PLP Train 1 – GTC 1 WHRU 1	40.0	2.90	-	-	-	-	-
PLP Train 1 – GTC 1 WHRU 2	40.0	2.90	-	-	-	-	-
PLP Train 1 – GTC 2	40.1	6.01	-	-	-	-	-

*Calculated ‘Effective’ stack height and stack diameter for flare

6. Modelling Methodology

6.1 Overview

The modelling methodology is based on the use of the CSIRO-developed 'TAPM' meteorological and air dispersion model (Hurley, 2008a; Hurley et al., 2008), for consistency with foundational air quality studies completed by CSIRO atmospheric scientists for the Burrup Peninsula; e.g. Hurley et al. (2004); Physick et al. (2004). The latest version of TAPM (V.4.0.5) was used for the modelling.

The modelling methodology was discussed with EPA air quality specialists prior to the commencement of modelling (Jacobs, 2019b). At the EPA meeting, it was proposed to use TAPM for the project primarily due to the legacy of TAPM modelling for the Pilbara environment. Several aspects about the model were raised including which version of the model to use for the project, and alternative modelling options were discussed. EPA's main concern was that a 'robust' model be used; i.e., a model that would be well-known to the scientific assessment community, and EPA and DWER air quality specialists. Subsequent meetings to discuss methodology model development findings, and preliminary outcomes were held with EPA and DWER between on 28 March and 13 May 2019.

This section provides a review of the literature around previous meteorological and air quality modelling studies undertaken specifically for the Pilbara and details the modelling configuration for the Pluto Expansion Project.

6.2 Review of Scientific Literature

Between 2000 and 2010 the air pollution sources on the Burrup Peninsula and the dispersion of pollutants was a focus of intense study including meteorological modelling, air emissions inventory, and air dispersion modelling. These studies included several TAPM modelling studies by the CSIRO Division of Atmospheric Research, SKM (now Jacobs), and other specialist air quality consultants. This section sets out the main findings from a review of those previous studies, important for establishing the modelling methods for this project.

Physick (2001) published a TAPM-Generic Reaction Set (GRS) modelling study on the meteorology and air quality of the Pilbara region, including comparisons with observations at six monitoring sites; this study found:

- There was strong seasonal variation of the monthly averaged winds at each site.
- There was little difference in the winds between the sites for any given month, especially for wind direction.
- Three dominant wind patterns were identified in the coastal region between Karratha and Port Hedland:
  - An easterly pattern in which winds varied between northeast and southeast over the diurnal period;
  - A westerly pattern in which the winds varied from northwest to southwest; and
  - A wind direction rotation anti-clockwise through 360 degrees over 24 hours.
- The rotation pattern was assessed as being likely to be important for the recirculation of pollutants, (therefore causing higher air pollutant concentrations around Burrup Peninsula).
- The rotation prevailed on some days throughout the year, but more frequently in March, April, August and September.

Apart from the importance of recirculation, Physick (2001) found that emissions from the Burrup Peninsula can meander up the coast to Port Hedland, moving onshore and offshore with sea breezes and nocturnal flows off the land. Thus, in this early phase of studying the atmospheric environment of the Burrup Peninsula, TAPM-GRS was found to be a suitable model to apply to the Pilbara region.

In relation to emissions from the Woodside gas processing facilities, Hurley et al. (2004) determined that buoyancy enhancement of the plumes from the Woodside facilities were important – the effect of plumes combining is to enhance the buoyancy of each individual plume ('plume merging'). The reactivity of the hydrocarbons known as VOCs emitted from several Woodside facility stacks was found to be important, and reactivity coefficients for the VOCs were updated. Biogenic emissions were an important consideration, with databases created to address this using a Department of Environmental Protection (DEP) gridded emission inventory (DEP, 2002).

Hurley et al. (2004) advised against assimilation of local wind observations due to the complexity of the region, the sparsity of the wind observations data (two stations only), and local influences such as trees on the wind measurements at Dampier.

Hurley et al. (2008b) reported the following improvements to TAPM V4 over V3:

- better performance for a number of annual meteorological verification datasets;
- better prediction of wind speed average;
- better prediction of temperature standard deviation;
- lower root mean square error (RMSE) for all variables;
- high index of agreement (IOA) for all variables; and
- good prediction of extreme pollution concentrations for several high-quality datasets in regions of varying complexity.

Hurley et al. (2009) provided a summary of some of the improvements in V.4 from V.3:

- Land surface parameterisation, nocturnal, low wind conditions, turbulence in the convective boundary layer, “in particular has resulted in improvements in prediction of near surface meteorology.”
- Wind and temperature performance for a number of regions of varying complexity—e.g. Kwinana, Kalgoorlie, Perth—"have shown consistently good performance for annual statistics with little mean bias, low RMSE and high IOA.”

In summary, in the 2000s the comparisons of TAPM results with monitoring data indicated TAPM was performing well given the complexity of the coastal meteorology of the Burrup Peninsula region (e.g. Physick et al., 2002), and the complexity of the emissions inventories used (e.g. Hurley et al., 2004).

The previous TAPM modelling and input data used were used as the basis for the modelling for the Pluto Expansion Project detailed in the next section.

6.3 Model Configuration

6.3.1 Grid Resolution and Vertical Levels

Horizontal and vertical spatial resolution (and time resolution) are key factors that impact on computer speed for a meteorological and air dispersion modelling run. The TAPM modelling for the Pluto Expansion Project drew on previous TAPM set-ups described in this section. Using TAPM, Physick and Blockley (2001) carried out simulations for the Burrup Peninsula with three grids centred near Dampier (each 21 x 21 x 20 grid points), with grid spacings of 10 km, 3 km and 1 km for the meteorology. The grid spacings for the corresponding air quality simulations over the same domains were 5 km, 1.5 km and 0.5 km.

Physick et al. (2004) completed simulations for only months in the summer (January 1999), winter (July 1998) and the transition season (April 1998). These simulations were carried out on three nests (each 40 x 40 x 20 grid-points) with grid spacings of 30 km, 10 km and 3 km, centred on Karratha. Vertical grid levels were at heights above the ground of 10, 50, 100, 150, 200, 300, 400, 500, 750, 1000, 1250, 1500, 2000, 2500, 3000, 4000, 5000, 6000, 7000 and 8000 m. Terrain elevation was obtained from Geoscience Australia’s gridded 9-second DEM data (approximately 250 m resolution).

For the Pluto Expansion Project, sensitivity tests were undertaken by comparisons of TAPM-predicted winds at Karratha Aerodrome with the BoM measurements of wind speed and wind direction at Karratha Aerodrome and Roebourne. Inclusion of an additional grid with finer horizontal resolution of 400 metres led to only a small improvement in the accuracy of TAPM-predicted winds. However, the added computational time expense of the additional grid was significant; i.e. weeks, given four scenarios required testing, with many model runs required. As such, 1 km resolution modelling was selected for the assessment (meteorological modelling run-times were approximately less than 40 hours for a simulated year).

Assimilation of local wind observational data was not used in TAPM to enable proper comparisons of results from modelling and monitoring, and to avoid the formation of unrealistic wind vector fields. Hurley et al. (2004) advised that meteorological data assimilation was not advisable for the Burrup Peninsula due to the complexity of the region, the sparsity of (quality) wind data (primarily BoM Karratha Aerodrome), and the local influences on observed wind speeds at Dampier such as trees.

For this Pluto Expansion Project assessment, a balance between computing speed and accuracy of results was achieved using the TAPM settings set out in Table 6-1.

Table 6-1: Model Configuration

TAPM Modelling Parameter	Input data	Notes / references
Grid centre coordinates	Lat. S. 20° 40'; Long. 116° 43'	MGA94 co-ordinates: East 470,489 m; North 7,714,717 m
Number of grids	3	Grid Spacings (10 km, 3 km, 1 km)
Outer grid spacing	10 km x 10 km	
Number of grid points	51 (west-east) x 51 (north-south) x 25 (vertical)	Total 2601 ground level grid receptors (inner grid).
Advanced/Experimental Options	Default settings	All defaults as 'Recommended' (Hurley, 2008a).
Modelling year	2014 selected due typical wind pattern as determined from analysis of Bureau of Met. Karratha Aerodrome observational data 2010-2018, and good examples of NO_2 and O_3 measurements at Karratha.	2014 was selected to support model verification of current routine operations against ambient air monitoring records representative of recent plant 'full rate' operations. 2012 was considered a back-up year due good examples of NO_2 and O_3 measurements, and typical wind pattern. However, Pluto GTP was not fully operational in 2012.
Vertical Layers (m)	25 vertical layers including: 10, 50, 100, 150, 200, 300, 400, 500, 750, 1000, 1250, 1500, 2000… up to 8000 metres.	

6.3.2 Land Use

TAPM uses terrain elevations and land use data to describe the geography of a study area that underlies the fields of three-dimensional meteorological data computed and allowed to evolve over the modelled study area. Land use data include important parameters for boundary layer meteorological computations where the meteorology makes contact with the land surface. One of these parameters is surface roughness, which influences turbulence in the atmospheric boundary layer or mixing layer, which in turn influences the dispersion of air pollutants that these lower layers.

Parameters for vegetation types defined in the TAPM model are set out in Table 6-2 (Hurley 2008a).

Table 6-2: TAPM Vegetation Characteristics

Type	Height (m)	Surface fraction (s_f)	Leaf Area Index	Minimum stomatal resistance (s^{-1})
Forest - low dense	9.00	0.75	3.9	200
Shrubland - tall mid-dense scrub	3.00	0.50	2.6	160
Shrubland - low mid-dense	1.00	0.50	1.4	90
Shrubland - low sparse	0.60	0.25	1.5	90
Grassland - mid-dense tussock	0.60	0.50	1.2	80
Pasture mid-dense	0.45	0.50	1.2	40
Urban and Industrial	10.00	0.75	2.0	100

The TAPM land use settings for the Burrup Peninsula were based on those of Physick and Blockley (2001). For the 1 km grid, land-use classification in the data set accompanying the TAPM modelling package was changed from a land category to water for grid points corresponding to the Dampier Salt Farm at the lower end of the Burrup Peninsula. A roughness length of 0.9 m was assigned to Burrup Peninsula grid points by changing the land-use category in that region to low dense forest, which simulates the rough rocky landscape. The final two nested grids (3 km and 1 km) used for the modelling are illustrated in the image extracts from the TAPM Graphical User Interface in Figure 6-1.

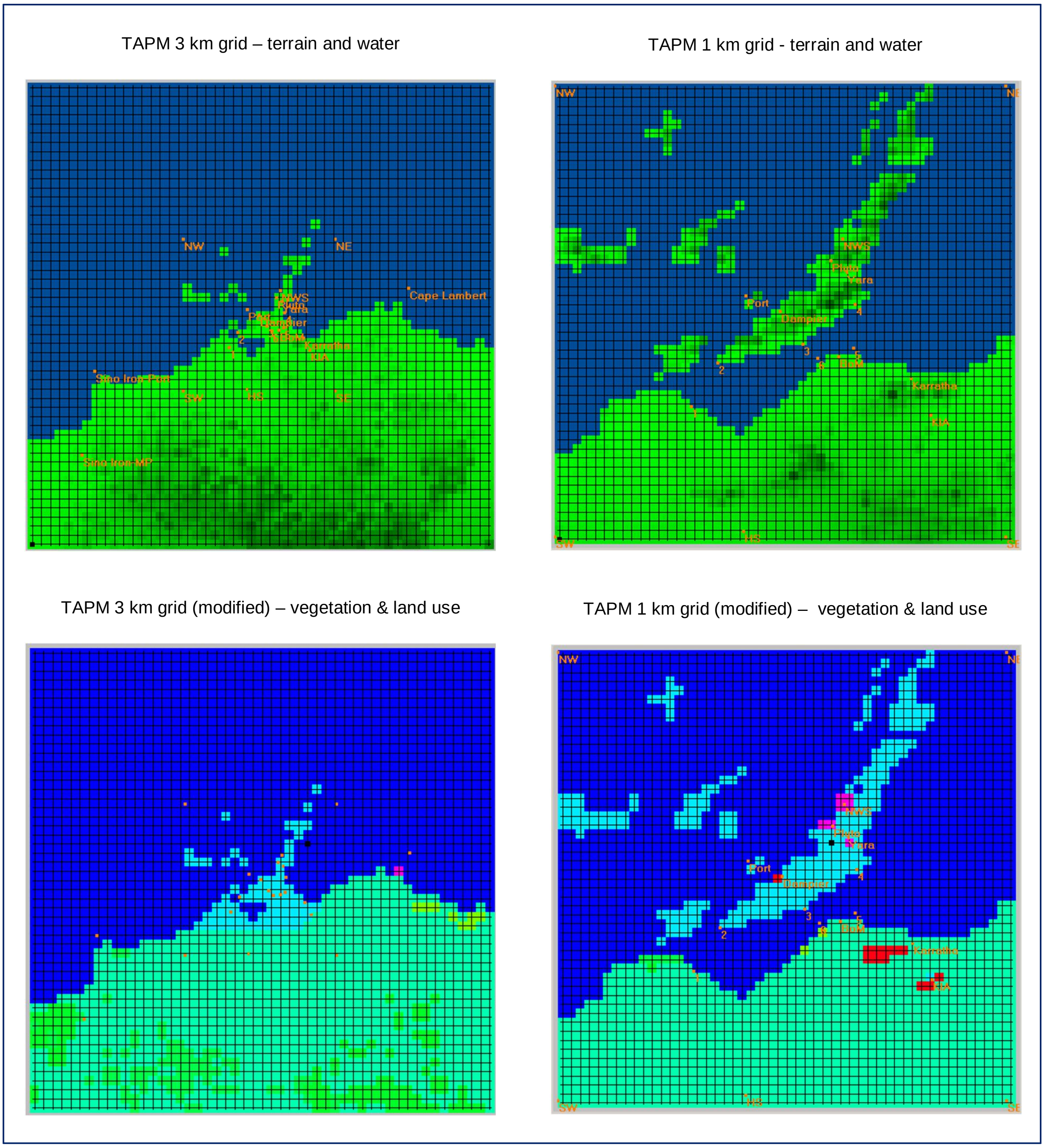

Figure 6-1: TAPM 3 km and 1 km Grids – Terrain, Vegetation and Land Use

6.3.3 Deep Soil Moisture Content

Estimates for monthly varying Deep Soil Moisture Content (DSMC) were interpolated linearly based on tests by Physick et al. (2004) that showed best agreement with wind data obtained using DSMC=0.05 m^3 m^{-3} for January and April; and DSMC=0.15 m^3 m^{-3} for July. The modified DSMC values used for the modelling assessment are shown in Figure 6-2.

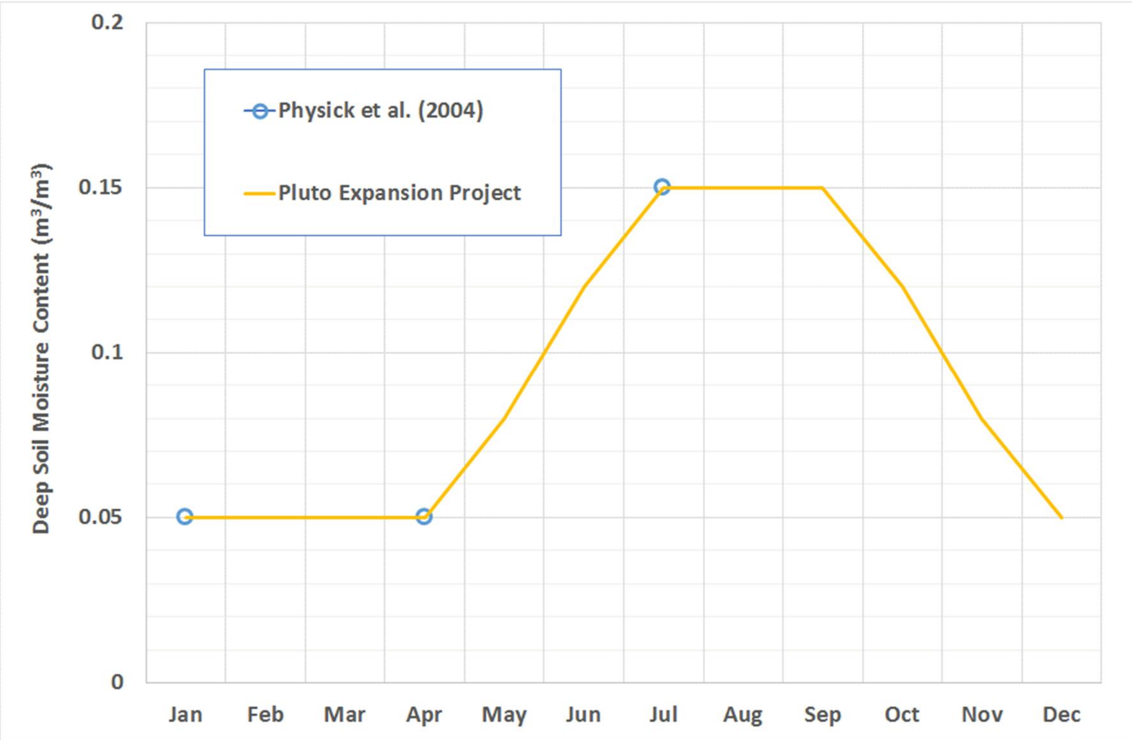

Figure 6-2: Deep Soil Moisture Content Settings

6.3.4 Photochemical Modelling

TAPM's in-built photochemical modelling scheme was used for this modelling assessment for consistency with previous CSIRO and SKM modelling studies. In TAPM, gas-phase photochemical modelling is based on the Generic Reaction Set (GRS) semi-empirical mechanism of Azzi et al. (1992) and the hydrogen peroxide modification of Venkatram et al. (1997). TAPM also includes gas-phase and aqueous-phase reactions of SO_2 and particles. Aqueous-phase reactions were based on Seinfeld and Pandis (1998).

TAPM simulates 10 chemical reactions for 13 species in GRS mode including: smog reactivity (R_{smog}), the radical pool (RP), hydrogen peroxide (H_2O_2), nitric oxide (NO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2). Further details are provided in Hurley (2008a).

More complex photochemical modelling could be undertaken for the Burrup Peninsula; e.g., using TAPM-CTM (Cope and Lee, 2009). However, the selection of TAPM-GRS provided an appropriate balance between model accuracy as determined by comparisons with monitoring results, and computational time cost. The use of TAPM-GRS also allowed for the efficient modelling of multiple year-long simulations, a feature important to make comparisons between annual averages for each scenario.

Comparisons of TAPM-GRS results with monitoring data obtained on the Burrup Peninsula were the key tests of model accuracy. The current application of TAPM-GRS to the Pilbara indicated the most substantial gains towards model accuracy were through improvements to the air emissions inventories used as input.

Using the previous CSIRO studies as the main foundational guides, inputs required at the user interface for the photochemical modelling included the following estimates for background air pollutant levels: NO_x (1 ppb), background smog reactivity or the so-called 'R_{smog}' parameter (0.2 ppb), and background O_3 (25 ppb). Values for R_{smog} were calculated for every modelled source using estimates for the total VOC emission rate (g/s) and an estimate of reactivity associated with the source type. Air Assessments (2010b) stated that generally it is the boundary (background) condition of R_{smog} that is most important, with 'surface sources contributing little R_{smog}'. Initially the estimate for background R_{smog} (0.2 ppb) was selected by Hurley et al. (2004).

TAPM also allows for the input of large-scale area emissions of air pollutants to include as background. Again using the previous CSIRO studies as a guide, the CSIRO biogenic emissions databases used with TAPM are illustrated in Figure 6-3 (NO_x), and Figure 6-4 (R_{smog}). The figures are overlaid on the base map image of the Burrup Peninsula study area, representing the TAPM inner-grid.

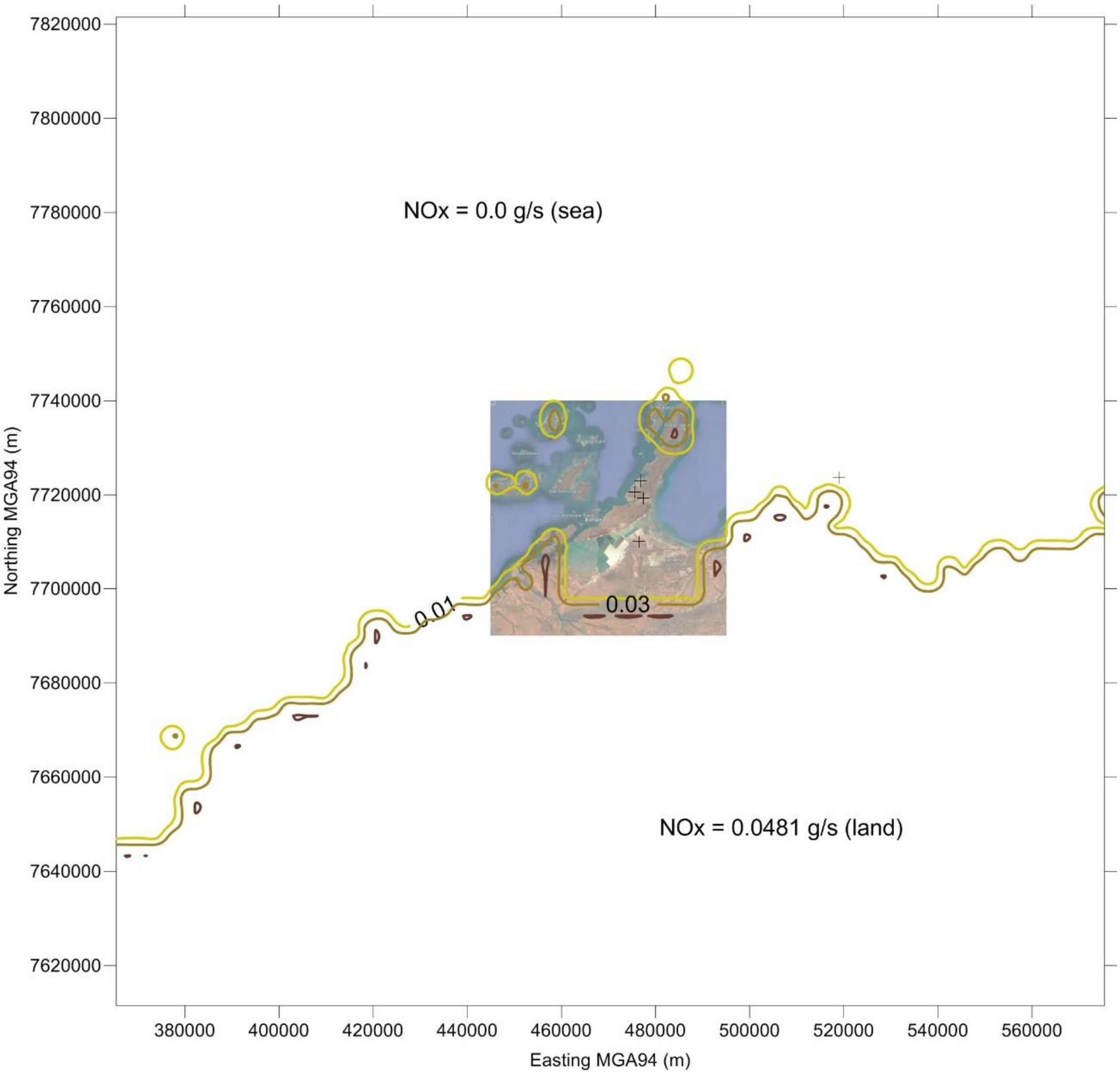

Figure 6-3: CSIRO Biogenic NO_x Area Emissions Database and Current Study Area (Inset)

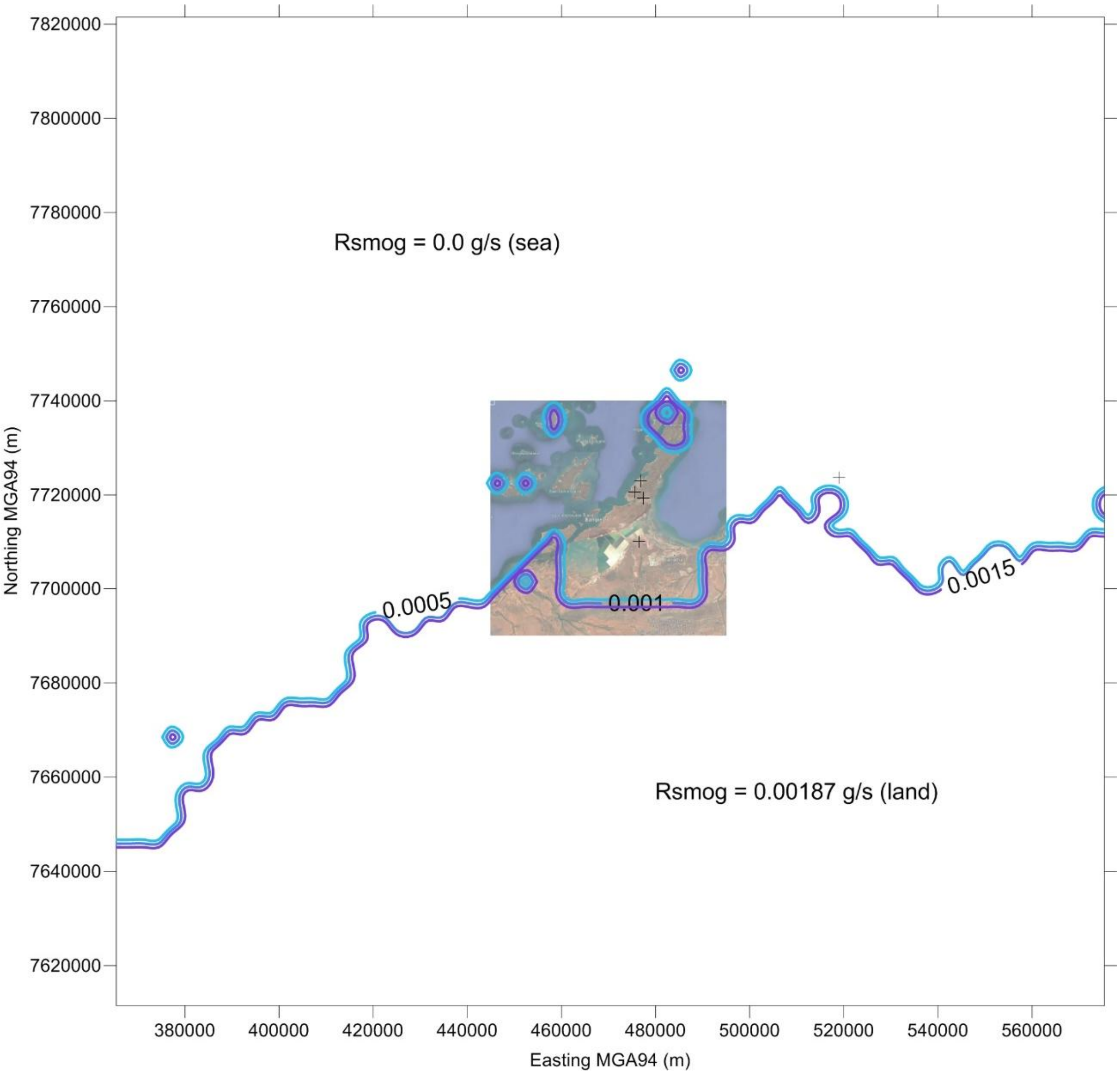

Figure 6-4: CSIRO Biogenic Area R_{smog} Emissions Database and Current Study Area (Inset)

Another area source file used with previous TAPM modelling included emissions from shipping and the relatively small townships of Dampier (population approximately 1100), and Karratha (population approximately 15,800). A weakness of this database of 'area sources' was overestimating the effects of the shipping emissions by excluding the effects of hot (buoyant) exhausts from ship engines, which should be treated as 'point sources' with assigned exhaust temperatures and velocities. This weakness in the emissions estimates for shipping was recognised by previous reviewers including Air Assessments (2010). For this project, the effects of shipping were modelled as auxiliary engine point sources running continuously throughout the simulated year, at every available berth on Burrup Peninsula and at Cape Lambert.

Area emissions from Dampier and Karratha were also excluded from the modelling because the small amounts of emissions from road traffic from these towns were insignificant relative to the industrial sources. In any case by including background levels of NO_x, O_3, particles and hydrocarbons in the modelling, the emissions from Dampier and Karratha were included implicitly.

6.3.5 Deposition flux of Nitrogen and Sulfur – NO_2 and SO_2 Contribution

TAPM-GRS modelling outputs were obtained for the NO_2 and SO_2 deposition components of these fluxes for the purpose of further analysis and in the absence of a relevant standard (an assessment of the impacts on rock art was outside the scope of this assessment).

The model results for NO_2 deposition were illustrated as contour plots in a similar way to the standard presentation of results for (airborne) GLCs. The results were provided in units of kg/ha/year to enable comparisons with previous assessment results; e.g. SKM (2009); and in units of meq/m^2/year to enable comparisons with previous monitoring results; e.g., Gillett (2008).

It is noted the TAPM calculations for dry and wet deposition of NO_2 and SO_2, which are detailed in Hurley (2008), use a similar method to that adopted by Gillett (2008) and Gillett (2012). The results may differ slightly between the methods depending on parameters such as deposition velocities of the gases and various resistance parameters used in the calculations by each study. Measured airborne concentrations are used to calculate dry deposition of a gas. Variabilities in the input parameters of approximately 10% (Gillett, 2008), means the TAPM calculations of deposition could differ from the 'measured' values by approximately 10% or slightly greater.

The conversion of the TAPM results for gaseous NO_2 deposition in units of mg/m^2/year to meq/m^2/year was calculated using the equation, $D = m/M \times z$, where m is the deposition mass (mg) predicted by TAPM, M is the molecular mass of NO_2 (46 g/mol), and z is the charge (see Gillett, 2014). The value of z was one with the assumption that all the deposited NO_2 formed nitric acid (HNO_3), with the charge on the nitrate ion (NO_3) being (minus) one.

6.3.6 Selection of Year for Modelling

The TAPM meteorological simulation year 2014 was selected as the basis for the Pluto Expansion Project. The process for selecting this representative year included a review of 9 years of hourly-average meteorological observations data from BoM Karratha Aerodrome (2010-2018). Annual statistics for wind speed and wind direction were examined for any annual meteorological variations in the Burrup region. This included a review of cyclones in the Pilbara to check the potential effects on Karratha wind speed (Appendix B).

The completeness and representativeness of air quality monitoring data was considered. The selection for the simulation was 2014, which was considered to be representative of meteorological conditions, combined with an annual air quality monitoring dataset that best represented the existing industrial air emissions situation.

Pluto was commissioned in 2012, ramped up in the later half 2012, and was at full production in 2013, although with some variability in the 2013 operations. The year 2014 was determined to be a good record of high KGP and PLP production rates and overlapped with a solid ambient air quality monitoring record. All factors combined, the year 2014 was selected as the best meteorological simulation year for TAPM.

TAPM was used to produce modelling results for wind speed and wind direction for 2014. The predicted meteorological outputs were compared with the 2014 hourly datasets from the Bureau of Meteorology (BoM) weather stations at Karratha, Roebourne and Legendre Island to assess the model's suitability for dispersion modelling. This comparison is outlined in Appendix C.

6.3.7 Consideration of Climate Change

Meteorological simulation of a climate change scenario was considered for the Project, however the uncertainties associated with creating an annual database of hourly average meteorological parameters were considered to be too high for input to modelling. It is acknowledged that Australian Government (2019) predicts future climate scenarios for areas within Australia; of these areas. the Proposal is located approximately between the 'Rangelands north' and 'Monsoonal NorthWest clusters. This adds to the uncertainties of climate change predictions for the Burrup region.

7. Results

7.1 Overview

The modelling results are presented in this section and comprise two parts: the current and expansion modelling scenarios (Current Baseline and Pluto Future State) and sensitivity modelling scenarios (FBSIA and Pluto Operational Upset Condition). Results show the TAPM and TAPM-GRS predicted GLCs for the list of air pollutants and NEPM (Ambient Air Quality) standards described below. Results are provided as contour plots of GLCs to enable direct comparisons with these standards. Statistical summaries of the numerical results are provided in each section for ease of comparison and results for discrete receptors (Dampier, Karratha and Burrup ambient air monitoring stations) are provided in section 0.

- Nitrogen dioxide:
  - Maximum hourly average NO_2 (NEPM (Ambient Air Quality) standard 120 ppb).
  - Annual average NO_2 (NEPM (Ambient Air Quality) standard 30 ppb).
- Ozone:
  - Maximum hourly average O_3 (NEPM (Ambient Air Quality) standard 100 ppb).
  - Maximum 4-hourly average O_3 (NEPM (Ambient Air Quality) standard 80 ppb).
- Sulfur dioxide:
  - Maximum hourly average SO_2 (NEPM (Ambient Air Quality) standard 200 ppb).
  - Maximum 24-hourly average SO_2 (NEPM (Ambient Air Quality) standard 80 ppb).
  - Annual average SO_2 (NEPM (Ambient Air Quality) standard 20 ppb).
- Deposition of NO_2 and SO_2 in units of kg/ha/year and meq/m^2/year (no approved standard).

The NO_2 and SO_2 deposition results have been presented to enable comparisons with monitoring data only; there are no approved deposition standards for the assessment of environmental impacts (GWA, 2019).

7.2 Current and Expanded Operations

7.2.1 Nitrogen Dioxide

7.2.1.1 Results for Maximum Hourly Average NO_2 GLC

TAPM-GRS results for maximum hourly average NO_2 GLCs (ppb) are provided as contour plots in Figure 7-1 (Current Baseline) and Figure 7-2 (Pluto Future State).

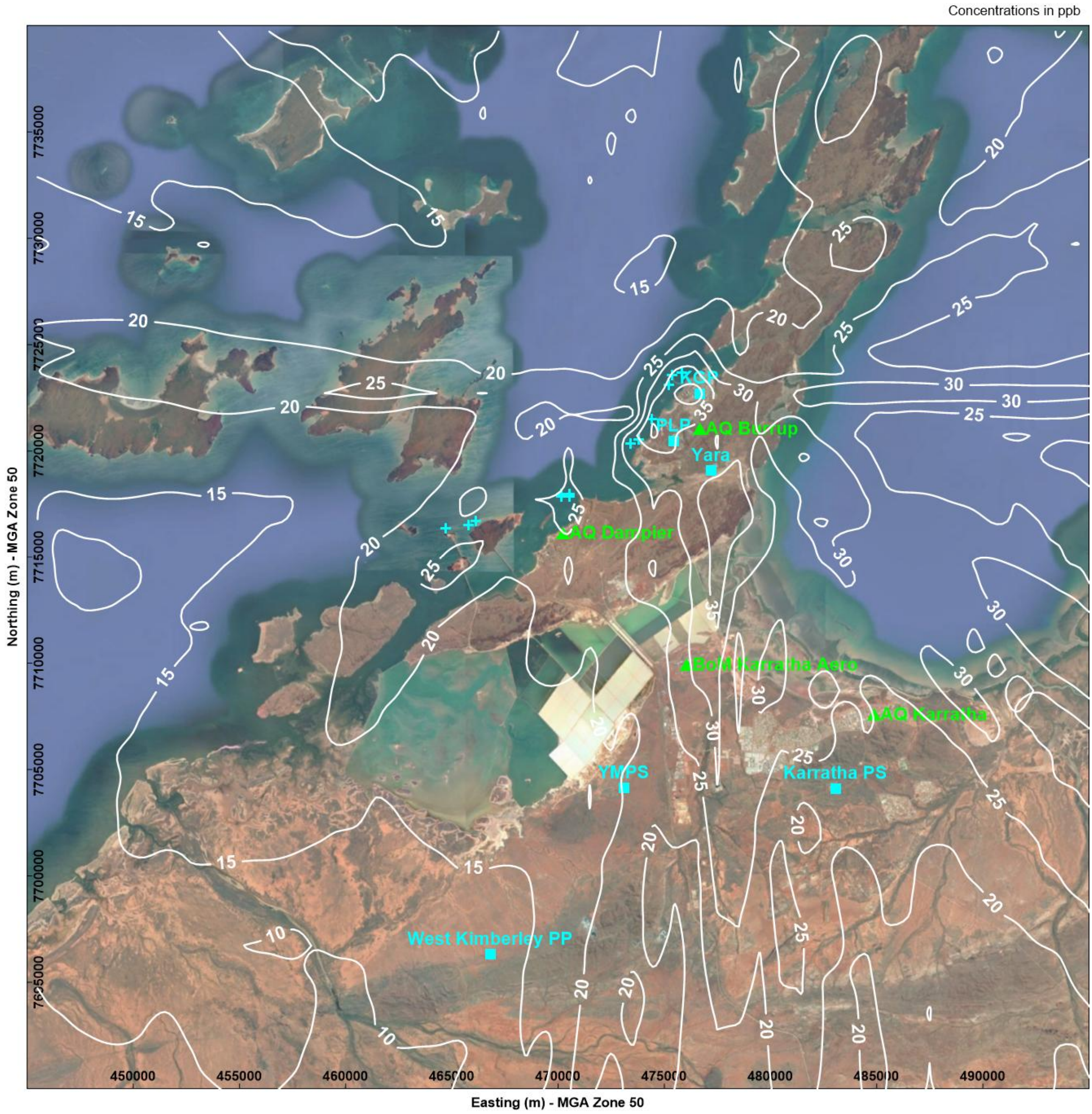

Figure 7-1: Current Baseline – Maximum 1h NO_2 GLC (ppb)

- Maximum grid receptor concentration, 42.6 ppb.
- NEPM (Ambient Air Quality) standard, 120 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

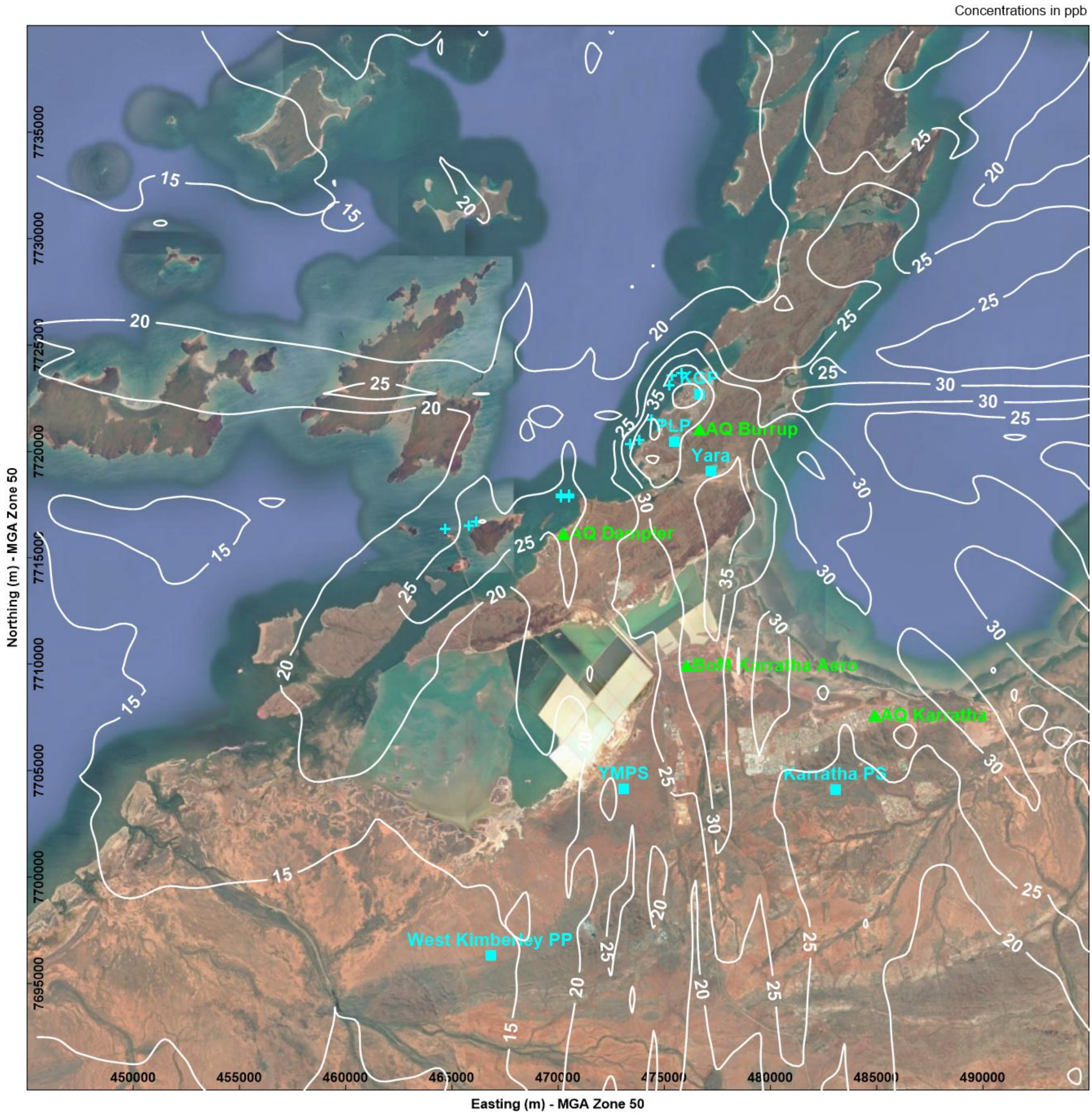

Figure 7-2: Pluto Future State – Maximum 1h NO_2 (ppb)

- Maximum grid receptor concentration, 42.6 ppb.
- NEPM (Ambient Air Quality) standard, 120 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.2.1.2 Results for Annual Average NO_2 GLC

TAPM-GRS results for annual average NO_2 GLCs (ppb) are provided as contour plots in Figure 7-3 (Current Baseline) and Figure 7-4 (Pluto Future State).

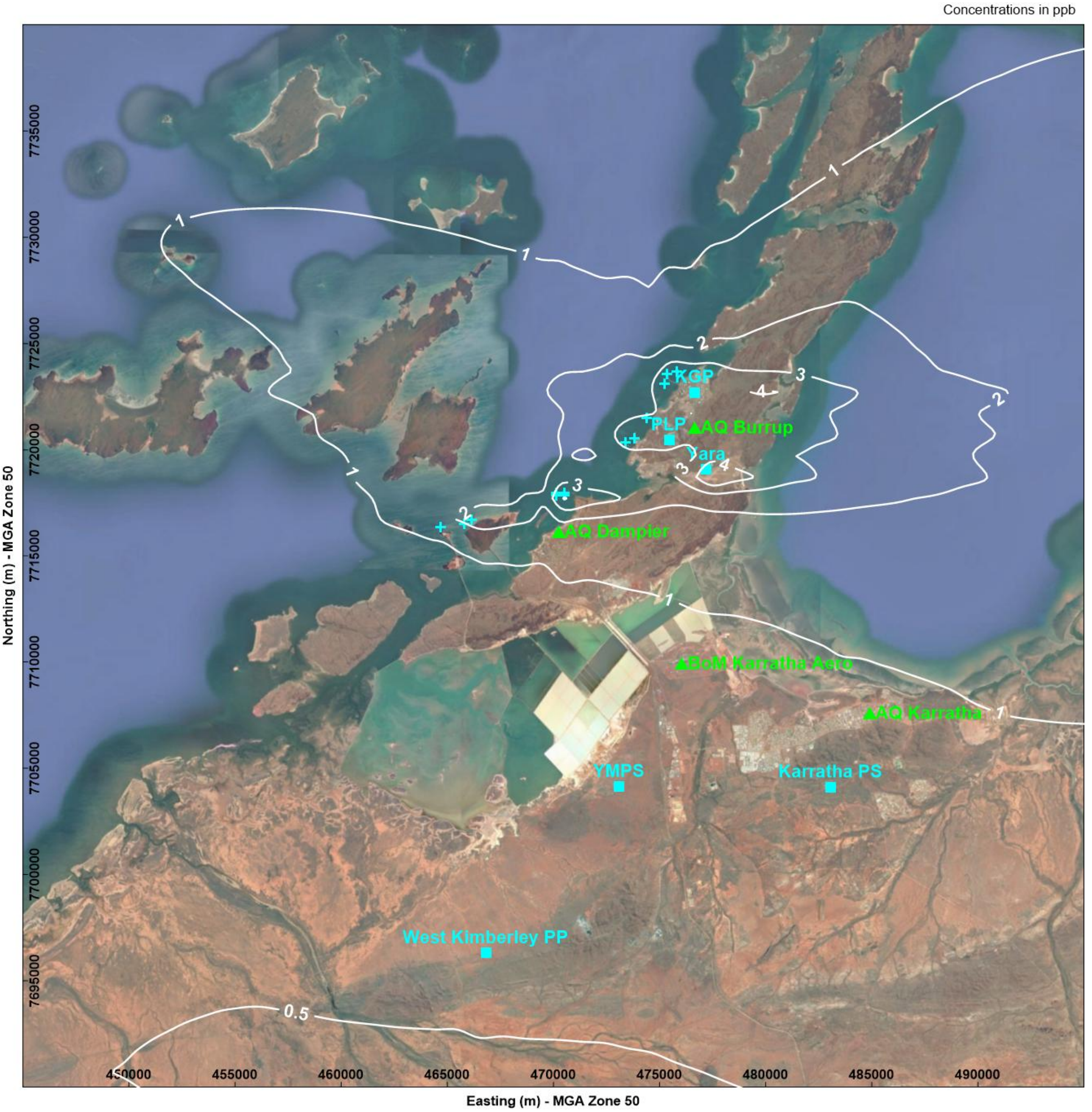

Figure 7-3: Current Baseline – Annual Average NO_2 GLC (ppb)

- Maximum grid receptor concentration, 5.0 ppb.
- NEPM (Ambient Air Quality) standard, 30 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

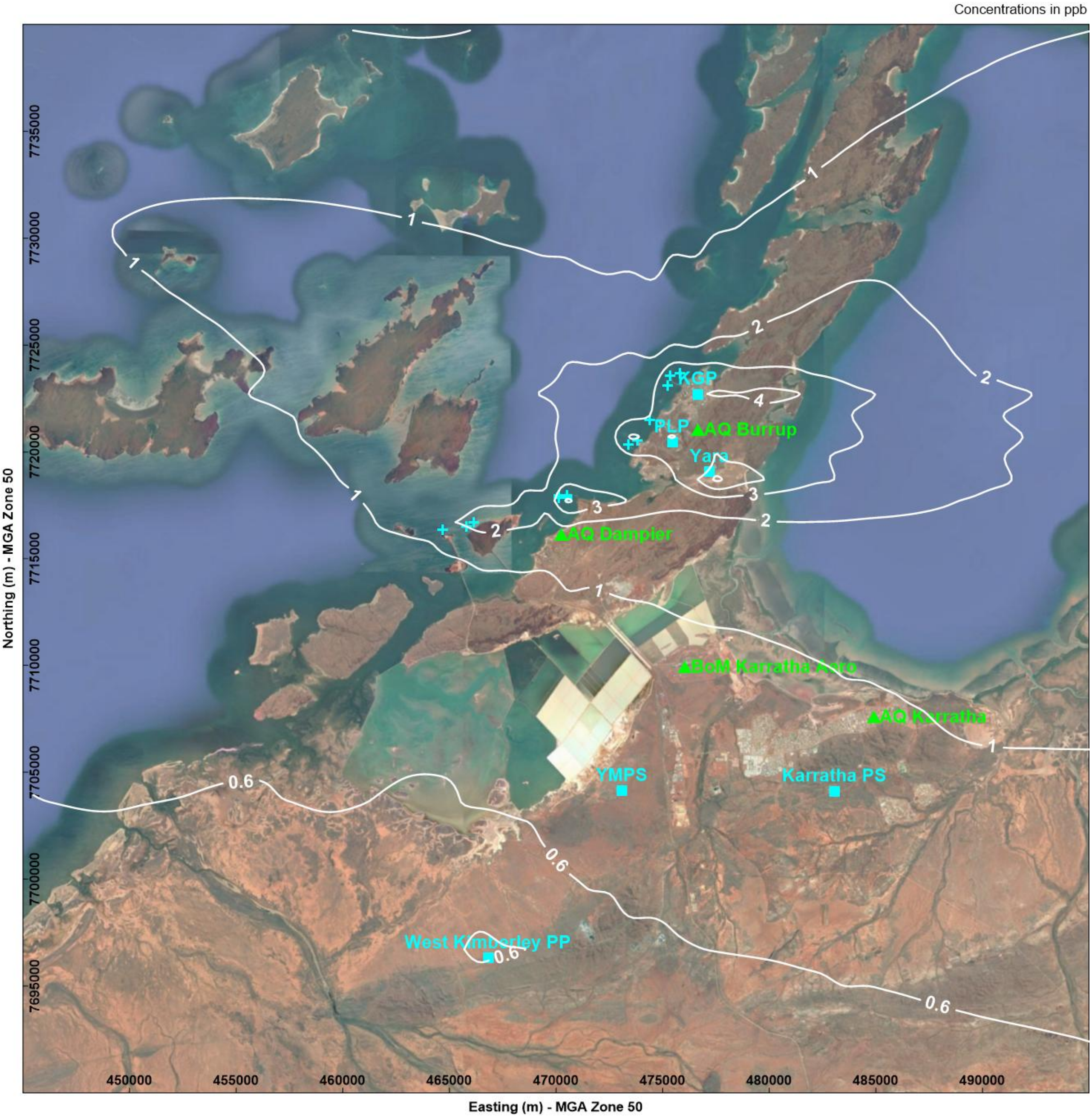

Figure 7-4: Pluto Future State – Annual NO_2 GLC (ppb)

- Maximum grid receptor concentration, 5.2 ppb.
- NEPM (Ambient Air Quality) standard, 30 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.2.1.3 Summary of TAPM-GRS Results for NO_2

A summary of the TAPM-GRS results for maximum hourly average and annual average NO_2 GLCs (ppb), for the maxima at each of the 2601 grid receptor points only, is provided in Table 7-1. There were no predicted exceedances of the corresponding NEPM (Ambient Air Quality) standards of 120 ppb and 30 ppb for any of the scenarios.

Table 7-1: Maximum 1-hour Average and Annual Average NO_2 concentrations – Grid Receptors

Scenario	Current Baseline	Pluto Future State	Current Baseline	Pluto Future State
NEPM statistic	Max 1h NO_2	Max 1h NO_2	Annual NO_2	Annual NO_2
NEPM standard (ppb)	120	120	30	30
Maximum grid point result (ppb)	42.6	42.6	5.0	5.2
Worst case fraction of NEPM	36%	36%	17%	17%

The TAPM results are in good agreement with the NO_2 monitoring data for 2014.; i.e. in a year with both KGP and PLP operating at or near capacity with ambient air monitoring data also being obtained. The combination of the analysis of the 2014 monitoring data and the TAPM-GRS modelling results provided in this section, confirm that NO_2 is, and will very likely remain, well below the NEPM (Ambient Air Quality) standards, and is considered a low-risk air pollutant for the Burrup Peninsula in terms of its potential to impact human health.

7.2.2 Ozone

7.2.2.1 Results for Maximum Hourly Average O_3 GLC

TAPM-GRS results for maximum hourly average O_3 GLCs (ppb) are provided as contour plots in Figure 7-5 (Current Baseline) and Figure 7-6 (Pluto Future State).

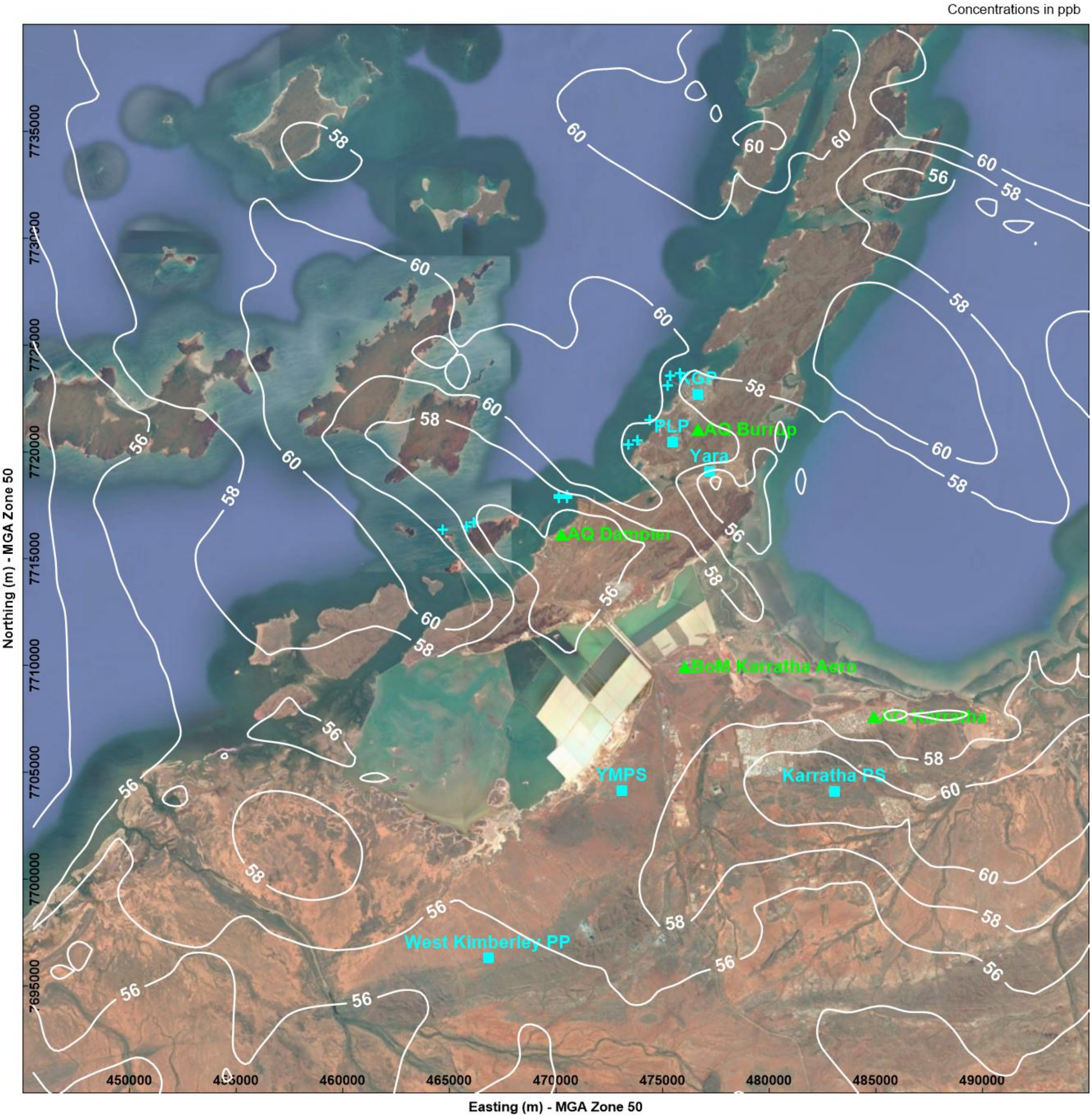

Figure 7-5: Current Baseline – Maximum 1h O_3 GLC (ppb)

- Maximum grid receptor concentration, 61.8 ppb.
- NEPM (Ambient Air Quality) standard, 100 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

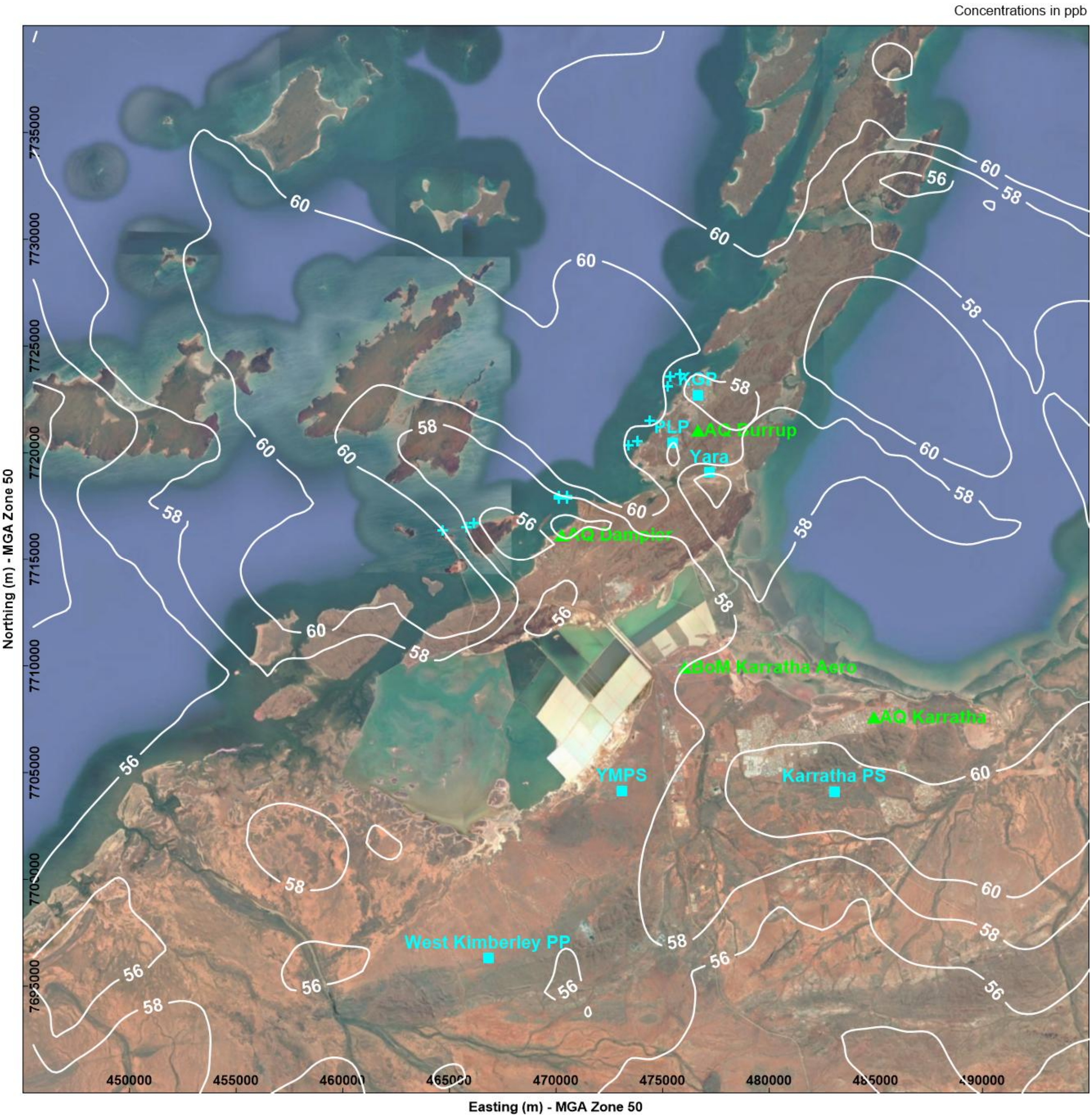

Figure 7-6: Pluto Future State – Maximum 1h O_3 GLC (ppb)

- Maximum grid receptor concentration, 62.3 ppb.
- NEPM (Ambient Air Quality) standard, 100 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.2.2.2 Results for Maximum 4-hourly Average O_3 GLC

The TAPM output for 4-hour average O_3 is not a 'rolling average' that would be needed for comparison with the NEPM (Ambient Air Quality) standard (80 ppb). Therefore the 4-hour average results have not been provided in this report. However, the step-wise 4-hour average O_3 results provided in the standard TAPM output should provide a reasonable indication of the rolling 4-hour averages; see Table 7-2.

7.2.2.3 Summary of TAPM-GRS Results for O_3

A summary of the TAPM-GRS results for the maximum hourly and maximum 4-hourly average O_3 GLCs (ppb) at each of the 2601 grid receptor points, for the current and expanded operations scenarios, is provided in Table 7-2. There were no predicted exceedances of the corresponding NEPM (Ambient Air Quality) standard of 100 ppb for either of the scenarios modelled. The results for 4-hour average O_3 GLCs indicate a low likelihood of exceedance of the corresponding NEPM (Ambient Air Quality) standard (80 ppb).

Table 7-2: Maximum 1-hour and 4-hour Average O_3 GLC – Grid Receptors

Scenario	Current Baseline	Pluto Future State	Current Baseline	Pluto Future State
NEPM statistic	Max 1h O_3	Max 1h O_3	Max 4h O_3	Max 4h O_3
NEPM standard (ppb)	100	100	80 (rolling)	80 (rolling)
Maximum	61.8	62.3	58.2 (step-wise)	58.6 (step-wise)
Worst case fraction of NEPM	62%	62%	Approx. 73%	Approx. 73%

As mentioned in the preceding section, the TAPM results for 4-hour average O_3 GLCs were sequential 4-hour averages, whereas the NEPM (Ambient Air Quality) standard is a rolling 4-hour average. However, the step-wise averages shown provide a good indication of the rolling averages.

The TAPM results are in good agreement with the O_3 monitoring data for 2014. The combination of the analysis of the 2014 monitoring data and the TAPM-GRS modelling results provided in this section, confirm that O_3 is a relatively low risk air pollutant for the Burrup Peninsula in terms of the potential for O_3 to impact human health. The modelling and monitoring results indicate that O_3 is a higher-risk air pollutant than NO_2, but is predicted to remain well below the NEPM (Ambient Air Quality) standards for all scenarios.

7.2.3 Sulfur Dioxide

The SO_2 emission rates varied by very little between the scenarios. As such, only one set of contour plots is provided in each of the following sub-sections – for the Current Baseline, which is representative of all four model scenarios (both the current and expanded operations as well as the two sensitivity scenarios).

7.2.3.1 Results for Maximum Hourly Average SO_2 GLC

TAPM-GRS results for maximum hourly average SO_2 GLCs (ppb) are provided in Figure 7-7 for the Current Baseline scenario.

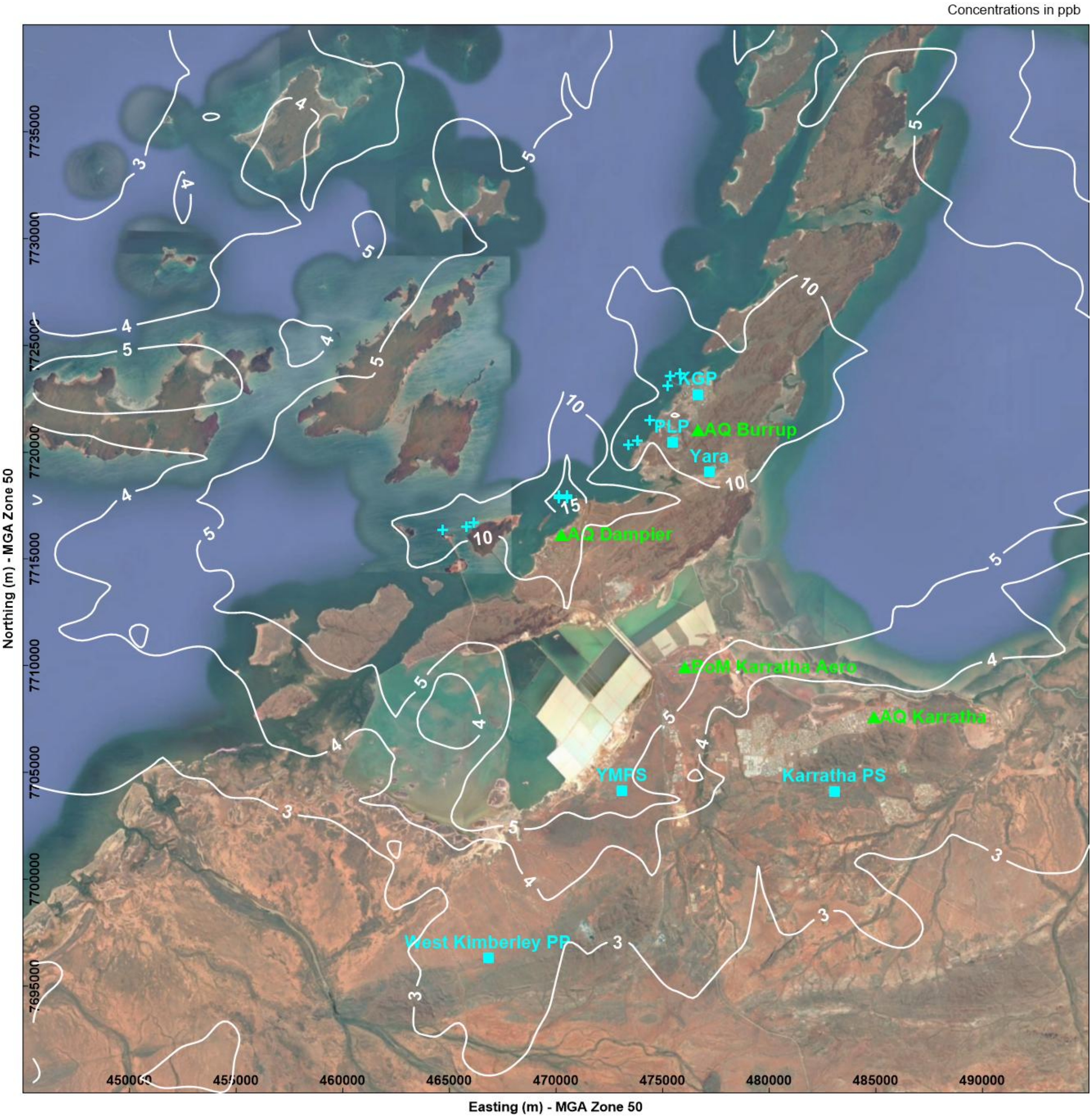

Figure 7-7: Current Baseline – Maximum 1h SO_2 GLC (ppb)

- Maximum grid receptor concentration, 18.1 ppb.
- NEPM (Ambient Air Quality) standard, 200 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.2.3.2 Results for Maximum 24-hour Average SO_2 GLC

TAPM-GRS results for maximum 24-hourly average SO_2 GLCs (ppb) are provided in Figure 7-8 for the Current Baseline scenario.

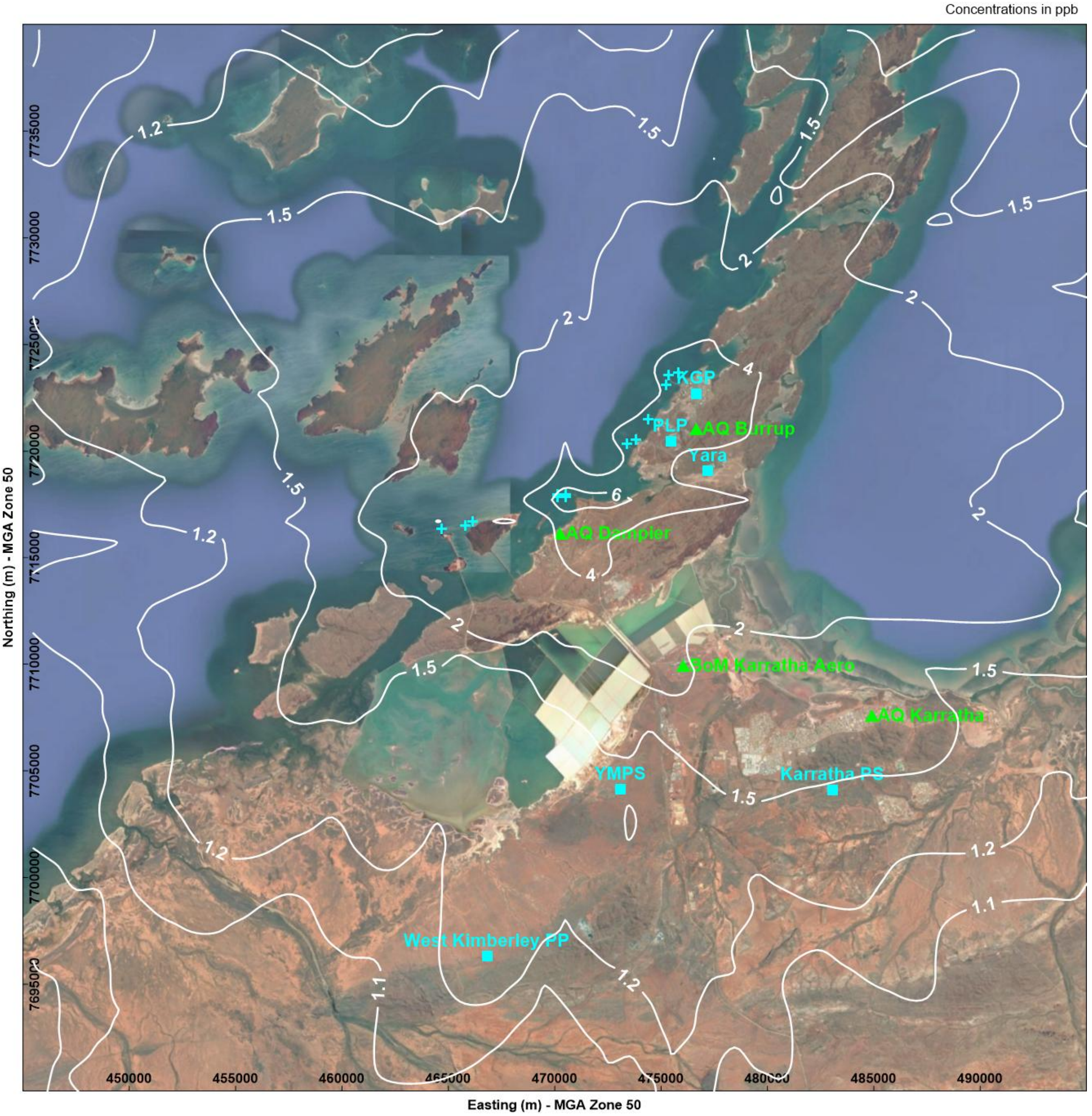

Figure 7-8: Current Baseline – Maximum 24h SO_2 GLC (ppb)

- Maximum grid receptor concentration, 7.0 ppb.
- NEPM (Ambient Air Quality) standard, 80 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.2.3.3 Results for Annual Average SO_2 GLC

TAPM-GRS results for annual average SO_2 GLCs (ppb) are provided in Figure 7-9 for the Current Baseline scenario.

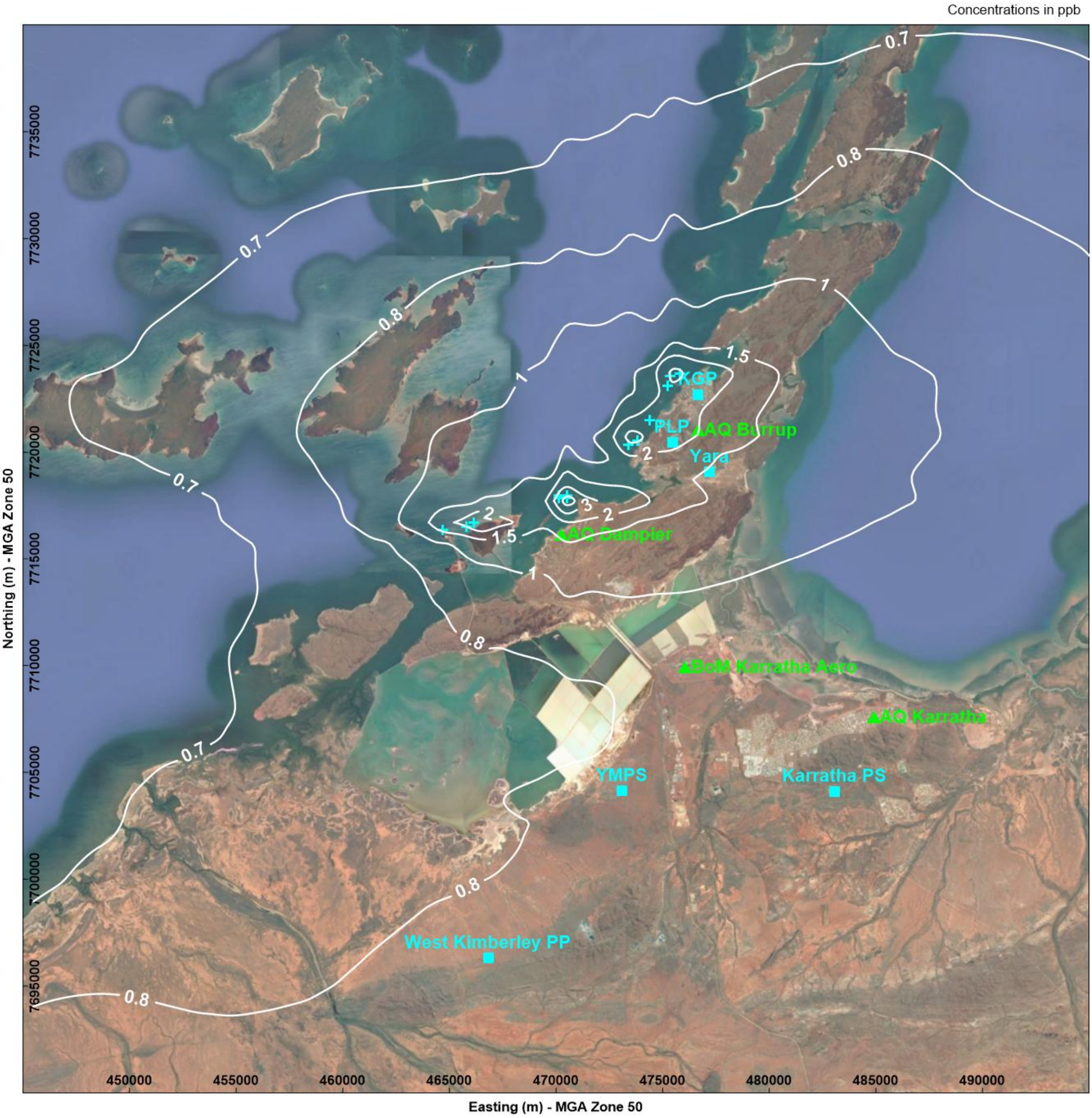

Figure 7-9: Current Baseline – Annual Average SO_2 GLC (ppb)

- Maximum grid receptor concentration, 4.5 ppb.
- NEPM (Ambient Air Quality) standard, 20 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.2.3.4 Summary of TAPM-GRS Results for SO_2

A summary of the TAPM-GRS results for the maximum hourly average SO_2 GLCs (ppb) from the 2601 grid receptor points, for the Current Baseline and Pluto Future State scenarios, is provided in Table 7-3. There were no predicted exceedances of the corresponding NEPM (Ambient Air Quality) standards for either of the scenarios modelled.

Table 7-3: Maximum 1-hour Average SO_2 GLC – Grid Receptors

Statistic	NEPM (Ambient Air Quality) Standard (ppb)	Current Baseline (ppb)	Pluto Future State (ppb)	Worst case fraction of NEPM (Ambient Air Quality) Standard
Max 1h avg.	200	18.1	18.1	9%
Max. 24 avg.	80	7.0	7.0	9%
Annual avg.	20	4.5	4.5	23%

The TAPM-GRS modelling results indicate that SO_2 will remain well below NEPM (Ambient Air Quality) standards, and is considered a low-risk air pollutant for the Burrup Peninsula in terms of its potential to impact human health.

7.2.4 Potential Effects on Vegetation

The purpose of this section is to provide the results of an assessment on the potential effects on vegetation health due to airborne NO_x and SO_2 emissions. The relevant standards for assessment are the project standards detailed in Section 2; also they are listed in Table 7-5 below.

The annual average SO_2 results were provided in Section 7.2.3.3 and Section 7.2.3.4. The worst-case grid receptor result was less than 5 ppb, which is less than the standard of 8 ppb (Table 7-5). The worst (highest) results were predicted for locations only near the shipping berths, which were conservatively modelled as operating continuously. International Maritime Organization (IMO) requirements to reduce the sulfur content of fuel for shipping will lower the future risk of impact on vegetation from SO_2 emissions, this requirement is due to come in force 1 January 2020 (AMSA, 2018).

The second substance for consideration for potential air quality impacts on vegetation is NO_x. The TAPM-GRS results for annual average NO_x GLCs (ppb) are provided as contour plots in Figure 7-10 (Current Baseline) and Figure 7-11 (Pluto Future State).

A summary of the results for assessment of effects on vegetation in this section, is provided in Table 7-5.

Table 7-4: Summary of Results for Assessment of Vegetation Effects – Grid Receptors

Substance, Statistic	EU 2008 Veg. Standard (ppb)	Current Baseline Max. (ppb)	Pluto Future State Max. (ppb)	Worst Case Fraction of Standard
Annual average SO_2	7.8 ppb (20 µg/m^3 at 30 °C)	4.5	4.5	56%
Annual average NO_x	16.2 ppb (30 µg/m^3 as NO_2 at 30 °C)	7.7	7.9	56%

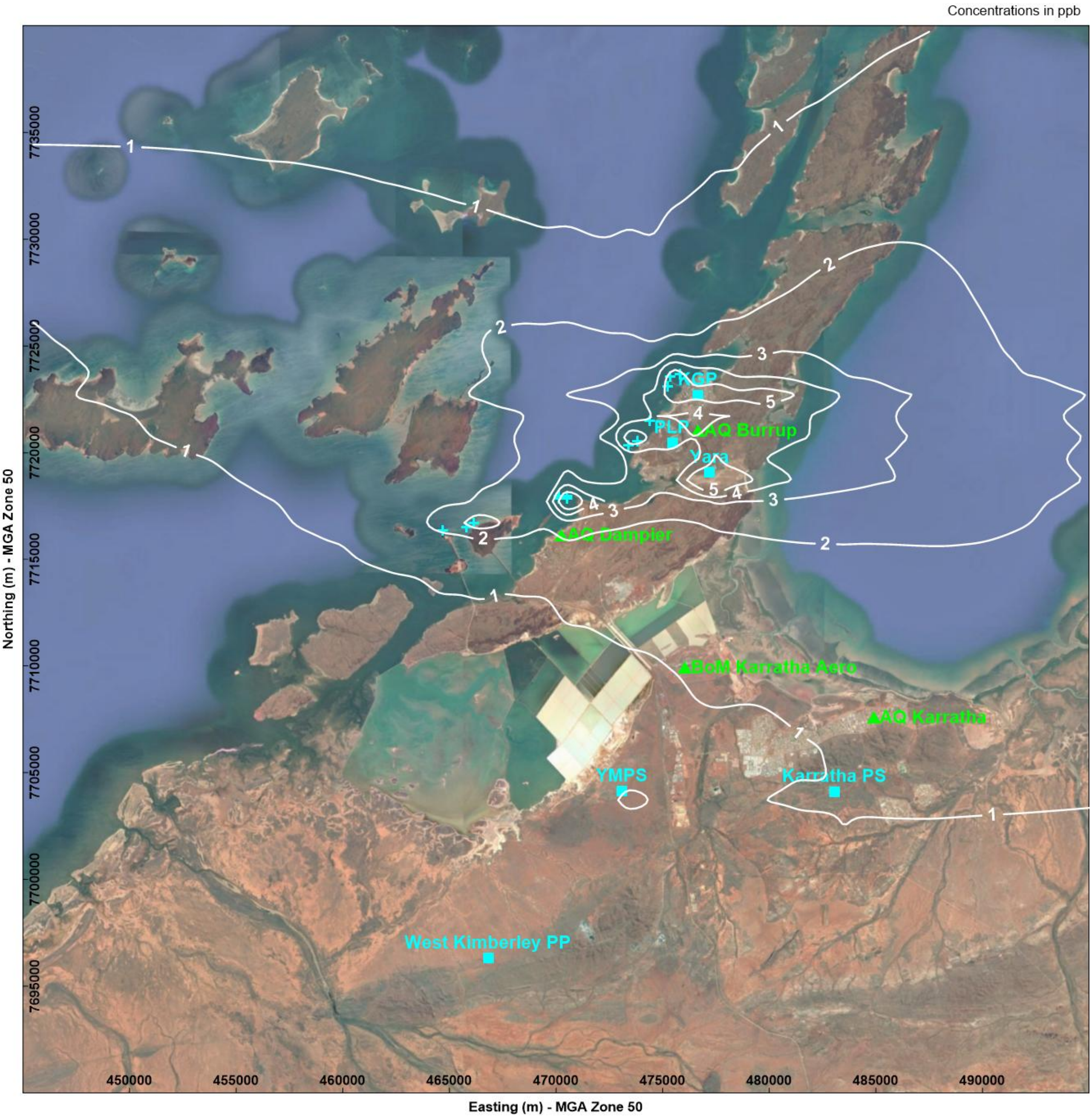

Figure 7-10: Current Baseline – Annual Average NO_X GLC (ppb)

- Maximum grid receptor concentration, 7.7 ppb.
- Project vegetation protection standard, 16 ppb.
- Result of vegetation impact assessment: no exceedances.

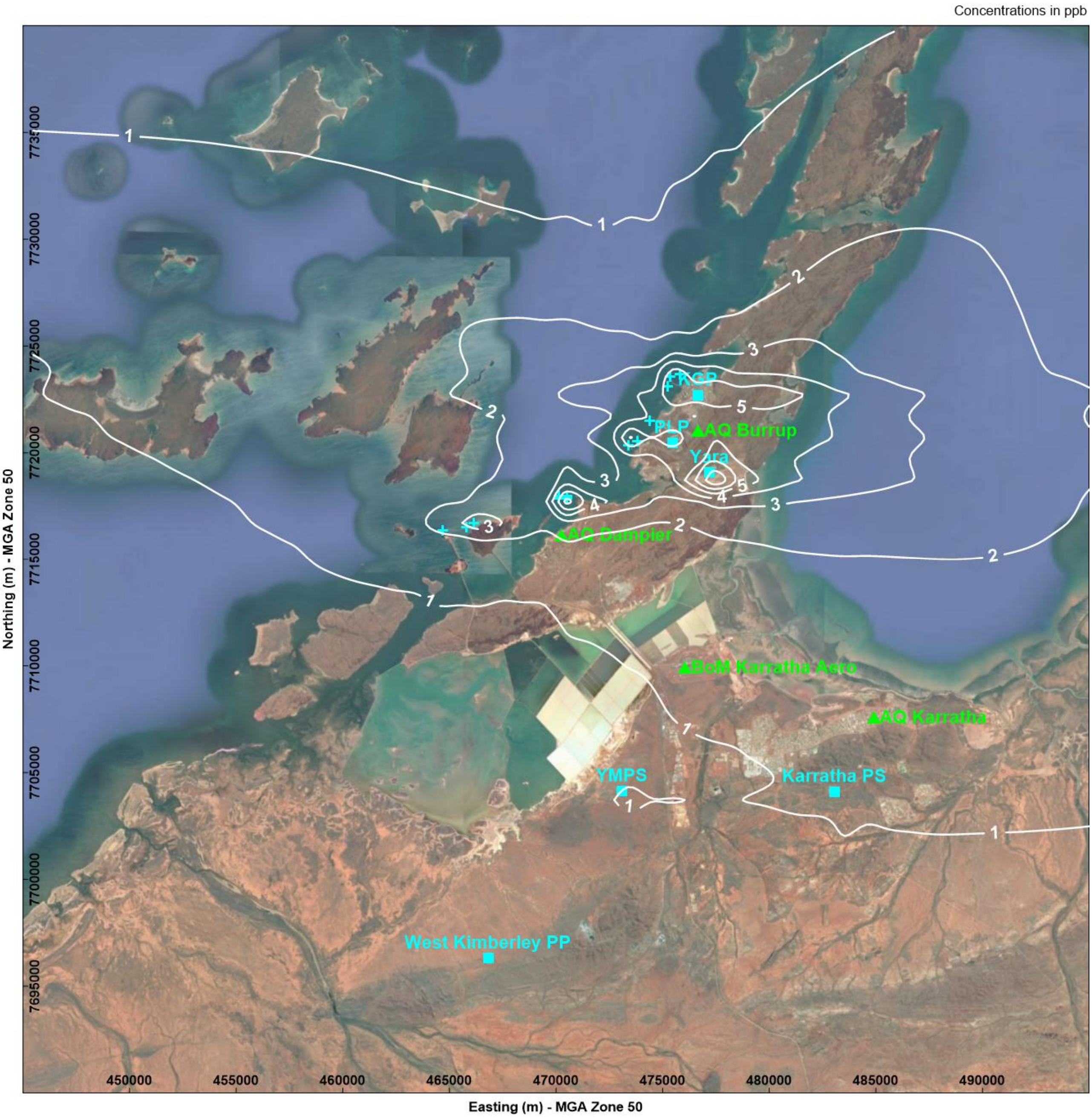

Figure 7-11: Pluto Future State – Annual Average NO_x GLC (ppb)

- Maximum grid receptor concentration, 7.9 ppb.
- Project vegetation protection standard, 16 ppb.
- Result of vegetation impact assessment: no exceedances.

7.2.5 Deposition of NO_2

This section provides provide a summary of modelling results for NO_2 deposition. The scope of works excludes an impact assessment or analysis of these results. (For the assessment of effects on vegetation health, see the results for annual average NO_x in Section 7.2.4). The modelling results for deposition are provided as contour plots in the following sub-sections.

7.2.5.1 Results for NO_2 Deposition (kg/ha/year)

TAPM-GRS results for annual average NO_2 deposition (kg/ha/year) are provided as contour plots in Figure 7-12 (Current Baseline) and Figure 7-13 (Pluto Future State).

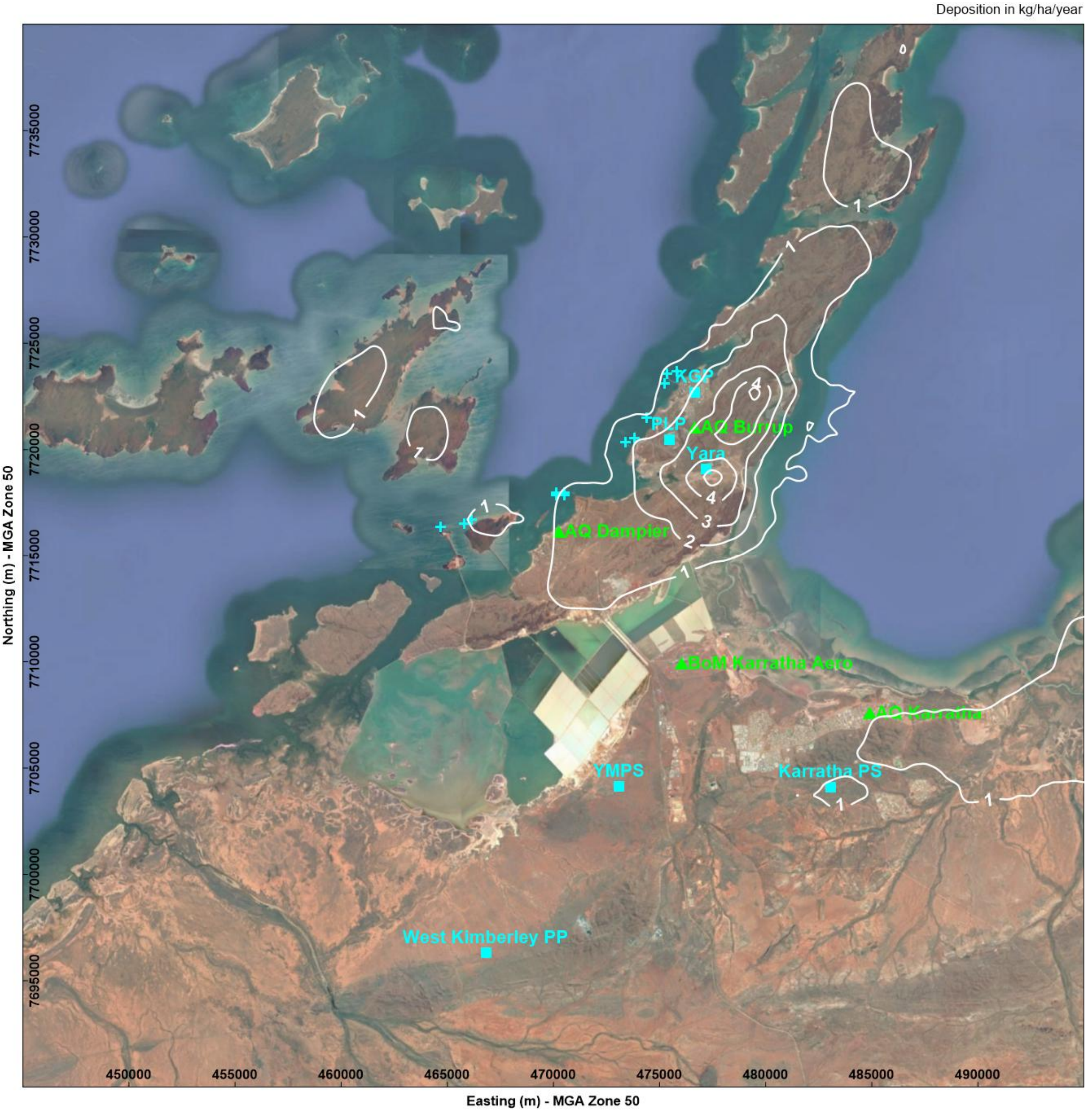

Figure 7-12: Current Baseline – NO_2 Deposition (kg/ha/year)

- Maximum grid receptor concentration, 5.7 kg/ha/year.
- For assessment of effects on vegetation health; see annual average NO_x.

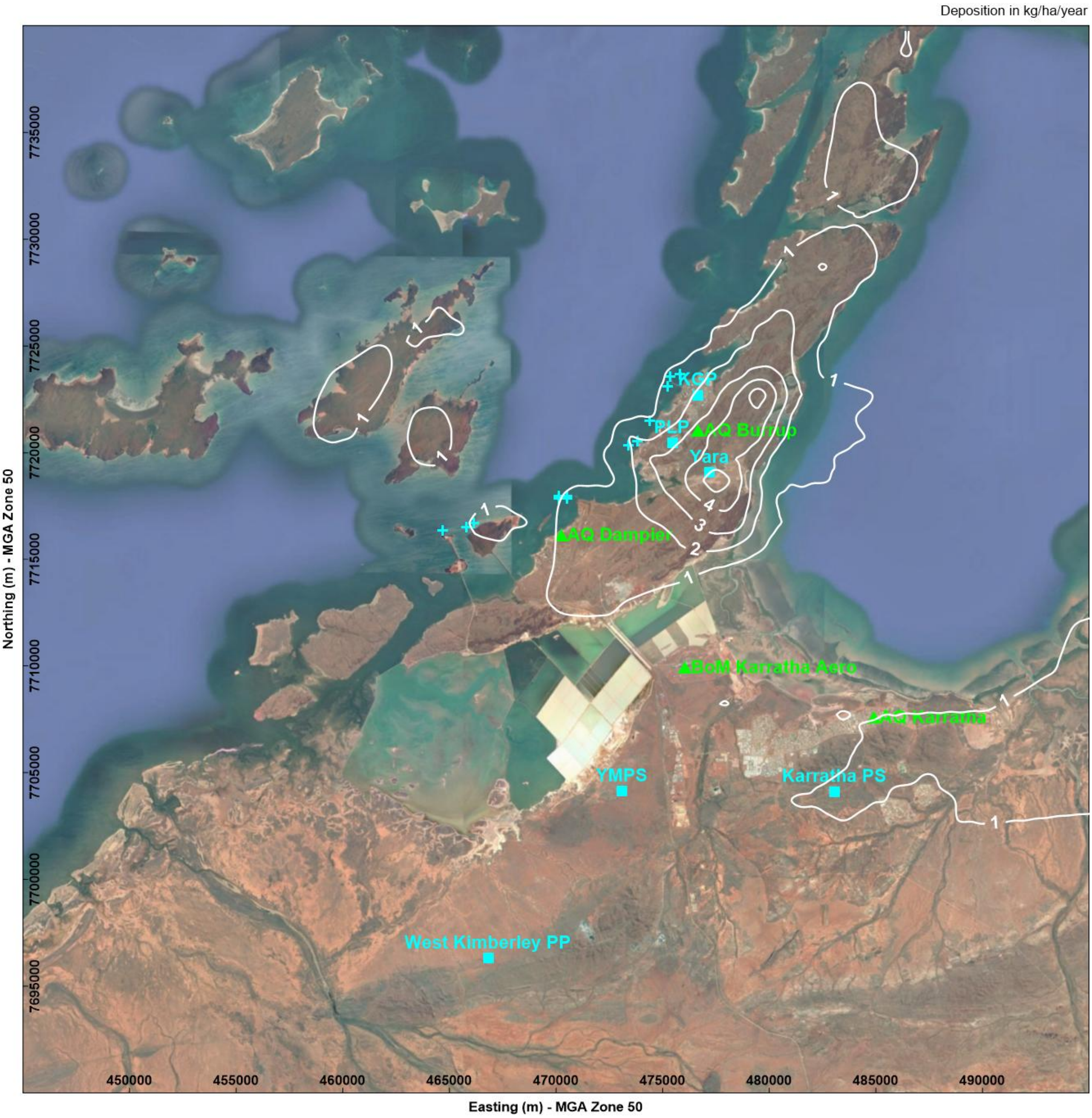

Figure 7-13: Pluto Future State – NO_2 Deposition (kg/ha/year)

- Maximum grid receptor concentration, 6.0 kg/ha/year.
- For assessment of effects on vegetation health; see annual average NO_x.

7.2.5.2 Results for NO_2 Deposition (meq/m^2/year)

TAPM-GRS results for annual average NO_2 deposition (meq/m^2/year) for the Current Baseline scenario are provided as contour plots in Figure 7-14 (Current Baseline) and Figure 7-15 (Pluto Future State).

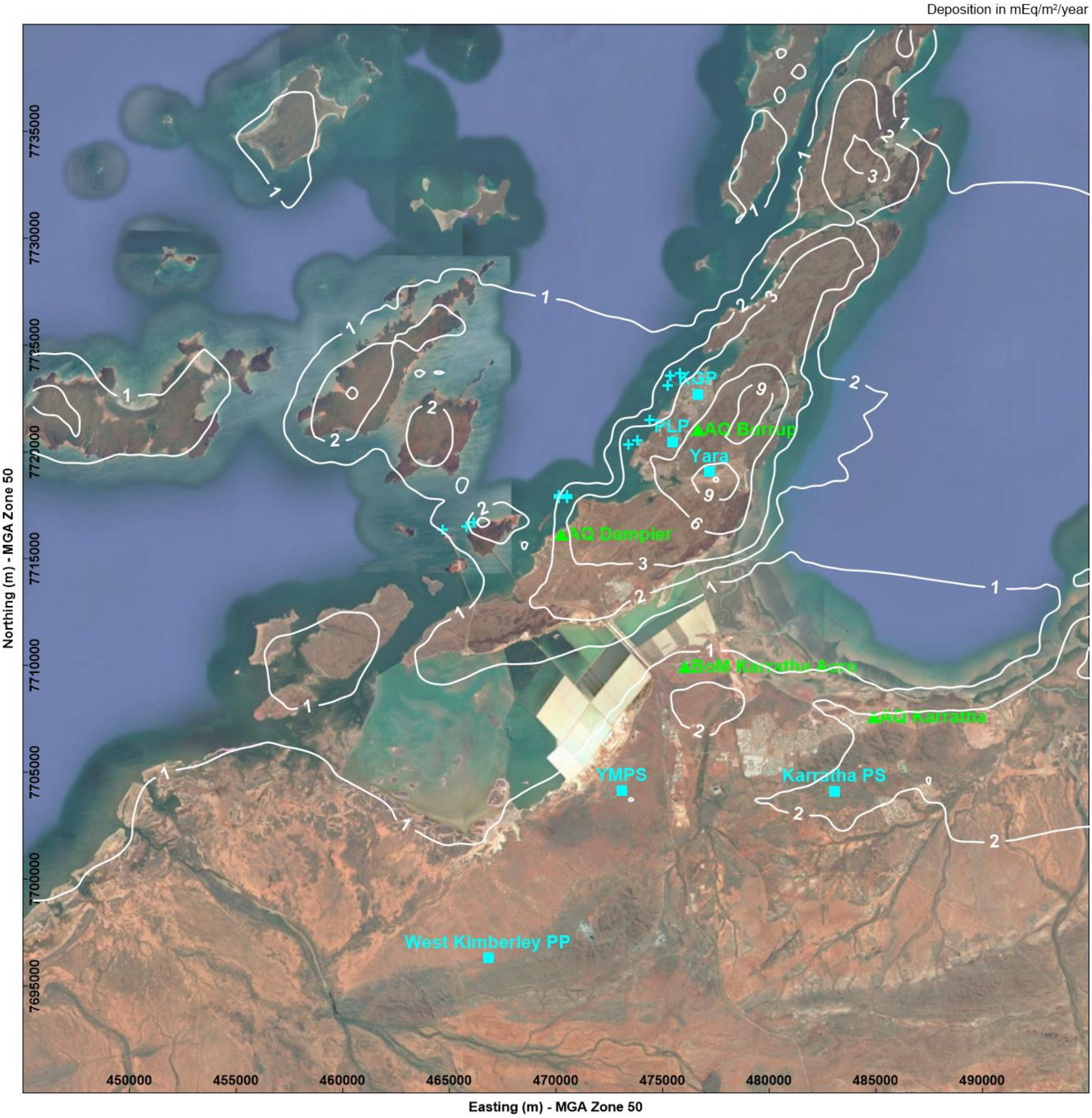

Figure 7-14: Current Baseline – NO_2 Deposition (meq/m^2/year)

- Maximum grid receptor concentration, 12.4 meq/m^2/year.
- For assessment of effects on vegetation health; see annual average NO_x.

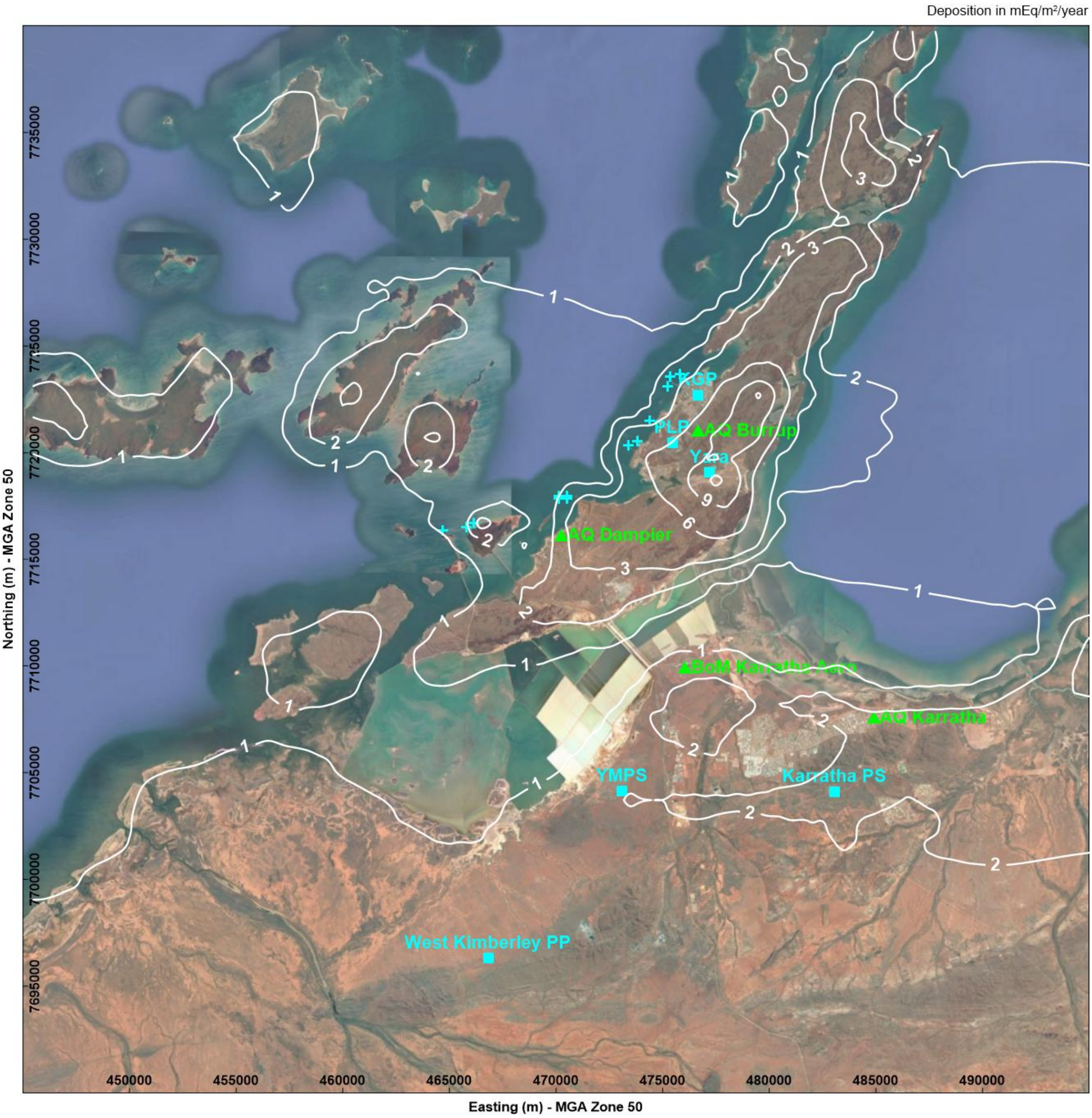

Figure 7-15: Pluto Future State – NO_2 Deposition (meq/m²/year)

- Maximum grid receptor concentration, 13.0 meq/m^2/year.

For assessment of effects on vegetation health; see annual average NO_X.

7.2.6 Deposition of SO_2

This section provides provide a summary of modelling results for SO_2 deposition. The scope of works excludes an impact assessment or analysis of these results. (For the assessment of effects on vegetation health, see the results for annual average SO_2 provided in Section 7.2.4).

TAPM-GRS results for annual average SO_2 deposition (kg/ha/year) for the Current Baseline scenario are provided as contour plots in Figure 7-16 (Current Baseline) and Figure 7-17 (Pluto Future State).

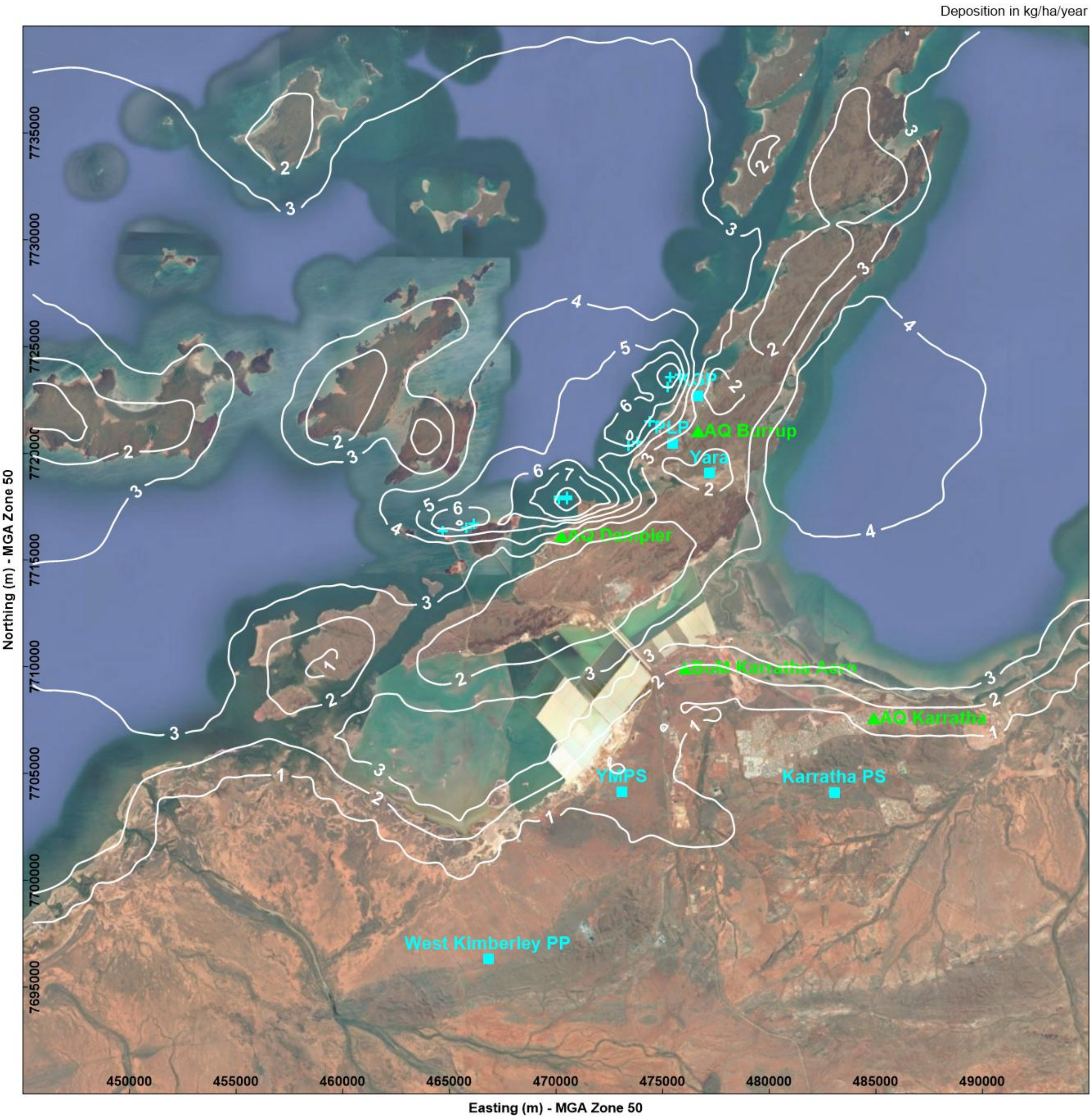

Figure 7-16: Current Baseline – SO_2 Deposition (kg/ha/year)

- Maximum grid receptor concentration, 13.6 kg/ha/year; higher depositions confined to shipping berths where continuously operating shipping sources were modelled
- .
- For assessment of effects on vegetation health; see annual average SO_2.

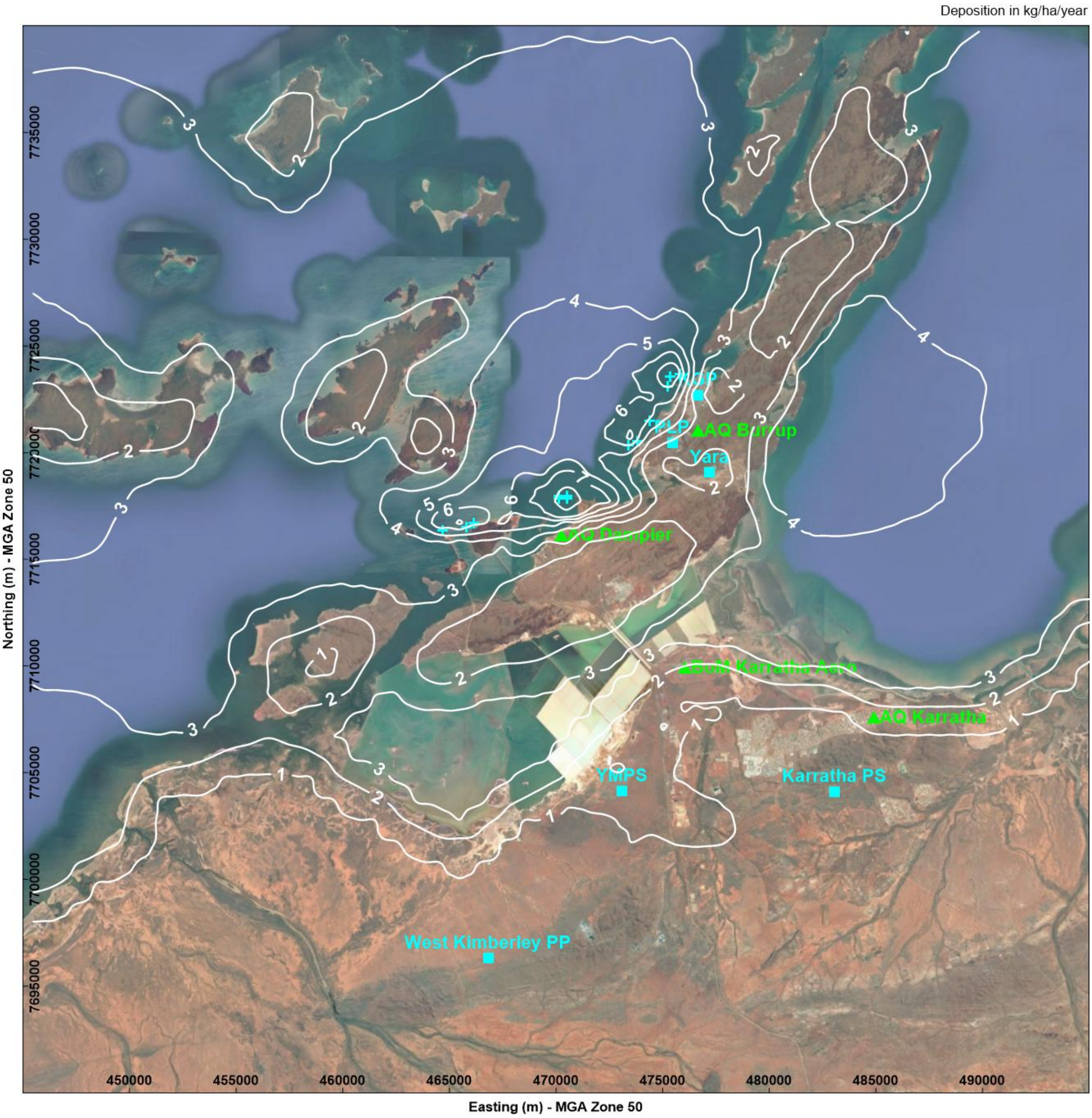

Figure 7-17: Future Pluto State – SO_2 Deposition (kg/ha/year)

- Maximum grid receptor concentration, 13.6 kg/ha/year; higher depositions confined to shipping berths where continuously operating shipping sources were modelled.
- For assessment of effects on vegetation health; see annual average SO_2.

7.3 Sensitivity Modelling

7.3.1 Nitrogen Dioxide

7.3.1.1 Results for Maximum Hourly Average NO_2 GLC

TAPM-GRS results for maximum hourly average NO_2 GLCs (ppb) are provided as contour plots in Figure 7-18 (FBSIA) and Figure 7-19 (Pluto Operational Upset Condition).

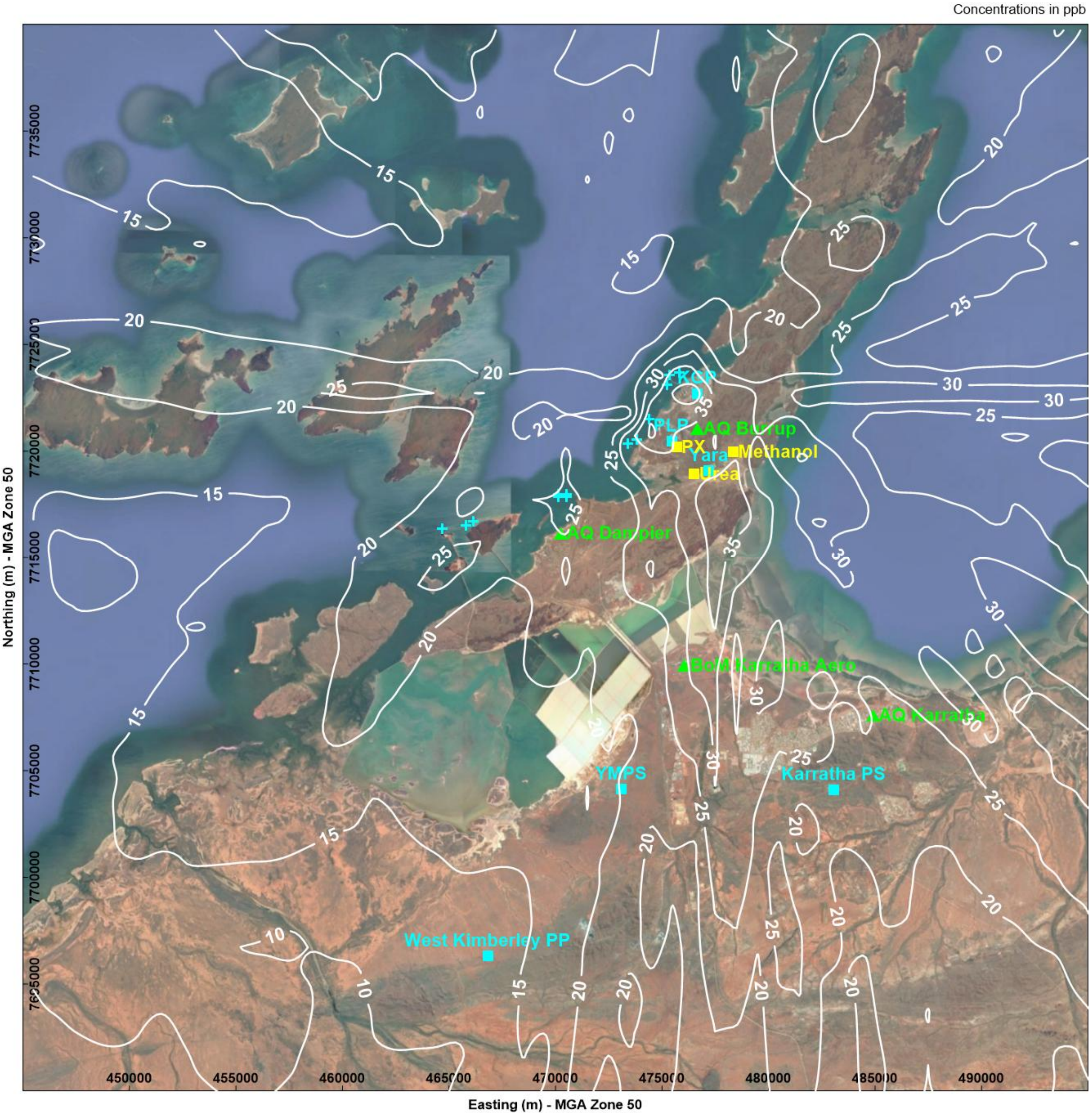

Figure 7-18: FBSIA – Maximum 1h NO_2 GLC (ppb)

- Maximum grid receptor concentration, 43.9 ppb.
- NEPM (Ambient Air Quality) standard, 120 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

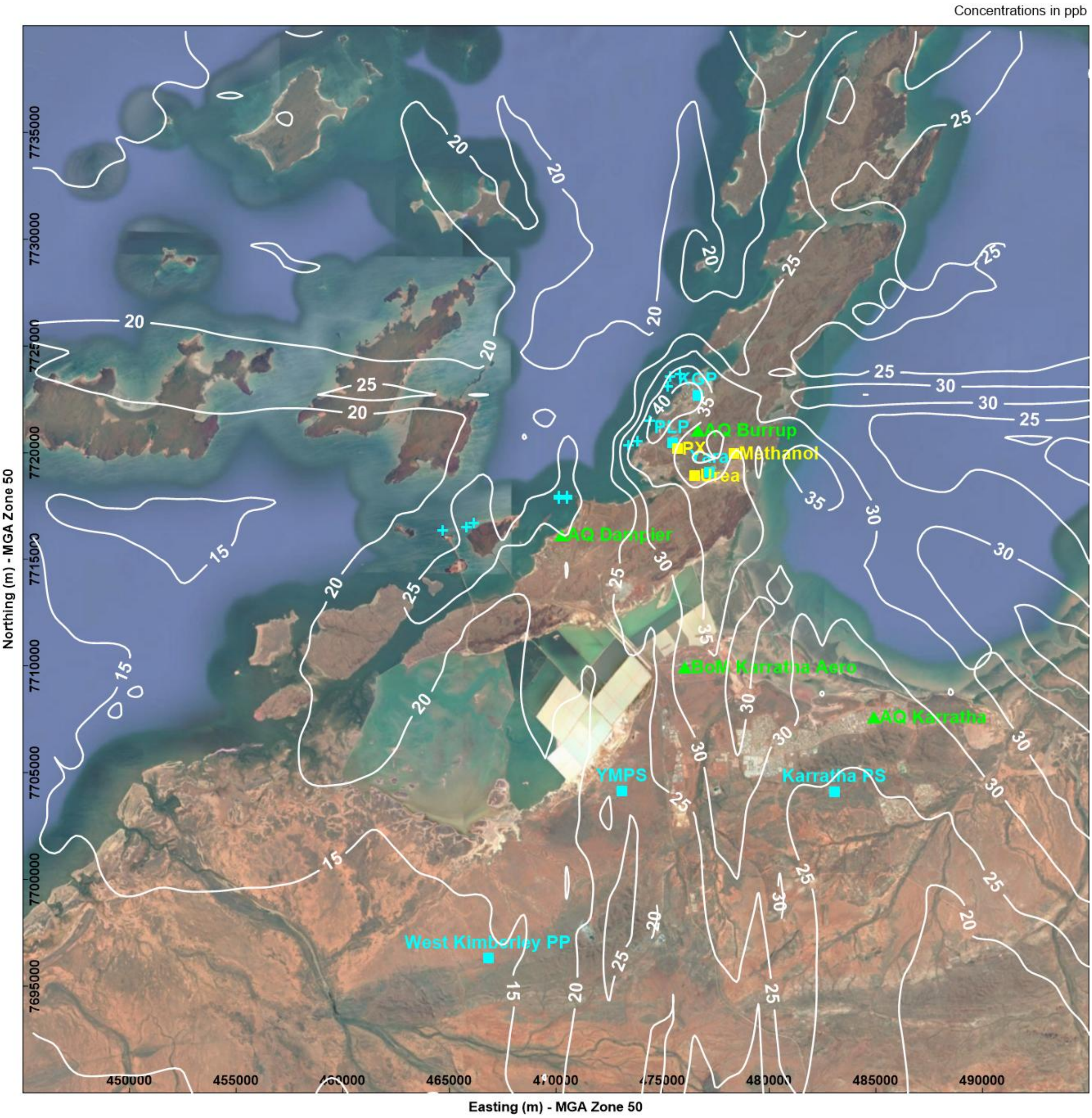

Figure 7-19: Pluto Operational Upset Condition – Maximum 1h NO_2 GLC (ppb)

- Maximum grid receptor concentration, 43.6 ppb.
- NEPM (Ambient Air Quality) standard, 120 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.3.1.2 Results for Annual Average NO_2 GLC

TAPM-GRS results for annual average NO_2 GLCs (ppb) are provided as contour plots in Figure 7-20 (FBSIA) and Figure 7-21 (Pluto Operational Upset Condition).

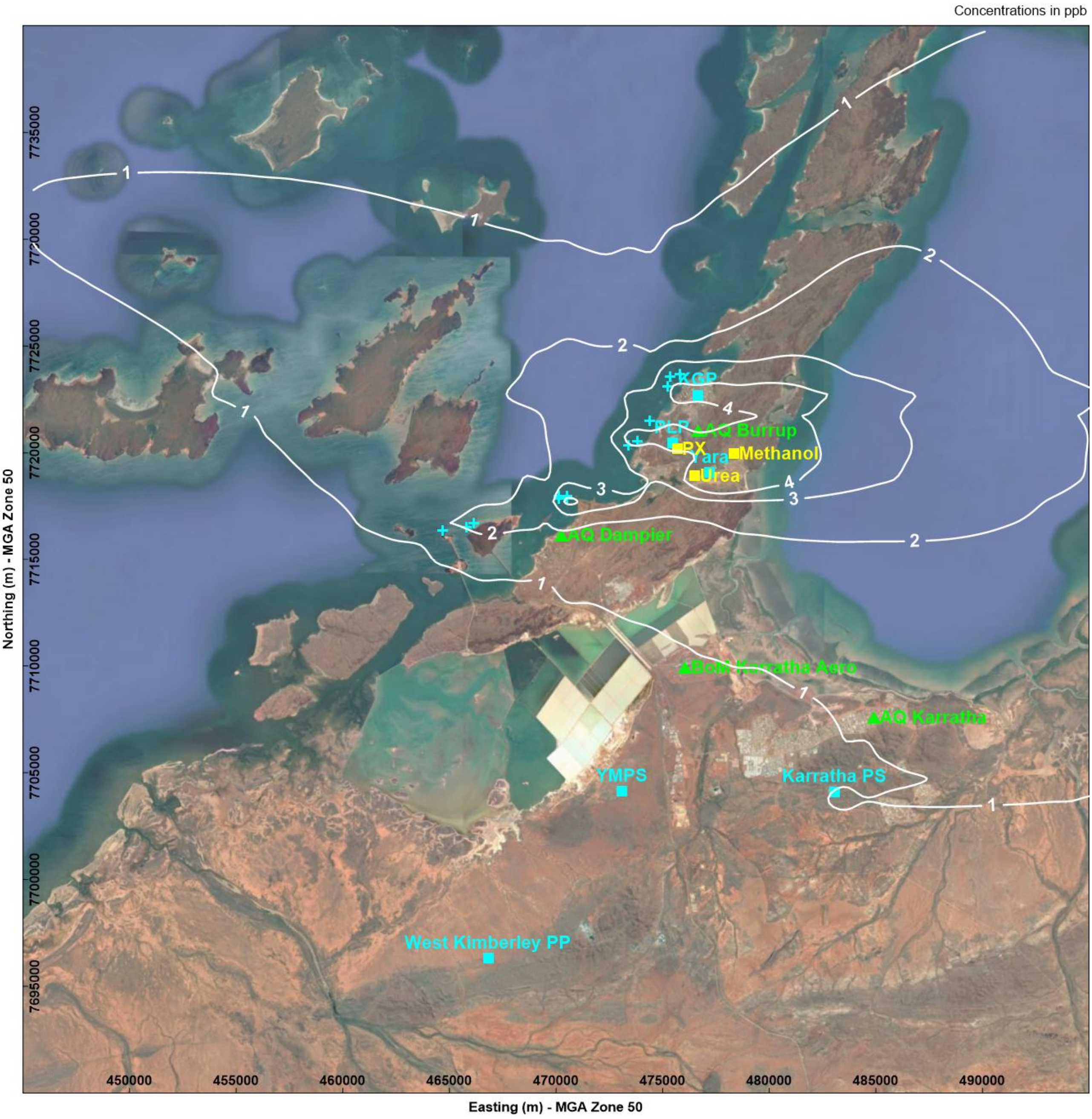

Figure 7-20: FBSIA – Annual Average NO_2 GLC (ppb)

- Maximum grid receptor concentration, 5.8 ppb.
- NEPM (Ambient Air Quality) standard, 30 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

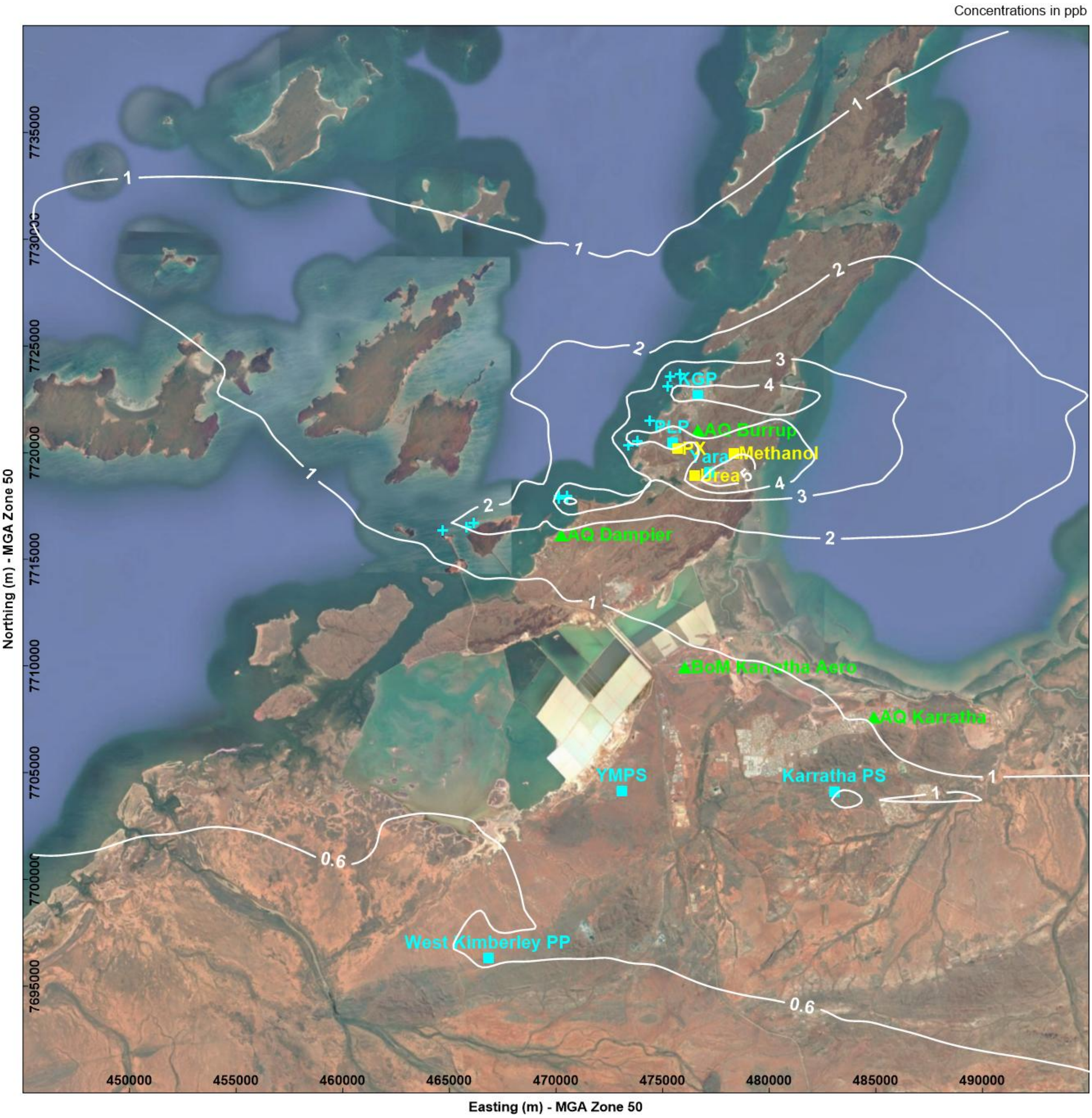

Figure 7-21: Pluto Operational Upset Condition – Annual Average NO_2 GLC (ppb)

- Maximum grid receptor concentration, 5.8 ppb.
- NEPM (Ambient Air Quality) standard, 30 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.3.1.3 Summary of TAPM-GRS Results for NO_2

A summary of the TAPM-GRS results for maximum hourly average and annual average NO_2 GLCs (ppb), for the maxima at each of the 2601 grid receptor points only, is provided in Table 7-5. There were no predicted exceedances of the corresponding NEPM (Ambient Air Quality) standards of 120 ppb and 30 ppb for any of the scenarios. Note the PUC scenario is not assessed against annual standards, as it is a short-term event lasting approximately 2 weeks.

Table 7-5: Maximum 1-hour Average NO_2 concentrations – Grid Receptors

Scenario and Statistic	FBSIA	PUC	FBSIA
Standard	Max 1h NO_2	Max 1h NO_2	Annual NO_2
NEPM (Ambient Air Quality) (ppb)	120	120	30
Maximum grid point result (ppb)	43.9	43.6	5.8
Worst case fraction of NEPM	37%	36%	19%

The TAPM-GRS modelling results provided in this section, confirm that NO_2 is, and will very likely remain, well below the NEPM (Ambient Air Quality) standards, and is considered a low-risk air pollutant for the Burrup Peninsula in terms of its potential to impact human health.

7.3.2 Ozone

7.3.2.1 Results for Maximum Hourly Average O_3 GLC

TAPM-GRS results for maximum hourly average O_3 GLCs (ppb) are provided as contour plots in Figure 7-22 (FBSIA) and Figure 7-23 (Pluto Operational Upset Condition).

Concentrations in ppb

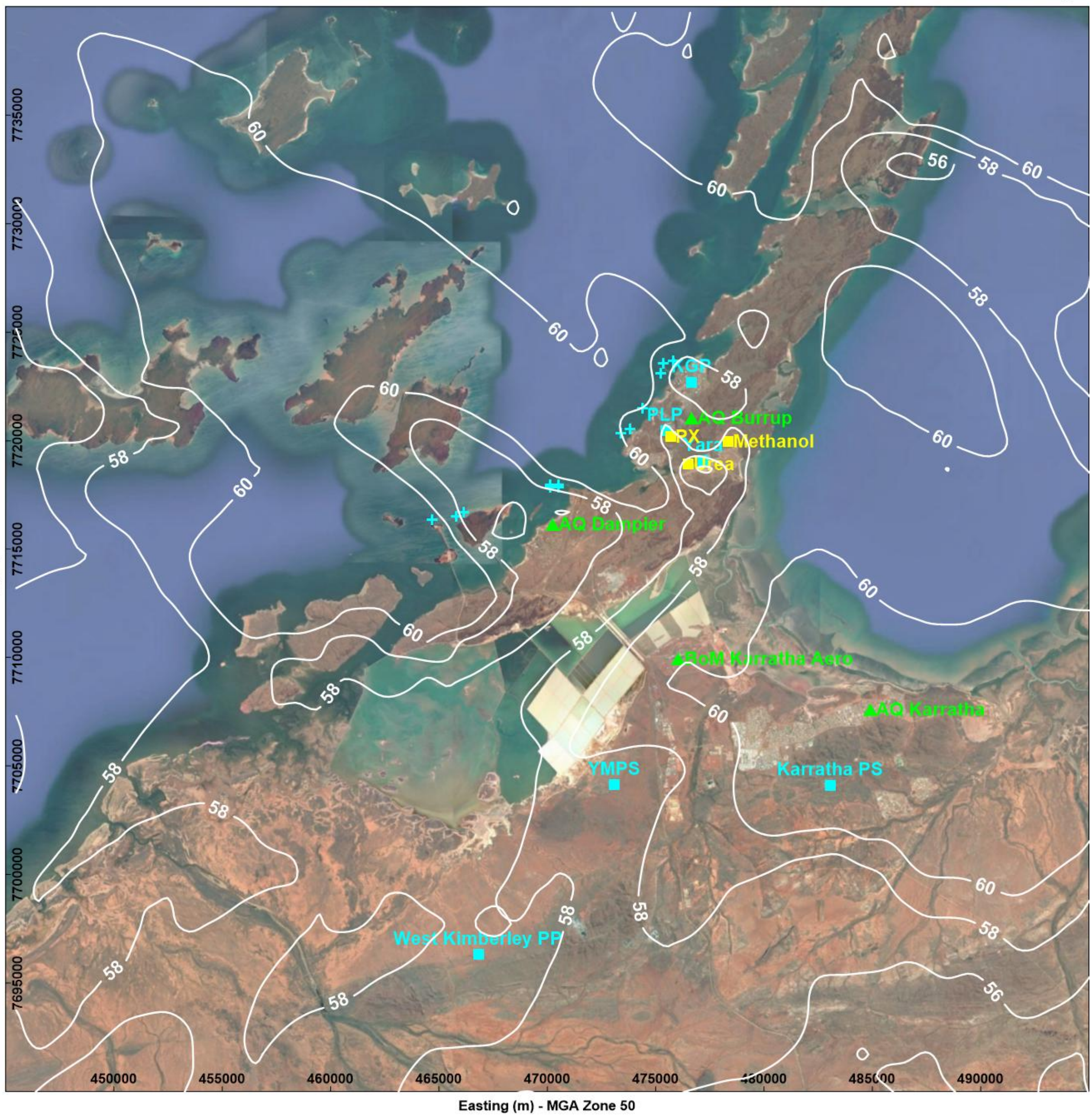

Figure 7-22: FBSIA – Maximum 1h O_3 GLC (ppb)

- Maximum grid receptor concentration, 63.0 ppb.
- NEPM (Ambient Air Quality) standard, 100 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

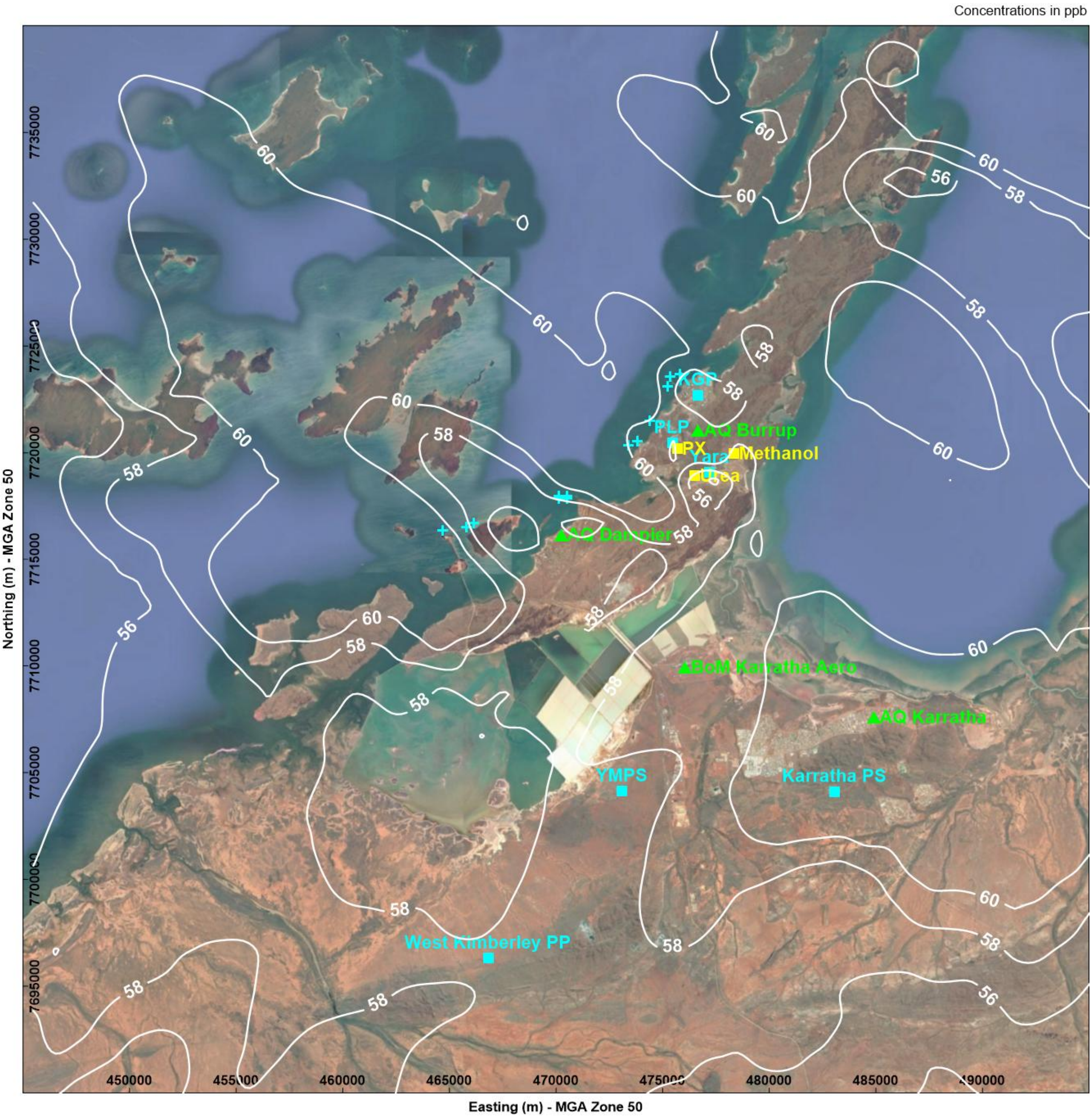

Figure 7-23: Pluto Operational Upset Condition – Maximum 1h O_3 GLC (ppb)

- Maximum grid receptor concentration, 62.9 ppb.
- NEPM (Ambient Air Quality) standard, 100 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.3.2.2 Results for Maximum 4-hourly Average O_3 GLC

A summary of TAPM-GRS results for 4-hour average O_3 concentrations are provided in Table 7-6.

7.3.2.3 Summary of TAPM-GRS Results for O_3

A statistical summary of the TAPM-GRS results for the maximum hourly average O_3 GLCs (ppb) at each of the 2601 grid receptor points, for the two sensitivity model scenarios, is provided in Table 7-6. There were no predicted exceedances of the corresponding NEPM (Ambient Air Quality) standard of 100 ppb for either of the scenarios modelled.

Table 7-6: Maximum 1-hour and 4-hour Average O_3 GLC – Grid Receptors

Scenario	FBSIA	PUC	FBSIA	PUC
NEPM statistic	Max 1h O_3	Max 1h O_3	Max 4h O_3	Max 4h O_3
NEPM standard (ppb)	100	100	80 (rolling)	80 (rolling)
Maximum	63.0	63.2	59.7 (step-wise)	59.4 (step-wise)
Worst case fraction of NEPM	63%	63%	75%	74%

The TAPM results are in good agreement with the O_3 monitoring data for 2014; i.e. in a year the KGP and PLP The TAPM-GRS modelling results provided in this section, confirm that O_3 is a relatively low risk air pollutant for the Burrup Peninsula in terms of the potential for O_3 to impact human health. The modelling and monitoring results indicate that O_3 is a higher-risk air pollutant than NO_2 but is predicted to remain well below the NEPM (Ambient Air Quality) standards for all scenarios.

7.3.3 Sulfur Dioxide

The SO_2 emission rates varied by very little between the scenarios. As such, only one set of contour plots was provided in this report; see Section 7.2.3. A summary of the TAPM-GRS results for the maximum hourly average SO_2 GLCs (ppb) from the 2601 grid receptor points, for the two sensitivity model scenarios, is provided in Table 7-7. There were no predicted exceedances of the corresponding NEPM (Ambient Air Quality) standards for either of the scenarios modelled. Note there are no significant numerical differences between the results shown in Table 7-7 and those for the previous two scenarios (Table 7-3). The reason is there were insignificant differences in the SO_2 emissions between the four scenarios.

Table 7-7: Maximum 1-hour Average SO_2 GLC – Grid Receptors

Statistic	NEPM (Ambient Air Quality) Standard (ppb)	FBSIA (ppb)	PUC (ppb)	Worst case fraction of NEPM standard
Max 1h avg.	200	18.1	18.1	9%
Max. 24 avg.	80	7.0	7.0	9%
Annual avg.	20	4.5	N/A	23%

The TAPM-GRS modelling results indicate that SO_2 will remain well below NEPM (Ambient Air Quality) standards, and is considered a low-risk air pollutant for the Burrup Peninsula in terms of its potential to impact human health.

7.3.4 Potential Effects on Vegetation

The purpose of this section is to provide the results of an assessment on the potential effects on vegetation health due to airborne NO_x and SO_2 emissions. The relevant standards for assessment are the project standards detailed in Section 2; also they are listed in Table 7-8 below.

The worst case annual average SO_2 results (4.5 ppb) were provided in Table 7-7; i.e., less than the relevant NEPM (Ambient Air Quality) standard of 8 ppb. The worst (highest) results were predicted for locations only near the shipping berths, which were conservatively modelled as operating continuously; see Figure 7-9 (representing all scenarios). Future reductions in the sulfur content of fuel for shipping means the future risk of impact on vegetation from SO_2 emissions will be lower.

The second substance for consideration for potential air quality impacts on vegetation is NO_x. The TAPM-GRS results for annual average NO_x GLCs (ppb) for the FBSIA Case is provided as a contour plot in Figure 7-24. Similar results are not provided for the Pluto Operational Upset Condition, as it is a short-term event lasting approximately 2 weeks.

A summary of the results for assessment of effects on vegetation in this section, is provided in Table 7-8.

Table 7-8: Summary of Results for Assessment of Vegetation Effects – Grid Receptors

Substance, Statistic	EU 2008 Veg. Standard (ppb)	FBSIA Max. (ppb)	Worst Case Fraction of Standard
Annual average SO_2	7.8 ppb (20 µg/m^3 at 30 ^oC)	4.5	56%
Annual average NO_x	16.2 ppb (30 µg/m^3 as NO_2 at 30 ^oC)	9.0	56%

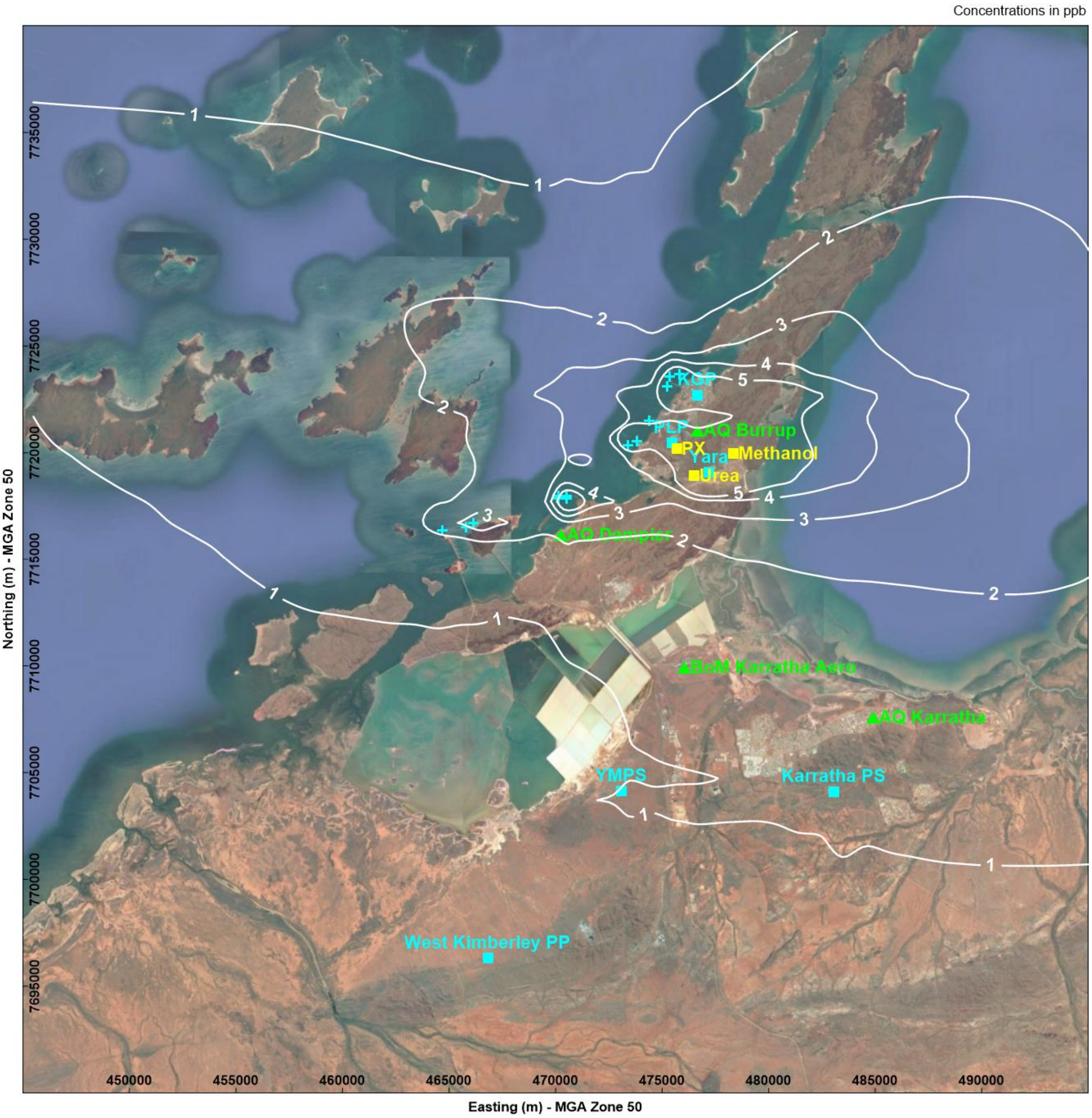

Figure 7-24: FBSIA – Annual Average NO_X GLC (ppb)

- Maximum grid receptor concentration, 9.0 ppb.
- Project vegetation protection standard, 16 ppb.
- Result of vegetation impact assessment: no exceedances.

7.3.5 Deposition of NO_2

This section provides a summary of modelling results for NO_2 deposition for sensitivity scenarios. The scope of works excludes an impact assessment or analysis of these results. (For the assessment of effects on vegetation health, see the results for annual average NO_x in Section 7.3.4). The modelling results for deposition are provided as contour plots in the following sub-sections.

7.3.5.1 Results for NO_2 Deposition (kg/ha/year)

TAPM-GRS results for annual average NO_2 deposition (kg/ha/year) for the FBSIA scenario are provided as a contour plot in Figure 7-25. Results are not provided for the Pluto Operational Upset Condition scenario, as it is a short-term event lasting approximately 2 weeks.

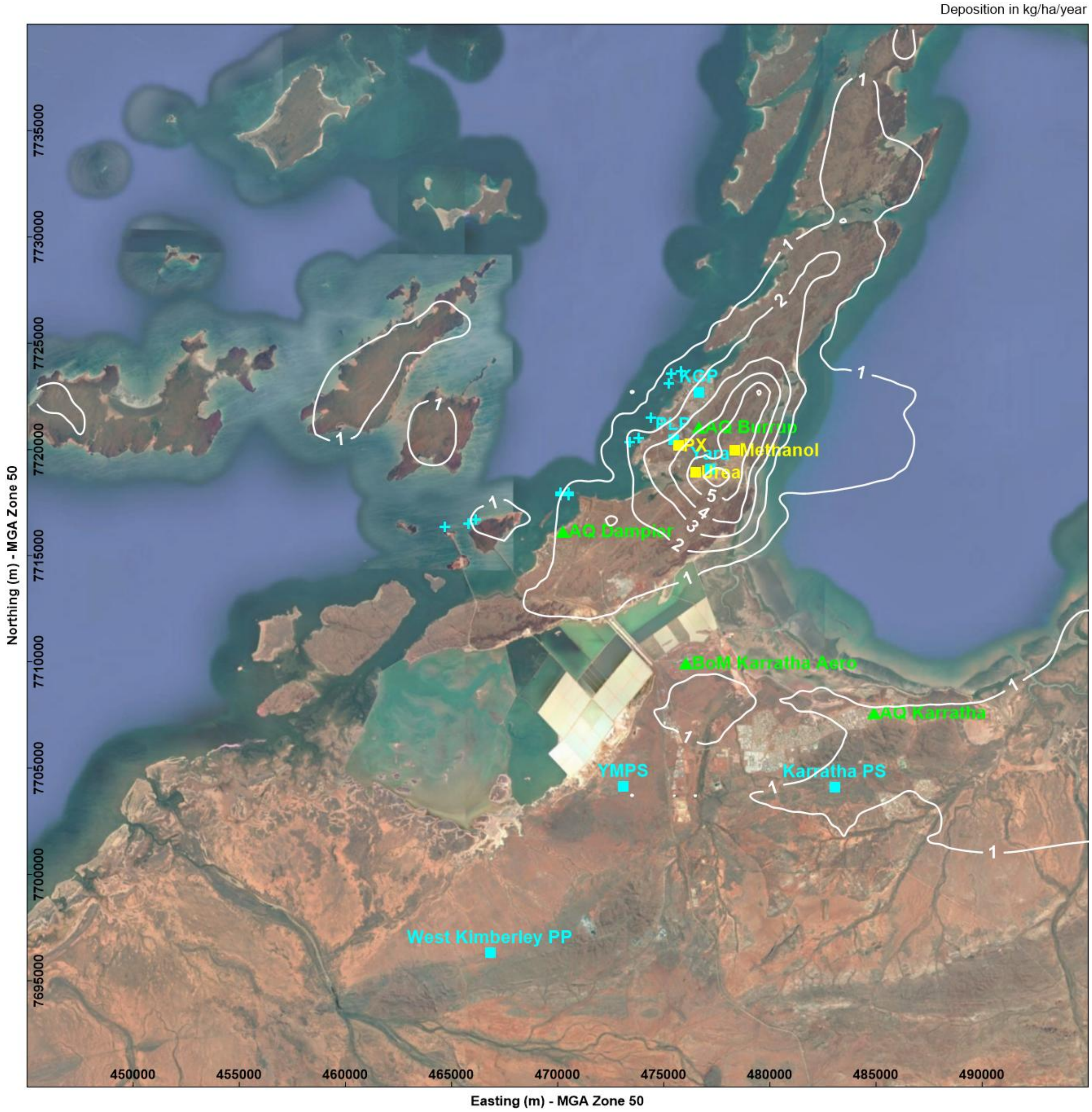

Figure 7-25: FBSIA – NO_2 Deposition (kg/ha/year)

- Maximum grid receptor concentration, 6.8 kg/ha/year.
- For assessment of effects on vegetation health; see annual average NO_x.

7.3.5.2 Results for NO_2 Deposition (meq/m^2/year)

TAPM-GRS results for annual average NO_2 deposition (meq/m^2/year) for the FBSIA scenario only are provided as a contour plot in Figure 7-26. Results are not provided for the Pluto Operational Upset Condition scenario, which is short-term event lasting approximately 2 weeks.

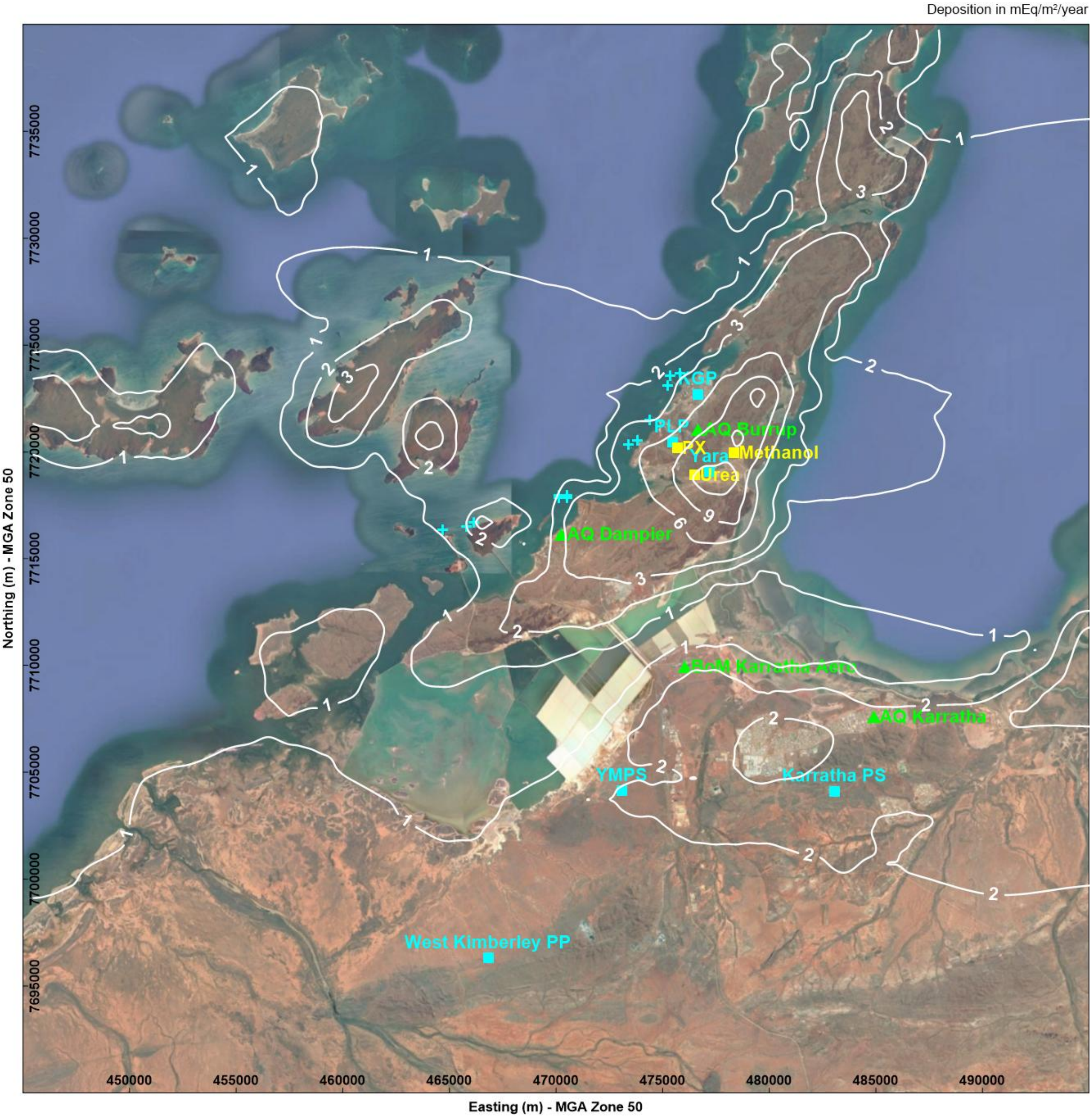

Figure 7-26: FBSIA – NO_2 Deposition (meq/m^2/year)

- Maximum grid receptor concentration, 14.8 meq/m^2/year.

7.3.6 Deposition of SO_2

This section provides provide a summary of modelling results for SO_2 deposition. The scope of works excludes an impact assessment or analysis of these results. (For the assessment of effects on vegetation health, see the results for annual average SO_2 provided in Section 7.3.4).

TAPM-GRS results for annual average SO_2 deposition (kg/ha/year) is provided as a contour plot in Figure 7-27 (FBSIA). Results are not provided for the Pluto Operational Upset Condition scenario, which is short-term event lasting approximately 2 weeks.

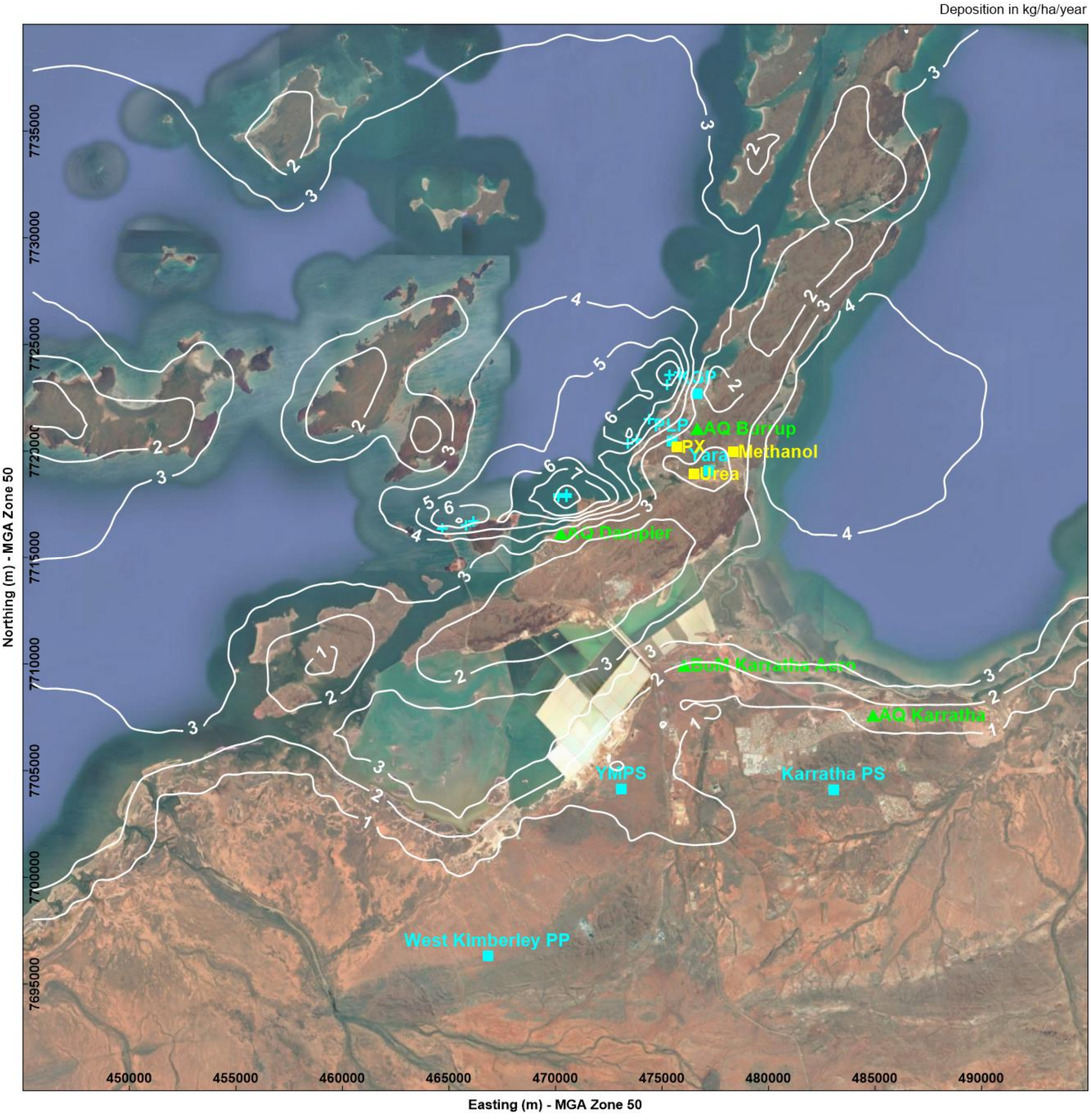

Figure 7-27: FBSIA – SO_2 Deposition (kg/ha/year)

- Maximum grid receptor concentration, 13.7 kg/ha/year; higher depositions confined to shipping berths where continuously operating shipping sources were modelled.
- For assessment of effects on vegetation health; see annual average SO_2.

7.4 Summary of Results

7.4.1 Summary of Results – Grid Receptors

A summary of the TAPM-GRS results for the grid receptor maxima used for the assessment against the NEPM (Ambient Air Quality) standards for the protection of human health is provided in Table 7-9.

Table 7-9: Summary of TAPM-GRS Results: Grid Receptor Maxima and NEPM Standards

Assessment Parameter (units)	CBM	FPS	FBSIA	PUC	NEPM (Ambient Air Quality) Standard
max 1h NO_2 (ppb)	42.6	42.6	43.9	43.6	120
annual NO_2 (ppb)	5.0	5.2	5.6	N/A	30
max 1h O_3 (ppb)	61.8	62.3	63.0	63.2	100
max 4h O_3 (ppb)	58.2	58.6	59.7	59.4	80
max 1h SO_2 (ppb)	18.1	18.1	18.1	18.1	200
max 24h SO_2 (ppb)	7.0	7.0	7.0	7.0	80
annual SO_2 (ppb)	4.5	4.5	4.5	N/A	20

A summary of the TAPM-GRS results for the grid receptor maxima used for the assessment against the EU (2008) standards for the protection of vegetation is provided in Table 7-10.

Table 7-10: Summary of TAPM-GRS Results: Grid Receptor Maxima and EU 2008 Standards

Assessment Parameter	CBM	FPS	FBSIA	EU 2008 Standard – Vegetation Protection
annual NO_x (ppb)	7.7	7.9	9.0	16 ppb at 30°C (15 ppb as NO_2 at 0°C), or 30 µg/m^3
annual SO_2 (ppb)	4.5	4.5	4.5	8 ppb at 30°C (7 ppb at 0°C), or 20 µg/m^3

A summary of the TAPM-GRS results for the grid receptor maxima used for the assessment against the EU (2008) standards for the protection of vegetation is provided in Table 7-10.

Table 7-11: TAPM-GRS Predictions for NO_2 and SO_2 Deposition: Grid Receptor Maxima (No Standards)

Deposition Parameter	CBM	FPS	FBSIA
annual NO_2 deposition (kg/ha/year)	5.7	6.0	6.8
annual NO_2 deposition (meq/m^2/year)	12.4	13.0	14.8
annual SO_2 deposition (kg/ha/year)	13.6	13.6	13.7

7.4.2 Summary of Results – Discrete Receptors

A summary of the TAPM-GRS results for the discrete (sensitive) receptor locations used in the assessment against NEPM (Ambient Air Quality) standards is provided in Table 7-12.

Table 7-12: Summary of TAPM-GRS Results for Discrete Receptor Locations

Monitoring Station	CBM	FPS	FBSIA	PUC	NEPM (Ambient Air Quality) Standards
Maximum 1 hour average NO_2 (ppb)					
AQ Karratha	24.8	25.9	28.3	27.5	120
AQ Burrup	33.4	33.8	34.2	33.2	120
AQ Dampier	24.8	25.8	25.8	24.9	120
Annual average NO_2 (ppb)					
AQ Karratha	0.9	0.9	1.0	N/A	30
AQ Burrup	3.2	3.5	4.0	N/A	30
AQ Dampier	1.7	1.7	1.8	N/A	30
Maximum 1 hour average O_3 (ppb)					
AQ Karratha	57.9	59.6	61.2	60.8	100
AQ Burrup	58.7	59.1	58.4	58.5	100
AQ Dampier	55.4	55.9	56.5	56.2	100
Maximum 4 hour average O_3 (ppb)					
AQ Karratha	56.3	57.8	59.1	58.8	80
AQ Burrup	54.3	54.1	53.7	53.9	80
AQ Dampier	52.5	52.9	53.6	53.5	80
Maximum 1 hour average SO_2 (ppb)					
AQ Karratha	3.6	3.6	3.6	3.6	200
AQ Burrup	11.3	11.4	11.4	11.4	200
AQ Dampier	12.9	12.9	12.9	12.9	200
Maximum 24 hour average SO_2 (ppb)					
AQ Karratha	1.7	1.7	1.7	1.7	80
AQ Burrup	4.7	4.8	4.8	4.7	80
AQ Dampier	4.6	4.6	4.6	4.6	80
Annual Average SO_2 (ppb)					
AQ Karratha	0.9	0.9	0.9	N/A	20
AQ Burrup	2.0	2.0	2.0	N/A	20
AQ Dampier	1.6	1.6	1.6	N/A	20

8. Comparisons with 2007 Results and 2014 Monitoring Data

8.1 Comparisons with 2007 Results

The purpose of this sub-section is to compare the TAPM-GRS modelling results for the current Pluto Expansion Project with the results from the 2007 Pluto LNG Development Works Approval Supporting Study (SKM, 2007c). It is emphasised that a comparison of the current modelling results with SKM (2007c), and comparisons with any other modelling results obtained in the previous assessment period from more than a decade ago, is problematic for two reasons:

1) The air emissions inventory used for the current Project—i.e. the Current Baseline scenario, which was used as a baseline for this assessment—is different in many of the details compared with the air emissions inventory used by SKM (2007c).

2) The current Project included many improvements to the air emissions inventory used as inputs to modelling, and there were improvements to the modelling methods; e.g. an improved scheme for modelling shipping emissions.

3) SKM (2007c) and previous studies used previous versions of TAPM.

However, the results of the comparisons with SKM (2007c) are set out in the following points:

- Maximum hourly average NO_2 concentrations – SKM (2007c) predicted maxima of around 80 ppb, well in excess of what has been found by monitoring and the results for both the existing and future proposed Woodside cases described in this report, with approximately 45 ppb being a current typical maximum.
- Annual average NO_2 concentrations – SKM (2007c) maxima were approximately 9 ppb, which is much higher than the predicted approximately 5-6 ppb for the current assessment.
- Maximum hourly average O_3 concentrations – SKM (2007c) predicted maxima of approximately 80 ppb, greater than found by monitoring (except for the handful of anomalies in 2012) and the results for both the existing and future proposed Woodside cases described in this report, with approximately 62 ppb being a typical maximum from the current modelling.

In summary, the NO_2 and O_3 results for the Pluto Expansion Project, which were obtained using substantial improvements to the air emissions inventories and TAPM-GRS modelling methods, produced results that were significantly less than the concomitant results from SKM (2007c).

8.2 Comparisons with 2014 Monitoring Results

The purpose of this section is to compare key statistical results from the current TAPM-GRS modelling with corresponding statistics from the 2014 monitoring results; 2014 was the simulated meteorological year for modelling; see Section 6.3.6.

Comparisons of the TAPM results for hourly average NO_2 GLCs (ppb) with monitoring data are set out in Table 8-1. The plots provide statistical summaries of the 8760 one-hour average NO_2 GLCs predicted by TAPM for three grid point locations representative of the Karratha (left), Dampier (middle) and Burrup Road (right) monitoring locations. The TAPM 'CLOC' parameter captures the maximum grid point concentration surrounding the selected point, so provides a better indication of the broader model results for each location.

A similar comparison of modelling vs. monitoring results (2014) is provided in Table 8-2 for O_3 – note in 2014, O_3 monitoring data were obtained from Karratha and Dampier monitoring stations only.

The Robust Highest Concentration (RHC) is an estimate of the maximum, which attempts to minimise over-estimates or under-estimates in a dataset; e.g., see Hurley (2008a). Estimates for the RHCs are also provided in the following tables. The hourly average statistics plotted (left-to-right) in each chart are: maximum, RHC, 99.9th percentile, 99th percentile, 70th percentile, 50th percentile (median), and (annual) average. An analysis of comparisons is provided below each chart.

The reliability of the TAPM-GRS results were determined primarily by comparisons of model results with monitoring records. These comparisons of statistical results indicated TAPM-GRS was performing well in terms of being able to accurately predict a variety of statistical results for NO_2 and O_3 as measured by Woodside as Burrup, Dampier and Karratha monitoring stations.

Table 8-1: Comparisons of TAPM Results with 2014 Monitoring Results for Hourly Average NO_2

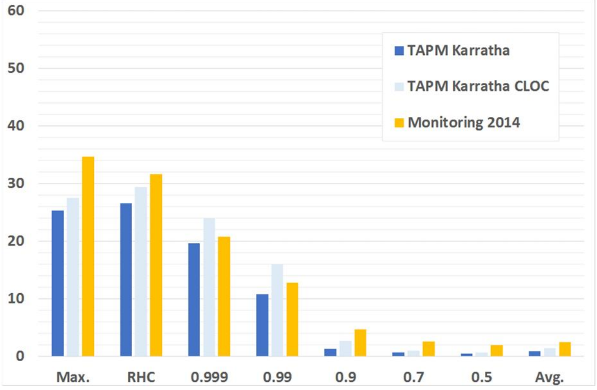	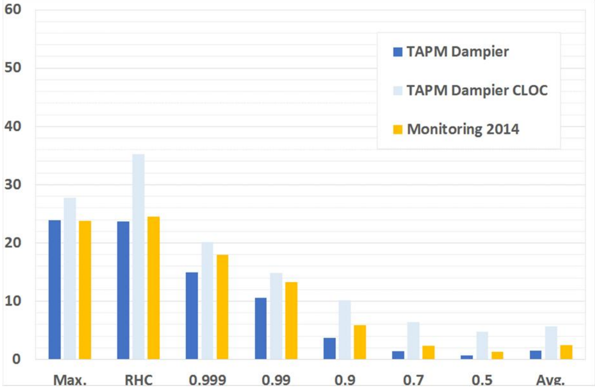	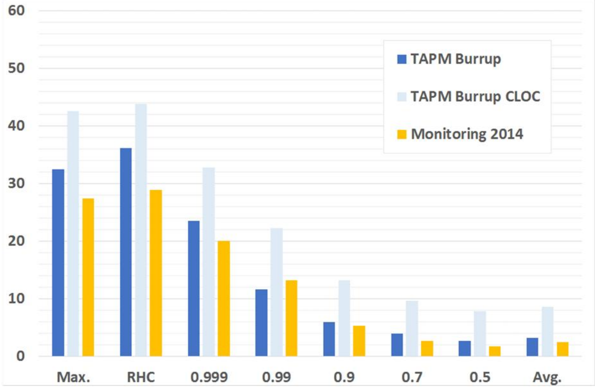
· Karratha 2014: 1-Hour Average NO_2 (ppb) · TAPM (blue) and monitoring (yellow) · Plotted range is 0-60 ppb · NEPM (Ambient Air Quality) standard 120 ppb	· Dampier 2014: 1-Hour Average NO_2 (ppb) · TAPM (blue) and monitoring (yellow) · Plotted range is 0-60 ppb · NEPM (Ambient Air Quality) standard 120 ppb	· Burrup 2014: 1-Hour Average NO_2 (ppb) · TAPM (blue) and monitoring (yellow) · Plotted range is 0-60 ppb · NEPM (Ambient Air Quality) standard 120 ppb
Analysis: Generally good agreement between the TAPM results and monitoring for the higher NO_2 concentrations in Karratha; e.g., the 99.9th percentile for the grid point selected to represent Karratha is almost an exact match. TAPM slightly underestimating annual average NO_2 for both point ‘Karratha’ and ‘CLOC’.	Analysis: Excellent agreement between the TAPM results and monitoring for the higher NO_2 concentrations in Dampier. CLOC parameter indicates the TAPM results are conservative, high. Excellent agreement for annual average NO_2 at Dampier, and TAPM slightly overestimating (conservative, high).	Analysis: Excellent agreement between the TAPM results (blue) and monitoring (yellow) for the higher NO_2 concentrations for Burrup Road; parameter ‘CLOC’ indicates the TAPM results are conservative, high). Good agreement for annual average NO_2 at Dampier, with TAPM overestimating (conservative, high).

Table 8-2: Comparisons of TAPM Results with 2014 Monitoring Results for Hourly Average O_3

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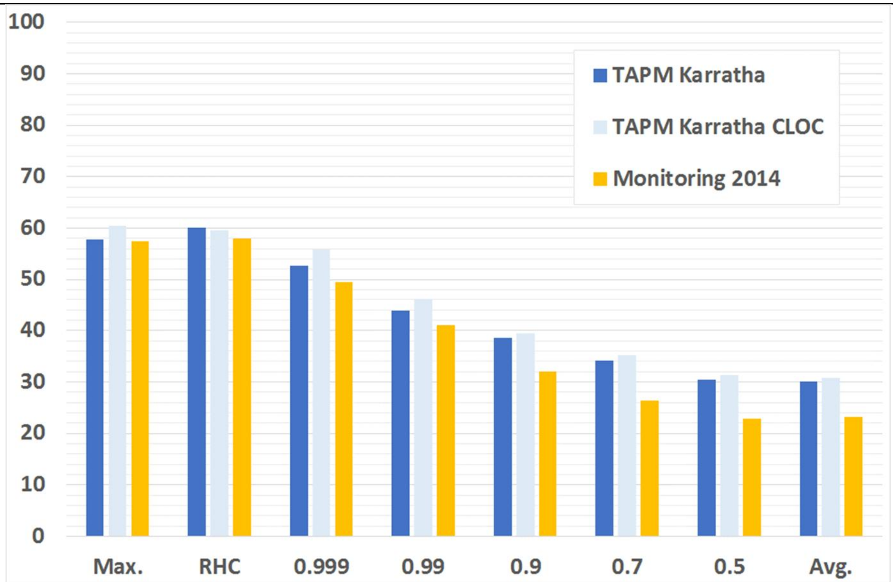
<tr>
<td>
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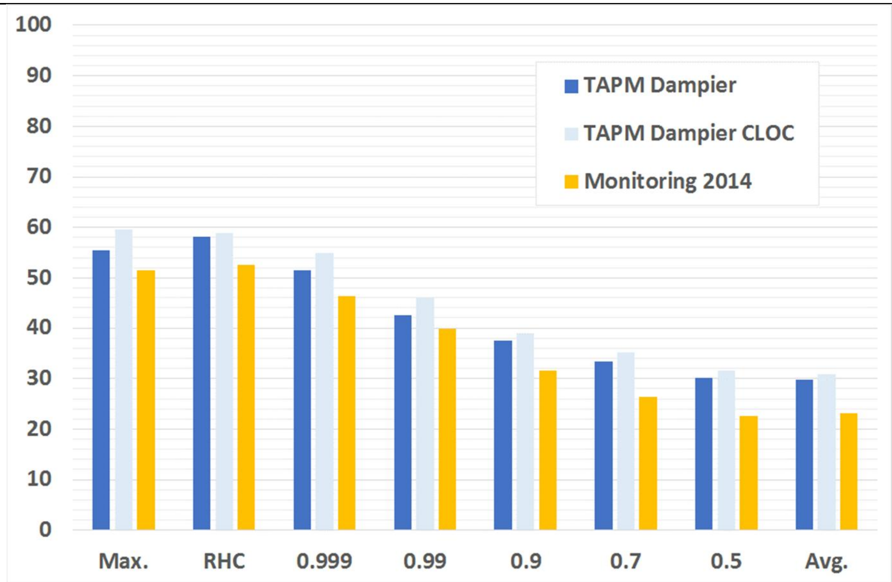
<td>
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<tr>
<td>· Karratha 2014: 1-Hour Average O_3 (ppb)
· TAPM (blue) and monitoring (yellow)
· Plotted range is 0-100 ppb
· NEPM (Ambient Air Quality) standard 100 ppb</td>
<td>· Dampier 2014: 1-Hour Average O_3 (ppb)
· TAPM (blue) and monitoring (yellow)
· Plotted range is 0-100 ppb
· NEPM (Ambient Air Quality) standard 100 ppb</td>
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<td>Excellent overall agreement between the TAPM results for hourly average O_3 concentrations and monitoring across the whole range of statistics. The comparisons of RHCs is perfect, with TAPM slightly conservative (slightly higher).

TAPM overestimating annual average O_3 (conservative).</td>
<td>Excellent overall agreement between the TAPM results for hourly average O_3 concentrations and monitoring across the whole range of statistics. The comparisons of RHCs is perfect, with TAPM slightly conservative (slightly higher).

TAPM overestimating annual average O_3 (conservative).</td>
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8.3 Testing of Model Results for Deposition

8.3.1 Model Results for NO_2 Deposition

Some quality testing of the model results for NO_2 deposition was undertaken by comparisons with measurements obtained by Gillett (2014). Model outputs for NO_2 deposition were extracted for the six monitoring locations and compared with the Gillett (2014) measurements of dry deposition of NO_2 (meq/m^2/year), and total nitrogen and sulphur deposition (also expressed in units of meq/m^2/year); the results are listed in Table 8-3. Inspection of these results shows reasonably good, overall agreement between the modelling and monitoring and indicates two satisfactory outcomes from the modelling: (1) the NO_x emissions inventory used as input to the model was sufficiently complete; and (2) the TAPM-GRS modelling of photochemistry, air pollutant dispersion, and the dry deposition of gases, was satisfactory. The results listed in Table 8-3 are also plotted in Figure 8-1.

Table 8-3 Summary of Monitoring and Model Results for NO_2 Deposition

Parameter	1^I Gap Ridge	2^I Fertiliser Plant	3^I BMF	4^I KGP	5^I Dom	6^B Backgnd
Monitoring 2012/2014 (CSIRO, 2014):						
Total nitrogen flux (meq/m^2/yr)	25.5	23.9	28.8	17.9	17.1	9.8
Dry NO_2 deposition (meq/m^2/yr)	4.4	4.0	7.7	4.4	5.8	1.3
Model results (this report):						
CBM NO_2 deposition (meq/m^2/yr)	1.8	8.5	5.0	5.7	6.2	approx. 1.0
FPS NO_2 deposition (meq/m^2/yr)	1.9	9.5	5.1	6.1	7.3	approx. 1.0

- Superscript 'B' indicates background monitoring site; superscript 'I' indicates monitor in industrial area.
- Site 1: Gap Ridge accommodation camp west of Karratha; Site 2 near Yara TAN plant; Sites 4 and 5 located near Pluto LNG.
- Modelled results for background were from southern-most parts of study grid; it is expected these low, but non-zero values were due to modelled biogenic NO_x emissions over land (nil emissions modelled over water).

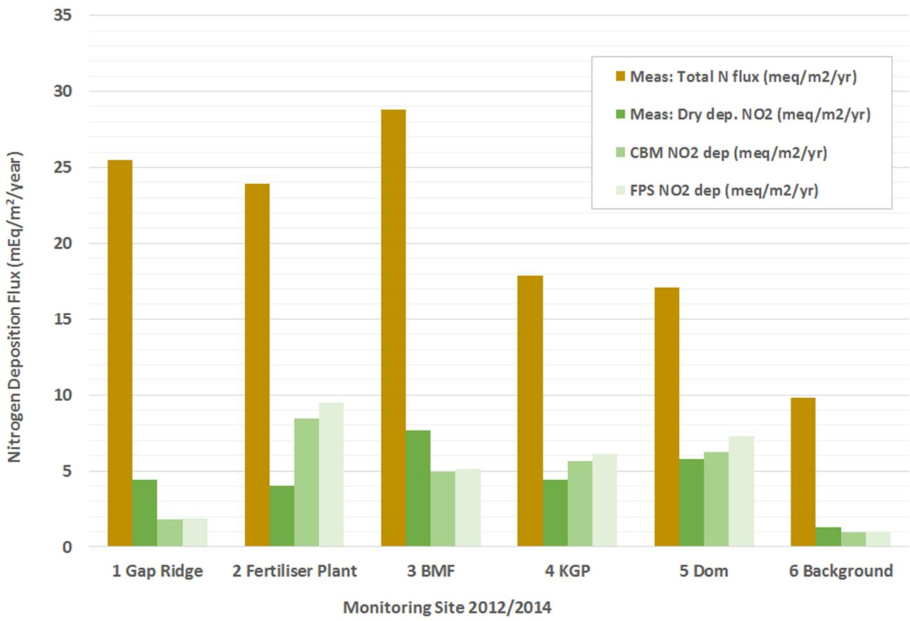

Figure 8-1: Measured and Modelled Nitrogen Fluxes (meq/m^2/year)

Some further analysis of the model results for NO_2 deposition was undertaken in an attempt to tease out differences between the modelled scenarios CBM and FPS, by a focus on the grid receptor results within the Dampier Archipelago National Heritage Place (DANHP) (AG, 2019). The 2601 grid receptor results were clipped using the National Heritage List Spatial Database (AG, 2019), to extract model results from within the DANHP only. The DANHP boundaries and 310 clipped points are illustrated in Figure 8-2.

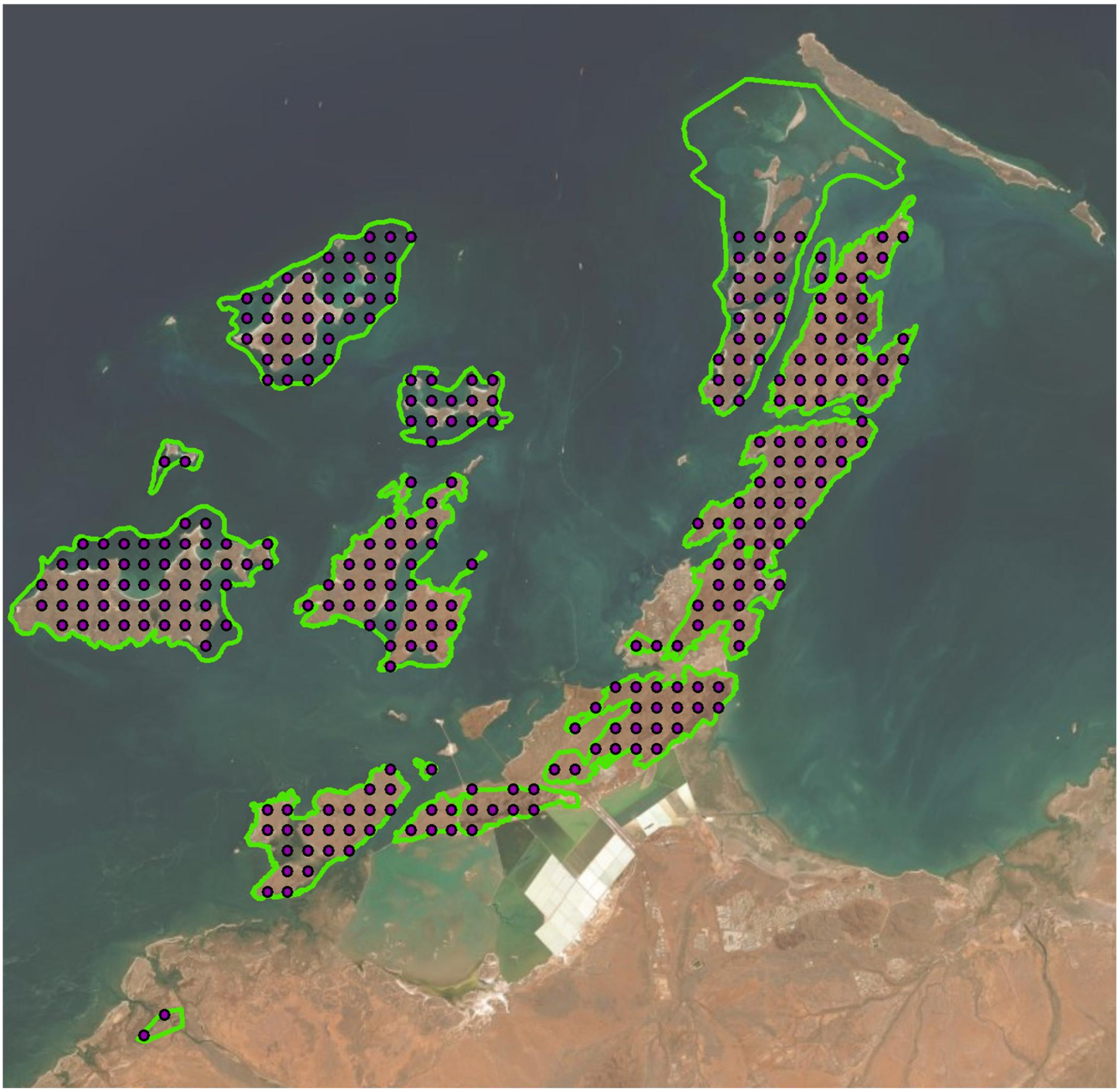

Figure 8-2: Model Grid Points Within Dampier Archipelago National Heritage Place

Histograms of the model results for NO_2 deposition (meq/m^2/year), for the CBM and FPS scenarios, for the model grid points within the DANHP boundaries (Figure 8-2), are provided in Figure 8-3. The majority of the NO_2 deposition results for the grid receptors within the DANHP are in the range 1-3 meq/m^2/year. There are slightly fewer FPS results in the lower deposition range of 1-3 meq/m^2/year, than for CBM, and in the range 4-5 meq/m^2/year, there are slightly fewer CBM results than those for FPS. Overall, there is very little to distinguish between the results for the two scenarios, and practically no difference between the results for NO_2 deposition greater than approximately 5 meq/m^2/year. Hence the addition of Pluto LNG (Train 2) emissions; i.e., the FPS scenario, had a very small effect on the baseline NO_2 deposition rate.

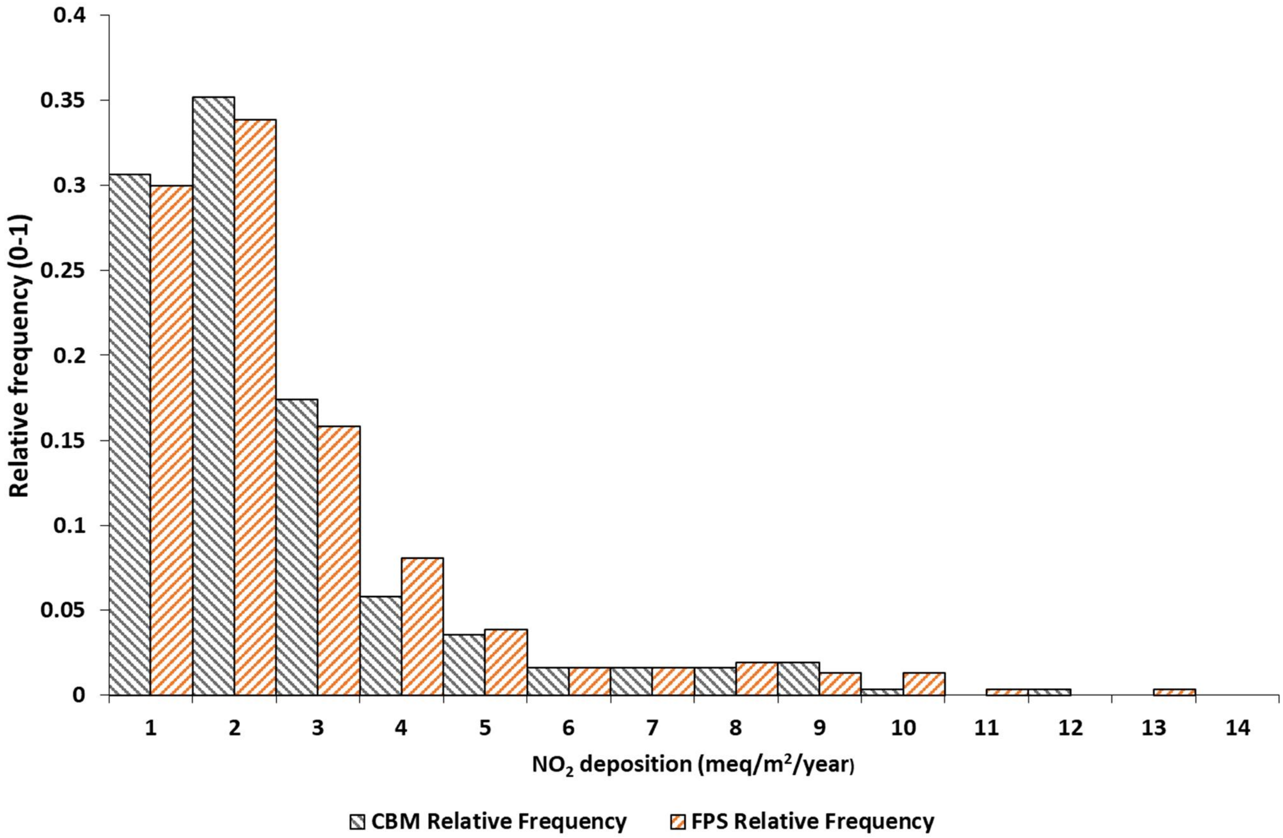

Figure 8-3: Frequency Distributions of Model Results for NO_2 Deposition Within DANHP

8.3.2 Model Results for SO_2 Deposition

The model results for SO_2 deposition (kg/ha/year), were highest around the main sources – the ship exhausts located at all berths around Burrup Peninsula; these were modelled as continuously operating. Typical values for modelled SO_2 deposition were 2-3 kg/ha/year around the Burrup Peninsula within approximately 1 km of the coastline. The deposition rate decreased to a minimum of approximately 1 kg/ha/year on the mainland, also within approximately 1 km of the coastline. The SO_2 deposition rates for the CBM and FPS scenarios were almost identical, showing only a very small effect on the baseline due to the addition of Pluto LNG Train 2 (FPS scenario). This is because there was only a very small difference in the SO_2 emissions profile between the modelled scenarios.

It is noted the modelled effects due to SO_2 emissions on the Burrup Peninsula are expected to have been over-estimated by the modelling undertaken for this project, which assumed SO_2 emissions from all the shipping berths in the study area operating continuously over the course of a year.

9. Conclusions

This report details the results of air quality modelling to support the Pluto Expansion Project. As a part of this assessment Current Baseline and Future Pluto State scenarios were developed for the Burrup Peninsula. Also, sensitivity modelling was undertaken for two additional potential future air emissions scenarios, FBSIA and Pluto Upset Condition, to understand the extent of the potential, cumulative air quality impacts and how various air emissions scenarios would affect air pollutant GLCs.

The modelling methodology was set out based on a literature review that included several key CSIRO papers from the early 2000s, and subsequent assessment reports completed by Woodside and specialist air quality consultants. The CSIRO meteorological, air dispersion and photochemical model, TAPM-GRS was selected for modelling for reasons of reliability and efficiency. The modelling methodology was discussed with EPA air quality specialists prior to the commencement of modelling (Jacobs, 2019b).

The reliability of the TAPM-GRS results was determined primarily by comparisons of model results with monitoring records. These comparisons of statistical results indicated TAPM-GRS was performing well in terms of being able to accurately predict a variety of statistical results for NO_2 and O_3 as previously measured at Burrup, Dampier and Karratha ambient air monitoring stations.

A comparison of the current model results with the previous assessment results of SKM (2007c) was undertaken. In summary, the NO_2 and O_3 model results of this Project, which were obtained using substantial improvements to the air emissions inventories and TAPM-GRS modelling methods, produced results that agreed well with the monitoring data from 2014 when KGP and PLP were operating at or near capacity. These results were significantly less than the concomitant results from SKM (2007c) which supported the original environmental approvals.

Key results for the Pluto Expansion Project air quality impact assessment are:

- There were no predicted exceedances of ambient air quality standards for NO_2, O_3, and SO_2. All these pollutants were well below the respective NEPM (Ambient Air Quality) standards.
- There were no predicted exceedances of European Union (2008) air quality standards for NO_x and SO_2 for the protection of vegetation.
- Results for NO_2 and SO_2 deposition were provided to assist any further assessment of impacts to land surfaces (no agreed standard for impacts).

In conclusion, there is a low risk of impacts to human health and vegetation from the Pluto Expansion Project's air emissions.

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Keywords: Best processing route; Contractual agreements; Natural gas processing; Plant configurations; Process units; Utilities

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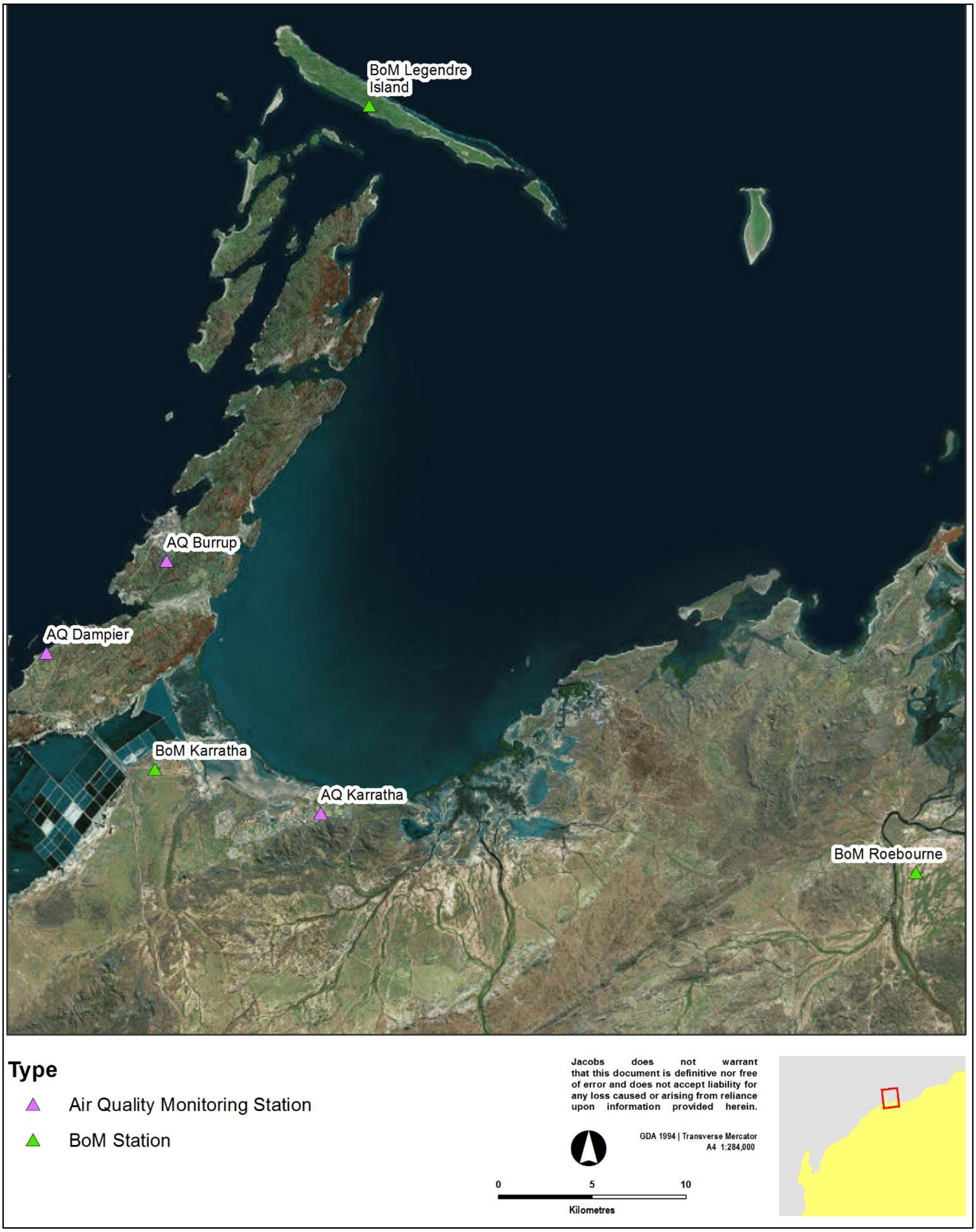
Appendix A. Location Map and Monitoring Stations



Appendix B. Local Meteorology

Overview

Local meteorology is a critical input for determining the direction and rate at which emissions from a source are likely to disperse, near ground level. This section provides climatological summaries of meteorological parameters representative of the Burrup Peninsula based on Bureau of Meteorology (BoM) observations. The closest BoM weather station to the Pluto LNG Development site is Karratha Aerodrome (BoM station number 004083, 20.71° S, 116.77° E, elevation 5.3m), which is located approximately 12 km south of the Pluto LNG Development site. The following sub-sections provide summaries of meteorological data acquired over more than two decades at Karratha Aerodrome.

Temperature

Monthly mean maximum and minimum temperatures for BoM Karratha Aerodrome for 1993-2018 are shown in Figure B- 1. Daily maximum and minimum temperatures have ranged from 48ºC in the wet season to only 7ºC in the dry season, from 1993 to 2018.

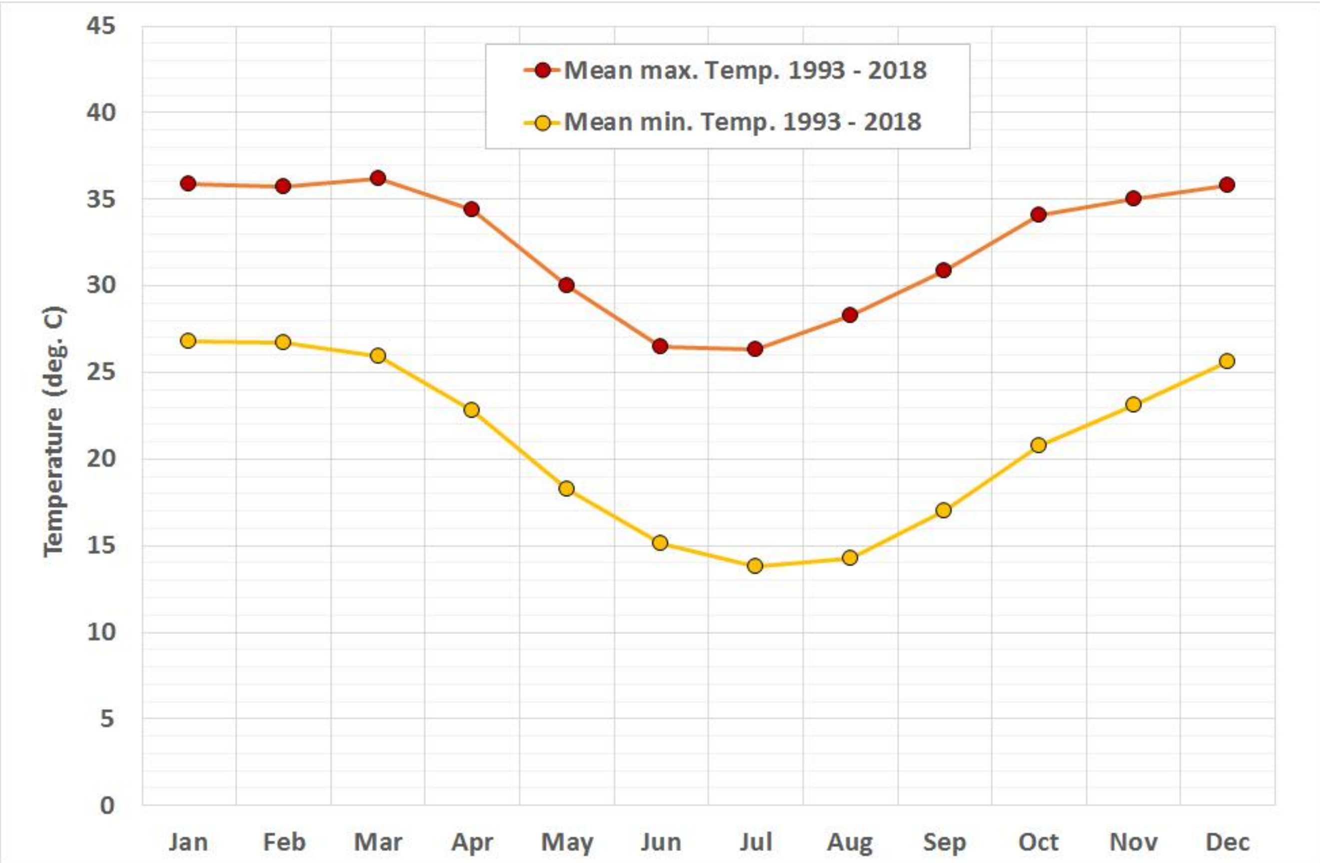


Figure B- 1: Monthly Mean-Maximum and Minimum Temperature – Karratha Aerodrome 1993-2018

Rainfall and Relative Humidity

Monthly rainfall statistics for BoM Karratha Aerodrome are shown in Figure B- 2, and monthly mean 9am and 3pm Relative Humidity (RH) for Karratha Aerodrome for 1993-2010 are shown in Figure B- 3. The rainfall observations clearly show the Burrup Peninsula wet season running from approximately January to June, and the dry season from approximately July to December.

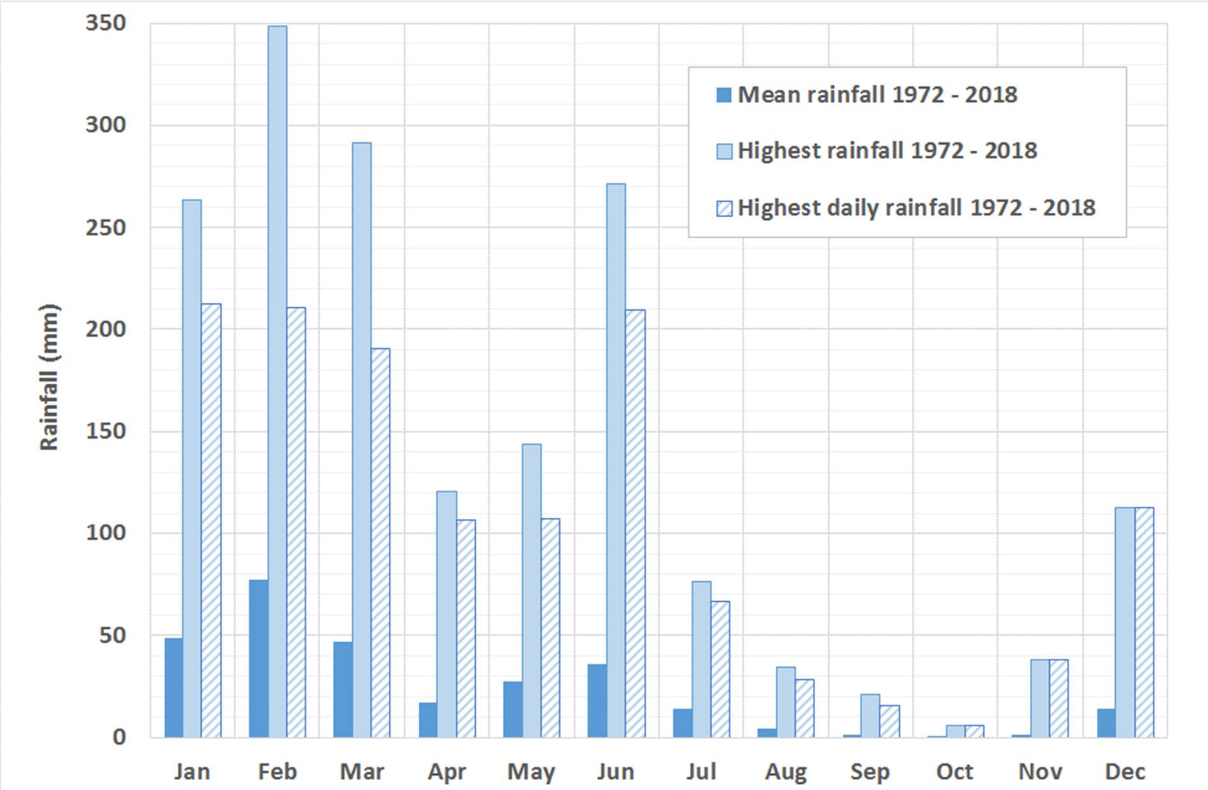


Figure B- 2: Monthly Rainfall – Karratha Aerodrome 1972-2018

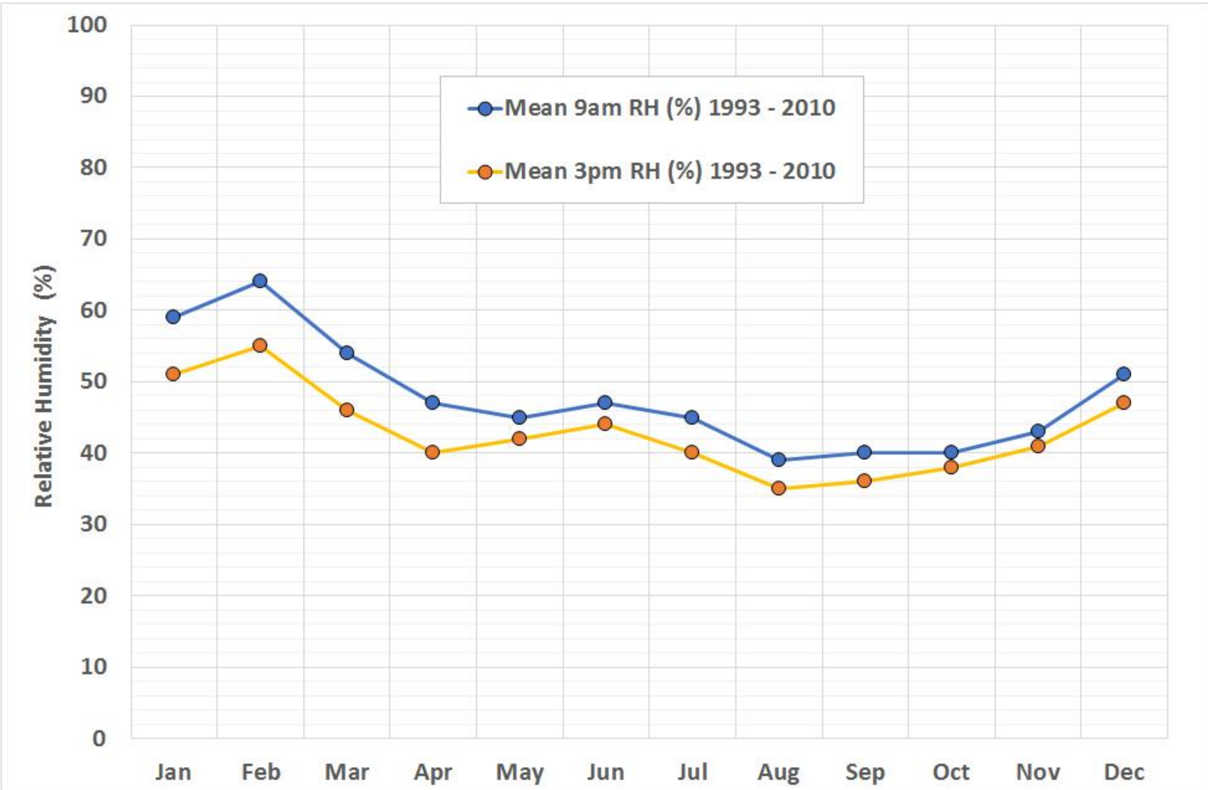


Figure B- 3: Monthly 9am and 3pm Relative Humidity – Karratha Aerodrome 1972-2018

Wind Speed and Wind Patterns

Monthly mean daily wind speeds and maximum wind gusts for BoM Karratha Aerodrome for 2003-2018 are shown in Figure B- 4.

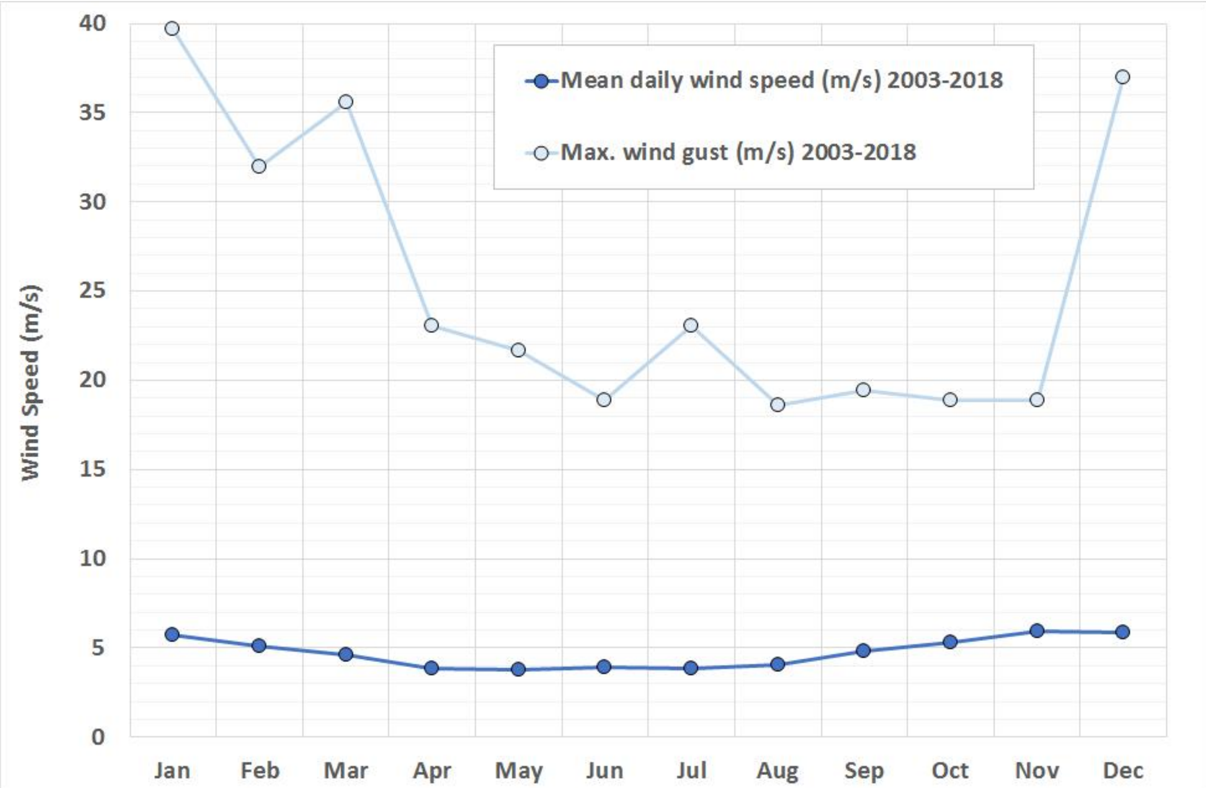


Figure B- 4: Mean Daily Wind Speed and Maximum Wind Gust – Karratha Aerodrome 1993-2018

The 2014 examples are shown in Figure B- 5. The wind roses show westerly winds were dominant during summer and spring over 2010-2018. There was significantly more annual variability in the wind patterns for autumn and winter (see Figure B- 4), but this may be an artefact of the artificial boundaries of those seasons in relation to the Pilbara's dry and wet seasons.

Hourly average wind speed statistics calculated from measurements at BoM Karratha and two other weather stations in the Burrup region in 2014, are compared in Table B- 1. The wind speeds at Karratha match those of Roebourne reasonably well. Higher wind speeds were observed at the more exposed site at Legendre Island just north of the peninsula.

Table B- 1: Wind Speed Comparisons – Burrup Peninsula 2014

Statistic	BoM Karratha Aerodrome	BoM Roebourne	BoM Legendre Island
Data Capture %	99.9%	99.9%	99.9%
Maximum (m/s)	13.1	13.4	16.1
90th percentile (m/s)	8.0	7.8	9.7
70th percentile (m/s)	6.2	5.7	7.1
Average (m/s)	5.0	4.5	6.0

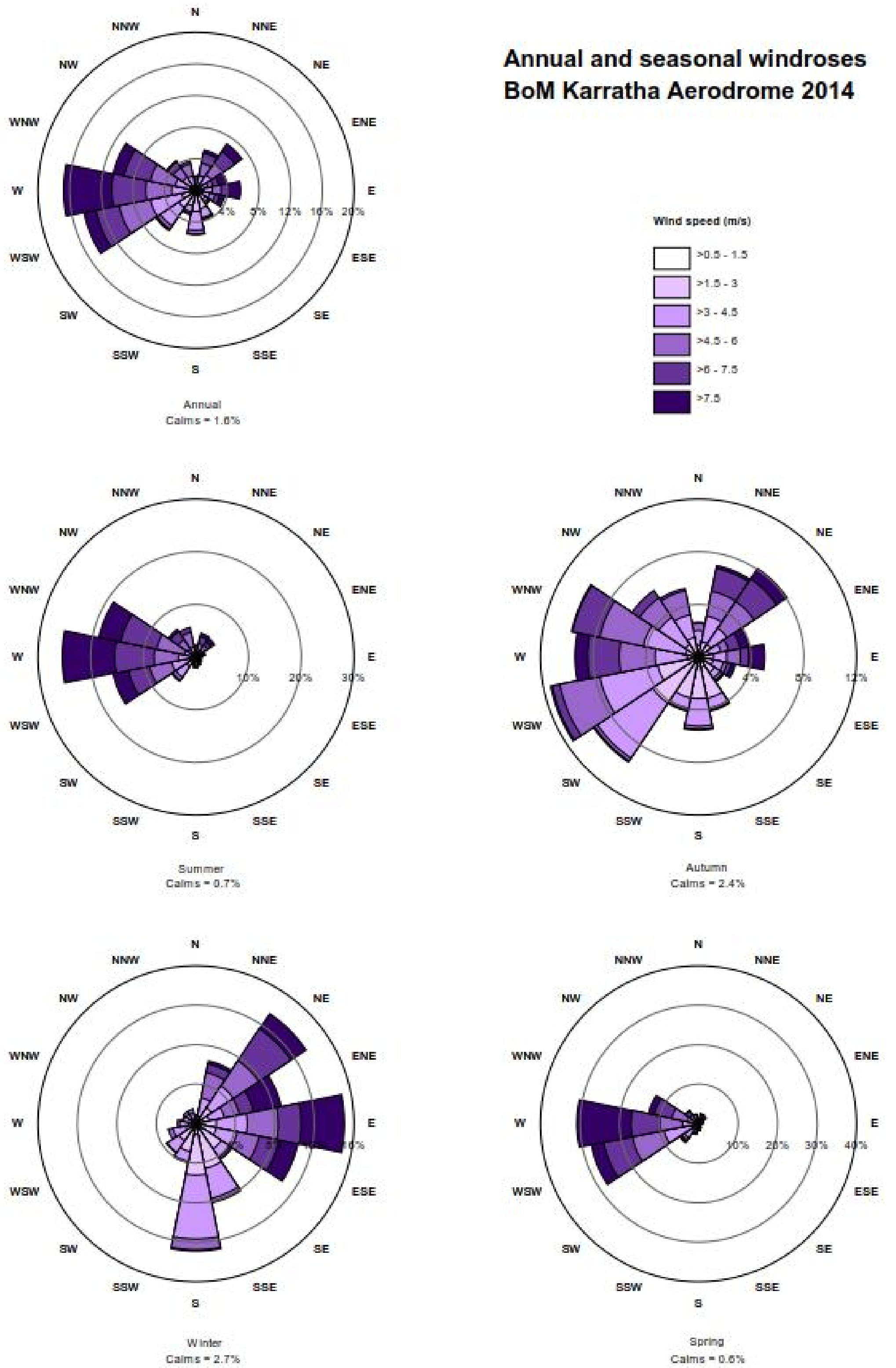


Figure B- 5: Annual and Seasonal Wind Roses for 2014 – BoM Karratha Aerodrome*

*A full set of BoM Karratha Aerodrome wind roses for 2010-2018 is provided in the final section of this Appendix.

Pilbara Cyclones

Cyclones have affected the coastal communities of Port Hedland, Karratha, Dampier, and Onslow, and parts of inland Pilbara. Typically, these cyclones form over warm ocean waters to the north, intensify before crossing the Pilbara coast, then track towards the south. The further south they move the more likely they will move south-easterly across inland parts of WA (BoM, 2019a). For example, the track of Tropical Cyclone Monty, 27 February to 2 March 2004, is shown in Figure B- 6 (BoM, 2019b).

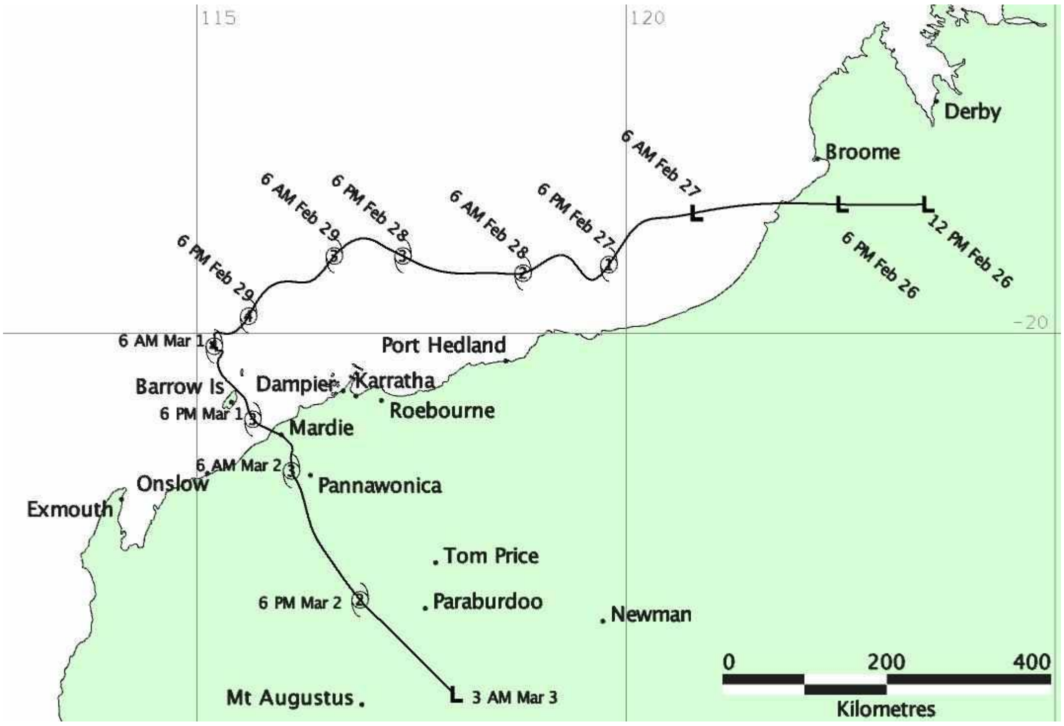


Figure B- 6: Track of Tropical Cyclone Monty 2004 (BoM, 2019b)

Heavy rainfall and flooding are the main impacts for most cyclonic events in inland Pilbara. The highest rainfall is usually found along or just east of the track for most systems. The flood potential of a cyclonic system is associated with its track, speed, areal extent and saturation of catchments from prior rainfall. Rainfall totals in excess of 100 mm are common with tropical lows that move over land (BoM, 2019a).

Cyclones have affected the Pluto study area. The three most recent, significant cyclones affecting the Pilbara were (BoM, 2019a):

- Cyclone Bobby, 24-25 February 1995 – crossed coast just east of Onslow between midnight and 1 am on the 25th February 1995. More than 400 mm of rain fell in the Onslow area during the event. Very heavy rain associated with the cyclone caused serious flooding in the west Pilbara, Gascoyne, Goldfields and Eucla regions. Rainfall associated with this event followed heavy rains over a large part of inland WA earlier in the month.

- Cyclone Olivia, 10-11 April 1996 – crossed coast near Mardie causing wind gusts of 257 km/h before accelerating to the southeast. Pannawonica recorded gusts to 158 km/h and was extensively damaged. As Olivia passed Paraburdoo after midnight it still produced gusts to 140 km/h.

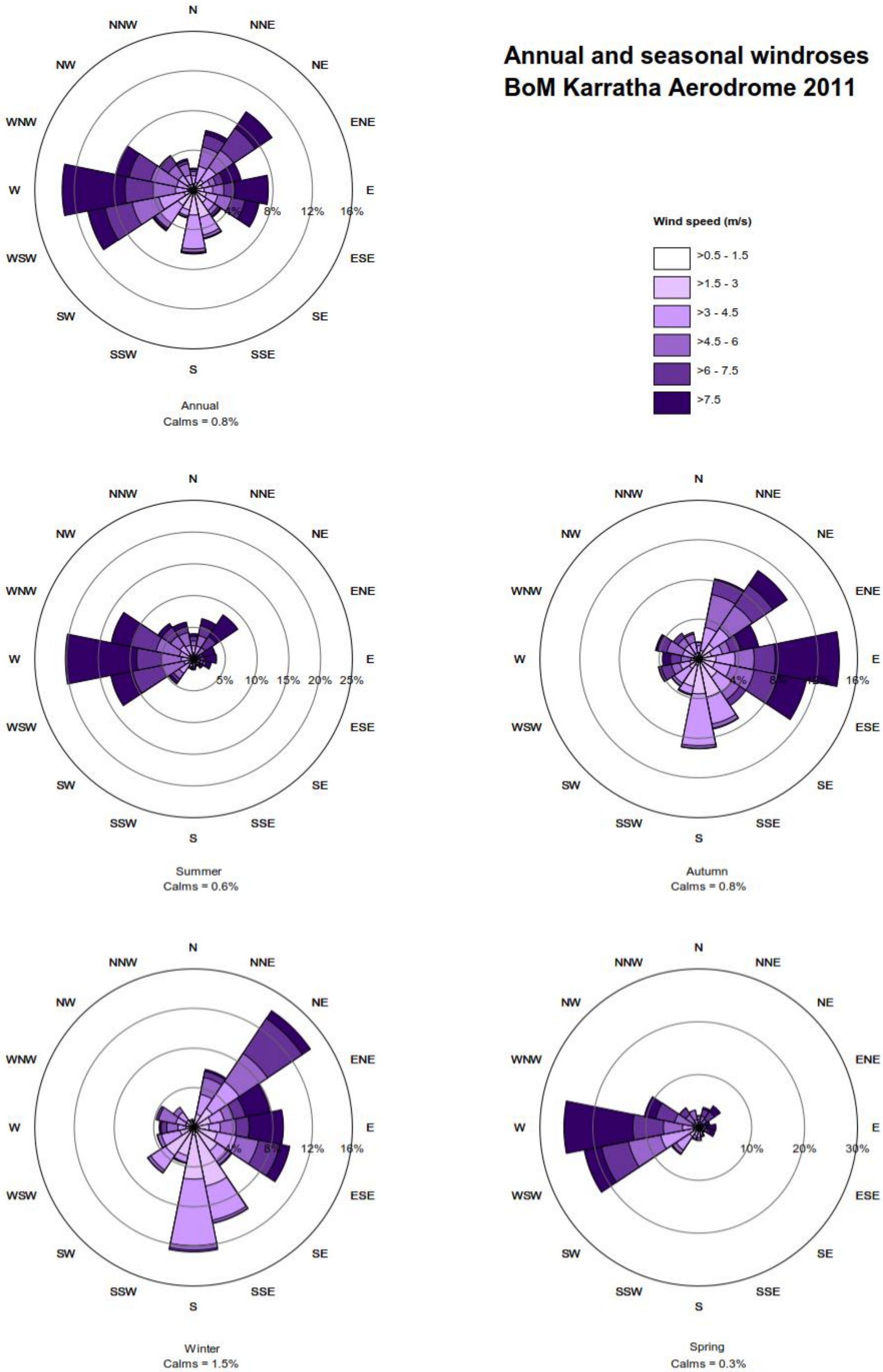
- Cyclone Monty, 1 March 2004 – passed over Mardie station west of Dampier before passing near Pannawonica where there was some damage, and the town of Pannawonica was cut-off due to flooding. Heavy rain flooded rivers. A large part of the bridge over the Maitland River on the Northwest coastal highway was washed away.

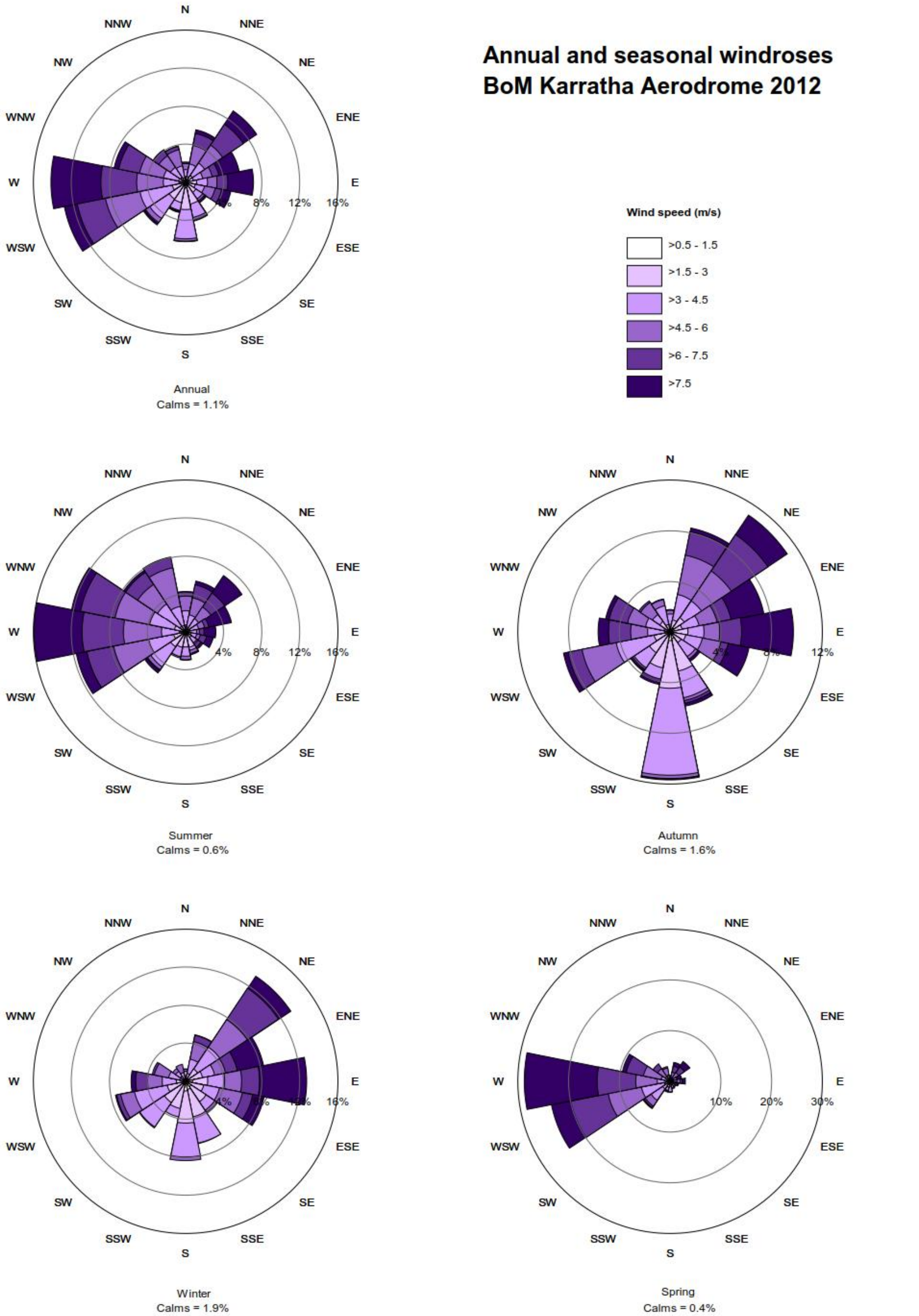
Other cyclones that probably affected Burrup Peninsula weather were (sources: BoM web site): Cyclone Dominic, 22-27 January 2009; Cyclone Laurence, 16-21 December 2009; Cyclone Heidi, 9 January 2011; Cyclone Bianca, 25 January 2011; Cyclone Carlos, 14 February 2011; Cyclone Lua, 17 March 2012; Cyclone Rusty, 22 February 2013; and Cyclone Peta, 23 January 2013.

Wind Roses

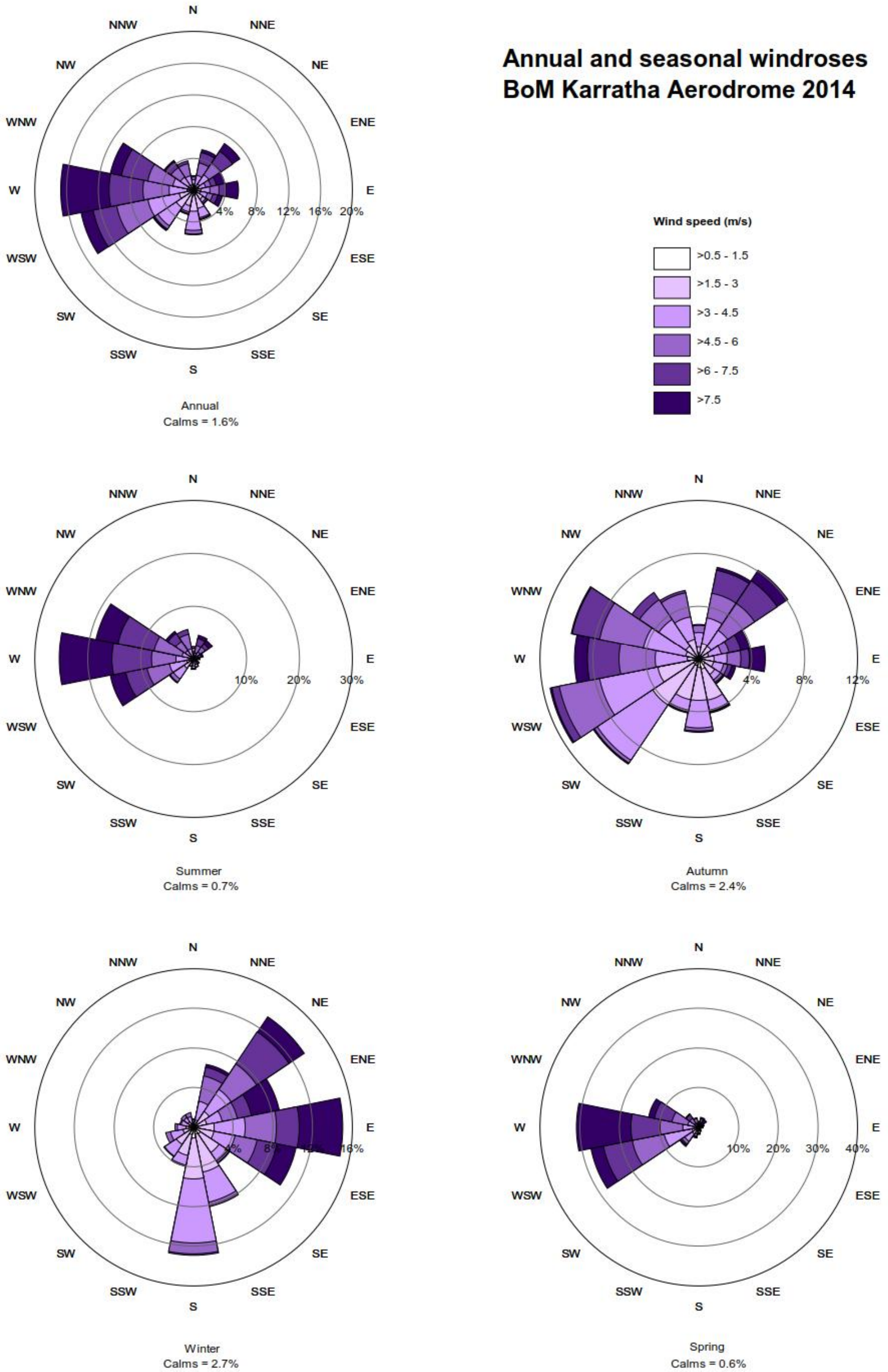
Annual and seasonal wind roses created from hourly wind speed and wind direction data for BoM Karratha Aerodrome 2010-2018 are provided overleaf.


Annual and seasonal windroses
BoM Karratha Aerodrome 2010
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
Annual
Calms = 0.7%
Summer
Calms = 0.1%
Autumn
Calms = 1.0%
Winter
Calms = 1.0%
Spring
Calms = 0.6%

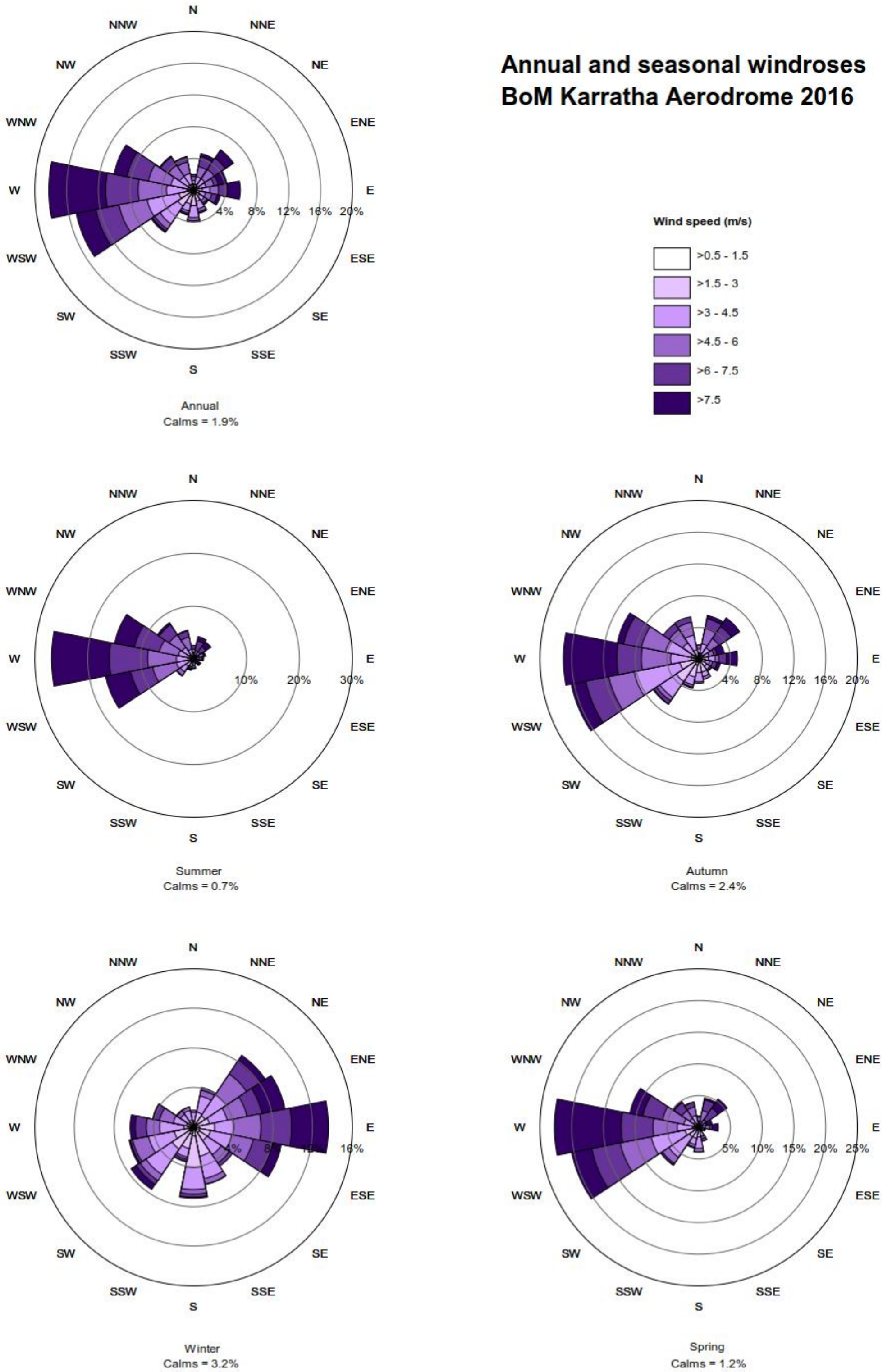

Annual and seasonal windroses
BoM Karratha Aerodrome 2011
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Annual
Calms = 0.8%
Summer
Calms = 0.6%
Autumn
Calms = 0.8%
Winter
Calms = 1.5%
Spring
Calms = 0.3%

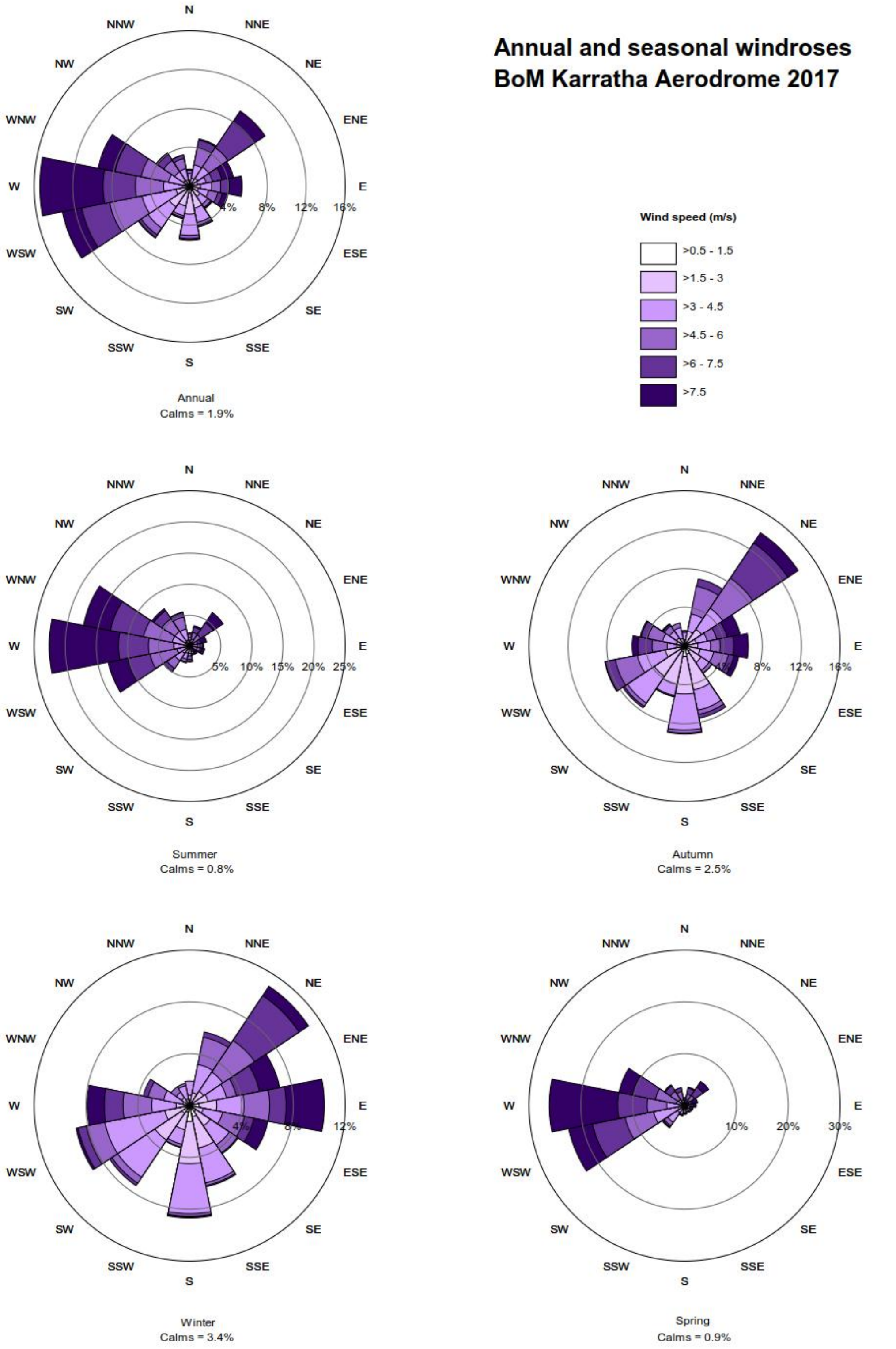

Annual and seasonal windroses
BoM Karratha Aerodrome 2012
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
Annual
Calms = 1.1%
Summer
Calms = 0.6%
Autumn
Calms = 1.6%
Winter
Calms = 1.9%
Spring
Calms = 0.4%


Annual and seasonal windroses
BoM Karratha Aerodrome 2013
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
4%
8%
12%
16%
10%
20%
30%
Annual
Calms = 1.0%
Summer
Calms = 0.5%
Autumn
Calms = 0.9%
Winter
Calms = 2.1%
Spring
Calms = 0.4%


Annual and seasonal windroses
BoM Karratha Aerodrome 2014
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
4%
8%
12%
16%
20%
Annual
Calms = 1.6%
10%
20%
30%
Summer
Calms = 0.7%
4%
8%
12%
Autumn
Calms = 2.4%
Winter
Calms = 2.7%
10%
20%
30%
40%
Spring
Calms = 0.6%


Annual and seasonal windroses
BoM Karratha Aerodrome 2015
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Annual
Calms = 1.3%
Summer
Calms = 0.2%
Autumn
Calms = 1.1%
Winter
Calms = 3.0%
Spring
Calms = 0.9%


Annual and seasonal windroses
BoM Karratha Aerodrome 2016
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
4% 8% 12% 16% 20%
Annual
Calms = 1.9%
10% 20% 30%
Summer
Calms = 0.7%
4% 8% 12% 16% 20%
Autumn
Calms = 2.4%
16%
Winter
Calms = 3.2%
5% 10% 15% 20% 25%
Spring
Calms = 1.2%


Annual and seasonal windroses
BoM Karratha Aerodrome 2017
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
8%
12%
16%
Annual
Calms = 1.9%
5%
10%
15%
20%
25%
Summer
Calms = 0.8%
8%
12%
16%
Autumn
Calms = 2.5%
4%
12%
Winter
Calms = 3.4%
10%
20%
30%
Spring
Calms = 0.9%


Annual and seasonal windroses
BoM Karratha Aerodrome 2018
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
Annual
Calms = 0.8%
Summer
Calms = 0.2%
Autumn
Calms = 1.3%
Winter
Calms = 1.5%
Spring
Calms = 0.3%

Appendix C. Results – Meteorological Modelling

This section provides a brief analysis of the modelling results for predicted wind speed and wind direction. The 2014 hourly datasets for the BoM weather stations at Karratha, Roebourne and Legendre Island were compared with modelled meteorological data output for the same locations, for 2014 (the simulated year used for the Pluto Expansion Project). The modelled predictions for wind patterns matched the observations reasonably well; annual wind roses generated from hourly data are compared in Figure C- 1.

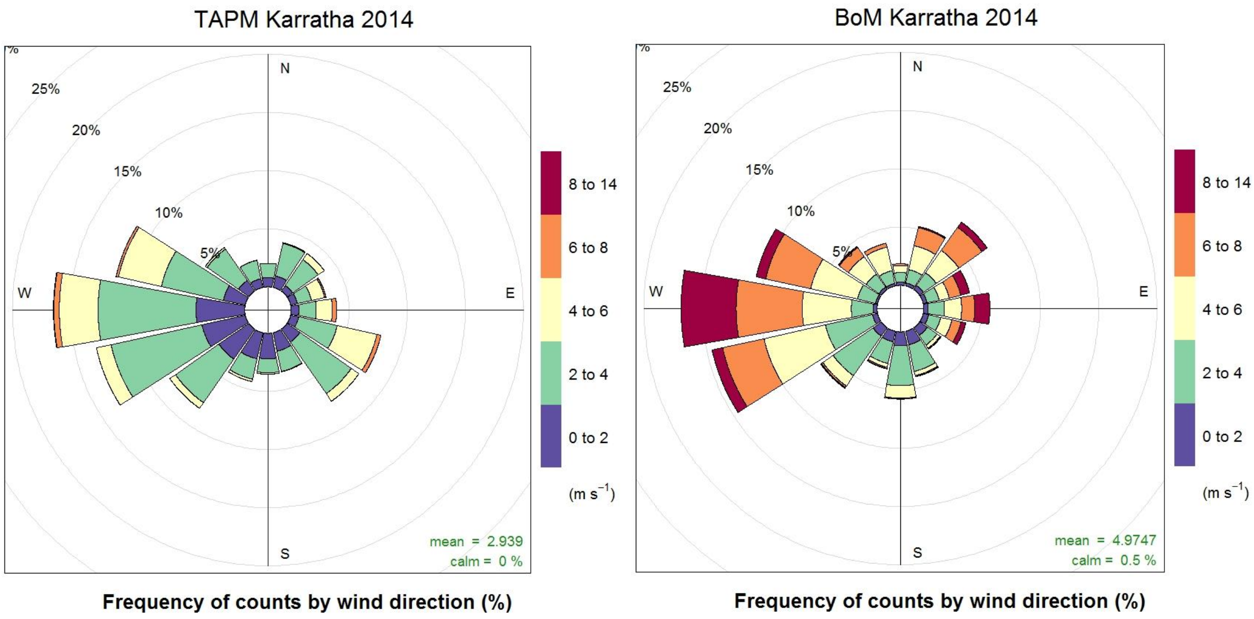


Figure C- 1: Annual Wind Roses Karratha 2014: TAPM (Left) and BoM Measurements (Right)

The wind speeds are compared in Table C- 1 and Figure C- 2. The comparisons show that TAPM consistently under-estimated wind speed for the Burrup Peninsula for 2014. Comparisons of results for other years indicated the problem is general, with TAPM underestimating wind speeds for other years also. While this is not ideal, nevertheless the TAPM estimates for air pollutant concentrations matched the air quality monitoring data reasonably well. Also, the use of these lower wind speeds in the modelling is considered to be a conservative step in the assessment, because the (modelled) dispersion is worse for lower wind speeds, therefore the predicted GLCs will be slightly higher.

Table C- 1: Comparisons of 2014 Hourly Average Wind Speeds

Station	Karratha Aero.		Roebourne		Legendre Is.	
Source	BoM	TAPM (1 km grid)	BoM	TAPM (3 km grid)	BoM	TAPM (3 km grid)
No. of averages	8755	8760	8759	8760	8756	8760
Maximum (m/s)	13.1	8.3	13.4	7	16.1	13.8
90th percentile (m/s)	8	4.6	7.8	4.3	9.7	7.2
80th percentile (m/s)	7	4	6.6	3.7	8.2	6.2
70th percentile (m/s)	6.2	3.6	5.7	3.2	7.1	5.2
60th percentile (m/s)	5.5	3.2	4.9	2.8	6.3	4.5
50th percentile (m/s)	4.8	2.8	4.2	2.4	5.6	3.9
Average (m/s)	4.97	2.94	4.49	2.63	5.98	4.08

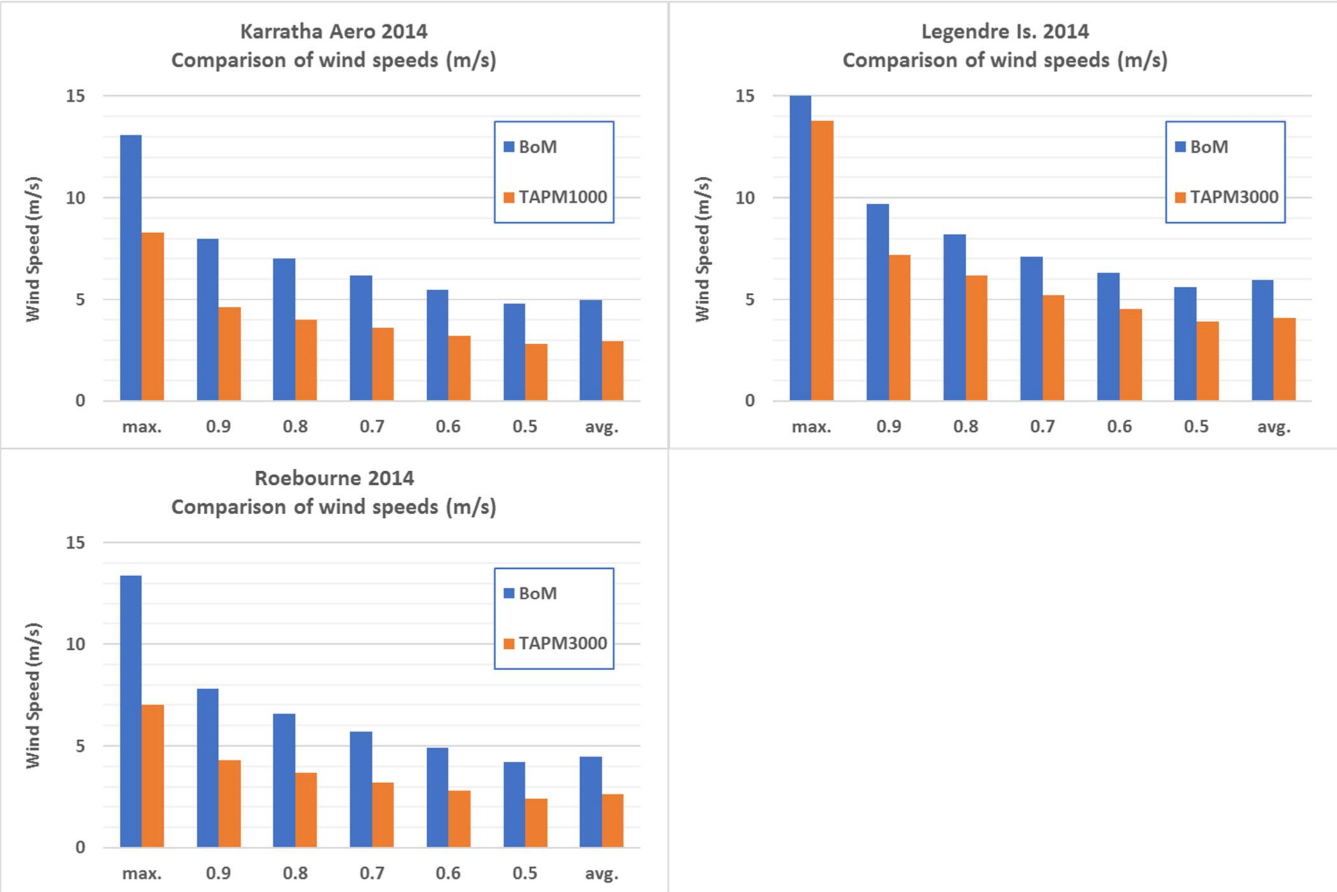


Figure C- 2: Model Results for Wind Speed Compared with 2014 Observations

In the charts shown in Figure C- 2, 'TAPM1000' means the results were obtained from the 1000-metre resolution grid; similarly 'TAPM3000' refers to the 3000-metre resolution grid (Legendre Is. and Roebourne monitoring stations were outside the TAPM study area with 1 km resolution).

APPENDIX B: Stakeholder Consultation

Date	Activity	Stakeholders Involved	Summary of Engagement
9 March 2018	Karratha Community Liaison Group	Attended by City of Karratha, LandCorp and Pilbara Development	Regular quarterly meeting, provided an overview of the Burrup Hub including Pluto Train 2
26 April 2018	Quarterly Karratha heritage meeting	Ngarluma Aboriginal Corporation, Yindjibarndi Aboriginal Corporation, Yaburara and Coastal Mardudhnuera Aboriginal Corporation, Wong-Goo-Tt-Oo	Regular quarterly meeting with Traditional Owner groups. Provided an update on approvals pathways and schedule for Burrup Hub projects including Pluto Train 2.
8 June 2018	Karratha Community Liaison Group	Attended by City of Karratha, Karratha Districts Chamber of Commerce and Industry, Pilbara Ports Authority, Department of Environment, Ngarluma Yindjibarndi Foundation Ltd, Department of Local Government, Arts, Culture and Sport and WA Police.	Regular quarterly meeting, provided an update on the Burrup Hub, including Pluto Train 2
12 June 2018	Burrup Hub meeting including Pluto Train 2	Murujuga Aboriginal Corporation	Provided an update on the Burrup Hub, including Pluto Train 2, heritage management and governance.
6 September 2018	Quarterly Karratha heritage meeting	Ngarluma Aboriginal Corporation, Yindjibarndi Aboriginal Corporation, Yaburara and Coastal Mardudhnuera Aboriginal Corporation, Wong-Goo-Tt-Oo	Regular quarterly meeting with Traditional Owner groups. Provided an update on approvals pathways and schedule for Burrup Hub projects including Pluto Train 2.
6 September 2018	Burrup Hub meeting	Environmental Protection Authority	Provided an overview of the Burrup Hub, including Pluto Train 2.
7 September 2018	Karratha Community Liaison Group	Attended by City of Karratha, WA Police, Karratha Community Association, Department of Education, Horizon	Provided an overview of the Burrup Hub activities and key environmental approvals required, including Pluto Train 2.

Date	Activity	Stakeholders Involved	Summary of Engagement
		Power, Pilbara Ports Authority, Pilbara Development Commission, Department of Sport and Recreation, Karratha Districts Chamber of Commerce and Industry	
11 September 2018	Burrup Hub update meeting including Pluto Train 2	Murujuga Aboriginal Corporation	Provided an update on the Burrup Hub, including Pluto Train 2, approvals pathways, schedule and proposed engagement approach.
11 September 2018	Burrup Hub meeting including Pluto Train 2	Environmental Protection Authority	Provided an update on the Burrup Hub, including Pluto Train 2. Discussion on environmental approvals and schedule.
19 September 2018	Burrup Hub update meeting including Pluto Train 2	Office of the WA Minister for Environment	Provided an update on the Burrup Hub, including Pluto Train 2, approvals pathways and schedule.
19 September 2018	Burrup Hub update meeting including Pluto Train 2	Office of the WA Premier and Minister for State Development	Provided an update on the Burrup Hub, including Pluto Train 2
20 September 2018	Burrup Hub update meeting including Pluto Train 2	Department of Industry, Innovation and Science	Provided an update on the Burrup Hub, including Pluto Train 2
20 September 2018	Burrup Hub update meeting including Pluto Train 2	Office of the Shadow Minister for Environment	Provided an update on the Burrup Hub, including Pluto Train 2
27 September 2018	Burrup Hub update meeting including Pluto Train 2	Office of the Leader of the Opposition, Public Sector Management, State Development, Jobs and Trade and Federal-State Relations	Provided an update on the Burrup Hub, including Pluto Train 2
28 September 2018	Burrup Hub update meeting Pluto Train 2	Department of the Environment and Energy	Provided an update on approvals for Burrup Hub projects, including Pluto Train 2
28 September 2018	Burrup Hub update meeting including Pluto Train 2	Office of the Federal Minister for Resources and Northern Australia	Provided an update on approvals for Burrup Hub projects, including Pluto Train 2
2 October 2018	Burrup Hub update	Office of the State Treasurer, Minister	Provided an update on the Burrup Hub, including Pluto Train 2

Date	Activity	Stakeholders Involved	Summary of Engagement
	meeting including Pluto Train 2	for Finance, Energy and Aboriginal Affairs	
2 October 2018	Burrup Hub update meeting including Pluto Train 2	Office of the State Minister for Transport, Planning and Lands	Provided an update on the Burrup Hub, including Pluto Train 2
10 October 2018	Burrup Hub update meeting including Train 2	Office of the Environmental Protection Authority	Provided an update on the Burrup Hub, including Pluto Train 2, approvals pathway and schedule.
12 October 2018	Burrup Hub update meeting including Pluto Train 2	Shadow Minister for Northern Australia	Provide update on approvals for Burrup Hub projects including Pluto Train 2
12 October 2018	Burrup Hub update meeting including Pluto Train 2	Senator for WA Patrick Dodson	Provided update on approvals for Burrup Hub projects including Pluto Train 2
12 October 2018	Burrup Hub update meeting including Pluto Train 2	Kimberley Land Council	Provided update on approvals for Burrup Hub projects including Pluto Train 2
18 October 2018	Burrup Hub update meeting including Pluto Train 2	Member for Kimberley Josie Farrer	Provide update on approvals pathways and schedule for Burrup Hub projects including Pluto Train 2
19 October 2018	Burrup Hub update meeting including Pluto Train 2	Office of the WA Minister for Regional Development	Provided update on approvals for Burrup Hub projects including Pluto Train 2
19 October 2018	Burrup Hub update meeting including Pluto Train 2	Environmental Protection Authority	Discuss Burrup Hub environmental approvals, including Pluto Train 2.
1 November 2018	Site tour	Environmental Protection Authority	Pluto LNG site tour.
9 November 2018	Burrup Hub update meeting including Pluto Train 2	Ngarluma Yindjibarndi Foundation	Provided update on approvals for Burrup Hub projects including Pluto Train 2
14 November 2018	Burrup Hub meeting including Pluto Train 2	Friends of Australian Rock Art	Burrup Hub environmental approvals briefing including Pluto Train 2
19 November 2018	Burrup Hub update meeting including Pluto Train 2	Chamber of Minerals and Energy of Western Australia Inc	Provided update on approvals for Burrup Hub projects including Pluto Train 2

Date	Activity	Stakeholders Involved	Summary of Engagement
21 November 2018	Regular Burrup Hub meeting	Environmental Protection Authority	Update on Burrup Hub projects, including Pluto Train 2 environmental approvals/management plans.
23 November 2018	Burrup Hub update meeting including Pluto Train 2	Member of Legislative Council-Mining and Pastoral Region	Provide update on approvals for Burrup Hub projects including Pluto Train 2
29 November 2018	Quarterly Karratha heritage meeting	Ngarluma Aboriginal Corporation, Yindjibarndi Aboriginal Corporation, Yaburara and Coastal Mardudhnuera Aboriginal Corporation, Wong-Goo-Tt-Oo	Regular quarterly meeting with Traditional Owner groups. Provided an update on approvals pathways and schedule for Burrup Hub projects including Pluto Train 2
29 November 2018	Burrup Hub meeting including Pluto Train 2	Environmental Protection Authority	Discussion on Burrup Hub environmental approvals, including Pluto Train 2.
9 January 2019	Burrup Hub meeting including Pluto Train 2	Murujuga Aboriginal Corporation	Ongoing engagement and progress update on Woodside's Burrup Hub, including Pluto Train 2.
22 January 2019	Burrup Hub Update Meeting including Pluto Train 2	Department of the Environment and Energy	Provide update on approvals for Burrup Hub projects (including Pluto Train 2) and referral of activities
22 January 2019	Burrup Hub meeting including Pluto Train 2	Department of Industry, Innovation and Science	Provided an update on the Burrup Hub projects, including Pluto Train 2, schedule and environmental approvals.
24 January 2019	Burrup Hub meeting including Pluto Train 2	Murujuga Aboriginal Corporation	Meeting to discuss ongoing engagement on the Burrup Hub, including Pluto Train 2.
29 January 2019	Burrup Hub meeting Pluto Train 2	Department of Primary Industries and Regional Development	Provided an overview of the Scarborough and Pluto Train 2 projects, including environmental approvals and stakeholder engagement moving forward.
5 February 2019	Burrup Hub meeting including Pluto Train 2	Department of Transport	Provided an overview of the Burrup Hub, including Pluto Train 2.
7 February 2019	Burrup Hub meeting including Pluto Train 2	City of Karratha	Provided an update on Burrup Hub projects, including Pluto Train 2, and environmental approvals.
21 February 2019	Meeting to discuss and cultural heritage	Department of the Environment and Energy	Discussion on environmental approvals and cultural heritage matters.
8 March 2019	Karratha Community Liaison Group	Attended by Ngarluma Yindjibarndi	Provided a briefing on the environmental approvals process and highlighted opportunities for public comment.

Date	Activity	Stakeholders Involved	Summary of Engagement
		Foundation Ltd, City of Karratha, Landcorp, WA Police, Dept Local Govt and Communities, Pilbara Ports, Karratha Districts Chamber of Commerce and Industry, Regional Development Australia, Pilbara Development Commission and Dampier Community Association	
12 March 2019	Quarterly meeting	City of Karratha	Discussion on Burrup Hub activities including Pluto Train 2
13 March 2019	Burrup Hub meeting including Pluto Train 2	Environmental Protection Authority	Monthly update of Burrup Hub developments provided, including Pluto Train 2
18 March 2019	Burrup Hub meeting including Pluto Train 2	Department of the Environment and Energy	Discussion on Burrup Hub matters, including assessment levels.
19 March 2019	Burrup Hub meeting including Pluto Train 2	Department of the Environment and Energy	Discussion on Burrup Hub approvals, Heritage Management and Conservation Agreement.
9 April 2019	Burrup Hub social impact assessment	Pilbara Port Authority	Discussion on preliminary social impacts and opportunities assessment for the Burrup Hub, including Pluto Train 2
9 April 2019	Burrup Hub social impact assessment	City of Karratha	Discussion on preliminary social impacts and opportunities assessment for the Burrup Hub, including Pluto Train 2
24 April 2019	Regular Burrup Hub meeting	Environmental Protection Authority	Discussion on Burrup Hub matters, including Pluto Train 2 environmental approvals.
7 May 2019	Burrup Hub meeting	Murujuga Aboriginal Corporation	Discussion on Burrup Hub matters, including and Pluto Train 2, approach to emissions, engagement and environmental approvals.
13 May 2019	Burrup Hub full council briefing	City of Karratha councillors	Provided an update on Woodside's Burrup Hub developments, including Pluto Train 2
15 – 16 May 2019	Burrup Hub public information sessions in Karratha and Roebourne	Various Karratha and Roebourne community members	Five public information sessions in Karratha and Roebourne, providing opportunities for local community stakeholders to engage with the project team, learn more about Scarborough and Pluto Train 2 and provide their general feedback. Of the 50 attendees, two comments were received on environmental approvals which were closed out during the relevant session. Public information sessions were advertised through the local community newspaper the Pilbara News, social media, community noticeboards and targeted communications.

Date	Activity	Stakeholders Involved	Summary of Engagement
6 June 2019	Quarterly Karratha heritage meeting	Attended by Ngarluma Aboriginal Corporation, Yaburara and Coastal Mardudhnuera Aboriginal Corporation and Wong-Goo-Tt-Oo Aboriginal Corporation	Update on Scarborough project and environmental approvals, including proposed Pluto Train 2 Works Approval submissions.
7 June 2019	Karratha Community Liaison Group meeting	Attended by City of Karratha; Pilbara Development Commission; LandCorp; Regional Development Australia; and Pilbara Port Authority	Update on Scarborough project including environmental approvals, including proposed Pluto Train 2 Works Approval submissions.
12 June 2019	Pluto Train 2 meeting	Department of Water and Environmental Regulation	Overview of Pluto Train 2 and discussion on licencing and works approvals
4 July 2019	Scarborough meeting	University of Western Australia	Overview of the proposed Scarborough to Pluto Train 2 development.
9 July 2019	Regular Burrup Hub meeting	Environmental Protection Authority	Update on Burrup Hub projects, including Pluto Train 2 environmental approvals/management plans.
25 July 2019	Regular Burrup Hub meeting	Environmental Protection Authority	Update on Burrup Hub projects, including Pluto Train 2 environmental approvals/management plans.
6 August 2019	Scarborough project meeting	Member for Pilbara	Overview of the Burrup Hub, including Pluto Train 2
16 August 2019	Regular Burrup Hub meeting	Environmental Protection Authority	Update on Burrup Hub projects, including Pluto Train 2 environmental approvals/management plans.
19 August 2019	Site visit	Department of Environment and Energy, Environmental Protection Authority and Murujuga Aboriginal Corporation	Tour of Woodside-operated facilities on the Burrup Peninsula.
6 September 2019	Karratha Community Liaison Group meeting	Attended by the City of Karratha, Horizon Power, Karratha Health Network, Pilbara Port Authority, Pilbara Development Commission, WA Police, Landcorp, Yara Pilbara Fertiliser, Karratha District Chamber of	Regular quarterly community meeting. Provided an update on Burrup Hub developments and environmental approvals, including Pluto Train 2.

Date	Activity	Stakeholders Involved	Summary of Engagement
		Commerce and Industry and Bechtel	
9 September 2019	Regular Burrup Hub meeting	Environmental Protection Authority	Update on Burrup Hub projects, including Pluto Train 2 environmental approvals/management plans.
26 September 2019	Regular Burrup Hub meeting	Environmental Protection Authority	Update on Burrup Hub projects, including Pluto Train 2 environmental approvals/management plans.
3 October 2019	Quarterly meeting	WA Minister for Environment and Environmental Protection Authority	Update on Burrup Hub projects, including Pluto Train 2 environmental approvals/management plans.

Pluto LNG Air Quality Management Plan

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