APPENDICES

APPENDIX A NORTH WEST SHELF PROJECT EXTENSION AIR QUALITY MANAGEMENT PLAN

Revision 1

Woodside

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Appendix A

North West Shelf Project Extension
Air Quality Management Plan

Revision 1

G2000RF1401194398

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1. Summary

Woodside Energy Ltd (Woodside), as operator for and on behalf of the North West Shelf (NWS) Joint Venture (NWSJV), is the proponent for the North West Shelf Project Extension Proposal (the Proposal).

In summary, the Proposal is for the ongoing operation of the NWS Project to enable the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities until around 2070. The Proposal is described in its entirety in Section 2 of the NWS Project Extension Environmental Review Document (Woodside, 2019) and is duplicated into **Section 2.1.1** of this Air Quality Management Plan (AQMP) for ease of reference.

This AQMP was prepared in accordance with the 'Instructions on how to prepare *Environmental Protection Act 1986* Part IV Environmental Management Plans' published by the Western Australian (WA) Environment Protection Authority (EPA) (EPA, 2018).

This AQMP details the measures required to manage the potential impacts to air quality from the Proposal. **Table 1-1** summarises the information contained in this AQMP. It should be noted that emissions of greenhouse gases are dealt with separately through the NWS Project Extension Greenhouse Gas Management Plan (Woodside ID G2000RF1401194400).

Table 1-1: AQMP Summary Table

Title of Proposal	North West Shelf Project Extension
Proponent Name	Woodside Energy Ltd., as operator for and on behalf of the NWSJV
Purpose of the AQMP	This Air Quality Management Plan identifies management and mitigation measures to ensure impacts to air quality from the Proposal are not greater than predicted.
Key Environmental Factor/s and Objective/s	**Key Environmental Factor:** Air Quality **EPA Objective:** To maintain air quality and minimise emissions so that environmental values are protected (EPA, 2016)
Key Provisions in the AQMP	Management of: • Gaseous emissions causing a reduction in ambient air quality impacting human health • Changes in air quality causing deposition on nearby heritage features, including National Heritage Places Through the implementation of the following key provisions: • Implementation of a facility emissions testing and verification program • Undertaking emissions performance monitoring and reporting • Monitoring ambient air concentrations of relevant emissions, that contribute to human health risks • Adoption of practicable and efficient technologies to reduce air emissions • Implementation of an adaptive management plan addressing the potential impact to rock art from industrial emissions • Support the implementation of, and participate in, the DWER Murujuga Rock Art Strategy

2. Context, Scope, and Rationale

2.1 Introduction

The NWS Project is one of the world's largest liquefied natural gas (LNG) producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. For more than 30 years, it has been WA's largest producer of domestic gas.

Woodside proposes to operate the NWS Project to around 2070 as an LNG facility that is commercially capable of accepting gas for processing from other resource owners. Therefore, the Proposal will include processing third-party gas and fluids and any remaining or new NWSJV field resources.

The Proposal is described in its entirety in Section 2 of the NWS Project Extension Environmental Review Document (Woodside, 2019) and is duplicated in **Section 2.1.1** of this AQMP for ease of reference.

This AQMP will be implemented following receipt of approval under the *Environmental Protection Act 1986* (WA) (EP Act) and *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBC Act). In the interim, the NWS Project will continue to operate under current licence conditions and management practices.

2.1.1 Proposal

To enable the future operation of the NWS Project and the ongoing supply of gas and fluids to domestic and international markets, the Proposal seeks approval to transition the Existing NWS Project facilities to a new phase of the NWS Project; which is commercially capable of accepting gas for processing from other resource owners. The NWS Project Extension Proposal is seeking approval for the:

- long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities, including:
    - changes to feed gas composition including changed content of inerts, hydrocarbons and other components
    - changes to the composition of environmental discharges and emissions, although annual volumes of emissions and discharges are expected to be in line with current levels
    - modifications to the Karratha Gas Plant (KGP) onshore receiving facilities (that would not otherwise be undertaken if not for the Proposal) to accommodate third-party gas and fluids, as well as upgrades to metering to facilitate processing of third-party gas and fluids
    - potential construction of additional operational equipment to accommodate changes to feed gas composition or management of discharges and emissions
- ongoing operation of the NWS Project (from the date of the approval of this Proposal) to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070, including:
    - ongoing use of existing NWS Project facilities to process third-party gas and fluids and NWSJV field resources
    - inspection, maintenance, and repair (IMR) and improvement programs for trunklines (TL), 1TL and 2TL
    - maintenance dredging associated with jetties and berthing pockets
    - replacing equipment, plant, and machinery as required that would not otherwise be replaced if not for the Proposal.

- ongoing, additional (and cumulative to existing approvals) emissions and discharges to the environment)
- monitoring and management of environmental impacts

2.2 Scope of the AQMP

Purpose of Management Plan

This AQMP outlines how air emissions will be monitored and managed for the Proposal so that the relevant environmental values are protected. Where the Proposal has potential impacts to environmental values, but those impacts are managed under other regulatory instruments, then those impacts and environmental values have not been considered in this AQMP. To determine the impacts from the Proposal that are within the scope of this AQMP these criteria were applied:

- if mitigation is implemented under other regulatory instruments, the impact was determined to be sufficiently managed.
- if an activity required management through design controls and those controls are already in place at the Proposal, the impact was determined to be sufficiently managed.

After applying these criteria, the following potential impacts were determined to be within the scope of this AQMP:

- Gaseous emissions causing a reduction in ambient air quality impacting human health; and
- Changes in air quality causing deposition on nearby heritage features, including National Heritage Places.

Scope

This AQMP applies to operational activities of the Proposal that generate atmospheric emissions and provides a framework for managing them. The key atmospheric emissions managed under this AQMP are described and assessed in the NWS Project Extension Environment Review Document (Woodside, 2019) and are summarised as:

- oxides of nitrogen (NO_x);
- ozone (O_3);
- volatile organic compounds (VOCs); and
- minor contribution of sulphur dioxide (SO_2).

Dark smoke, which has potential to cause impacts to amenity; is managed through monitoring and reporting in accordance with Part V of the EP Act Operational Licence requirements and therefore management of dark smoke is not within the scope of this management plan.

All other atmospheric emissions are outside the scope of this AQMP. Emissions of greenhouse gases are addressed in the NWS Project Extension Greenhouse Gas Management Plan (GHGMP) (Woodside ID G2000RF1401194400).

2.3 Key Environmental Factors

This AQMP specifically relates to the ‘Air Quality’ environmental factor, as defined by the EPA. The objective for this factor is:

To maintain air quality and minimise emissions so that environmental values are protected.

‘Environmental values’ are defined under the EP Act as ‘a beneficial use, or an ecosystem health condition’. The ecosystem health values related to air quality are defined by the EPA as being human health and amenity (EPA, 2016). In addition to this, this AQMP recognises the value of the Burrup Peninsula from an Aboriginal cultural perspective, particularly from the presence of rock art. Therefore, this AQMP also considers Aboriginal cultural heritage as an environmental value.

2.3.1 Proposal Activities Potentially Affecting Key Environmental Factors

The principal emissions from the Proposal in terms of potential air quality impacts arise from the combustion of fuel gas in gas turbines for power generation, flaring associated with the gas processing plant, and gas conditioning process vents (such as for CO_2 removal from reservoir gas).

The most significant by-products of gas combustion and facility emissions include: oxides of nitrogen (NO_x), carbon monoxide (CO), methane, and unburnt volatile organic compounds (VOCs).

An air quality study and risk assessment was undertaken based on a broad survey of Burrup Peninsula air quality studies, historical ambient monitoring records, emission inventories and other information. The NWS Project Extension Environment Review Document (ERD) (Woodside, 2019), together with the air quality impact assessment and modelling (**Appendix E**) was undertaken for key parameters applicable to contribution by the Proposal to understand cumulative potential air quality impacts. Further detail is available in the ERD with supporting **Appendix E**.

NO_x was determined to be the predominant risk emission from the facility associated with air quality potentially impacting human health with applicable nitrogen dioxide (NO_2) and ozone (O_3) health criteria. Ozone is not emitted directly from the Proposal but is formed through anthropogenic sources via chemical reactions between oxides of nitrogen and other emissions such as VOCs and CO in the presence of ultraviolet light.

There may also be traces of particulate matter (PM) and sulphur dioxide (SO_2) but such emissions are generally considered negligible associated with the Proposal due to the firing of very low sulphur content natural gas in a controlled environment. Emissions of PM from the Proposal are negligible in relation to background and other industrial sources. Ventilation readily disperses methane and CO emissions, with benzene, toulene, ethylbenzene and xylene (BTEX) as a health indicator for VOCs determined to have insignificant air quality effects at sensitive receptors.

Potential for nuisance odours are assessed as posing low risk of loss of public amenity or reduced amenity to heritage features in the NWS Project Extension ERD (Woodside, 2019) and are not expected, with a long operational history without reports of nuisance odours. Impacts to vegetation of conservation or heritage significance are not expected, and of low risk, with ambient levels assessed consistently below applicable thresholds.

The presence of heavy industry on the Burrup Peninsula has generated concerns that industrial emissions may lead to an accelerated weathering or deterioration of rock art. These concerns centre on the issue that deposition of NO_x, SO_x and ammonia (NH_3) from anthropogenic industrial sources have the potential to increase the acidity of the rock surface through chemical and/or biological processes.

Key emissions as they relate to this Proposal's power generation and process emissions therefore are summarised as: NO_x, secondary formation of O_3, VOCs (pertaining to photochemical intensity of NO/NO_2 and Ozone formation), and very minor contribution of SO_2.

2.4 Rationale and Approach

This AQMP outlines how air emissions from the Proposal will be managed and monitored so that the environmental values of the Burrup Peninsula are protected.

The objective of this AQMP is to manage air emissions from the Proposal and to minimise the Proposal's contribution to ambient air quality. This objective acknowledges that planned, continuous emissions to air from the Proposal will occur and that associated risks (potential impacts) can be minimised to acceptable levels through the implementation of this AQMP.

In developing this AQMP, the following points were assessed:

- results of ambient air quality monitoring (including the WA Government's Pilbara Air Quality Study, and Woodside's Burrup Ambient Air Monitoring Program [BAAMP]) to understand the existing air quality on the Burrup Peninsula
- outcomes of ambient air quality modelling for the Proposal and the Burrup Peninsula

- uncertainties as to the potential for accelerated weathering of Aboriginal rock art on the Burrup Peninsula due to industrial emissions.

Based on this assessment, this plan leverages facility technical emissions control technologies, and sets out a suite of operational management practices and contains provisions for measuring, monitoring and reporting emissions from the Proposal. The approach to managing the Proposal's atmospheric emissions combines impact assessment, early response indicators, adaptive management and implementation of the principle of waste minimisation.

Additionally, some potential impacts managed under this AQMP are the subject of ongoing scientific research; therefore, the understanding of how these impacts are best managed may change during implementation of the Proposal. To address the uncertainty associated with these potential impacts, an adaptive management approach will be implemented, together with the Proposal providing for opportunities to substantially reduce NO_x and VOC emissions.

The management approach for this AQMP also identifies several existing statutory mechanisms for managing emissions to air (**Section 3.2**). Where appropriate, this AQMP will refer to these existing mechanisms rather than propose new mechanisms.

3. Internal and Regulatory Framework

3.1 Internal Management Mechanisms Relevant to this AQMP

3.1.1 Woodside Management System

The Woodside Management System (WMS) defines how Woodside delivers its business objectives and the boundaries within which all Woodside employees and contractors are expected to work. Environmental management is one of the components of the overall WMS.

The overall direction for Environment is set through Woodside's corporate Health Safety, Environment and Quality (HSEQ) Policy. The policy provides a public statement of Woodside's commitment to minimising adverse effects on the environment from its activities and to improving environmental performance. It sets out the principles for achieving the objectives for the environment and how these are to be applied. The policy is applied to all Woodside's activities, and employees, contractors and Joint Venture partners engaging in activities under Woodside operational control.

3.1.2 Environmental Performance

The following environmental performance requirements are applicable to all Woodside developments and production assets, including the KGP.

- All existing and future production and support facilities must measure, monitor or estimate air emission streams.
- Air emissions must not unreasonably interfere with the health, welfare, convenience, comfort or amenity of nearby persons/communities.

3.1.3 Opportunity Management Process

Each potential new third-party gas source to be introduced to KGP is assessed under Woodside's Opportunity Management Process (OMP) which aims to find the best way to develop an identified opportunity, present a compelling business case for execution and then realise the value. The OMP applies a structured decision making, planning, governance and delivery approach to ensure opportunities are matured based on good decisions, and that those decisions are knowledge based and account for uncertainty and residual risk. An opportunity lifecycle typically consists of:

- Assess whether there is commercial merit in progressing the opportunity.
- Select the optimum development solution in line with project objectives and define the concept for development of the opportunity.
- Develop a design, an execution plan, and mobilise a team ready to deliver the project to the promised outcomes.
- Execute the plan, and handover the assets and operations organisation ready for start-up at the execute phase.

Under the OMP appropriate to the nature and scale of the opportunity, the process may consider the following activities in relation to air emissions:

- Risk assessment which identifies any changes (e.g. processing of varied gas compositions) which may impact the character of an existing emission and/or discharge.
- Review of existing approvals to identify any additional requirements. This contemplates the impact of an opportunity on existing environmental approvals and relevant regulatory limits.
- Studies, such as modelling which may assist with predicting likely or possible outcomes which can then be interpreted in the context of the existing environment to quantify potential impacts and risks. Modelling may also be used to evaluate alternative designs.
- Engineering assessment which consider requirements for emission monitoring requirements.

3.2 Regulatory Management Mechanisms Relevant to this AQMP

3.2.1 National Environmental Protection (Ambient Air Quality) Measure

The National Environment Protection Council (NEPC), comprising Commonwealth, State, and Territory Ministers, finalised the NEPM (Ambient Air Quality), on 26 June 1998. The *National Environment Protection Council Act 1994* (Cth)*,* allows the National Environment Protection Council to make National Environment Protection Measures (NEPMs). NEPMs are a special set of national objectives designed to assist in protecting or managing particular aspects of the environment. The NEPM [Ambient Air Quality] outlines (set) ambient air quality monitoring protocol that allows for the adequate protection of human health and well-being (NEPC, 2019).

Table 3-1 lists the NEPM (Ambient Air Quality) criteria relevant to the emissions in scope of this AQEMP for human health.

Table 3-1: Relevant NEPM (Ambient Air Quality) Standards

Pollutant	Averaging Period	Maximum Concentration Standard	Maximum Allowable Exceedances
Photochemical oxidants (as O_3)	1 hour 4 hours	0.10 ppm 0.08 ppm	1 day a year 1 day a year
Nitrogen dioxide (NO_2)	1 hour 1 year	0.12 ppm 0.03 ppm	1 day a year None

3.2.2 National Environment Protection (Air Toxics) Measure

The NEPM (Air Toxics) sets monitoring investigation levels for particular air toxics. If the levels set by NEPM (Air Toxics) is exceeded, an investigation into the exceedance must be undertaken. Air toxics potentially relevant to the Proposal include BTX as trigger indicators for potential VOC ambient levels.,

For this reason, the NEPM (Air Toxics) is relevant and the standards listed in **Table 3-2** are considered when managing emissions to air from the Proposal.

Table 3-2: Relevant NEPM (Air Toxics) Standards

Air Toxics	Averaging Period	Monitoring Investigation Levels (ppm)
Benzene	1 year[1]	0.003
Toluene	1 day[2] 1 year[1]	1.0 0.1
Xylene (as a total or ortho-, meta-, and para-isomers)	1 day[2] 1 year[1]	0.25 0.2

Note 1: For this measure, the annual average concentrations are the arithmetic mean concentrations of 24-hour monitoring results.

Note 2: For this measure, monitoring over a 24-hour period is to be conducted from midnight to midnight.

3.2.3 National Pollutant Inventory

The National Pollutant Inventory (NPI) is a public database that provides information on 93 selected air pollutants and their emissions, produced as a result of industry, transport, commercial premise, and household activities, and emitted to air, land, and water in Australia. The NPI is a Commonwealth Government initiative and each state and territory is responsible for implementing the program.

The objective of the NPI is to inform the community about emissions to water, air, and land and acceptable emissions levels. It also provides information for policy and decision making, environmental planning and management, and minimising waste.

Woodside have been reporting emission data from the NWS Project to the NPI annually since the 1998/1999 reporting period. For the purpose of NPI reporting the NWS Project is referred to as the "Karratha Onshore Gas Treatment Plant".

3.3 Other Management Mechanisms Relevant to this AQMP

3.3.1 Murujuga Rock Art Strategy and Murujuga Rock Art Stakeholder Reference Group

The Murujuga Rock Art Strategy (the Strategy) provides a long-term framework to guide the protection of rock art on the Burrup Peninsula and surrounding islands of the Dampier Archipelago. The strategy aims to 'build on previous work on the Burrup Peninsula to deliver a scientifically rigorous, world's best practice monitoring program and risk-based approach to the management of impacts to the rock art, consistent with legislative responsibilities under the EP Act' (DWER, 2019a). The WA Department of Water and Environmental Regulation (DWER) and Murujuga Aboriginal Corporation (MAC) are responsible for the day-to-day implementation of the strategy, including ongoing consultation with key stakeholders (DWER, 2019a).

The scope of the strategy is to:

- establish an Environmental Quality Management Framework (EQMF), including the derivation and implementation of environmental quality criteria
- develop and implement a robust program of monitoring and analysis to determine whether change is occurring to the rock art on Murujuga
- identify and commission scientific studies to support the implementation of the monitoring and analysis program and management
- establish governance arrangements to ensure that:
  - monitoring, analysis and reporting are undertaken in such a way as to provide confidence to the Traditional Owner, the community, industry, scientists and other stakeholders about the integrity, robustness, repeatability and reliability of the monitoring data and results
  - government is provided with accurate and appropriate recommendations regarding the protection of the rock art, consistent with legislative responsibilities
- develop and implement a communication strategy in consultation with stakeholders.

DWER plans to use the EQMF to provide a risk-based and robust framework for implementing the monitoring and management that is required to protect rock art from anthropogenic emissions. The EQMF comprises of:

- Environmental values – ecosystem conditions that require protection from environmental harm
- Environmental quality objectives – specific management goals that must be achieved to protect the environmental values
- Environmental quality criteria – scientifically determined limits of reasonable change. These criteria are the standards against which environmental monitoring data are compared to determine the extent to which environmental quality objectives have been met (DWER 2019a)

DWER, in partnership with MAC, plan to implement a revised Murujuga Rock Art Monitoring Program, based on the results from the past 15 years of scientific studies and monitoring of the petroglyphs. This monitoring program potentially includes, but is not limited to, the parameters of colour change, pH/acidity, microbiology, and sources of pollutants (DWER, 2019b). The program should be able to distinguish between changes in condition of the petroglyphs attributed to anthropogenic emissions versus other unrelated causes. The program comprises cost-efficient, best-practice technologies and methods.

Monitoring and analysis results will be published on DWER's website (https://www.der.wa.gov.au/our-work/programs/36-murujuga-rock-art-monitoring-program). The strategy will be reviewed every five years or when significant new information becomes available to ensure that the strategy and governance procedures remain relevant and reflect the most recent scientific knowledge and management practices.

The Murujuga Rock Art Stakeholder Reference Group (Stakeholder Reference Group) was established in 2018 to facilitate engagement between key government, industry and community representatives as the Strategy is developed. Woodside is a member of the Stakeholder Reference Group and as such will participate in the following activities, as per the terms of reference (DWER, ND):

- Contribute constructively to the monitoring and protection of rock art, being considerate of the views of all stakeholders. This includes the provision of advice to DWER and the Minister for Environment on the design, implementation and analysis of the scientific monitoring and analysis program.
- Consult, inform and educate other stakeholders on other matters referred by DWER for input or comment, including further development of the Strategy, implementation of the Strategy and 5 yearly reviews
- Inform the Government's broader consideration of other strategic issues relating to the protection of the rock art on Murujuga.

Where key emissions from the Proposal have potential to impact the Murujuga rock art, management measures have been proposed in line with the work that Woodside is participating in through the Strategy and the Stakeholder Reference Group.

4. EMP Provisions

This section describes the provisions of this AQMP, which when implemented, will achieve the objectives of the air quality environment factor and this AQMP, uphold the relevant environmental values and manage impact to air quality from the NWS Project. **Table 4-1** summarises the provisions that will be implemented. These are based on the approach described in **Section 2.4** and are described in full in **Section 5.2**. Existing air quality management measures for the NWS Project have been included in the AQMP.

Each of the provisions follow a management-based approach. This is on the basis that those aspects of the environment that can be objectively managed through the implementation of trigger values are currently managed through other mechanisms (for example the EP Act Part V Operational Licence) with the remaining aspects are better suited to a management-based approach.

4.1 Management Based Provisions Summary

Table 4-1: Management-based Provisions

Management Actions	Targets	Monitoring	Reporting
MA1: Implement a facility emissions testing and verification program	Quarterly point source emission testing and review program undertaken on applicable and representative equipment to complement and verify routine maintenance and operational surveillance of equipment. Emissions performance meets Part V Licence L5491/1984/18 (the operating licence) limits	Every three months in accordance with the method specified in the operating licence	Results of emissions performance reported in the Annual Environment Report (AER). Quarterly results reviewed, and any exceedances reported to DWER as per the operating licence requirement.
MA2: Undertake emissions performance monitoring and reporting	Monitor, estimate and report air emissions (in accordance with NPI) to inform management practices and minimise potential environmental impacts of emissions.	Monitor, estimate and report air emissions (in accordance with NPI)	Annual reporting in accordance with the NPI.
MA3: Monitor ambient air concentrations of relevant emissions, that contribute to human health risks	No exceedance of relevant NEPM (Ambient Air Quality) and NEPM (Air Toxics) criteria attributable to Proposal emissions	Implementation of an monitoring program to monitor ambient air quality against NEPM (Ambient Air Quality) and NEPM (Air Toxics) assessment criteria.	Ambient air quality monitoring results summarised in the AER including any exceedances of ambient air quality standards, results of analysis of the cause, and any contingency actions implemented.
MA4: Adopt practicable and efficient technologies to reduce air emissions	40%[1] reduction of NO_x achieved by 31 December 2030 Substantially reduce VOC emissions by 31 December 2030.	Monitor, estimate and report facility emissions after installation of technologies to verify achievement of emission reduction targets.	Performance against emission reduction targets summarised in the AER
MA 5: Implement an adaptive	See **Section 5**.		

Management Actions	Targets	Monitoring	Reporting
management plan addressing the potential impact to rock art from industrial emissions			
MA6: Support the implementation of, and participate in, the DWER Murujuga Rock Art Strategy[2]			

Note 1: Based on the percentage of reported emissions from the KGP over the five-year annual average, covering the 2013/2014 to 2017/2018 financial years

Note 2: DWER is responsible for awarding monitoring studies in support of the Murujuga Rock Art Strategy.

4.2 Management Actions

4.2.1 MA1 – Implement a facility emissions testing and verification program

Woodside applies a range of air emissions management practices at the NWS Project, consistent with industry standards, internal management system requirements, environmental regulations and the operating licence requirements (as revised or renewed from time to time). These may include, but are not limited to:

- combustion equipment control and optimisation;
- routine maintenance and inspection;
- efficiency optimisation and emissions tuning;
- stack emissions testing;
- dark smoke monitoring; and
- emissions performance reporting.

The quarterly point source emission testing and review program complements and verifies that routine maintenance and operations surveillance of equipment pertaining to emissions performance is being undertaken. Results of this emission testing are compared against the operating licence limits.

The conditions of the operating licence, albeit subject to change, require Woodside to monitor 19 point-sources quarterly and emissions from these sources must be within prescribed limits. Results of this monitoring are reported to the DWER in accordance with the operating licence.

4.2.2 MA2 – Undertake emissions performance monitoring and reporting

Emissions monitoring will be undertaken after emission-reduction opportunities have been implemented to verify that the reduction opportunities have been realised. This monitoring will be fit-for-purpose in duration and methodology and may include a combination of regulatory factors, engineering calculations, source monitoring, estimation and/or package combustion monitoring data. Results obtained through this monitoring will be used to demonstrate compliance with proposed air emission reductions.

4.2.3 MA3 – Monitor ambient air concentrations of relevant emissions, that contribute to human health risks

The NWS Project voluntarily established BAAMP in 2008, which continued until 2011. The intent of the program was to gain a better understanding of how operations on the Burrup Peninsula may affect local air quality. Aspects of the program continued to support the Woodside operated Pluto LNG Development from 2011 through to the end of 2015.

The BAAMP allowed for the comparison of observed ground level concentration air emissions to that of the Proposal 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 have occurred throughout the program, including an independent review process which was coordinated by Woodside using an independent peer reviewer and review methodology endorsed by the OEPA (now DWER - EPA Services). Reviewer reports accompanied Pluto LNG program compliance reporting to the OEPA.

Review of the BAAMP confirmed that nitrogen dioxide levels were below Australian standard levels currently set to protect human health and well-being and are also below the World Health Organisation and United States EPA levels designated for protection of vegetation (Golder, 2014).

In advance of potential changes to industrial air emissions on the Burrup Peninsula, Woodside voluntarily recommenced ambient air monitoring in 2019 to further understand ambient air quality in the region. The program is expected to extend the historical dataset and complement ambient air quality monitoring proposed under the Murujuga Rock Art Strategy.

It is Woodside's intention to continue the ambient air monitoring program until its absorption or replacement with the coordinated approach established under the Murujuga Rock Art Strategy.

Woodside's current ambient air monitoring program uses up to three powered monitoring stations to continuously monitor applicable pollutant gases and meteorological conditions, such as wind speed and direction. The 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 4-2** and **Figure 4-1**) including:

- 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
- applicable standards.
- The program may be updated from time to time in accordance with **Section 5**.

Table 4-2: Ambient Air Monitoring Locations

Monitoring Station	Location	
	Easting	Northing
Karratha (K)	484,892	7,707,575
Burrup Road (BR)	476,665	7,721,038
Dampier South (DS)	470,239	7,716,142

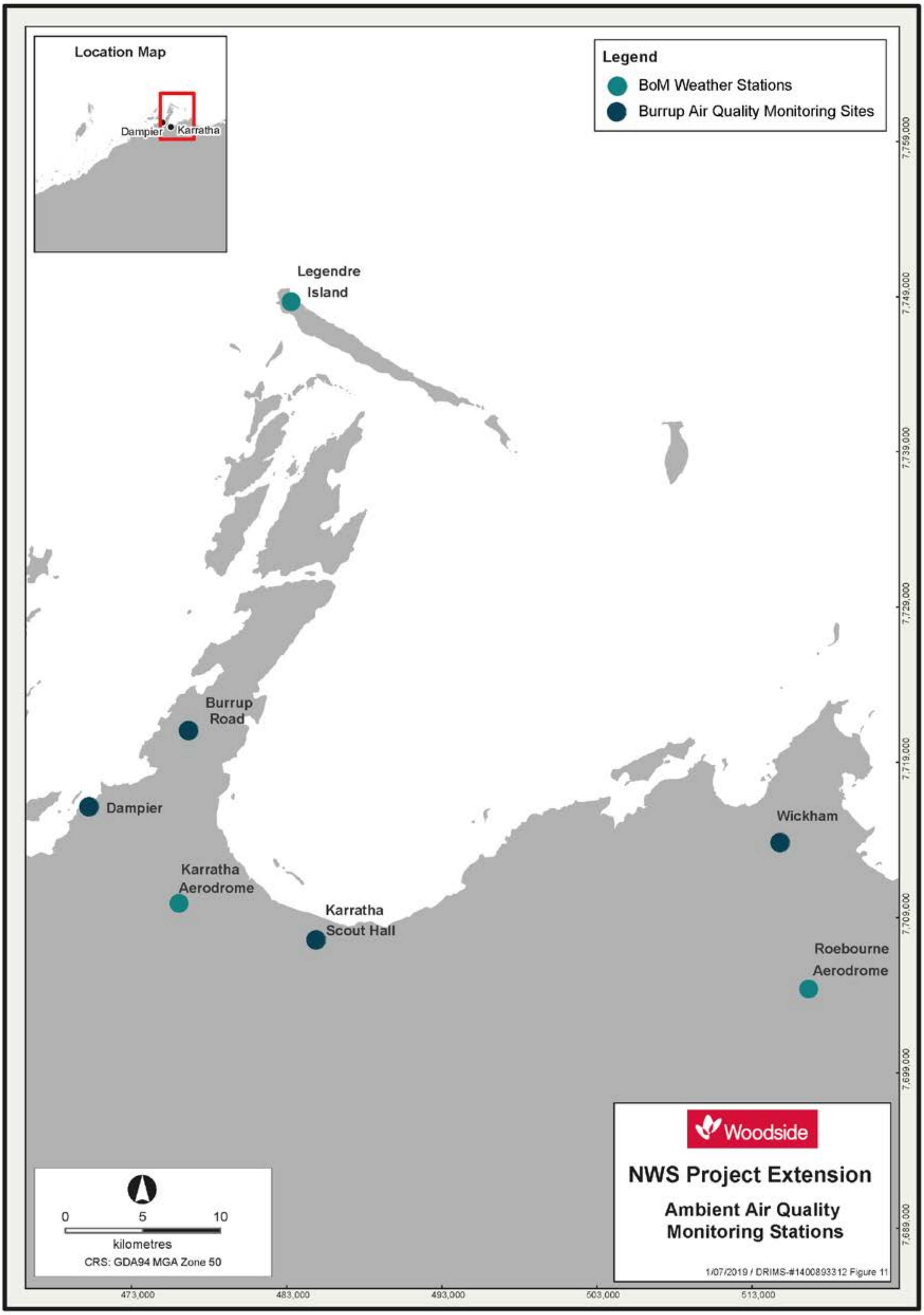

Figure 4-1: Regional BAAMP Ambient (AQ) and Bureau of Meteorology (BoM) monitoring stations

Ambient air quality is monitored based on the details in **Table 4-3** and compared to the assessment criteria in **Table 4-4**.

Table 4-3: Ambient Air Monitoring Parameters

Parameter	5-minute Averaged	15-minute Averaged	1-hour Averaged	24-hour Averaged	Stations
NO_x	✓	-	✓	✓	K, DS, BR
O_3	✓	-	✓	✓	K, DS
BTX	-	✓	✓	✓	BR
Temperature and relative humidity	✓	-	✓	✓	K, DS, BR
Wind speed and direction	✓	-	✓	✓	K, DS, BR
Global solar radiation	✓	-	✓	✓	K, DS, BR

Table 4-4: Ambient Air Monitoring Criteria

Parameter	Ambient Air Quality Standards		
	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: It is acknowledged that the Commonwealth of Australia has published a Notice of Intention to vary the NEPM (Ambient Air Quality). Implementation of NEPM Standards for the Ambient Air Monitoring Program will duly reflect the most up-to-date in-force NEPM standard.

All monitoring stations are checked and maintained regularly. During maintenance and outages, a record is kept of equipment downtimes, durations, and causes.

The Annual Environment Report will summarise the results of the ambient air monitoring program. Presentation of results will record the data recovery rate and history, including exception reports, maintenance notes, and statistical representation of captured data. Data statistics will include maximum, 99th, 95th, 90th, and 70th percentiles, median, averages, and a comparison of recorded data to the standards outlined in **Table 4-4**.

Any exceedances of relevant ambient air quality standards will be investigated and reported using Woodside's incident reporting procedure. A screening analysis (based on the wind direction immediately before and during the exceedance) will be undertaken to identify the possible source of the exceedance, if required. If it is determined that operation of the Proposal is a likely source, then the exceedance will be investigated further, and may consider:

- confirming that the source of the exceedance is likely to be the operation of the Proposal;
- implementing remedial controls to control or eliminate the source of the exceedance;
- identifying the root cause of the exceedance and the circumstances surrounding the exceedance event;
- identifying appropriate corrective and preventive controls to prevent any future such exceedances;
- implementing controls; and
- monitoring the situation thereafter.

All exceedances of ambient air quality standards, including analysis of the cause, and any contingency actions implemented by Woodside, will be presented with the Annual Environment Report.

4.2.4 MA4 – Adopt practicable and efficient technologies to reduce air emissions

NO_x and VOC emissions will be managed using the hierarchy of controls. Woodside has identified and evaluated credible opportunities to achieve a long-term reduction in air emissions and as a result is making a commitment to reduce NO_X emissions from the Proposal by 40%[1] and substantially and substantially reduce VOC emissions by 31 December 2030[2]. Monitoring of performance against this target will be performed annually and progress reported through the Annual Environment Report.

If substantial emissions reductions can be achieved through installation of new equipment (particularly emission reduction equipment), point source emissions will be monitored before and after installation to verify that the equipment operates within the expected parameters.

Woodside will present the results of the point source emissions testing against anticipated emissions reduction performance in the annual environment report.

4.2.5 MA5 – Implement an adaptive management plan addressing the potential impact to rock art from industrial emissions

The adaptive management approach adopted in this AQMP (**Section 5**) has been developed cognisant of the Strategy and the EQMF (**Section 3.3.1**). The management actions in this AQMP will be updated once the environmental quality criteria for management of the rock art on the Burrup Peninsula are released. This management plan will be revised in accordance with **Section 5.**

4.2.6 MA6 – Support the implementation of, and participate in, the DWER Murujuga Rock Art Strategy

Woodside propose to manage potential impacts to Aboriginal rock art on the Burrup Peninsula in accordance with the Strategy and as a member of the Stakeholder Reference Group.

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[1] Based on the percentage of reported emissions from KGP over the five-year annual average, covering the 2013/14 to 2017/18 financial years.

[2] Woodside is undertaking further studies at the KGP to identify and evaluate credible opportunities to achieve a long-term reduction in air emissions, and confirm the selection of improvement options to achieve the percentage emissions reductions. For NO_X emission reductions, Woodside is reviewing current best practice in low NO_X technology available for gas turbines. The most recent LNG trains (Trains 4 and 5) constructed at the KGP are already equipped with low NO_X technology. For VOC emission reductions, opportunities are being reviewed to determine where current best practice technology can be applied within the constraints of an existing plant and brownfield environment. Woodside anticipates that these studies will be completed in 2020, with a status update to be provided in the relevant Annual Environmental Report.

As described in **Section 3.3.1**, the purpose of the strategy is to protect the Aboriginal rock art on the Burrup Peninsula by providing a long term framework for monitoring and analysing potential changes to the rock art and describing a process by which management responses should be put in place to address adverse impact on the rock art. The monitoring program and associated scientific studies are being designed and implemented by DWER to monitor, evaluate and report on changes and trends in the integrity of the rock art, specifically to determine whether anthropogenic emissions are accelerating the natural weathering/alternation/degradation of Aboriginal rock art.

The implementation of the Strategy, Framework and Monitoring Program (DWER, 2019a) will remove much uncertainty surrounding potential pathways linking industrial emission and accelerated weathering, and allow for timely investigation and management where required. The proposed program of monitoring and analysis will determine whether change is occurring to the rock art and if this change is being accelerated by industrial emissions. Monitoring of rock, and rock art in particular allows for early warning indicators and response mechanisms to ensure that long term significant impact due to accelerated weathering is avoided. The implementation of the risk based, adaptive management program using guidelines and standards, derived from sound scientific information, will ensure that the rock art is protected from potentially significant harm associated with industrial emissions.

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.

5. Adaptive Management and Review of the AQMP

The ability to respond to scientific advances is particularly important for managing potential impacts from air emissions (in particular NO_x) on the rock art of the Burrup Peninsula. Currently, there is a lack of scientific understanding of the impacts of air emissions on petroglyphs and thus it is difficult to set appropriate management actions in this AQMP. In line with the concept of adaptive management, the management actions presented in this AQMP shall be monitored, reviewed, evaluated and updated, as required, considering:

- outcomes of any technical review of and evaluation of the emissions and ambient air quality monitoring programs
- new scientific information published, as part of the Murujuga Rock Art Strategy, about the potential impacts of industrial air emissions on Aboriginal rock art of the Burrup Peninsula and that information suggests new or updated provisions should be included in this AQMP.
- new and relevant data/information gained as a result of implementing this AQMP, or from external sources
- effectiveness of proposed emission reduction technologies in achieving proposed targets
- changes in State or Commonwealth legislation or policy.

With relevant updates included in a revised AQMP. In addition, this AQMP may be reviewed:

- based on EPA and decision-making authorities (DMAs) comments during the Environmental Review Document (ERD) approval process
- after any new or revised operating licence is issued under Part V of the *Environmental Protection Act 1986* (WA)
- if a significant environmental incident occurs related to the protection of ambient air quality and human health
- if a new process or activity is proposed to be introduced that has the potential to alter the emissions from the Proposal (and that is not in accordance with this AQMP)

Technical review and evaluation of the management actions outlined in this AQMP will be conducted every five years[1] (if not initiated prior to that time) to ensure the management actions are adequately addressing the key risks and meeting EPA objectives. If, as a result of any review, any significant changes are required to be made to the monitoring program or any other aspect of this AQMP, a revised AQMP will be provided to the EPA for approval.

When the five-yearly review cycle is triggered, or if a significant change to either the facility, activity, or risk is identified, a revised AQMP will be submitted to the EPA. When approved, the revised plan will be made publicly available.

[1] Frequency no more than annually.

6. Stakeholder Consultation

This AQMP is included as an appendix to the ERD for the Proposal (Woodside, 2019) and therefore is to be reviewed by the EPA, key DMAs, and the general public as part of the assessment process for the ERD. Comments received from the EPA and DMAs during the initial review are incorporated into this AQMP before publication of the ERD (and associated management plans) for public review and comment. All comments received during the public review period that relate to this AQMP are to be considered, and changes made to this AQMP where required.

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8. Terms

Terms	Definitions
~	Approximately
µg	Microgram
AGRU	Acid Gas Removal Unit
AQMP	Air Quality Management Plan
BR	Burrup Road (monitoring station)
BTX	Benzene, toluene, and xylene compounds
CO	Carbon monoxide
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent
DMA	Decision-making Authority
DS	Dampier South (monitoring station)
DWER	Western Australian Department of Water and Environmental Regulation
EPA	Western Australian Environmental Protection Authority
ERD	Environmental Review Document. The document that the EPA uses to define the form, content, timing and procedure of an environmental review and/or the public review period for the environmental review or other additional assessment information.
g/s	Grams per second
GHG	Greenhouse gas
GHGMP	Greenhouse Gas Management Plan
ha	Hectare
K	Karratha (monitoring station)
KGP	Karratha Gas Plant
km	Kilometre
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
m^3	Cubic metre
m^3/s	Cubic metres per second
mg/m^3	Milligrams per cubic metre
mtpa	Million tonnes per annum
NEPC	National Environment Protection Council
NEPM	National Environmental Protection Measure
NO_2	Nitrogen dioxide
North West Shelf (NWS) Project	The North West Shelf (NWS) Project is one of the world's largest liquefied natural gas producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. The NWS Project is owned by the NWSJV participants and for more than 30 years, it has been Western Australia's largest producer of domestic gas. The NWS Project currently processes resources owned by the NWSJV and CNOOC NWS Private Limited and is proposed to also process third-party gas and fluids as part of the NWS Project Extension Proposal.

Terms	Definitions
North West Shelf Joint Venture (NWSJV)	A joint venture comprising six companies; Woodside Energy Ltd. (operator), BHP Billiton Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Australia Pty Ltd, Japan Australia LNG (MIMI) Pty Ltd, and Shell Australia Pty Ltd. The North West Shelf Joint Venture owns the infrastructure used as part of the North West Shelf Project and, together with CNOOC NWS Private Limited, the North West Shelf Joint Venture owns the resources processed as part of the NWS Project.
NO_x	Oxides of nitrogen
NPI	National Pollutant Inventory
NWS	North West Shelf
NWS Project Extension Proposal (the Proposal)	The Proposal as described in the NWS Project Extension Section 38 Referral Supporting Information (November 2018) to continue to use the existing NWS Project facilities for the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities; and ongoing operation of the NWS Project to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070.
NWSJV	See North West Shelf Joint Venture
O_3	Ozone
PAQS	Pilbara Air Quality Study
PM	Particulate matter
PM_{10}	A dust fraction with an aerodynamic diameter of less than 10 microns
$PM_{2.5}$	A dust fraction with an aerodynamic diameter of less than 2.5 microns
ppb	Parts per billion
ppm	Parts per million
Proposal	*See* NWS Project Extension Proposal
Section 38 referral	Referral to EPA under the *Environmental Protection Act 1986* (WA)
SO_2	Sulphur dioxide
SOx	Sulphur oxides
Third-party gas and fluids	Gas and associated fluids from sources other than those produced by the NWSJV and CNOOC NWS Private Limited. The processing of third-party gas and fluids is subject to the necessary commercial arrangements being in place between the NWSJV and the relevant third parties as well as all relevant joint venture and regulatory approvals being obtained.
VOC	Volatile organic compound
WA	Western Australia
Woodside	Woodside Energy Ltd. Proponent of the NWS Project Extension Proposal and the Operator of the NWS Project on behalf of the NWS Joint Venture.

North West Shelf Project Extension Air Quality Management Plan

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APPENDIX B NORTH WEST SHELF PROJECT EXTENSION GREENHOUSE GAS MANAGEMENT PLAN

Revision 1

Woodside

Appendix B

North West Shelf Project Extension Greenhouse Gas Management Plan

Revision 1

G2000RF1401194400

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1. Summary

Woodside Energy Ltd (Woodside), as operator for and on behalf of the North West Shelf (NWS) Joint Venture (NWSJV), is the proponent for the North West Shelf Project Extension Proposal (the Proposal).

In summary, the Proposal is for the ongoing operation of the NWS Project to enable the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities until around 2070. The Proposal is described in its entirety in Section 2 of the NWS Project Extension Environmental Review Document (Woodside, 2019) and is duplicated into **Section 2.1.1** of this Greenhouse Gas Management Plan (GHGMP) for ease of reference.

This GHGMP was prepared in accordance with the 'Instructions on how to prepare *Environmental Protection Act 1986* (WA) (EP Act) Part IV Environmental Management Plans' published April 2018 by the Western Australian (WA) Environment Protection Authority (EPA) (EPA, 2018).

This GHGMP details the measures that are required to manage Greenhouse Gas (GHG) emissions from the Proposal**. Table 1-1** summarises the information contained in this GHGMP.

Table 1-1: GHG Management Plan Summary Table

Title of Proposal	North West Shelf Project Extension
Proponent Name	Woodside Energy Ltd., as operator for and on behalf of the NWSJV
Purpose of the GHGMP	This GHG Management Plan identifies management and mitigation measures to ensure impacts from GHG emissions associated with the Proposal are not greater than predicted.
Key Environmental Factor/s and Objective/s	**Key Environmental Factor**: Air Quality **EPA Objective:** To maintain air quality and minimise emissions so that environmental values are protected (EPA, 2016)
Key Provisions in the GHGMP	Management of the contribution to global GHG concentrations from the emission of Scope 1 and Scope 2 emissions through the implementation of the following key provisions: • Adoption of practicable and efficient technologies to reduce GHG emissions of the Proposal. • Annual fuel and flare targets. • Routine emission monitoring and reporting in accordance with the National Greenhouse and Energy Reporting Act • Monitor relevant changes and modifications to Proposal to prevent GHG emissions from exceeding 7.7 mtpa • Implementation of the KGP Energy Management Plan to manage GHG emissions • Compliance with National Safeguard Mechanism to maintain emissions within the NWS Project Baseline • Adherence to Methane Guiding Principles

2. Context, Scope and Rationale

2.1 Introduction

The NWS Project is one of the world's largest liquefied natural gas (LNG) producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. For more than 30 years, it has been WA's largest producer of domestic gas.

Woodside proposes to operate the NWS Project to around 2070 as an LNG facility that is commercially capable of accepting gas for processing from other resource owners. Therefore, this Proposal includes processing third-party gas and fluids and any remaining or new NWSJV field resources.

The Proposal is described in its entirety in Section 2 of the NWS Project Extension Environmental Review Document (Woodside 2019) and is duplicated in **Section 2.1.1** of this GHGMP for ease of reference.

This GHGMP will be implemented following receipt of approval under the *Environmental Protection Act 1986* (WA) (EP Act) and *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBC Act). In the interim, the NWS Project will continue to operate under current licence conditions and management practices.

2.1.1 Proposal

To enable the future operation of the NWS Project and the ongoing supply of gas and fluids to domestic and international markets, the Proposal seeks approval to transition the Existing NWS Project facilities to a new phase of the NWS Project; which is commercially capable of accepting gas for processing from other resource owners. The NWS Project Extension Proposal is seeking approval for the:

- long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities, including:
    - changes to feed gas composition including changed content of inerts, hydrocarbons and other components
    - changes to the composition of environmental discharges and emissions, although annual volumes of emissions and discharges are expected to be in line with current levels
    - modifications to the Karratha Gas Plant (KGP) onshore receiving facilities (that would not otherwise be undertaken if not for the Proposal) to accommodate third-party gas and fluids, as well as upgrades to metering to facilitate processing of third-party gas and fluids
    - potential construction of additional operational equipment to accommodate changes to feed gas composition or management of discharges and emissions
- ongoing operation of the NWS Project (from the date of the approval of this Proposal) to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070, including:
    - ongoing use of existing NWS Project facilities to process third-party gas and fluids and NWSJV field resources
    - inspection, maintenance, and repair (IMR) and improvement programs for trunklines (TL), 1TL and 2TL
    - maintenance dredging associated with jetties and berthing pockets
    - replacing equipment, plant, and machinery as required that would not otherwise be replaced if not for the Proposal.
    - ongoing, additional (and cumulative to existing approvals) emissions and discharges to the environment

- monitoring and management of environmental impacts.

2.2 Scope of the GHGMP

Purpose of Management Plan

This GHGMP outlines how GHG emissions are monitored and managed for the Proposal so that the relevant environmental values are protected. Where the Proposal has potential impacts to environmental values, but those impacts are managed under other regulatory instruments, those impacts and environmental values have not been considered in this GHGMP.

Scope

This GHGMP applies to Scope 1 emissions from activities associated with the Proposal that are within the operational control of Woodside (as defined under the *National Greenhouse and Energy Reporting Act 2007* (NGER Act)). Other air emissions (e.g. oxides of nitrogen, ozone etc) are addressed in the NWS Project Extension Air Quality Management Plan (AQMP) (Woodside ID G2000RF1401194398).

This GHGMP manages the Proposal's contribution to global GHG concentrations from the emission of Scope 1 and Scope 2 emissions.

2.3 Key Environmental Factors

This GHGMP specifically relates to the 'Air Quality' environmental factor, as defined by the EPA. The objective for this factor is:

To maintain air quality and minimise emissions so that environmental values are protected.

At the time of writing, the 'Air Quality' environmental factor includes GHG emissions. The Environmental Factor Guideline - Air Quality requires the characterisation of GHG emission sources in accordance with the NGER Act and an analysis of GHG intensity, which are presented within this GHGMP.

2.3.1 Proposal Activities Potentially Affecting Key Environmental Factors

The major emission types of GHG emissions from KGP are carbon dioxide (CO_2), nitrogen oxide (N_2O) and methane (CH_4). The principal sources of GHG emissions include:

- gas turbine compressors: operating gas turbine compressors used to compress refrigerant to liquefy natural gas.
- acid gas removal: removing CO_2 from the gas stream through Acid Gas Removal Unit (AGRU) venting. This vent stream also includes some residual methane, volatile organic compounds (VOCs) and other incidental substances associated with gas processing.
- electricity generation: operating gas turbine generators that use gas from the Proposal to generate electricity to run the Proposal.
- flaring: flaring is required to safely dispose of hydrocarbons.
- fugitive emissions: small emissions of gas to the atmosphere from various areas throughout the Proposal, such as flanges, valves and process safety vents.

An estimate of Scope 1, Scope 2 and Scope 3 emissions associated with the NWS Project are:

- Scope 1 and 2 emissions are up to 7.7 mtpa CO_2e predominantly from the sources described above (based on an LNG production of 18.5 million tonnes per annum (mtpa)).
- Scope 2 emissions are approximately 0.002 mtpa CO_2e from electricity consumption at King Bay Supply Base (KBSB), as per the 2017 - 2018 National Greenhouse and Energy Reporting period. All electricity consumed at the KGP is generated on site and therefore GHG emissions

associated with this electricity generation is considered in the Scope 1 emissions detailed above. There are currently no other Scope 2 emissions associated with the Proposal.

- Scope 3 emissions are approximately 80.19 mtpa CO_2e predominantly associated with final combustion and use of LNG, LPG, Domgas and condensate products. Emissions associated with transport and distribution of LPG and condensate products are considered to be negligible when compared to the total Scope 3 emissions estimate and therefore have not been included in these calculations.

2.4 Rationale and Approach

This GHGMP outlines how GHG emissions from the Proposal are monitored and managed to minimise the Proposal's contribution to global GHG emissions. This objective acknowledges that planned, continuous emissions to air from the Proposal occur and that the impacts from these can be mitigated by implementing this GHGMP.

To determine whether there is a risk of activities failing to minimise emissions to protect environmental values, emission-impact pathways were reviewed, and the following criteria applied:

- where mitigation is implemented for the activity under other regulatory instruments, the risk was determined to be sufficiently managed (refer to existing regulatory requirements in **Section 3.2**)
- where the activity required management through design controls and those controls are already in place at the NWS Project, the risk was determined to be sufficiently managed.

Through this review it was demonstrated that no additional specific provisions are required to manage GHG emissions at the NWS Project. This rationale is based on NWS Project facilities existing systems and management controls which are implemented and maintained through the environmental management system embedded at the NWS Project to successfully monitor, reduce and manage GHG emissions, aligned with the principle of waste minimisation.

In accordance with Woodside's commitment to implementing its Climate Change Strategy and Policy and using existing management controls, greenhouse gas reduction initiatives and projects are driven at a corporate level with oversight of operational level processes (described in **Section 3.1**).

2.4.1 Studies and Surveys

A GHG benchmarking assessment was undertaken in 2019 to compare the GHG emissions performance of the KGP against other comparable Australian and International LNG facilities. In total, 10 Australian and 8 International LNG facilities were selected for benchmarking and comparison with the KGP, including Gorgon LNG, Darwin LNG, Gladstone LNG, Australia-Pacific LNG, Snohvit LNG, Qatargas and Cove Point. This provides a range of different aged facilities with varying production capacity with which to compare KGP against. GHG emission performance was assessed using the GHG intensity (t CO_2-e/t LNG) for each facility.

The benchmarking assessment considered Scope 1 emissions with the following considered to be out of scope:

- GHG emissions from upstream operations associated with the extraction and compression of raw gas, i.e. upstream of the Trunkline Onshore Terminals (TOT1 and TOT2).
- Scope 2 emissions.
- Scope 3 emissions.
- Emissions associated with handling, transport and use of gas product downstream of the fiscal product meter.

The assessment found that the GHG emissions intensity of KGP, excluding reservoir CO_2 (0.33 t CO_2-e/t LNG) is slightly higher than the average for the Australian facilities analysed (0.31 t CO_2-e/t LNG). When assessed against International LNG facilities, the GHG performance of the KGP was found to be very similar to those facilities located in a similar climate and of similar age.

3. Internal and Regulatory Framework

3.1 Internal Management Mechanisms Relevant to this GHGMP

Woodside supports the global effort to reduce GHG emissions and accepts it has a responsibility to minimise the GHG impact of its own operations. Woodside's key priority is to reduce GHG emissions at source, either through energy efficiency improvements or technological solutions. Woodside has already achieved significant emission reductions on 'business as usual' projections and continues to invest in a range of GHG abatement measures.

3.1.1 Woodside Management System

The Woodside Management System (WMS) defines how Woodside delivers business objectives and the boundaries within which all Woodside employees and contractors are expected to work. Environmental management is one of the components of the overall WMS.

The overall direction for Environment is set through Woodside's Corporate Health Safety, Environment and Quality (HSEQ) Policy. The policy provides a public statement of Woodside's commitment to minimising adverse effects on the environment from its activities and to improving environmental performance. It sets out the principles for achieving the objectives for the environment and how these are to be applied. The policy is applied to all Woodside's activities, and employees, contractors and Joint Venture partners engaging in activities under Woodside operational control.

Woodside's Climate Change Policy outlines that Woodside recognises the scientific consensus on climate change and the challenge of providing safe, clean, affordable and reliable energy whilst reducing emissions. A key principle of this policy states that Woodside will set and publish targets to encourage innovation and drive reductions in Woodside's carbon footprint and energy use.

3.1.2 Environmental Performance

Environmental performance requirements are applicable to all Woodside developments and production assets with projected GHG emissions in excess of 25,000 tonnes of CO_2e per annum. In general, environmental performance requirements consider:

- design and operation to minimise GHG emissions and energy intensity.
- monitoring and measuring GHG emissions.
- consideration of carbon price (as per Woodside or Joint Venture approved economic assumptions) in development/production asset economics.
- identification of opportunities to reduce GHG emissions and energy intensity.

3.1.3 Opportunity Management Process

Each potential new third-party gas source to be introduced under the Proposal, will be assessed under Woodside's Opportunity Management Process which aims to find the best way to develop an identified opportunity, present a compelling business case for execution and then realise the value. The process outlines a framework for structured decision making, planning, governance and delivery approach to ensure opportunities are matured based on good decisions, and that those decisions are knowledge based and account for uncertainty and residual risk. An opportunity lifecycle typically consists of:

- Assess whether there is commercial merit in progressing the opportunity and select the optimum development solution in line with project objectives.
- Define the concept for development of the opportunity; and develop an execution plan and a team ready to deliver the project to the promised outcomes.
- Handover the assets and operations organisation ready for start-up at the execute phase.

Under the Opportunity Management framework, an opportunity process may consider the following activities in relation to GHG emissions:

- Review of existing approvals to identify any additional requirements. This contemplates the impact of an opportunity on existing environmental approvals and relevant regulatory limits.
- Risk assessment which identifies any additional gas components which may impact the character of an existing emission and/or discharge.
- Studies, such as modelling which may assist with predicting likely or possible outcomes which can then be interpreted in the context of the existing environment to quantify impact. Modelling may also be used to evaluate alternative designs.
- Engineering assessment which consider requirements for emission monitoring requirements.

3.1.4 Energy Management Framework

Woodside's Energy Management Framework aims to improve energy efficiency across Woodside's operations in order to:

- Add significant value to our business and maximises shareholder returns.
- Minimise environmental impacts through reduced GHG emissions which contribute to climate change.
- Enhance our reputation as a partner of choice.

The Energy Management Procedure (Woodside ID WM0000PG1400343649) defines the minimum mandatory requirements for energy management at Woodside to deliver continuous improvement in energy performance. Requirements for energy management are outlined in the Opportunity Management Framework (Refer to **Section 3.1.3**). The Energy Management Framework requires that an Energy Management Plan is established, implemented and maintained for each operating asset or group of assets which are required to measure, analyse and communicate energy performance.

Opportunities to improve energy performance are to be identified and captured in accordance with the Production Optimisation and Opportunity Management Procedure (refer to **Section 3.1.5**), such that energy opportunities are considered alongside other opportunities and constraints.

The KGP has an Energy Management Plan (Woodside ID 1400355329) which is implemented to achieve the following objectives:

- Improve energy efficiency monitoring and reporting
- Promote energy efficiency improvements by:
    - Identifying and utilising efficiency 'handles' to maximise efficiency at any given production rate; and
    - Identifying opportunities to change processes or equipment to improve the maximum efficiency of the plant.

3.1.5 Production Optimisation Process

In accordance with the Production Optimisation and Opportunity Management Procedure (Woodside ID W0000PP10115808), the KGP is required to develop an Optimisation Reference Plan (ORP) (Woodside ID G2000RG1401116495) which identifies and implements opportunities to improve production and energy efficiency whilst reducing emissions. The ORP recognises that any reduction in emissions is also identified as a production opportunity, as gas that can be diverted from fuel or flare streams can potentially be turned into a saleable product.

The ORP, prepared annually, delivers a ranked list of opportunities used to justify further study/implementation of each opportunity listed. Results are then incorporated into relevant plans to ensure consideration for funding / resourcing. A decision to progress/implement opportunities is based on a number of economic and environmental considerations:

- opportunities are prioritised based upon Net Present Value (NPV), their contribution to Woodside corporate initiatives for GHG reduction, and the confidence of return (CoR) to ensure efficient capital allocation. The CoR is estimated based upon maturity, complexity, technology novelty and ease of implementation
- NPV and value / investment ratio (VIR) are calculated using the NWS Project Gas Economic Screening Portal, which is used to estimate the benefit for each opportunity
- production enhancing opportunities need to meet set criteria to be considered economic and reviewed for recommendation. Opportunities may not be recommended if economics are marginal and there is low probability of success, however opportunities that do not meet the economic criteria can still be recommended if there is environmental/strategic merit (e.g. emissions reduction benefit).

The full ORP Opportunity Lifecycle process is shown in **Figure 3-1**.

Figure 3-1: Optimisation Reference Plan - Opportunity Lifecycle Process

3.1.6 Corporate Initiatives

Methane Guiding Principles

In April 2018, Woodside became a signatory to the Methane Guiding Principles[1], an initiative to reduce methane emissions across the natural gas value chain. Woodside's methane emissions are approximately 4% of total operated emissions (CO_2-equivalent basis). Reducing methane emissions supports the goal of reducing (net) emissions.

[1] Reducing methane emissions across the natural gas value chain guiding principles: https://files.woodside/docs/default-source/sustainability-documents/climate-change/reducing-methane-guiding-principles-april-2018.pdf?sfvrsn=a92de0bd_6

Each signatory is committed to undertake the principles and implement them by way of a defined action plan. Woodside's priority activities to deliver on the Guiding Principles in the near term include:

- Conducting a methane emissions survey at the KGP;
- Delivering methane emissions reductions through the ORP; and
- Improving leak detection and repair programs across all facilities.

3.2 Regulatory Management Mechanisms Relevant to this GHGMP

3.2.1 Commonwealth Regulation and Policy

3.2.1.1 National Greenhouse and Energy Reporting (NGER)

The NGER Act was introduced in 2007 and is a single national framework for reporting and disseminating company information about GHG emissions, energy production, energy consumption. and other information specified under the NGER Act.

The objectives of the NGER Scheme are to:

- inform government policy and the Australian public
- help meet Australia's international reporting obligations
- assist Commonwealth, State and Territory government programs and activities
- avoid duplicating reporting requirements in the states and territories.

The methods and criteria for calculating GHG emissions and energy data under the NGER Act are detailed in the *National Greenhouse and Energy Reporting (Measurement) Determination 2008* (DoEE, 2008). NWS Project emissions are reported annually under the NGER Scheme.

Safeguarding Mechanism Baselining

The Emissions Reduction Fund (ERF) is the central component of the Commonwealth Government's Climate Solutions Package, which has a primary goal to deliver on Australia's nationally determined contribution under the Paris Agreement, to 'reduce emissions by 26 – 28% below 2005 levels by 2030'. The ERF is enacted through the *Carbon Credits (Carbon Farming Initiative) Act 2011.* The ERF has three key elements: crediting, purchasing, and safeguarding emission reductions.

The Safeguard Mechanism (SGM) seeks to impose limits on large GHG-emitting facilities to ensure that net emissions are kept below a defined baseline in accordance with the National Greenhouse and Energy Reporting (Safeguard Mechanism) Rule 2015 (SGM) administered by the Clean Energy Regulator. The SGM applies to facilities with Scope 1 emissions (covered emissions) of more than 100,000 tonnes of CO_2e per year.

Baselines have been set by either taking the historical highpoint of emissions between FY 2009/10 to FY 2013/14 (for existing facilities) or by site-specific emission factors based on production forecasts (for new facilities). Currently, the NWS Project (defined as KGP, offshore platforms and a floating production storage offloading facility) has a baseline of 7.57 mtpa CO_2e per financial year (SGM baseline). If emissions exceed this baseline, the NWS Project can either use one of the compliance clauses within the SGM (if eligible) or purchase allowable offsets to bring net emissions number below its baseline.

The SGM was amended in March 2019 and will require all large emitters to re-apply for a new baseline before October 2020. This updated baseline will be published after approval from the Clean Energy Regulator.

3.2.2 State Regulation and Policy

In August 2019, the Western Australian Government announced its Greenhouse Gas Emissions Policy for Major Projects (State GHG Policy) to guide Government decision making for major projects that are assessed by the EPA. The Minister for the Environment will consider the particular characteristics of each project and the advice and recommendations of the EPA.

In this context, Woodside has included this GHGMP as an Appendix to the ERD for the Proposal to be reviewed by EPA, key DMAs and the general public as part of the assessment process for the ERD. **Table 3-1** details how the contents of a GHG Management Plan (as defined by the State GHG Policy), is proposed to be addressed.

Table 3-1: Addressing Contents of GHGMP per State GHG Policy

State GHG Policy on Contents of the Plan	Woodside response
The policy supports the development of GHGMPs for proponents which: Outline strategies to avoid, reduce, mitigate and offset the project's direct (Scope 1) emissions contributing towards the State's aspiration of net zero by 2050	The NWS Project Extension is a significant opportunity for Western Australia that will enable the development of further natural gas resources and the use of established processing infrastructure for decades to come. The additional pipeline gas that the State will receive under its Domestic Gas Reservation Policy will contribute to the State's 2050 net zero target by extending access to natural gas. Natural gas is both the lowest carbon fossil fuel and also enables greater use of renewables by matching their intermittent nature with dispatchable power.Strategies to avoid, reduce and mitigate Scope 1 emissions from the Proposal are outlined in **Section 4**. They include LNG Train Design considerations, improvement opportunities, and the setting of annual fuel and flare targets. The Proposal scope is for an extension in duration of operation rather than construction of new infrastructure (i.e. LNG Trains). This use of established infrastructure means that wholesale reductions in emissions are difficult to achieve. Strategies to offset emissions are encompassed in the Proposal's compliance with the Safeguard Mechanism. The supporting regulations of the Safeguard Mechanism establish the allowable methodologies for valid offsets. Woodside anticipates that additional emissions reductions may be achieved via ongoing application of the ORP process; agreed by the NWSJV on an annual basis.
Are unique to a proposal's specific circumstances	The Proposal for extension of life of an existing facility designed to produce low emissions natural gas fuel into domestic and international markets. The costs associated with modifying an existing operating facility are significantly higher than for modifying the design of a new facility. Despite this, emissions from the Proposal are not significantly greater than emissions from the most recently constructed Australian LNG facilities. The Proposal will deliver pipeline and export natural gas will contribute to meeting the world's energy needs and reduce emissions by avoiding the use of higher-carbon fuels whilst also partnering with renewables, as a dispatchable power source that can enable their greater use. These downstream customer benefits (Scope 3 benefits) are outside the scope of this regulatory approval but inform consideration of the Proposal's specific circumstances.
Allow proponents to take account of opportunities at either facility level or across national operations	The Proposal is made by the NWSJV, which itself does not have additional operations. Its respective owners may do, but these are not part of the scope of this document.
Allow proponents to propose their own timeframes and targets;	The current Commonwealth requirements are included in the Federal Government's Climate Solutions Package which sets out how Australia will meet its initial Nationally Determined Contribution (NDC) (to 2030) under the Paris Agreement. The Safeguard Mechanism sets the limits (baselines) allowable for industrial emitters such as the Proposal that are consistent with achieving the NDC.

Include requirements for periodic public reporting against their targets; and Account for and align with Commonwealth requirements.	The revised baseline for the Proposal under the Safeguard Mechanism is currently being determined. Further targets may be established as part of the Commonwealth's future consideration of further NDCs under the Paris Agreement. Reporting will be undertaken in accordance with the NGER Act. This GHGMP includes a Management Action to implement greenhouse reduction initiatives that either avoid, reduce or offset 330,000 tonnes CO_2e from the Karratha Gas Plant by 2030.
Consistent with the Government's focus on economic development and diversification, plans that include undertakings to develop Western Australian expertise, carry out research, pilot new initiatives and technologies, and support local communities are encouraged.	Woodside will ensure benefits to local communities and local industry participation via the NWS Project Extension Proposal.

4. EMP Provisions

This section describes the provisions of this GHGMP, which when implemented, will achieve the objective of the air quality (greenhouse gas emissions) environment factor and the objective of this GHGMP, uphold the relevant environmental values and manage impact to air quality from the Proposal. Woodside has incorporated a suite of contemporary best practice management and mitigation measures (each included as Management Actions) to ensure ongoing, long-term reduction in Greenhouse Gas emissions will be achieved. **Table 4-1** lists the management-based provisions that will be implemented with the Proposal. These are based on the rationale and approach described in **Section 2.4**.

4.1 Management Based Provisions Summary

Table 4-1: Management-based Provisions

Management Actions	Targets	Monitoring	Reporting
MA1: Establish and achieve an interim emissions target.	Implement greenhouse reduction initiatives that either avoid, reduce or offset 330,000 tonnes CO_2e annually from the Karratha Gas Plant by 2030.	Performance against targets will be monitored. The magnitude of any reductions achieved by each reduction initiative is to be independently verified by an auditor accredited under the NGER Act.	Reporting on outcomes of reduction initiatives within the Annual Environment Report.
MA2: Continue to identify and adopt practicable management and mitigation measures to reduce GHG emissions from the Proposal	Optimisation and opportunity management processes will continue to be implemented to identify and prioritise enhancement opportunities including improving energy efficiency, reducing fuel use and intensity and minimising flaring.	Identify and assess opportunities in accordance with the Production Optimisation and Opportunity Management Procedure.	Identified opportunities tracked in the relevant optimisation reference plan. A summary of delivered opportunities will be presented in the Annual Environment Report (AER).
MA3: Fuel and flare targets are set annually to drive continuous improvement	Annual targets for the amount of gas to be flared and fuel to be consumed by the Proposal will be established.	Performance against targets will be monitored. Potential sources or causes for exceedance will be explained.	Performance against flare and fuel targets summarised in AER
MA4: Routine emissions monitoring and reporting is undertaken in accordance with the National Greenhouse and Energy Reporting Act	Direct GHG emissions (e.g. fuel, flare, fugitive and venting emissions) from the proposal will be measured and reported in accordance with the NGER Act.	Scope 1 and 2 emissions will be measured in accordance with the requirements of the National Greenhouse and Energy Reporting Measurement Determination. Monthly compositional analysis of fuel gas in compliance with NGER Act.	Annual reporting of emissions is performed in accordance with the NGER Act. Emissions from the NWS Project (including offshore and FPSO) will be reported annually through the SGM.

Management Actions	Targets	Monitoring	Reporting
MA5: Monitor relevant changes and modifications to Proposal to prevent GHG emissions from exceeding 7.7mtpa	Potential GHG emissions changes will be assessed in accordance with the opportunity management process or Management of Change to ensure that changes or modifications will not result in total GHG emissions exceeding 7.7 mtpa CO_2e	Any relevant changes or modifications will be reviewed and impact on GHG emissions generation will be assessed.	Exceedance of the Scope 1 emissions limit will be reported to DWER in the Annual Audit Compliance Report.
MA 6: Implement KGP Energy Management Plan to manage GHG emissions	The KGP Energy Management Plan (or equivalent) covering material energy sources from the Proposal will be implemented to improve energy efficiency monitoring and describes the process for executing improvement opportunities.	Performance against management measures within the Energy Management Plan will be tracked at frequency appropriate to the nature of the measure through established internal reporting mechanisms.	Performance against management measures within the Energy Management Plan will be reported internally
MA 7: Comply with Safeguard Mechanism to maintain emissions within NWS Project baseline	Proposal emissions will be managed to ensure net emissions are below the SGM baseline. Allowable offsets will be purchased and surrendered equivalent to the amount of emissions above the baseline level.	Monitoring of net emissions performed in accordance with MA 3. Monitoring of annual volume of offsets required, purchased and surrendered in accordance with SGM.	Summary of purchase and surrender of allowable offsets included in AER and published as part of annual SGM data tables by the Clean Energy Regulator.
MA 8: Adherence to Methane Guiding Principles	Management of methane emissions performed in accordance with the Methane Guiding Principles.	Methane reduction initiatives monitored through the implementation of the ORP	Performance against the Methane Guiding Principles will be monitored internally. Methane emissions reported annually in Woodside Sustainability Report.
MA 9: Undertake 5-yearly assessment of reasonable and practicable emission reduction equipment and technologies that could be implemented to	Assessment will identify practicable and reasonable opportunities and their feasibility of implementation to improve GHG	Any relevant changes or modifications will be reviewed and impact on GHG emissions generation will be assessed.	Summary of assessment presented in AER every 5 years.

Management Actions	Targets	Monitoring	Reporting
improve GHG emissions.	emissions performance.		

4.2 Management Actions

4.2.1 MA 1 - Establish and achieve an interim emissions target.

Woodside has a demonstrated history of implementing emissions reduction opportunities at the Karratha Gas Plant and continues to identify new opportunities each year. Woodside has identified all reasonable and practicable management measures, emissions reduction equipment and technologies for GHG emissions reductions.

Woodside is making a commitment to avoid, reduce or offset 330,000 tpa CO_2e from the Karratha Gas Plant by 2030. As part of this GHGMP, Woodside will achieve demonstrable emissions reductions from KGP equivalent or greater than this by 2030. There are a range of other emissions opportunities being pursued by Woodside, particularly through the ORP process (MA2), but have not undergone sufficient engineering or design stages to provide certainty as to the magnitude of the expected reduction or their expected timing.

This emissions reduction target is complemented by the 8 other management actions within this plan, all of which aim to achieve ongoing reductions in greenhouse gas emissions and improvements to emissions intensity, as has been demonstrated consistently throughout the operation of the NWS to date.

The quantity of emissions avoided, reduced or offset in accordance with MA1 will be reported annually in the Annual Environment Report. To verify the accuracy of values reported against MA1, an Auditor on the Register of Greenhouse and Energy Auditors, established under section 75A of the NGER Act, will be commissioned to conduct an independent review of reported figures. This is to independently verify the accuracy of reported values.

4.2.2 MA 2 – Continue to identify and adopt practicable and efficient technologies to reduce greenhouse gas emissions from the Proposal

Process for Continuous Identification of Additional Emission Reduction Opportunities

The ORP process is used to identify cost efficient and practicable efficiency opportunities at NWS Project facilities. Energy efficiency opportunities can be identified at any time, however annual workshops are the major contributor to opportunity/idea generation. Opportunities are evaluated by the value of the proposition and the confidence of return, in accordance with the Production Optimisation Process (refer to **Section 3.1.5**), while considering other emissions reduction requirements (i.e. methane guiding principles). These workshops are typically conducted annually, enabling the output to feed into the following year's budgeting cycle. Each budget approved opportunity is then planned for execution, and implementation tracked and reported as part of the ORP process.

A summary of opportunities that have been recently implemented or to be implemented are presented in **Table 4-2.**

Table 4-2: Emission Reduction Opportunities identified under the Optimisation Reference Plan (ORP)

Trains	Opportunities Identified under the ORP	Estimated Emission Savings
Implemented		
LNG Trains 1-3	Stage 1 of the LNG 1 - 3 Mixed Refrigerant Optimisation Project was implemented at the KGP. The project increased LNG Production on LNG 1 - 3 through installing a pressure gauge at the base of the main cryogenic heat exchanger (MCHE) on each train to observe liquid level and implementing modifications to the APC system. The project delivered an increase in production and improvement to energy efficiency for no extra power demand.	Emission Intensity Improvement Opportunity

Trains	Opportunities Identified under the ORP	Estimated Emission Savings
LNG Trains 4 - 5	Efficient Particulate Air Filters (EPAs) installed on LNG 5 to reduce turbine axial air compressor fouling to improve efficiency of turbines and increase available power. The project delivered an increase in available power for no additional emissions.	Emission Intensity Improvement Opportunity
	Optimisation of operating conditions for the LNG 4 - 5 AGRU process in order to increase methane recovery and reduce vented methane from this system.	12 kt CO_2e per year
Domgas	A Domgas K2420 (compressor) was switched off over the 2018/19 summer period for fuel gas savings when capacity was not required. During winter months when LNG rates are higher and therefore HP fuel gas production is higher, it is required to have two K2420's online to avoid backing out the HP fuel gas header and causing excessive flaring.	12 kt CO_2e per year
Considered for Implementation		
All trains	Woodside is investigating an opportunity to reduce fuel gas consumption at KGP by reducing power generation spinning reserve to a permanent N + 1 – 10MW philosophy. Fuel gas savings can be achieved by biasing loading from the Frame 5 Gas Turbine Generators (GTGs) to the more efficient LM 6000's GTGs. Reducing fuel gas usage can deliver substantial CO_2e savings. Final decision regarding the opportunity will include, but not be limited to, consideration of safety risk, potential production impact, fuel gas savings and economic and environmental impacts.	Forecasted average of 44 kt CO_2e per year

LNG Train Design Considerations

Due to the nature of major infrastructure developments such as the KGP, the most efficient timing for implementing emissions reductions is during the design phase of a project lifecycle. There are significant additional costs incurred in retrofitting an existing, active operational facility. As demonstration to the significant reductions achieved in the design of KGP, **Table 4-3** summarises key design elements that have been incorporated into the NWS Project LNG trains.

Table 4-3: Design Emission Reduction Technologies

Trains	Emission Reduction Technologies Applied during Design	Potential mt CO_2e Savings (annually)
	Avoid	
LNG Trains 1 - 3	• Re-route of flash gas generated during the acid gas removal process, to prevent gas being flared and instead be utilised as a low pressure fuel source.	0.5
	Minimise	
	• Solvent change-over from sulfinol to activated methyl diethanolamine (aMDEA), to significantly reduce the co-absorption and subsequent venting of methane.	0.35
LNG Trains 4 - 5	**Avoid**	
	• Propane pre-cooled / mixed refrigerant (C3/MR) liquefaction process employing high efficiency Frame 7 gas turbines with power recovery via hydraulic turbines.	0.552

	• Use of high-efficiency, aero-derivative gas turbines for electrical power generation to reduce generation of GHG emissions.	0.148
	• Installation of a waste heat recovery unit (WHRU) on the exhaust of the Frame 7 gas turbine driving the propane compressor. The WHRU provides heat to the process via the heated water system, and to regenerate the molecular sieve adsorber beds, used for feed gas dehydration. Harvesting of waste heat avoids the need for separate fired heaters, fuel gas consumption and emissions.	0.171
	• Routing flash gas from the horizontal three phase separator of the AGRU to the low pressure fuel gas system, avoiding flaring.	0.489
	Minimise	
	• The use of activated methyl diethanolamine (aMDEA) to reduce co-absorption of hydrocarbons in the AGRU	~ 0.001
	• Routing the start-up vent from the AGRU to the flare system, rather than direct venting of the gas stream to atmosphere therefore reducing GHG emissions.	0.001
	• Utilisation of dry gas seals, or double oil seals, with seal gas losses routed back to compressor suction, to reduce venting to atmosphere.	0.060

4.2.3 MA 3 – Fuel and flare targets set annually

Corporate GHG emissions intensity target is set to support Woodside's objectives stated in the Climate Change Policy by reducing emissions intensity from a company-wide perspective incorporating emissions reduction from the ORP process.

The emissions intensity target incorporates major Scope 1 GHG emissions across Woodside operated assets whilst also considering fugitive emissions streams. Scope 2 emissions from grid-connected electricity consumption are not included in this target. Emissions estimates utilise the best available data, sourced from the fuel and flare targets, production forecasts and engineering calculations where applicable for the year in question.

Fuel and flare targets, set at a facility level, support of the achievement of the corporate target. KGP fuel and flare targets are developed annually, according to the requirements set out in Woodside's Greenhouse Gas, Energy and Flare Target Setting Guideline (Woodside ID WM0000MH1400512800). Flaring and fuel gas intensity targets are included on the monthly KGP asset scorecard and asset report.

4.2.4 MA 4 – Routine emissions monitoring and reporting is undertaken in accordance with the National Greenhouse and Energy Reporting Act

Monitoring, auditing, and reporting of GHG emissions for the Proposal is used to measure ongoing performance and provide data that aids in the identification of improvement opportunities. Monitoring, and reporting of GHG emissions is carried out in accordance with the requirements of the NGER Act.

The effectiveness of the greenhouse management minimisation measures is monitored on an ongoing basis. During monitoring, actions may be identified for improvement. Monitoring and reporting regarding completion of ORP initiatives is undertaken at a site level. Woodside currently carries out reporting to meet a number of statutory requirements. Woodside will address GHG reporting via existing procedures established to meet the requirements of the NGER Act.

Auditing of the environmental and GHG emission performance of the Proposal will include:

- internal and external environmental audits of compliance to its statutory obligations and management plans

- external auditing (as required) of GHG emissions data reporting as required under the NGER Act.

4.2.5 MA 5 – Monitor relevant changes and modifications to Proposal to prevent GHG emissions from exceeding 7.7 mtpa

The amount of CO_2e vented from KGP depends on the composition of feed gas and the CO_2e content of the hydrocarbon reservoir from which the feed was sourced. Minor modifications to the plant can also affect the amount of CO_2e venting.

Potential GHG characteristic changes from the introduction of third party gas or minor modifications to the facility will be managed in accordance with the Opportunity Management Process to ensure that gas received will not lead to GHG emissions from the NWS Project exceeding 7.7 mtpa CO_2e. This may include:

- Review of existing approvals to identify any additional requirements.
- Risk assessment which identifies any additional gas components which may impact the character of an existing emission and/or discharge.
- Engineering assessment which consider requirements for emission monitoring requirements.

4.2.6 MA 6 – Implement KGP Energy Management Plan (or equivalent) to manage GHG emissions

Woodside's Energy Management Framework requires that the KGP maintains an Energy Management Plan (or equivalent). The Energy Management Plan aims to improve efficiency monitoring and reporting, focussing including identifying opportunities to change processes or equipment to improve the maximum efficiency of the plant.

Energy efficiency improvements can be made in two key areas; process improvements and capital improvements. Both require understanding of the efficiency of current operations and efficiency losses that are being incurred, if any. Once these have been identified, improvements are required to the way these are evaluated and opportunities for improvement are executed.

4.2.7 MA 7 – Comply with Safeguard Mechanism to maintain emissions within NWS Project baseline

Under the SGM, the NWS Project is to measure its GHG emissions performance against its baseline. This baseline represents NWS Project's gross covered emissions and includes the KGP, offshore platforms and floating production storage offloading facilities. If emissions exceed this baseline, the facility can either use one of the compliance clauses within the SGM (if eligible) or purchase allowable offsets to bring net emissions number below its baseline.

4.2.8 MA 8 - Adherence to Methane Guiding Principles

Woodside is a signatory to the Methane Guiding Principles[2]. These principles, developed by the Climate and Clean Air Coalition, address priority areas for action and focus on reducing methane emissions across the natural gas value chain. In pursuing significant emission reductions through these principles, signatories will consider cost effectiveness and efficiency of the measures. Relevant guiding principles that apply to this GHGMP are:

- Principle 1 – Continually reduce methane emissions
- Principle 3 – Improve accuracy of methane emissions data

[2] Further information on the Methane Guiding Principles is available from: https://www.ccacoalition.org/en/resources/reducing-methane-emissions-across-natural-gas-value-chain-guiding-principles

- Principle 5 – Increase transparency

Woodside is preparing to undertake a methane leak detection program in Q1 2020 that will be used to inform future targeted maintenance activities.

4.2.9 MA 9 - Undertake a 5-yearly assessment of reasonable and practicable emission reduction equipment and technologies that could be implemented to improve GHG emissions.

In addition to the ORP which routinely analyses KGP operations to identify reasonable and practicable efficiency opportunities, Woodside will undertake a 5-yearly assessment of potential equipment and technologies to improve KGPs GHG emissions performance. This assessment may include consideration of best practice equipment and technology and its feasibility for implementation. Outcomes of this assessment will be summarised in the relevant annual environment report.

5. Adaptive Management and Review of the GHGMP

In line with the concept of adaptive management, the management actions presented in this GHGMP shall be monitored, reviewed, evaluated and updated, as required, considering:

- outcomes of any technical review of and evaluation of any routine emissions monitoring
- new and relevant data/information gained as a result of implementing this GHGMP, or from external sources
- effectiveness of internal processes and procedures to reduction and management of GHG emissions
- changes in State or Commonwealth legislation or policy.

With relevant updates included in a revised GHGMP. In addition, this GHGMP may be reviewed:

- based on EPA and decision-making authorities (DMAs) comments during the Environmental Review Document (ERD) approval process
- after any new or revised operating licence is issued under Part V of the EP Act
- if a new process or activity is proposed to be introduced that has the potential to alter the emissions from the Proposal (and that is not in accordance with this GHGMP)

Technical review and evaluation of the management actions outlined in this GHGMP will be conducted every five years[1] (if not initiated prior to that time) to ensure the management actions are adequately addressing the key risks and meeting EPA objectives. If, as a result of any review, any significant changes are required to be made to the monitoring program or any other aspect of this GHGMP, a revised GHGMP will be provided to the EPA for approval.

When the five-yearly review cycle is triggered, or if a significant change to either the facility, activity, or risk is identified, a revised GHGMP will be submitted to the EPA. When approved, the revised plan will be made publicly available.

[1] Frequency no more than annually.

6. Stakeholder Consultation

This GHGMP is included as an Appendix to the ERD for the Proposal (Woodside, 2019) and therefore is to be reviewed by the EPA, key DMAs, and the general public as part of the assessment process for the ERD. Comments received from the EPA and DMAs during the initial review are incorporated into this GHGMP before publication of the ERD (and associated management plans) for public review and comment. All comments received during the public review period that relate to this GHGMP are to be considered, and changes made to this GHGMP where required.

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8. Terms

Terms	Definitions
CO_2	Carbon dioxide
CH_4	Methane
CO_2e	Carbon dioxide equivalent
DMP	Department of Mines and Petroleum
DoE	Former Western Australian Department of Environment (now Department of Water and Environmental Regulation)
DEC	Department of Environment and Conservation
DMIRS	Western Australian Department of Mines, Industry Regulation and Safety
DoEE	The Commonwealth of Australia's Department of the Environment and Energy
DPLH	Western Australian Department of Planning, Lands and Heritage
DWER	Western Australian Department of Water and Environmental Regulation
EP Act	*Environmental Protection Act 1986* (Western Australia)
EPA	Western Australian Environmental Protection Authority
ha	Hectare
HVAC	Heating, Ventilation and Air Conditioning.
KGP	Karratha Gas Plant
km	Kilometre
ktpa	Thousand tonnes per annum
LNG	Liquefied natural gas
MCHE	main cryonic heat exchanger
MS	Ministerial Statement (Western Australian)
mtpa	Million tonnes per annum
NGER	National Greenhouse and Energy Reporting
N_2O	Nitrous oxide
NO_x	Nitrogen oxides
NWS	North West Shelf
NWS Project	The North West Shelf (NWS) Project is one of the world's largest LNG producers, supplying oil and gas to Australian and international markets from

Terms	Definitions
	offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. The NWS Project is owned by the NWSJV participants and for more than 30 years, it has been WA's largest producer of domestic gas. The NWS Project currently processes resources owned by the NWSJV and CNOOC NWS Private Limited; it is proposed to also process third-party gas and fluids as part of the NWS Project Extension Proposal.
NWSJV	North West Shelf Joint Venture. A joint venture comprising six companies: Woodside Energy Ltd. (operator), BHP Billiton Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Australia Pty Ltd, Japan Australia LNG (MIMI) Pty Ltd, and Shell Australia Pty Ltd. The NWSJV owns the infrastructure used as part of the NWS Project and, together with CNOOC NWS Private Limited, the NWSJV owns the resources processed as part of the NWS Project.
ORP	Optimisation Reference Plan
State Agreement	North West Gas Development (Woodside) Agreement Act 1979 (WA) (State Agreement)
t	Tonne
Third-party gas and fluids	Gas and associated fluids from sources other than those produced by the NWSJV and CNOOC NWS Private Limited. The processing of third-party gas and fluids is subject to the necessary commercial arrangements being in place between the NWSJV and the relevant third parties as well as all relevant joint venture and regulatory approvals being obtained.
WA	Western Australia
WEL	Woodside Energy Limited
Woodside	Woodside Energy Ltd., the operator of the NWS Project on behalf of the NWSJV.

North West Shelf Project Extension Greenhouse Gas Management Plan

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APPENDIX C NORTH WEST SHELF PROJECT EXTENSION CULTURAL HERITAGE MANAGEMENT PLAN

Revision 1

Woodside

Appendix C

North West Shelf Project Extension Cultural Heritage Management Plan

Revision 1

G2000RF1401194398

Contents

Tables

1. Summary

Woodside Energy Ltd (Woodside), as operator for and on behalf of the North West Shelf (NWS) Joint Venture (NWSJV), is the proponent for the North West Shelf Project Extension Proposal (the Proposal).

In summary, the Proposal is for ongoing operation of the NWS Project to enable the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities until around 2070. The Proposal is described in its entirety in Section 2 of the NWS Project Extension Environmental Review Document (Woodside, 2019) and is duplicated into **Section 2.1.1** of this Cultural Heritage Management Plan (CHMP) for ease of reference.

This CHMP was prepared in accordance with the 'Instructions on how to prepare *Environmental Protection Act 1986* Part IV Environmental Management Plans' published by the Western Australian (WA) Environment Protection Authority (EPA) (EPA, 2018).

This CHMP details the measures required to manage the potential impacts to social surroundings (Heritage) from the Proposal. **Table 1-1** summarises the information contained in this CHMP.

Table 1-1: CHMP Summary Table

Title of Proposal	North West Shelf Project Extension
Proponent Name	Woodside Energy Ltd., as Operator for and on behalf of the NWSJV
Purpose of the CHMP	To identify management and mitigation measures that could be implemented over time to reduce impacts to heritage features on the Burrup Peninsula
Key Environmental Factor/s and Objective/s	**Key Environmental Factor:** Social Surroundings (Heritage) **EPA Objective:** to protect social surroundings from significant harm
Key Provisions in the CHMP	Management of: • Potential accelerated weathering of rock art due to industrial emissions • Direct, accidental physical damage to heritage features within the development envelope • Continued restricted access to heritage features within the development envelope until around 2070 • Reduced amenity to heritage features outside the development envelope as a result of odorous substances (e.g. odour from atmospheric emissions) Through the implementation of the following key provisions: • Educating NWS Project personnel on the sensitivity of the cultural heritage features on the Burrup Peninsula • Providing access for Traditional Owners to Aboriginal cultural heritage sites within the Proposal development envelope when requested • Investigating and responding to instances of odour complaints from the Murujuga National Park or the National Heritage Place • Implementing an adaptive management plan addressing the potential impact to rock art from industrial emissions • Supporting the implementation of, and participate in, the DWER Murujuga Rock Art Strategy

2. Context, Scope, and Rationale

2.1 Introduction

The NWS Project is one of the world's largest liquefied natural gas (LNG) producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. For more than 30 years, it has been WA's largest producer of domestic gas.

Woodside proposes to operate the NWS Project to around 2070 as an LNG facility that is commercially capable of accepting gas for processing from other resource owners. Therefore, this Proposal includes processing third-party gas and fluids and any remaining or new NWSJV field resources.

The Proposal is described in its entirety in Section 2 of the NWS Project Extension Environmental Review Document (ERD) (Woodside, 2019) and is duplicated in **Section 2.1.1** of this CHMP for ease of reference.

This CHMP will be implemented following receipt of approval under the *Environmental Protection Act 1986* (WA) (EP Act) and *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBC Act). In the interim, the NWS Project will continue to operate under current licence conditions and management practices.

2.1.1 Proposal

To enable the future operation of the NWS Project and the ongoing supply of gas and fluids to domestic and international markets, the Proposal seeks approval to transition the Existing NWS Project facilities to a new phase of the NWS Project; which is commercially capable of accepting gas for processing from other resource owners. The NWS Project Extension Proposal is seeking approval for the:

- long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities, including:
    - changes to feed gas composition including changed content of inerts, hydrocarbons and other components
    - changes to the composition of environmental discharges and emissions, although annual volumes of emissions and discharges are expected to be in line with current levels
    - modifications to the KGP onshore receiving facilities (that would not otherwise be undertaken if not for the Proposal) to accommodate third-party gas and fluids, as well as upgrades to metering to facilitate processing of third-party gas and fluids
    - potential construction of additional operational equipment to accommodate changes to feed gas composition or management of discharges and emissions
- ongoing operation of the NWS Project (from the date of the approval of this Proposal) to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070, including:
    - ongoing use of existing NWS Project facilities to process third-party gas and fluids and NWSJV field resources
    - inspection, maintenance, and repair (IMR) and improvement programs for trunklines (TL), 1TL and 2TL
    - maintenance dredging associated with jetties and berthing pockets
    - replacing equipment, plant, and machinery as required that would not otherwise be replaced if not for the Proposal.

- ongoing, additional (and cumulative to existing approvals) emissions and discharges to the environment (Woodside, as operator for and on behalf of the NWS Project, will implement emission reduction opportunities that will result in a staged decrease in emissions over time)
- monitoring and management of environmental impacts.

2.2 Scope of the CHMP

Purpose of Management Plan

This CHMP has been prepared to ensure operation of the NWS Project does not compromise the environmental values of the Burrup Peninsula (including the National Heritage Place and Murujuga National Park) and to manage potential impacts of the Proposal on cultural heritage. The approach to managing the Proposal in a way that achieves the objective of avoiding significant harm to Aboriginal cultural heritage is based on a combination of impact assessment (refer to **Section 6.4** in the NWS Project Extension ERD (Woodside, 2019)), early response indicators, and adaptive management.

This CHMP outlines how aspects of the Proposal that have the potential to impact Aboriginal heritage places and objects (referred herein as heritage features) will be monitored and managed so that the relevant environmental values are protected. The provisions in this CHMP manage the potential impacts of the activities from the Proposal that are not otherwise managed under other regulatory instruments, including other Proposal management plans.

This CHMP is aligned with Woodside's Cultural Heritage Management Procedure (Woodside ID WM0000PG10178231).

Scope

This CHMP applies to activities of the Proposal that have the potential to impact Aboriginal cultural heritage features on the Burrup Peninsula and provides a framework for managing them. The NWS Project Extension ERD (Woodside, 2019) assesses potential impacts to the social surroundings (Heritage) from these activities:

- ongoing emissions to air from the Proposal until around 2070
- continued presence and activity of people, vehicles, vessels, and equipment in the development envelope
- ongoing marine discharges from the operation of the NWS Project facilities.

Therefore, the scope of this CHMP addresses the following:

- potential accelerated weathering of rock art due to industrial emissions
- direct, accidental physical damage to heritage features within the development envelope
- continued restricted access to heritage features within the development envelope until around 2070
- reduced amenity to heritage features outside the development envelope as a result of odorous substances (e.g. odour from atmospheric emissions).

When considering the impacts of air emissions on heritage features, there is strong link between this CHMP and the NWS Project Extension Air Quality Management Plan (AQMP) (Woodside ID G2000RF1401194398). To avoid duplication between these plans, the scope of this CHMP specifically focuses on the potential impacts of air emissions on the rock art on the Burrup Peninsula and does not seek to manage the sources of the emissions. Impacts from air emissions are managed under the NWS Project Extension AQMP (Woodside ID G2000RF1401194398).

Marine discharges from the Proposal are outside the scope of this CHMP. Although marine discharges do have the potential to impact heritage features within the marine environment, the impacts from marine discharge activities are wholly managed by the NWS Project Extension Marine Environment Quality Management Plan (Woodside ID G2000RF1401194400).

2.3 Key Environmental Factors

This CHMP relates to the ‘Social Surroundings’ environmental factor, specifically Aboriginal heritage and culture. The EPA objective for this environmental factor is:

To protect social surroundings from significant harm

This objective is intended to ensure that social surroundings are not significantly affected by a proposal.

The Environmental Factor Guideline – Social Surroundings (EPA, 2016) acknowledges that social surroundings include: Aboriginal heritage and culture; natural and historical heritage; amenity; and economic surroundings. For the purpose of this CHMP, the only aspect of the social surroundings environmental factor that is relevant to the Proposal is Aboriginal heritage and culture. This was determined by the EPA and is consistent with the NWS Project Extension referral decision dated 4 December 2018 (Woodside, 2018).

As part of the social surroundings environmental factor and specifically in relation to Aboriginal heritage and culture, the EPA states that the EP Act complements the *Aboriginal Heritage Act 1972* (WA) to preserve Aboriginal heritage sites, particularly when ‘actual physical protection of the environment is required to protect sites of heritage significance’ (EPA, 2016).

EPA guidance also states that in addition to Aboriginal heritage, ‘matters of Aboriginal cultural associations, including traditional Aboriginal customs, directly linked to the physical or biological aspects of the environment, may also be considered significant.’

2.3.1 Proposal Activities Potentially Affecting Key Environmental Factors

The Burrup Peninsula features numerous Aboriginal cultural heritage sites and places that are highly significant to Aboriginal people. State records and Woodside’s own surveys have identified a range of Aboriginal heritage site types, inside and adjacent to the Proposal development envelope. Heritage features of the Burrup Peninsula include petroglyph sites (rock art), ceremonial/restricted access sites, ethnographic sites, standing stones, shell middens, artefact scatters, quarries, grinding patches, and coastal fishing and foraging opportunities. The environmental value associated with the use of the Burrup Peninsula by Aboriginal people is best defined by those people. Therefore, this CHMP assumes that all known recorded uses of the Proposal development envelope and areas immediately adjacent to it by Aboriginal people holds environmental value.

The presence of heavy industry on the Burrup Peninsula has generated concerns that industrial emissions may lead to an accelerated weathering or deterioration of rock art. These concerns centre on the issue that deposition of nitrogen oxides (NO_x), sulphur oxides (SO_x) and ammonia (NH_3) from anthropogenic industrial sources have the potential to increase the acidity of the rock surface through chemical and/or biological processes. The key emissions from the Proposal in terms of potential impact to rock art include NO_X, volatile organic compounds (VOCs) pertaining to photochemical intensity of NO/NO_2 formation) and small contributions of sulphur dioxide (SO_2) arising from power generation and process emissions. Direct, accidental damage to those heritage features and sites within the Proposal development envelope could occur through direct interactions with NWS Project workforce (e.g. inappropriate human behaviour [climbing on/over or marking heritage features or leaving rubbish at these sites], driving of vehicles over heritage features, objects accidentally dropped on heritage features, or spills from operational activities).

Woodside recognises the ‘living connection’ that Aboriginal people have to heritage and the need to access heritage areas today and in the future. Continued restricted access within the Proposal development envelope until around 2070 may disrupt ongoing connection to culturally significant heritage sites for local Aboriginal groups. Woodside has an established process to provide Traditional Owners with access to heritage features within the development envelope when requested.

Murujuga National Park and the listed National Heritage Place of the Dampier Archipelago (including the Burrup Peninsula) are located east of the Proposal development envelope (DoEE, 2007; DEC, 2013). Reduced amenity to heritage features within these areas may occur as a result of Proposal activities.

Unreasonable emissions of odorous substances from the Proposal have the potential to cause nuisance or public amenity concerns. Potential trace levels of odorous substances associated with the Proposal can include VOCs (including BTEX) and sulphurous compounds (such as hydrogen sulphide [H_2S]). Potential for nuisance odours are assessed as posing low risk of loss of public amenity or reduced amenity to heritage features in the NWS Project Extension Environment Review Document (Woodside, 2019).

Dark smoke can be caused by the incomplete or low temperature combustion of flared gas. Dark smoke events occur infrequently at the NWS Project and it is unlikely that a dark smoke event will cause a significant impact to the amenity of heritage features adjacent to the Proposal development envelope. Dark smoke is managed through monitoring and reporting in accordance with Part V of the EP Act Operational Licence requirements.

2.4 Rationale and Approach

Woodside's approach to the management of Aboriginal heritage has been developed to ensure the requirements of the *Aboriginal Heritage Act 1972* (WA), the *Environment Protection and Biodiversity Conservation Act 1999* (Cth), and the environmental objectives of the Social Surroundings environmental factor are met.

In developing this CHMP, the following points were assessed:

- results of heritage audits, surveys and consultation undertaken with Aboriginal groups
- outcomes of ambient air quality modelling for the Proposal and the Burrup Peninsula as this relates to deposition of NO_x and SO_x
- uncertainties as to the potential for accelerated weathering of Aboriginal rock art on the Burrup Peninsula due to industrial emissions.

Based on this assessment, and as the nature of potential impacts from the Proposal on social surroundings do not relate to aspects of the environment that can be quantitatively measured, a management-based approach has been taken to manage the cultural heritage values of the Burrup Peninsula. In the absence of management measures that can be objectively measured, the management-based provisions are supported by an adaptive management approach containing clear triggers for when these provisions should be revised via update of this Management Plan.

Additionally, some potential impacts managed under this CHMP, namely accelerated weathering of rock art, are the subject of ongoing scientific research; therefore, the understanding of how these impacts are best managed may change during the implementation of the Proposal. To address the uncertainty associated with these potential impacts, an adaptive management approach will be implemented, together with the Proposal providing for opportunity to substantially reduce air emissions of concern (NO_X and VOC emissions).

The management approach for this CHMP also identifies WA Government responsibilities in relation to the protection of rock art on the Burrup Peninsula and surrounding islands of the Dampier Archipelago.

3. Internal and Regulatory Framework

3.1 Internal Management Mechanisms Relevant to this CHMP

3.1.1 Woodside Management System

The Woodside Management System (WMS) defines how Woodside delivers its business objectives and the boundaries within which all Woodside employees and contractors are expected to work. Environmental and cultural heritage management are components of the overall WMS.

The overall direction for management of Aboriginal heritage is set through Woodside's corporate Indigenous Communities Policy. The policy provides a public statement of Woodside's commitment to building long-lasting relationships with Indigenous communities in which Woodside operates and to demonstrate respect and act with integrity as we generate positive economic, social and cultural outcomes. It sets out the principles for achieving the objectives and how these are to be applied. The policy is applied to all Woodside's activities, and employees, contractors and Joint Venture partners engaging in activities under Woodside operational control.

3.1.2 Cultural Heritage Management Procedure

Woodside's Cultural Heritage Management Procedure (Woodside ID WM0000PG10178231) defines:

- requirements to meet statutory obligations and commitments for Cultural Heritage
- requirements for Stakeholder Engagement, Cultural Heritage Assessment and Cultural Heritage Management
- accountabilities for reputation, Cultural Risk Assessments, Cultural Heritage Assessments and Cultural Heritage Management
- processes for escalating and reporting non-compliance with the requirements.

This CHMP ensures that the above requirements are met.

3.1.3 Incident Reporting

An incident is defined as any event that breaches or threatens the ability of any person or company to meet the objectives or management actions listed in this CHMP.

Specifically, an incident is defined as one or a combination of the following:

- Non-compliance with this CHMP
- Unexpected damage or loss to any heritage site or item within the development envelope
- Discovery of a new heritage site within the development envelope
- Discovery of skeletal remains within the development envelope
- Any trespass outside of the operational area of the development envelope without appropriate authorisation.

Incidents are reported to Woodside's Senior Heritage Adviser or equivalent corporate heritage representative and in accordance with the Health Safety and Environment Event Reporting and Investigation Procedure (Woodside ID WM0000PG9905421). Community grievances are handled through Woodside's Community Grievance Mechanism Procedure (Woodside ID WM0000PG9539696).

3.2 Regulatory Management Mechanisms Relevant to this CHMP

3.2.1 Commonwealth Legislation

Aboriginal and Torres Strait Islander Heritage Protection Act 1984 (Cth)

The *Aboriginal and Torres Strait Islander Heritage Protection Act 1984* (ATSIHP Act) provides a mechanism for the Commonwealth Environment Minister to make declarations regarding the protection of an Aboriginal site when the Minister is satisfied that, under State or Territory law, there is ineffective protection of the area from a threat of injury or desecration. Declarations made under this Act may involve restricting activities and/or access to an Aboriginal site.

If the requirements of the *Aboriginal Heritage Act 1972* (WA) are adhered to, the ATSIHP Act is unlikely to have relevance for Aboriginal sites found to exist within the development envelope.

Environment Protection and Biodiversity Conservation Act 1999 (Cth)

The *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBC Act) establishes the National Heritage List, which includes natural, Indigenous and historic places that are of outstanding heritage value to the nation. There are penalties for anyone who takes an action that has or will have a significant impact on the heritage values of a place recognised in the National Heritage List. The EPBC Act also establishes the Commonwealth Heritage List, which includes places on Commonwealth lands and waters or under Australian Government control that have heritage significance.

Native Title Act 1983 (Cth)

The Native Title Act 1993 (NT Act) adopts the common law definition of native title, defined as the rights and interests that are possessed under the traditional laws and customs of Aboriginal people in land and waters, and that are recognised by the common law. These rights may exist over Crown Land but do not exist over land held as freehold title.

The NT Act recognises the existence of an Indigenous land ownership tradition where connections to country have been maintained and where acts of government have not extinguished this connection. This Act does not apply over the NWS Project development envelope as native title has been found not to exist over these areas.

Underwater Cultural Heritage Act 2018 (Cth)

The *Underwater Cultural Heritage Act 2018* prescribes penalties for damage to protected underwater cultural heritage without a permit under Section 30 or in contravention of a permit in Section 28. Under Section 16, protected underwater cultural heritage automatically includes the remains and associated artefacts of any vessel or aircraft that has been in Australian waters for 75 years, whether known or unknown. This protection is also extended to underwater cultural heritage specified by the Commonwealth Minister for Environment under Section 17, which may include Aboriginal or other types of heritage. There are no recorded underwater heritage sites within the NWS Project development envelope.

3.2.2 State Legislation

Aboriginal Heritage Act 1972 (WA)

The *Aboriginal Heritage Act 1972* (WA) (AH Act) is the principle legislation for providing protection and preservation of all Aboriginal cultural heritage places and objects within WA. This Act is currently administered by the WA Department of Planning, Lands, and Heritage (DPLH). Under Section 17 of the AH Act it is an offence to excavate, destroy, damage, conceal, or in any way alter any Aboriginal site or artefact.

3.3 Other Management Mechanisms Relevant to this CHMP

3.3.1 Murujuga Rock Art Strategy and Murujuga Rock Art Stakeholder

The Murujuga Rock Art Strategy (the Strategy) provides a long-term framework to guide the protection of rock art on the Burrup Peninsula and surrounding islands of the Dampier Archipelago. The strategy aims to 'build on previous work on the Burrup Peninsula to deliver a scientifically rigorous, world's best practice monitoring program and risk-based approach to the management of impacts to the rock art, consistent with legislative responsibilities under the EP Act (DWER, 2019a). The WA Department of Water and Environmental Regulation (DWER) and Murujuga Aboriginal Corporation (MAC) are responsible for the day-to-day implementation of the strategy, including ongoing consultation with key stakeholders (DWER, 2019a).

The scope of the Strategy is to:

- establish an Environmental Quality Management Framework (EQMF), including the derivation and implementation of environmental quality criteria
- develop and implement a robust program of monitoring and analysis to determine whether change is occurring to the rock art on Murujuga
- identify and commission scientific studies to support the implementation of the monitoring and analysis program and management
- establish governance arrangements to ensure that:
    - monitoring, analysis and reporting are undertaken in such a way as to provide confidence to the Traditional Owner, the community, industry, scientists and other stakeholders about the integrity, robustness, repeatability and reliability of the monitoring data and results
    - government is provided with accurate and appropriate recommendations regarding the protection of the rock art, consistent with legislative responsibilities
- develop and implement a communication strategy in consultation with stakeholders.

DWER plans to use the EQMF to provide a risk-based and robust framework for implementing the monitoring and management that is required to protect rock art from anthropogenic emissions. The EQMF comprises of:

- Environmental values – ecosystem conditions that require protection from environmental harm
- Environmental quality objectives – specific management goals that must be achieved to protect the environmental values
- Environmental quality criteria – scientifically determined limits of reasonable change. These criteria are the standards against which environmental monitoring data are compared to determine the extent to which environmental quality objectives have been met (DWER, 2019a)

DWER, in partnership with MAC, plan to implement a revised Murujuga Rock Art Monitoring Program, based on the results from the past 15 years of scientific studies and monitoring of the petroglyphs. This monitoring program potentially includes, but is not limited to, the parameters of colour change, pH/acidity, microbiology, and sources of pollutants (DWER, 2019b). The program should be able to distinguish between changes in condition of the petroglyphs attributed to anthropogenic emissions versus other unrelated causes. The program comprises cost-efficient, best-practice technologies and methods.

Monitoring and analysis results will be published on DWER's website (https://www.der.wa.gov.au/our-work/programs/36-murujuga-rock-art-monitoring-program). The strategy will be reviewed every five years or when significant new information becomes available to ensure that the strategy and governance procedures remain relevant and reflect the most recent scientific knowledge and management practices.

The Murujuga Rock Art Stakeholder Reference Group (Stakeholder Reference Group) was established in 2018 to facilitate engagement between key government, industry and community representatives as the Strategy is developed. Woodside is a member of the Stakeholder Reference Group and as such will participate in the following activities, as per the terms of reference (DWER, ND):

- contribute constructively to the monitoring and protection of rock art, being considerate of the views of all stakeholders. This includes the provision of advice to DWER and the Minister for Environment on the design, implementation and analysis of the scientific monitoring and analysis program.
- consult, inform and educate other stakeholders on other matters referred by DWER for input or comment, including further development of the Strategy, implementation of the Strategy and 5 yearly reviews
- inform the Government's broader consideration of other strategic issues relating to the protection of the rock art on Murujuga.

Where key emissions from the Proposal have potential to impact the Murujuga rock art, management measures have been proposed in line with the work that Woodside is participating in through the Strategy and the Stakeholder Reference Group.

4. EMP Provisions

This section describes the provisions of this CHMP which, when implemented, achieve the objective of the Social Surroundings (Heritage) environment factor and the objective of the CHMP, to uphold the relevant environmental values and avoid potential impact to heritage features from the Proposal**.**

Table 4-1 lists the management-based provisions that will be implemented with the Proposal. These are based on the rationale and approach described in **Section 2.4**. Existing cultural heritage management measures for the NWS Project have been included in this CHMP.

4.1 Management Based Provisions Summary

Table 4-1: Management-based Provisions

Management Actions	Targets	Monitoring	Reporting
MA 1: Educate Project personnel on the sensitivity of the cultural heritage features on the Burrup Peninsula	No direct or indirect disturbance to rock art within the Proposal development envelope attributable to Project personnel All personnel entering the Project facilities attend relevant inductions.	Annual audits of at risk rock art within the Proposal development envelope are conducted by a qualified archaeologist accompanied by Traditional Owners. Rock art subject to audit will be determined annually based on advice from a qualified archaeologist considering likely sources of impact, and Traditional Owner requests. Induction attendance is recorded and confirmation that all personnel have attended is required.	Instances of direct or indirect physical damage to rock art within the Proposal development envelope are reported in an annual environment report to the EPA.
MA 2: Provide access for Traditional Owners to Aboriginal cultural heritage sites within the Proposal development envelope when requested	Access provided to the NWS Project for Traditional Owners when requested	Requests for access and outcomes to be recorded in a register and monitored for unaddressed/unmet requests.	Record of instances of Traditional Owners requests for access and outcomes of those requests are maintained internally.
MA 3: Investigate and respond to instances of odour complaints from the Murujuga National Park or the National Heritage Place	Respond to all complaints of odour from within the Murujuga National Park or the National Heritage in accordance with Woodside's Community Grievance Mechanism Procedure.	Community complaints are monitored for instances of recorded odour complaints from within the Murujuga National Park or the National Heritage Place, and investigated to determine whether they are attributable to the Proposal	All instances of odour complaints from within the Murujuga National Park or the National Heritage Place and Woodside response to those complaints are reported in the annual environment report

MA4: Adopt practicable and efficient technologies to reduce air emissions to prevent impacts to terrestrial and nearshore vegetation of heritage and conservation value	40% reduction of NO_x achieved by 31 December 2030.	Monitor, estimate and report facility emissions after installation of emission reduction technologies to verify achievement of emission reduction targets.	Performance against emission reduction targets summarised in the AER Annual reporting in accordance with the NPI.
MA 5: Implement an adaptive management plan addressing the potential impact to rock art from industrial emissions	See **Section 5**.		
MA6: Support the implementation of, and participate in, the DWER Murujuga Rock Art Strategy[1]			

Note 1: DWER is responsible for awarding monitoring studies in support of the Murujuga Rock Art Strategy.

4.2 Management Actions

4.2.1 MA1 – Educate project personnel on the sensitivity of the cultural heritage features on the Burrup Peninsula

All personnel, including third party contractors and visitors are required to undertake a site induction prior to accessing the NWS Project. The induction informs personnel of the sensitivity of the cultural heritage features on the Burrup Peninsula and their obligations under the AH Act.

Discrete disturbance zones have been established for the NWS Project development envelope to ensure operational activities do not damage Aboriginal cultural heritage. All activities must remain within the designated disturbance zones unless appropriate permits and approvals have been obtained. The North West Shelf Cultural Heritage Management Procedures – Onshore Operations (Woodside ID 8915252) provides detail on the required procedures (including the permit system and notifications) in the event that:

- Ground disturbance work is required outside the designated disturbance zone;
- Access is required outside the designated disturbance zone;
- Human skeletal remains are discovered;
- New cultural heritage material or site is discovered;
- An incident occurs; or
- Traditional Owners request access to the NWS Project development envelope

As defined in the procedure, personnel wanting to access areas outside the KGP disturbance zone or undertake ground-disturbing activities must submit a request form to the NWS Project Heritage Manager for approval. The Heritage Manager assesses the potential for impact to heritage sites from the execution of the proposed activity and issues a permit that contains conditions to ensure compliance with the AH Act and this CHMP.

In addition, Woodside maintains a register of Aboriginal heritage sites within the NWS Project development envelope and undertakes annual heritage audits over the onshore components to monitor and report on the condition of heritage features within the Proposal development envelope. The location of monitoring sites is determined on an annual basis, from advice provide by an independent qualified archaeologist and any specific Traditional Owner requests received. Considerations for the archaeologist in selecting sites include proximity to operational areas, sources of likely impact, sensitivity and exposure of sites and continuity with previous audits to enable identification of any changes or impacts.

The annual selection of sites offers the flexibility to incorporate additional sites where deemed necessary or exclude those that do not merit regular inspection in the opinion of the independent archaeologist, however the need for consistent results is recognised and required in the site selection process.

Traditional Owner requests to inspect sites are subject to their own concerns and priorities which are not prescribed by Woodside. Due to the cultural sensitivity of these sites, the specific monitoring locations are confidential. Initial records of heritage sites from early surveys of the NWS lease areas have been recently augmented with uniform digital recording forms, digital photography and DGPS spatial recording. These form the current baseline conditions for which future audits are compared against.

A paper archive of individual heritage features within the development envelope is maintained and is used in the field during annual heritage audits to ensure correct site features are visited and to visually compare the condition of those features over time. Annual heritage audits are conducted by a qualified archaeologist and accompanied by Traditional Owners. Discussions about the state of the site and nearby impacts is held with Traditional Owners to identify risks and appropriate mitigation measures. The audit report provides recommendations for future heritage work to ensure the continued protection and preservation of heritage features within the NWS Project development envelope.

4.2.2 MA2 – Provide access for Traditional Owners to Aboriginal cultural heritage sites within the Proposal development envelope when requested

The Traditional Owners of the area have requested ongoing access to NWS Project development envelope to visit heritage sites. The NWS Project welcomes the Traditional Owners and facilitates access subject to site access protocols, operational and safety considerations. To arrange access, Traditional Owners contact Woodside Karratha or Roebourne offices, who can organise access and the associated safety inductions. Woodside endeavours to meet each request, noting that on-site activities may dictate the timing, number of visitors and/or duration of any site visit.

The NWS Project heritage manager must:

- Confirm the area to be visited, duration of the visit and the names of people attending.
- Develop a Job Hazard Analysis, prior to the visit in accordance with Woodside's Golden Safety Rules and appropriate steps taken to consider gender.
- Be present during the site visit as safety focal point and will not attend the site visit with the Traditional Owners unless requested by the group to do so. However, the NWS heritage manager or nominee is to stay in visual contact with the visiting party to ensure safety obligations are met and an immediate response in the case of an emergency can be enacted.

4.2.3 MA3 - Investigate and respond to instances of odour complaints from within the Murujuga National Park or the National Heritage Place

Woodside has an established community grievance mechanism procedure (Woodside ID WM0000PG9539696) to report, review and remedy community grievances. Any concerns in relation to odour from within the Murujuga National Park or the National Heritage Place can be raised through a variety of communication channels including:

- The online form on the Woodside internet page [https://www.woodside.com.au/contact]
- Email via commuities@woodside.com.au or feedback@woodside.com.au
- Telephone Woodside's head office or regional offices in Karratha or Roebourne
- Hardcopy letter.

4.2.4 MA4 - Adopt practicable and efficient technologies to reduce air emissions to prevent impacts to terrestrial and nearshore vegetation of heritage and conservation value

There is limited information available regarding the impacts of atmospheric deposition on Australia flora and vegetation in arid conditions and very little is known regarding air pollution impacts on vegetation occurring on the Burrup Peninsula. All predicted concentrations of NO_x and SO_2 are below the EU Air Quality Standards for the Protection of Vegetation (EU, 2008), as such significant impacts to vegetation of heritage or conservation significance are not expected due to emissions contribution from the Proposal.

In accordance with the principle of waste minimisation and application of the hierarchy of controls, Woodside will take reasonable and practicable measures to minimise emissions to air and therefore will reduce NO_x emissions by 40%[1] by 31 December 2030. Monitoring of performance against this target will be performed annually and progress reported through the Annual Environment Report.

If substantial emissions reductions can be achieved through installation of new equipment (particularly emission reduction equipment), point source emissions will be monitored before and after installation to verify that the equipment operates within the expected parameters.

Woodside will present the results of the point source emissions testing against anticipated emissions reduction performance in the annual environment report.

4.2.5 MA5 - Implement an adaptive management plan addressing the potential impact to rock art from industrial emissions

The adaptive management approach adopted in this CHMP (**Section 5**) has been developed cognisant of the Strategy and the EQMF that will be implemented. Woodside anticipate that the management framework in this CHMP will be updated once the environmental quality criteria for management of the rock art on the Burrup Peninsula are released. This management plan will be revised in accordance with **Section 5**.

4.2.6 MA6 - Support the implementation of, and participate in, the DWER Murujuga Rock Art Strategy

Woodside propose to manage potential impacts to Aboriginal rock art on the Burrup Peninsula in accordance with the Strategy and as a member of the Stakeholder Reference Group.

As described in **Section 3.3.1**, the purpose of the strategy is to protect the Aboriginal rock art on the Burrup Peninsula by providing a long term framework for monitoring and analysing potential changes to the rock art and describing a process by which management responses should be put in place to address adverse impact on the rock art. The monitoring program and associated scientific studies are being designed and implemented by DWER to monitor, evaluate and report on changes and trends in the integrity of the rock art, specifically to determine whether anthropogenic emissions are accelerating the natural weathering/alternation/degradation of Aboriginal rock art.

The implementation of the Strategy, Framework and Monitoring Program (DWER, 2019a)[1] will remove much uncertainty surrounding potential pathways linking industrial emission and accelerated weathering, and allow for timely investigation and management where required. The proposed program of monitoring and analysis will determine whether change is occurring to the rock art and if this change is being accelerated by industrial emissions. Monitoring of rock, and rock art in particular allows for early warning indicators and response mechanisms to ensure that long term significant impact due to accelerated weathering is avoided. The implementation of the risk based, adaptive management program using guidelines and standards, derived from sound scientific information, will

[1] Based on the percentage of reported emissions from KGP over the five-year annual average, covering the 2013/14 to 2017/18 financial years.

ensure that the rock art is protected from potentially significant harm associated with industrial emissions.

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.

5. Adaptive Management and Review of the CHMP

The ability to respond to scientific advances is particularly important for managing potential impacts from air emissions (in particular NO_x) on the rock art of the Burrup Peninsula. Currently, there is a lack of scientific understanding of the impacts of air emissions on petroglyphs and therefore it is difficult to set appropriate management actions in this CHMP. In line with the concept of adaptive management, the management actions presented in this CHMP shall be monitored, reviewed, evaluated and updated, as required, considering:

- outcomes of any technical review of and evaluation of the emissions and ambient air quality monitoring programs (undertaken in accordance with the NWS Project Extension Air Quality Management Plan).
- new scientific information is published, as part of the Strategy, about the potential impacts of industrial air emissions on Aboriginal rock art of the Burrup Peninsula and that information suggests new or updated provisions should be included in this CHMP.
- new and relevant data/information gained as a result of implementing this CHMP, or from external sources
- changes in State or Commonwealth legislation or policy.

With relevant updates included in a revised CHMP. In addition, this CHMP may be reviewed:

- based on EPA and decision-making authorities (DMAs) comments during the ERD approval process
- if a significant incident occurs related to the protection of Aboriginal heritage.
- Traditional Owners request that a review is undertaken due to a relevant concern
- complaints indicate instances of odour within the Murujuga National Park or the National Heritage Place
- If relevant legislative requirements are updated or amended in relation to Aboriginal Heritage

Technical review and evaluation of the management actions outlined in this CHMP will be conducted every five years[1] (if not initiated prior to that time) to ensure the management actions are adequately addressing the key risks and meeting EPA objectives. If, as a result of any review, any significant changes are required to be made to this CHMP, a revised CHMP will be provided to the EPA for approval.

When the five-yearly review cycle is triggered, or if a significant change to either the facility, activity, or risk is identified, a revised CHMP will be submitted to the EPA. When approved, the revised plan will be made publicly available.

[1] Frequency no more than annually.

6. Stakeholder Consultation

This CHMP is included as an appendix to the ERD for the Proposal (Woodside, 2019) and therefore will be reviewed by the EPA, key DMAs, and the general public as part of the assessment process for the ERD. Comments received from the EPA and DMAs during the initial review will be incorporated into this CHMP before publication of the ERD (and associated management plans) for public review and comment. All comments received during the public review period that relate to this CHMP will be considered, and changes made to this CHMP where required.

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8. Terms

Terms	Definitions
AQMP	Air Quality Management Plan
ATSIHP Act	*Aboriginal and Torres Strait Islander Heritage Protection Act 1984* (Cth)
AH Act	*Aboriginal Heritage Act 1972* (WA)
CHMP	Cultural Heritage Management Plan
DMA	Decision-making Authority
DPLH	Western Australian Department of Planning, Lands and Heritage
DWER	Western Australian Department of Water and Environmental Regulation
CHMP	Cultural Heritage Management Plan
EP Act	WA *Environmental Protection Act 1986* (EP Act)
EPBC Act	Commonwealth *Environment Protection and Biodiversity Conservation Act 1999*
EPA	Western Australia Environmental Protection Authority
ERD	Environmental Review Document
IMR	Inspection, Maintenance and Repair Program
KGP	Karratha Gas Plant
LNG	Liquefied Natural Gas
MAC	Murujuga Aboriginal Corporation
MCMP	Murujuga Cultural Management Plan
MEQMP	Marine Environment Quality Management Plan
Murujuga	Traditional name for the Burrup Peninsula and surrounding islands of the Dampier Archipelago
NT Act	*Native Title Act 1983* (Cth)
National Heritage Place	National Heritage Place – Dampier Archipelago (including Burrup Peninsula)
NWS	North West Shelf
NWSJV	North West Shelf Joint Venture
North West Shelf Joint Venture	A joint venture comprising six companies; Woodside Energy Ltd. (operator), BHP Billiton Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Australia Pty Ltd, Japan Australia LNG (MIMI) Pty Ltd, and Shell Australia Pty Ltd. The North West Shelf Joint Venture owns the infrastructure used as part of the North West Shelf Project and, together with CNOOC NWS Private Limited, the North West Shelf Joint Venture owns the resources processed as part of the NWS Project.
North West Shelf Project	The North West Shelf Project is one of the world's largest liquefied natural gas producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. The NWS Project is owned by the NWSJV participants and for more than 30 years, it has been Western Australia's largest producer of domestic gas. The NWS Project currently processes resources owned by the NWSJV and CNOOC NWS Private Limited and is proposed to also process third-party gas and fluids as part of the NWS Project Extension Proposal.

Terms	Definitions
NWS Project Extension Proposal (the Proposal)	The Proposal as described in the NWS Project Extension Section 38 Referral Supporting Information (November 2018) to continue to use the existing NWS Project facilities for the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities; and Ongoing operation of the NWS Project to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070.
pH	Measure of acidity or basicity of a solution
TL	Trunklines
WA	Western Australia
WMS	Woodside Management System
Woodside	Woodside Energy Ltd

North West Shelf Project Extension Cultural Heritage Management Plan

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APPENDIX D
NORTH WEST SHELF PROJECT EXTENSION MARINE ENVIRONMENTAL QUALITY MANAGEMENT PLAN

Revision 1

Woodside

Appendix D

North West Shelf Project Extension

Marine Environmental Quality Management Plan

Revision 1

G2000RF1401194403

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1. Summary

Woodside Energy Ltd (Woodside), as Operator for and on behalf of the North West Shelf (NWS) Joint Venture (NWSJV), is the proponent for the North West Shelf Project Extension Proposal (the Proposal).

In summary, the Proposal is for the ongoing operation of the NWS Project to enable the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities until around 2070. The Proposal is described in its entirety in **Section 2** of the NWS Project Extension Environmental Review Document (Woodside, 2019) and is duplicated into **Section 2.1.1** of this Marine Environmental Quality Management Plan (MEQMP) for ease of reference.

This MEQMP was prepared in accordance with the 'Instructions on how to prepare *Environmental Protection Act 1986* Part IV Environmental Management Plans' published April 2018 by the Western Australian (WA) Environment Protection Authority (EPA) (EPA, 2018a).

This MEQMP details the measures that are required to manage the potential impacts to marine environmental quality from the Proposal. **Table 1-1** summarises the information contained in this MEQMP.

Table 1-1: MEQMP summary table

Title of Proposal	North West Shelf Project Extension
Proponent Name	Woodside Energy Ltd., as Operator for and on behalf of the NWSJV
Purpose of the EMP	This Marine Environmental Quality Management Plan: • identifies the environmental values (EVs) to be protected. • establishes the Environmental Quality Objectives (EQOs) to ensure the selected environmental values (marine environmental quality) are maintained. • establishes Environmental Quality Criteria (EQC) for indicators relevant to the discharges. • spatially defines areas of low, moderate, and high ecological protection around the wastewater discharge points (Jetty Outfall and Administration Drain) in alignment with the *Revised Pilbara Coastal Water Quality Consultation Outcomes: Environmental Values and Environmental Quality Objectives* (DoE, 2006). • presents monitoring required to demonstrate that discharges meet the levels of ecological protection (LEPs) assigned to the discharge areas and EQC are achieved. • presents an adaptive management program based on the environmental quality management framework (EQMF as defined in EPA (2016a) designed to ensure the EQO continues to be achieved in the event of specified changes to the discharge or other factors.
Key Environmental Factor/s and Objective/s	**Key Environmental Factor:** Marine Environmental Quality **EPA Objective:** To maintain the quality of water, sediment, and biota so that environmental values are protected (EPA, 2018b) **Environmental Quality Management Framework Objective:** Maintain ecosystem integrity (DoE, 2006)
Key Provisions in the EMP	Management of discharges to the marine environment to maintain ecosystem integrity

2. Context, Scope, and Rationale

2.1 Introduction

The NWS Project is one of the world's largest liquefied natural gas (LNG) producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. For more than 30 years, it has been WA's largest producer of domestic gas.

Woodside proposes to operate of the NWS Project to around 2070 as an LNG facility that is commercially capable of accepting gas for processing from other resource owners. Therefore, this Proposal will include processing third-party gas and fluids and any remaining or new NWSJV field resources.

The Proposal is described in its entirety in Section 2 of the NWS Project Extension Environmental Review Document (Woodside, 2019) and is duplicated into **Section 2.2** of this MEQMP for ease of reference.

This MEQMP will be implemented following receipt of approval under the *Environmental Protection Act 1986* (WA) (EP Act) and *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBC Act). In the interim, the NWS Project will continue to operate under current license conditions and management practices.

2.1.1 Proposal

To enable the future operation of the NWS Project and the ongoing supply of gas and fluids to domestic and international markets, the Proposal seeks approval to transition the Existing NWS Project facilities to a new phase of the NWS Project; which is commercially capable of accepting gas for processing from other resource owners. The NWS Project Extension Proposal is seeking approval for the:

- long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities, including:
  - changes to feed gas composition including changed content of inerts, hydrocarbons and other components
  - changes to the composition of environmental discharges and emissions, although annual volumes of emissions and discharges are expected to be in line with current levels
  - modifications to the KGP onshore receiving facilities (that would not otherwise be undertaken if not for the Proposal) to accommodate third-party gas and fluids, as well as upgrades to metering to facilitate processing of third-party gas and fluids
  - potential construction of additional operational equipment to accommodate changes to feed gas composition or management of discharges and emissions
- ongoing operation of the NWS Project (from the date of the approval of this Proposal) to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070, including:
  - ongoing use of existing NWS Project facilities to process third-party gas and fluids and NWSJV field resources
  - inspection, maintenance, and repair (IMR) and improvement programs for trunklines (TL), 1TL and 2TL
  - maintenance dredging associated with jetties and berthing pockets
  - replacing equipment, plant, and machinery as required that would not otherwise be replaced if not for the Proposal.

- ongoing, additional (and cumulative to existing approvals) emissions and discharges to the environment (Woodside, as operator for and on behalf of the NWS Project, will implement emission reduction opportunities that will result in a staged decrease in emissions over time)
- monitoring and management of environmental impacts.

2.2 Scope of the MEQMP

Purpose of Management Plan

This MEQMP was written in accordance with the Technical Guidance – Protecting the Quality of Western Australia's Marine Environment (EPA, 2016a). This document sets out an Environmental Quality Management Framework (EQMF) to achieve the objective of maintaining ecosystem integrity within the WA marine environment. The approach to managing the Proposal in a way that achieves this objective is based on a combination of impact assessment, early response indicators, and past environmental performance of the NWS Project.

The impact pathways were assessed to determine if there is a risk of the Proposal activities impacting maintenance of ecosystem integrity. These criteria were applied:

- where mitigation for, and management of the activity is implemented under other regulatory instruments (e.g. Operational Licence approved under Part V of the EP Act or approved environment plan), the risk was determined to be sufficiently managed
- where the activity required management through design controls and those controls are already in place at the NWS Project, the risk was determined to be sufficiently managed.

The KGP Part V Operational Licence sets out monitoring requirements that apply to all planned marine discharges from the Proposal.

This MEQMP acknowledges that the nature of liquid discharges and the state of the receiving environment may change over the life of the Proposal. Therefore, this MEQMP includes an adaptive management program (**Section 8**) to confirm that the management measures proposed continue to be appropriate and ensure protection of the environment value.

Scope

This MEQMP specifically addresses the management of potential environmental impacts to the marine environment from planned discharges from the Proposal, via the KGP Jetty Outfall and Administration Drain, further described in **Section 6**.

These aspects and NWS Project components are outside the scope of this MEQMP:

- Trunklines 1TL and 2TL, which are managed under the North West Shelf Trunklines State Waters Operations Environment Plan (State Waters EP).
- Inspection, maintenance, monitoring, and repair activities, which are managed under the State Waters EP.
- Shipping, including ship loading. Woodside does not have direct control over these operations. Shipping is managed by vessel operators under the requirements of Marine Orders.
- Unplanned discharges from onshore or offshore accidents or emergencies, which are managed under the State Waters EP and Emergency Management Plan for the KGP.
- Presence and management of existing onshore contamination, which is managed in accordance with the *Contaminated Sites Act 2003* (WA).
- King Bay Supply Base (KBSB): Discharges from the KBSB are limited to treated sewage and site run-off from areas with a low likelihood of contamination by oils or other chemicals. These discharges are considered low risk in the context of the port environment and below thresholds for management under Part V of the EP Act.

- Recreational use of areas affected by marine discharges, including fishing and swimming: the areas likely to be affected by marine discharges are not accessible to the public.

2.3 Key Environmental Factors

This MEQMP addresses potential impacts from planned marine discharges on the key environmental factor, Marine Environmental Quality. Marine environmental quality is defined by the EPA (EPA, 2016b) as:

The term 'environmental quality' refers to the level of contaminants in water, sediments or biota or to changes in the physical or chemical properties of waters and sediments relative to a natural state. It does not include noise pollution, which is dealt with separately under the marine fauna factor.

The EPA's objective for this environmental factor is:

To maintain the quality of water, sediment, and biota so that environmental values are protected (EPA, 2018b)*.*

A set of five environmental values (EVs) that require protection from the effects of pollution, waste discharges, and deposits in marine environments were agreed by all State, Territory and Commonwealth governments through the National Water Quality Management Strategy (NWQMS) (EPA, 2016b).

The EV relevant to the Proposal is 'Ecosystem Health'. Justification for the selection of this EV and management approach is outlined below.

2.4 Rationale and Approach

The development of this MEQMP follows EPA 'Instructions on how to prepare *Environmental Protection Act 1986* Part IV Environmental Management Plans' (EPA, 2018a) and Technical Guidance – Protecting the Quality of Western Australia's Marine Environment (EPA, 2016a). EPA (2016a) describes an outline of an EQMF.

As required to enact the EQMF, this MEQMP includes these sections:

- identification of EVs relevant to the particular area (**Section 3.1**)
- establishment of spatially defined Environmental Quality Objectives (EQOs). Maintenance of the EQOs are designed to ensure that the associated EVs are protected (**Section 5**)
- The EQOs are represented spatially as part of the Environment Quality Plan (EQP)
- establishment of Environmental Quality Criteria (EQC). EQC represent scientifically based limits of acceptable change to a measurable environmental quality indicator that is important for the protection of the associated environmental value (**Section 5.2**).

The EQMF requires appropriate EQC to be established to ensure an appropriate framework is in place for measuring the extent to which the EQO is maintained and therefore demonstrating the EV is being protected.

Two types of EQC are defined under the EQMF:

- Environmental Quality Guidelines (EQGs). These are quantitative investigative triggers that, if achieved, indicate there is a low probability that the EQO is not being achieved
- Environmental Quality Standards (EQSs). These are management triggers based on multiple lines of evidence, which, if exceeded, signify that the EQO is not being met and that a management response is required.

The framework of this MEQMP is outlined in **Figure 2-1**.

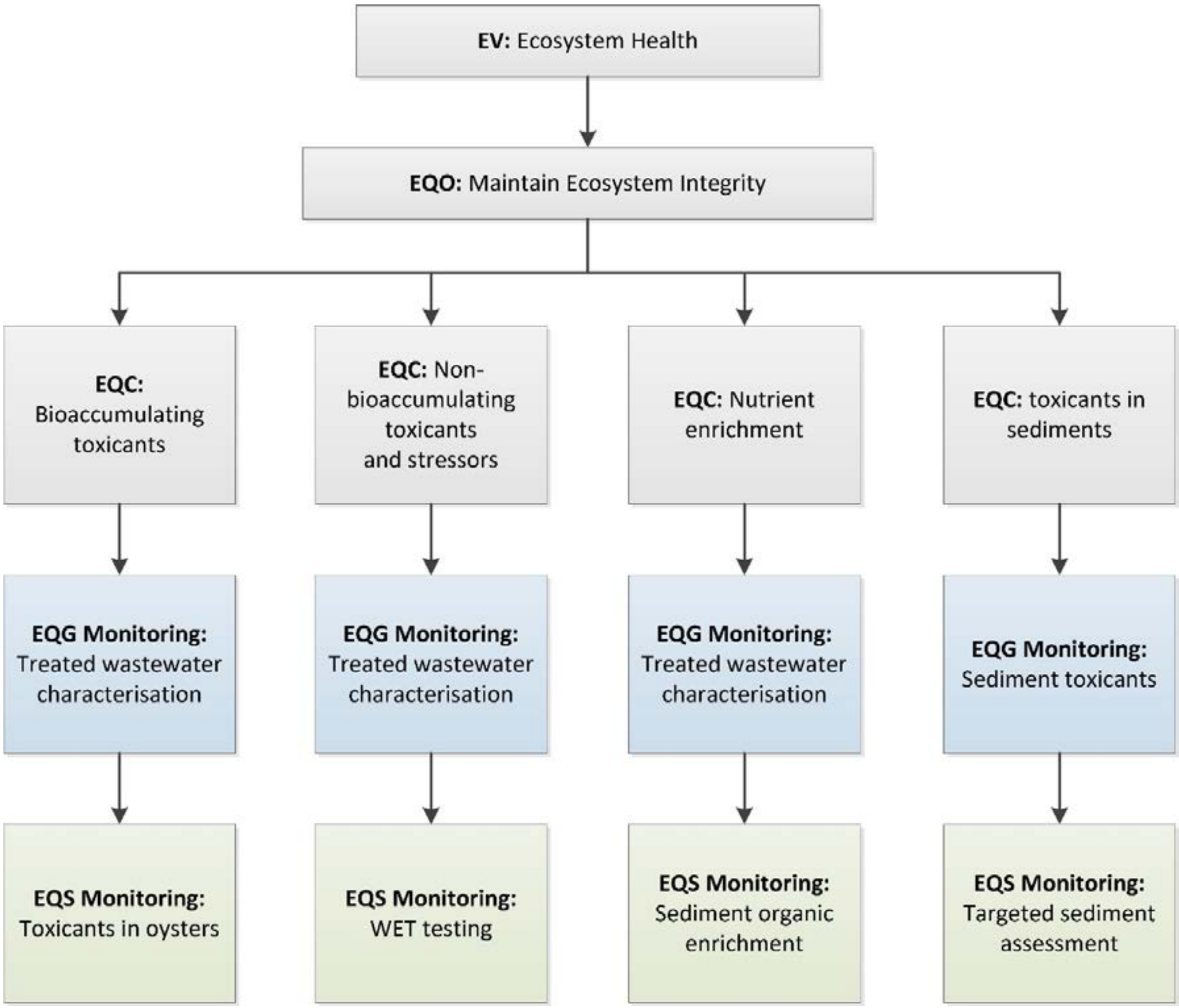

Figure 2-1 Environmental quality objectives, criteria, and monitoring programs for maintaining the environmental value Ecosystem Health

3. Existing Environment

The existing marine environment near the Proposal, while still largely a natural environment, is influenced by industrial activity, including shipping, and the presence of the existing NWS Project infrastructure and other industrial premises. Although Mermaid Sound and the wider marine environment have areas of high environmental quality that sustain significant marine ecosystems and important coastal processes, the existing marine disturbance footprint of the NWS Project is designated as a low or moderate environmental protection area because of the presence of trunklines and dredged areas on the seabed. The benthic environment was dredged to allow for liquefied natural gas (LNG), liquefied petroleum gas, and condensate vessels to transit to and from the NWS Project's product loading jetties at the KGP and is regularly traversed by large commercial vessels.

A large (minimum 800 m) public safety exclusion zone surrounds the NWS Project infrastructure, including the product loading jetties. Fishing, aquaculture, or recreational activities are not permitted in this zone, which is under constant surveillance. No extraction of water for domestic or industrial purposes occurs near the Proposal development envelope.

A full description of the existing environment is contained in the NWS Project Extension Environmental Review Document (ERD) (Woodside, 2019).

3.1 Site-specific Environmental Values

The EPA has identified five EVs for marine environmental quality that should generally be protected through WA coastal waters:

- Ecosystem health;
- Fishing and aquaculture;
- Recreation and aesthetics;
- Industrial water supply; and
- Cultural and spiritual.

The only values identified as relevant to the Proposal are 'Ecosystem Health' and 'Cultural and Spiritual'. As per EPA guidance (EPA, 2016a), in the absence of any specific environmental quality requirements for protection of 'Cultural and Spiritual' values, it is assumed that if water quality is managed to protect ecosystem integrity, then this may go some way towards maintaining cultural values. No Environmental Quality Guidelines (EQGs) were identified specifically for protecting cultural and spiritual values.

The remaining EVs were not identified as being relevant to this MEQMP for these reasons:

- Fishing and aquaculture - There is a boating exclusion zone of a minimum of 800 m from the nearest discharge point—therefore no fishing is permitted in this zone. Shore based fishing/seafood collection is not permitted and controlled via restrictions to the site as noted below. Areas zoned for potential aquaculture are at least 10 km from the Proposal development envelope. The measures to ensure the maintenance of ecosystem health are designed to ensure impacts on fishing or aquaculture do not occur beyond the exclusion zone, where a high level of ecological protection (LEP) is maintained.
- Recreation and aesthetics - There is public exclusion zone, which extends a distance of at least 800 m from the nearest discharge point. No public access is permitted in this zone. The nearest public beach to the Proposal is more than 2.5 km from a discharge point.
- Industrial water supply - There are no nearby industrial water intakes.

This MEQMP was developed to manage those aspects of the Proposal that have the potential to affect ecosystem health or that may vary from the objective of maintaining ecosystem integrity.

For the 'Ecosystem Health' EV, there are effectively four different EQOs based on whether a low, moderate, high, or maximum LEP is applied (EPA, 2016a). In the context of the EP Act, these four levels equate to four levels of ecosystem health condition.

3.1.1 Existing Environment

The existing environment and habitats potentially influenced by the planned discharges are described in **Section 5.1**.

4. Impact Assessment

4.1 Activities Potentially Impacting Identified Environmental Values

Two existing discharges to the ocean from the KGP are licensed under Part V of the EP Act - the Jetty Outfall and the Administration Drain. As outlined in **Section 2.2**, this MEQMP only applies to discharges from these two licensed discharge points. Both discharge points have the potential to impact 'Ecosystem Health' and are subject to the management provisions described in this MEQMP. This section describes the waste streams, treatment technology, and discharge regimes for these two discharges.

4.2 Jetty Outfall

4.2.1 System Description

The KGP uses an oil-contaminated water (OCW) system to collect and treat, contaminated and potentially contaminated water generated on site for subsequent discharge. The OCW comprises two networks (LNG and Domestic Gas (Domgas)) for water collection, a series of holding basins for holding and treating collected water. Water from both systems is then combined in a common buffer tank to balance inflows and a final holding basin is utilised for final treatment and to allow for the collection of a representative sample prior to discharge. Water in this final holding basin is sampled and tested against internal discharge limits before being discharged to a diffuser located on Berth 1 of the KGP LNG jetty, known as the Jetty Outfall (**Figure 4-1**). Sources of potential contaminated water inflows into the OCW are listed below. Equipment and collection zones are shown in **Figure 4-1**.

Sources of inflow to the LNG OCW system include:

- Process wastewater and bunded / collection areas within:
  - all LNG trains;
  - all fractionation units;
  - both trunkline onshore terminals;
  - utilities and power generation (excluding GT4009 and GT4010)
  - condensate pumping station; and
  - condensate tanks 3 and 4.
- Dewatering of condensate storage tanks.

Sources of inflow to the Domgas OCW system include:

- Process wastewater and bunded areas within:
  - domgas processing units;
  - stabilisation units;
  - flare units;
  - utilities, including diesel oil systems, HP fuel gas, GT4009-10, firewater, and fuel gas; and
  - condensate tanks 1 and 2.
- Domgas processing units (U1300 dehydration) and flare knockout drums.

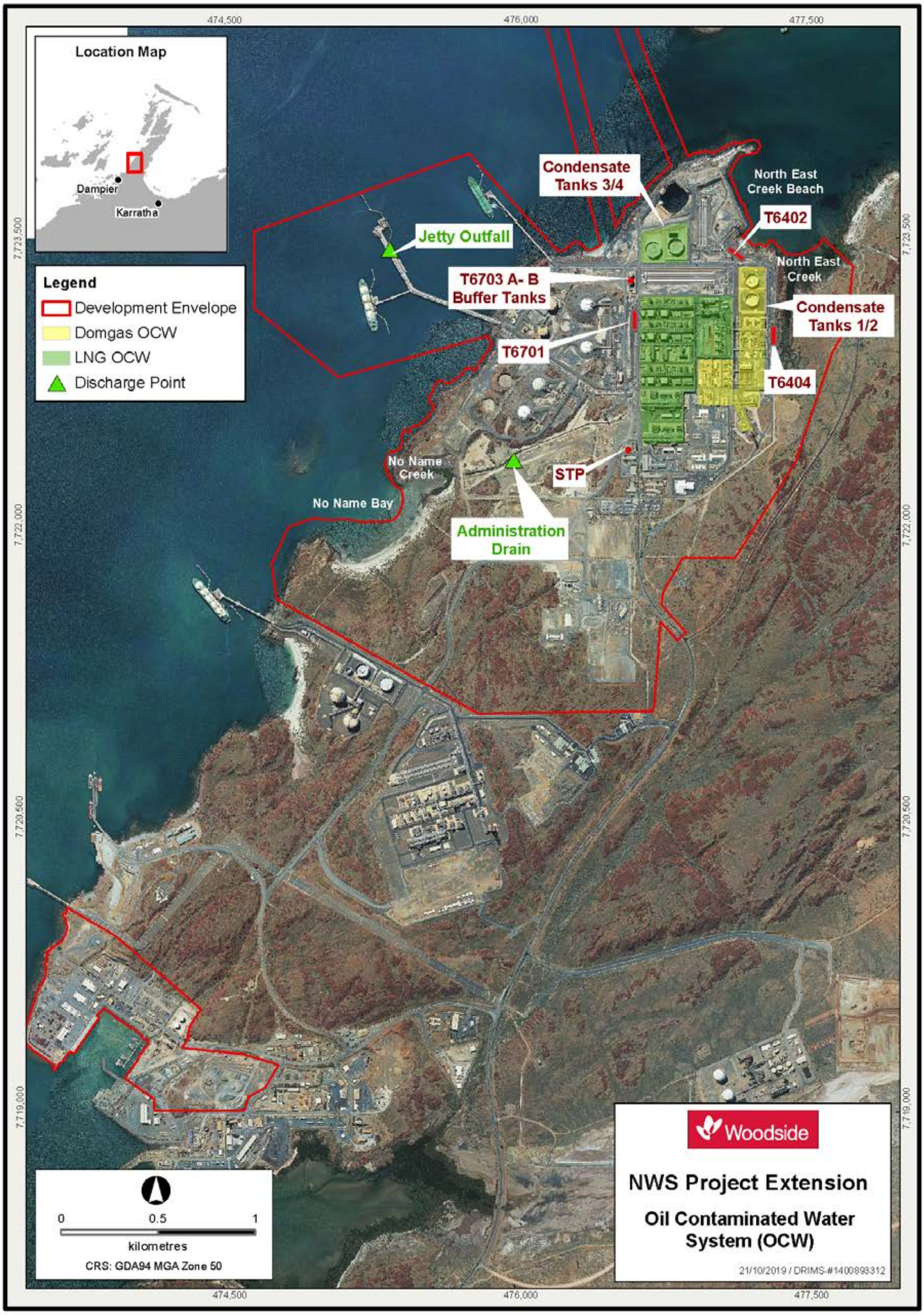

Figure 4-1: Layout of the KGP Oil Water Contaminated (OCW) System

4.2.2 OCW Treatment System

Once collected through the drainage networks, water is directed to the two intermediate holding/treatment basins (LNG –T6402 and Domgas – T6404) located on the northern and eastern sides of the KGP (**Figure 4-1**). Each system has a corrugated plate interceptor as the primary treatment to remove oil from the effluent streams, and a holding basin to allow settling, residence time, and aeration to remove organic and chemical contaminants. The recovered oil from each system is collected in a dedicated oil collection sump, from where it is sent to oil storage tanks and back into the main production process.

Once wastewater from each drainage network has passed through its dedicated holding/treatment basin, the treated water is pumped to a common buffer tank. The buffer tank provides capacity to manage water inflow to the final treatment system and provides additional storage capacity during high rainfall events.

A third common holding/treatment basin (T6701; the final holding basin) also has a corrugated plate interceptor for further oil/water separation. Samples of this water are collected and analysed by a National Association of Testing Authorities (NATA) accredited lab, to determine whether wastewater meets the discharge criteria (See **Section 4.4**).

If the discharge requirements are not met, the wastewater is retained in the final holding basin for further treatment until the discharge criteria are met. If discharge criteria cannot be achieved, alternative disposal options are evaluated and used as appropriate. Options include transferring to the on-site evaporation pond, using temporary treatment systems, or transferring to an appropriately licensed third-party disposal facility.

4.2.3 Jetty Outfall

Water is discharged in batches to the marine environment, via a subsurface diffuser located beneath Berth 1 on the LNG loading jetty. A discharge event will typically discharge up to 350 m^3 of water over two to three hours. Discharges typically occur between every three to seven days. Rainfall volumes are the primary determinant in the frequency of discharges and annual discharge volumes, as water volumes generated by onsite processes are relatively constant throughout the year. The buffer tank allows discharges to be sufficiently spaced to eliminate the risk of cumulative impacts from sequential discharges. Discharge events are targeted to occur at least three days apart, but may occur more frequently for certain reasons, such as if cyclonic rain is expected to occur or an aspect of the system requires maintenance.

4.2.4 Jetty Outfall - Contaminants of Concern

The Jetty Outfall receives wastewater from various facility process streams and bunded process areas as outlined in **Section 4.2.1**. Cause–effect pathways for potential impacts on marine environmental quality are associated with emissions from the production of gas and fluids by KGP processes.

Each batch discharge is analysed for the presence of 18 contaminants, in accordance with the KGP Part V Operational Licence, and the historic average concentrations of these is shown in **Table 4-1**. Internal approval to discharge is informed by a subset of the licence parameters identified as potentially driving acute toxicity, with the remaining reviewed on a regular basis. Every year, a representative sample of water discharged via the Jetty Outfall is analysed for an extended suite of potential chemical contaminants, informed by a list of contaminants that could be associated with oil and gas operations, to ensure the regularly monitored contaminants are aligned to the expected contaminants of concern present in the waste streams. Based on these results and the nature of the receiving environment, the following parameters are considered to be those which will govern the toxicity of the discharge:

- bioaccumulating toxicants:
  - cadmium
  - mercury

- non-bioaccumulating toxicants and stressors:
    - petroleum hydrocarbons (measured as total oil, in accordance with the KGP Part V Operational Licence)
    - ammonia-N
    - copper
    - lead
    - zinc
    - aMDEA
    - tri-ethylene glycol
    - sulphide
    - pH

Table 4-1 Average annual concentration of licensed discharge parameters in discharges to the Jetty Outfall

Parameters	Unit	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
a-MDEA	mg/L	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR
Anionic Surfactant	mg/L	2.6	6.8	18.1	15.8	11.6	6.1	9.1	1.2
COD	mg/L	205.5	411.7	154.9	84.9	75	76.9	605.9	85.8
Conductivity	µS/cm	3135.5	4058.9	3302.9	1157.6	2097.3	1269.2	1013.6	676.3
Mercury	µg/L	N/A[1]	N/A[1]	N/A[1]	0.3	0.1	0.4	1.8	0.1
pH	mg/L	8	8	8.3	7.8	8.1	6.9	6.6	8.1
Sulphate	mg/L	934	1114.6	947.6	143.9	380.5	86.2	28.5	18.8
Sulphide	mg/L	23	38.5	18.2	0.8	4.9	0.3	2.8	0.2
Cadmium	µg/L	0.1	N/A[1]	0.1	0.1	0.3	0.2	1.8	0.5
Copper	µg/L	2	0	1.9	4.7	14.6	28.2	18.4	6.1
Lead	µg/L	0.8	0	2.2	< LOR	9.9	1.2	9	2.9
Total Nitrogen	mg/L	3.2	3.6	4.5	2.9	4.4	3	4.3	1.9
Total Oil	mg/L	1.8	2.6	1.3	1.3	1	0.6	5	0.7
Total Phosphorous	mg/L	0.6	0.9	1.2	0.6	1.3	1	0.6	0.4
Total Suspended Solids	mg/L	19.5	25.7	14	16.4	14.7	22.5	27	21.2
Zinc	µg/L	45	100	43.8	44.2	31.5	39	194	90.9
Turbidity	NTU	81.5	84.5	50.4	18	18.7	12.3	43.6	18.3
Tri-ethylene glycol	mg/L	12.1	56.3	14	5.5	5.7	0	19.9	5.4
Volume (annual total)	m^3	19,869	26,506	12,430	11,907	6,819	10,352	16,065	21,061

Note 1: Not measured in this period.

4.3 Administration Drain

4.3.1 System Overview

The Administration Drain is a concrete-lined open drain that discharges into No Name Creek, an unlined mangrove-fringed watercourse that terminates at a culvert at the site boundary, beyond which water continues to flow into the adjacent mangrove-fringed No Name Bay and Mermaid Sound. No Name Bay is within the general exclusion zone that applies to the KGP and no public access is permitted within 1.5 km of the discharge point.

The Administration Drain receives water from these KGP sources:

- treated sewage from the sewage treatment plant (STP);
- water discharged from the demineralisation water plant (DWP); and
- stormwater run-off.

4.3.2 Sewage Treatment Plant

The KGP STP is licensed to treat and discharge all sewage generated on site, with a maximum design capacity of 170 m^3/day of treated effluent. Peak volumes correspond to periods of elevated staffing, such as during major maintenance events. Average effluent discharge rates during steady state operations are approximately 55 m^3/day.

The STP uses membrane bioreactor technology to treat sewage generated on site, and discharges tertiary-treated effluent to the Administration Drain. Discharges occur automatically approximately two to four times per day, once the buffer tanks reach a specified level. The current STP was commissioned in 2018 and is designed to treat effluent to a very high quality. The STP has discharge specifications to meet water quality parameters (**Table 4-2**) as outlined in the KGP Operational Licence issued in accordance with Part V of the EP Act (L5491/1984).

Table 4-2: Current sewage treatment plant discharge specifications

Parameter	Target
pH	6.5 to 8.5
Total Suspended Solids	< 50 mg/L
Biological oxygen demand	< 20 mg/L
Chemical oxygen demand (COD)	< 125 mg/L
Total nitrogen	< 10 mg/L
Total phosphorus	< 2 mg/L
Total coliforms	< 500 CFU/100 mL
Heavy metals	Below detection limit

Source: KGP Operational Licence L5491/1984. Version 18a at the time of MEQMP preparation.

4.3.3 Demineralisation Water Plant

The KGP DWP treats potable scheme water (using reverse osmosis membrane technology) with a maximum design capacity of 600 m^3/day of demineralised water produced for operational use. Depending on the incoming quality of the supplied scheme water, between 10% and 25% of it will be rejected as brine to the Administration Drain. Because the DWP's only input is potable water, the level for potential impact from discharges from this plant is very low. The brine released from the DWP is designed to achieve TDS levels of less than 4,000mg/l in the reject brine.

4.3.4 Stormwater Run-off

In addition to inflows from the STP and DWP, the Administration Drain also receives stormwater from various areas of the KGP. This stormwater run-off has the potential to be contaminated with residual oils or chemicals, if it has come from areas where there may be residues of these contaminants.

To minimise the risk of accidental spills being discharged together with rainwater, most of the stormwater drainage network has a system have a series of weirs which aim to separate out any oil and allow cleaner stormwater to underflow. In advance of heavy rainfall (e.g. cyclonic rains), these drains are proactively sampled and emptied, as they may overflow during heavy rainfall events. Any overflow would then typically only contain clean run-off, with any residual contaminants being highly diluted with rainwater. Discharge targets applicable to stormwater are shown in **Table 4-3.**

In addition to the general site stormwater collection system, site run-off collected in the main site stormwater drain (referred to as the Road 14 drain) is isolated under normal flow conditions from the discharge point, which is the administration drain. Water held up in the Road 14 drain must meet the discharge criteria or undergo a risk assessment (per **Table 4-3**) before it can be released to the Administration Drain.

Table 4-3: Current stormwater discharge targets

Parameter	Target
pH	6 to 9
aMDEA	15 mg/L
Total oil	10 mg/L

4.3.5 Administration Drain – Potential Contaminants

The Administration Drain receives wastewater from the STP, DWP, and site run-off. Cause–effect pathways for potential impacts on marine environmental quality are associated with emissions from nutrients/organic matter in discharge from the STP, and concentration of contaminants by the reverse osmosis process and potentially contaminated stormwater.

Monthly samples of discharges to the Administration Drain are analysed for the presence of 18 contaminants identified in the KGP Part V Operational Licence and the average results of this sampling are shown in **Table 4-4**. Based on these results and the nature of the receiving environment, the following parameters are considered to be those which will govern the toxicity of the discharge:

- bioaccumulating toxicants:
  - cadmium
  - mercury
- non-bioaccumulating toxicants and stressors:
  - ammonia-N
  - copper
  - lead
  - zinc
  - anionic surfactants
  - aMDEA
  - Total Petroleum Hydrocarbons
  - tri-ethylene glycol
  - sulphide

- nutrients and organics:
- Total Nitrogen
- Total Phosphorus
- pH
- chemical oxygen demand

Table 4-4: Average concentration of licensed discharge parameters in the Administration Drain

Parameter	Units	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
COD	mg/L	17.9	50.5	24	17.2	18	16.8	11.9	18.1
Conductivity	µS/cm	1807.8	1849.6	2239	1639.3	2380.9	2010.6	1715.9	1485.2
Total Nitrogen	mg/L	11.3	11.4	7.3	5.2	19.2	29	20.4	5.1
Total Phosphorous	mg/L	0.5	0.8	1	1.4	1.4	1.4	0.4	0.6
pH	mg/L	8.6	8.8	8.8	9.1	8.4	8.5	8.7	8.9
Sulphate	mg/L	224.8	226.8	563.3	296.2	492.9	319.5	252.3	220.7
Sulphide	mg/L	0	0	0.2	0	0	0	0.5	0.1
Surfactants	mg/L	45.7	4	19	17.5	7.8	9.5	8.1	1.1
Total Suspended Solids	mg/L	16.7	11.8	33.4	13	12	39.2	18.2	250.3
Turbidity	NTU	3.9	4.7	8.5	4	5.8	7.5	4.7	68.9
aMDEA	mg/L	<LOR	<LOR	<LOR	30.2	7.5	0	<LOR	<LOR
Copper	µg/L	5	4	3	4.3	3.1	2.8	2	9.3
Zinc	µg/L	100	50	80	32.5	71.3	157.3	60.5	852.2
Cadmium	µg/L	0.1	nd	0.1	0.1	nd	nd	0.6	1
Lead	µg/L	9	nd	1	nd	3.8	0.9	2.8	6.3
Mercury	µg/L	nd	nd	nd	0.1	nd	nd	0.1	0.1
Total Oil	mg/L	1.2	8.4	1.3	0.9	0.5	0.5	0.9	0.3
Discharge Volume (annual total)	m^3	13,901	16,870	28,683	40,509	31,131	29,673	23,874	27,984

nd = no data,

4.4 Whole Effluent Toxicity Results

Toxicity of discharges from the KGP to the Jetty Outfall have been sampled on five previous occasions. The most recent results were conducted in 2018, as part of the monitoring program that is in place. A detailed description of WET testing methodology and results are presented in Jacobs (2018) and are summarised below. Toxicity testing of discharges to the Administration Drain has not been conducted as, being primarily a sewage discharge, the nature of contaminants in this discharge are less complex and well understood.

The WET testing, conducted on the Jetty Outfall sample from the KGP sampled on 26 June 2018, included eight toxicity tests incorporating a range of tropical and temperate Australian marine species, which were selected based on their ecological relevance, known sensitivity to contaminants, availability of robust test protocols, and known reproducibility and sensitivity as test species for assessing discharge effluent in marine environments.

The tests included:

- bacterial 5- and 15-minute luminescence using *Vibrio fischeri* (acute, temperate)
- microalgal 72-hour growth rate inhibition using *Nitzschia closterium* (chronic, tropical)
- copepod 7-day early life stage development test with *Gladioferens imparipes* (chronic, temperate)
- sea urchin 72-hour larval development with *Echinometra mathaei* (chronic, tropical/subtropical)
- sea urchin 1-hour fertilisation test with *Heliocidaris tuberculata* (chronic, temperate)
- oyster 48-hour larval development test with *Saccostrea echinata* (chronic, tropical)
- sea anemone 8-day pedal lacerate development with *Aiptasia pulchella* (chronic, tropical)
- fish 7-day larval development using *Seriola lalandi* (chronic, tropical/subtropical/temperate).

Toxicity was observed in all eight tests conducted on the KGP effluent, with EC_{50} values ranging from 12% to 65% concentration of effluent. The sea urchin fertilisation test (EC_{50} value of 12% and EC_{10} value of 1.9%) and the 7-day fish embryo development test (EC_{50} value of 12% and EC_{10} value of 9.6%) were most sensitive to the effluent, while the 5-minute Microtox test was the least sensitive (EC_{50} = 65% and EC_{10} = 22%).

The guideline values derived from the species sensitivity distribution in 2018 included a concentration that is protective of 95% of species [(PC95) = 1.7% wastewater] and a concentration that is protective of 99% of species [(PC99) = 0.36% wastewater]. This equates to corresponding safe dilution estimates of 1:59 and 1:280 respectively. The 95% and 99% safe dilutions of the KGP wastewater were 1:340 and 1:2,500 in 2006, indicating that a reduction in wastewater toxicity has occurred. This may be attributable to improvements in wastewater management practices, such as installation of a recirculation system, which was commissioned in 2017.

4.5 Dilution Modelling

4.5.1 Jetty Outfall

Typically expected dilution values from discharges to the Jetty Outfall were modelled using a stochastic model (RPC, 2019). For the stochastical analysis, 150 scenarios were undertaken with wind, tide and phase-of-discharge relative to tide selected randomly for each simulation. Measured winds from a nearby meteorological station over a two-year period between 2016 and 2017 were applied.

The model was run for 24 hours and predicted concentrations stored every hour over the whole grid. Concentrations were converted to dilutions and the durations that they exceeded specified levels of dilution (50, 100, 200, 300, 400, 560) were calculated for each grid cell.

For the 150 scenarios, probability of dilutions exceeding the specified dilution levels for one hour or more were calculated. The 5% probability levels were plotted to provide the minimum dilutions achieved for 95% of modelled scenarios (i.e. 5% of worst-case scenarios were excluded from the plots). These are the minimum number of dilutions expected to be achieved under 95% of typical weather conditions. The results of the model are shown in **Figure 4-2**. While the model only shows the results for 95% of weather conditions, onsite management measures are in place to prohibit discharges from occurring during these worst conditions. However, it was not considered valid to remove these scenarios from the ambient conditions randomly selected for the modelling runs. The worst-case conditions occur on days with a high tidal range, but near still winds (less than 2 m/s). These conditions allow the discharge to be quickly carried out of the nearfield mixing zone and beyond the MEPA boundary before adequate dilution can occur.

The modelled dilution at the boundary of the Jetty Outfall low and moderate ecological protection areas was a minimum of 1:100. The modelled dilutions showed dilution sufficient to achieve the 99% species protection value (PC99 = 0.36% wastewater, equivalent to 280 dilutions – See **Section 4.3**) was always achieved within 400m of the discharge point, but generally occur within 300m (**Figure 4-2**). A theoretical circumstance in which toxicity of the discharge was double was also modelled. It showed only minor exceedance of the current MEPA boundary. Refer to **Section 5** for a description of the ecological protection zone boundaries (i.e. the LEPA & MEPA).

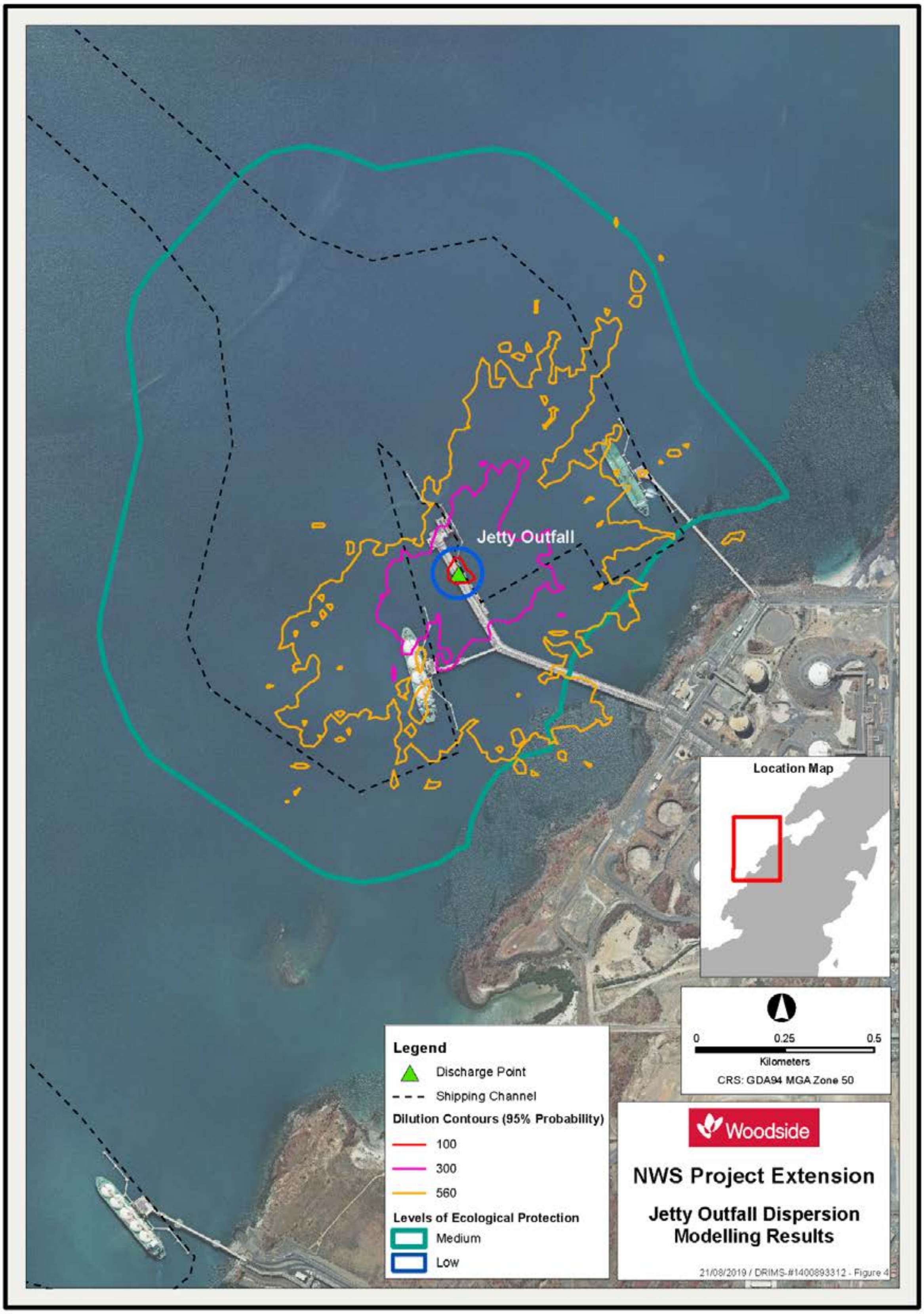

Figure 4-2: Dilution modelling results for the Jetty Outfall (RPC, 2019)

4.5.2 Administration Drain

The Administration Drain discharges into a 300 m long unlined channel known as No Name Creek (NNC) which is tidally inundated with each high tide. Water in NNC can only flow into the receiving marine environment, No Name Bay (NNB), via a series 10" culverts that pass the boundary road at the western edge of the Karratha Gas Plant.

When water is flowing into NNC (with the incoming tide) discharges from the Administration Drain are prevented by the inflowing tide from entering the marine environment. It is not until the tide begins to recede that the now diluted wastewater can flow into NNB. At low tide, the tidal flat extends at least 100m from the point where NNC outflows to NNB and approximately 500 m from where the Administration Drain discharges to the ocean (discharge point). The distance between the Administration Drain discharge point and NNB means that there is insufficient water volume to reach the marine environment unless carried with the outgoing tide. It must first mix with the incoming tide, within NNC, for this to occur.

NNC is densely inhabited by mangroves (where there is tidal influence) and a dense reed bed exists between the intertidal region and the concrete-lined Administration Drain. These mangroves and reeds have all naturally re-colonised NNC, which originally existed as an intertidal creek system which was altered as part of the original KGP development.

The modelling results demonstrate discharges from the Administration Drain receive approximately 150 to 830 dilutions (including the 12.5 dilutions received in the Inner Channel) when it first enters the Bay (depending on the tidal discharge rate). Thereafter, it is dispersed by tide and wind towards the west. At 70m from the discharge location concentrations range from 0% (dilution not applicable) on the flood tide to around 0.08% (1:1,200 dilutions) on the ebb tide (RPC, 2019).

Stochastic modelling was not undertaken for the Administration Drain discharge, as the nature of the receiving environment (into a shallow bay, close to the shoreline) means tidal forcing is the primary factor determining dilution rates. Tidal cycles are predictable and conservative tidal scenario was used to determine the minimum number of expected dilutions at the MEPA boundary. A minimum of 150 dilutions are expected to be achieved at the MEPA boundary in all scenarios. Refer to **Section 5.1** for a description of the ecological protection zone boundaries (i.e. the MEPA).

5. Management Framework

5.1 Environment Quality Plan

The EQO 'maintenance of ecosystem integrity' is to maintain a healthy and diverse ecosystem. For this EQO there are potentially four (low, moderate, high, or maximum) Levels of Ecological Protection (LEP) that may be applied, each corresponding to a different target environmental quality condition (**Table 5-1**). This method is seen as a practicable and auditable way of setting an objective for maintenance of ecosystem integrity while allowing for some discharge of waste to the marine environment in certain areas and under strictly controlled conditions,

Table 5-1: Definition of allowable changes to natural background under levels of ecological protection (EPA 2016a)

LEP	Definition
Low	Allows large changes in abundance and biomass of marine life, biodiversity, and rates of ecosystem processes, but only within a confined area.
Moderate	Applied to relatively small areas within inner ports and adjacent to heavy industrial premises where pollution from current and/or historical activities may have compromised a high LEP.
High	Allows for small measurable changes in the quality of water, sediment, and biota, but not to a level that changes ecosystem processes, biodiversity, or abundance and biomass of marine life beyond the limits of natural variation.
Maximum	Activities to be managed so that there were no changes beyond natural variation in ecosystem processes, biodiversity, abundance, and biomass of marine life or in the quality of water, sediment, and biota.

In 2006, the WA Department of Environment (DoE) published *Pilbara Coastal Water Quality Consultation Outcomes Environmental Values and Environmental Quality Objectives*, aimed at establishing an EQMF for the Pilbara region to help manage and protect the marine environment from the effects of waste inputs and pollution (DoE, 2006). Minor updates to this document were made in 2019, not affecting areas around the NWS Project Facilities. DoE (2006) identified EVs and EQOs relevant to Pilbara coastal waters and outlined the process for developing EQC.

The EPA (2016a) has published Technical Guidance – Protecting the Quality of Western Australia's Marine Environment (EPA, 2016a) that has established DoE (2006) as the approved 'Environmental Quality Plan' for spatially defining LEP for Pilbara coastal waters. The EQP includes a map showing notional LEPs around key infrastructure in Mermaid Sound, included below in **Figure 5-1**.

The EQP establishes required levels of protection for regions immediately surrounding both KGP Discharge points. This document establishes a Marine Environment Quality Management Plan to ensure requirements of the EQP are consistently and reliably achieved. There are no planned or identified likely deviations from the EQP that were identified as occurring with the implementation of this MEQMP.

The nearest point assigned a maximum LEP is approximately 8 km away from the Jetty Outfall, at the entrance to Flying Foam Passage.

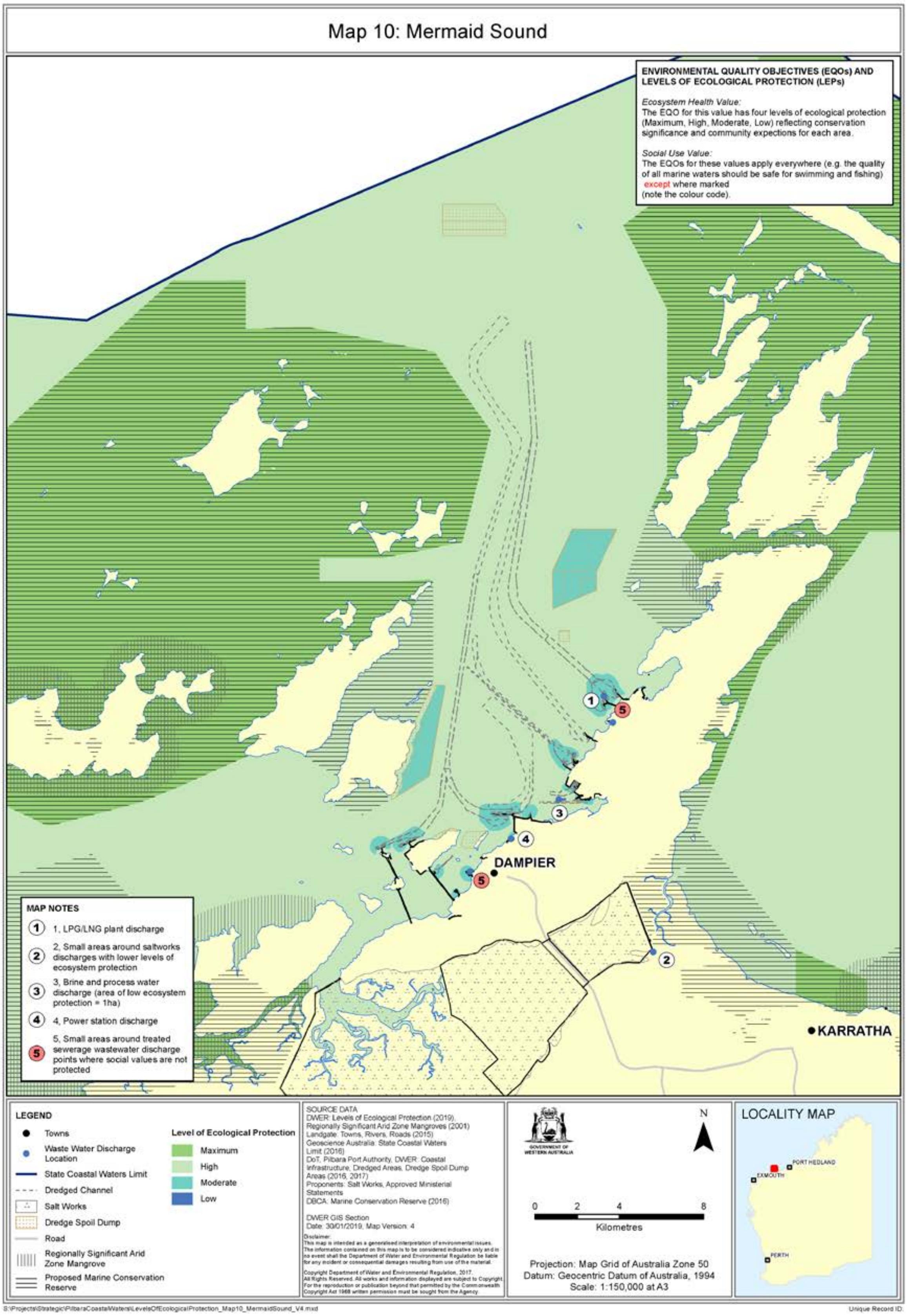

Figure 5-1: Environment Quality Plan for Mermaid Sound, showing infrastructure and established levels of ecological protection (DoE, 2006)

Ecological Protection Areas

Jetty Outfall

Under the existing EQP (**Figure 5-1**), there is a zone of Low Ecological Protection Area (LEPA) (i.e. area in which at least a ‘low’ level of ecological protection is maintained) extending 70m in all directions from the discharge point. Beyond this, the EQP requires a medium level of ecological protection to be maintained (i.e. a Medium Ecological Protection Area (MEPA)), which extends 250 m beyond the turning basins and berthing pockets surrounding the KGP LNG loading jetty, excluding areas where this is within 200 m of the shoreline. While not a uniform shape, the MEPA extends a minimum of 600m from the jetty outfall. The benthic habitats occurring within both the LEPA and MEPA are all classified as ‘silt’ (**Figure 5-2**). Despite the MEPA extending out to a minimum distance of 600m from the Jetty Outfall, WET testing results indicate that enough dilution to achieve the specified 99% species protection value (sufficient to achieve a high level of ecological protection) occurs within 400m of the discharge point, well within the MEPA.

Administration Drain

Within this MEQMP, a MEPA is established extending 70 m in all directions from the point where the artificial channel known as “No Name Creek” discharges into “No Name Bay” via a culvert under the site boundary road. This is shown in **Figure 5-3** as the outfall to ocean.

Within this MEQMP, Environment Quality Criteria (EQC) pertaining to discharges from the Administration Drain are set at a level consistent with achieving Moderate Ecological Protection Area (MEPA) for all water entering in to No Name Bay. Beyond the 70m MEPA, a high level of ecological protection zone applies. All EQC are consistent with values to achieve a high level of ecological protection by this point. All EQC are measured at the existing ‘Administration Drain’ licenced discharge point, as shown in **Figure 5-3**.

As the Administration Drain discharges into a tidally influenced bay, there are no benthic primary producer habitats present (**Figure 5-3**). There are a strand of mangroves lining the Bay into which the discharge occurs as well as an artificially constructed rock embankment that has been colonised by intertidal organisms typical of the region.

The health of the mangroves is monitored as part of the NWS Project ChEMMS program. Currently, mangrove health is monitored annually using the Normalised Difference Vegetative Index (NDVI) assessed using images captured from drone imagery. There have been no anthropogenically derived changes to mangrove health in NNB identified through these surveys.

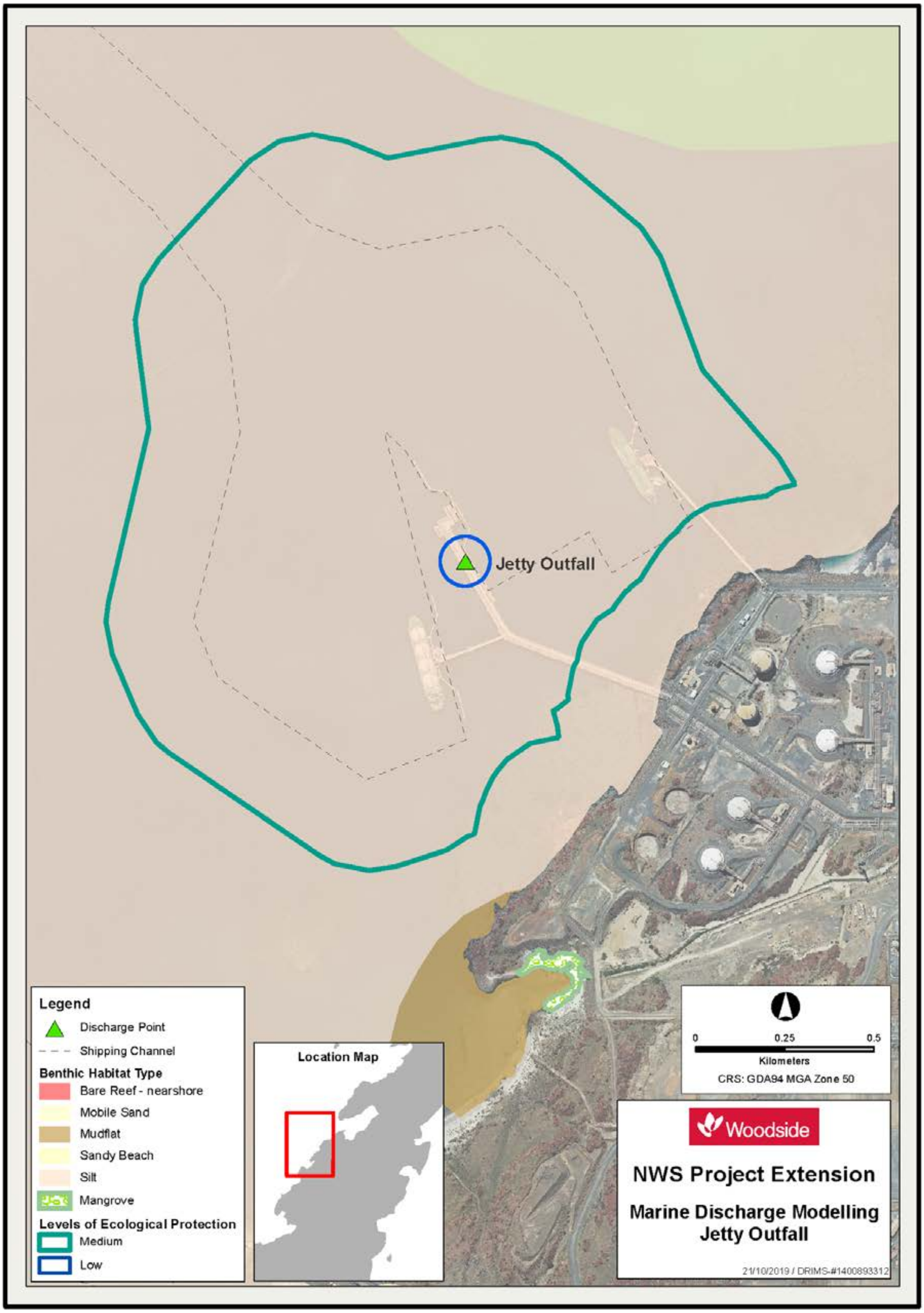

Figure 5-2: Habitats types and ecological protection areas surrounding the KGP Jetty Outfall

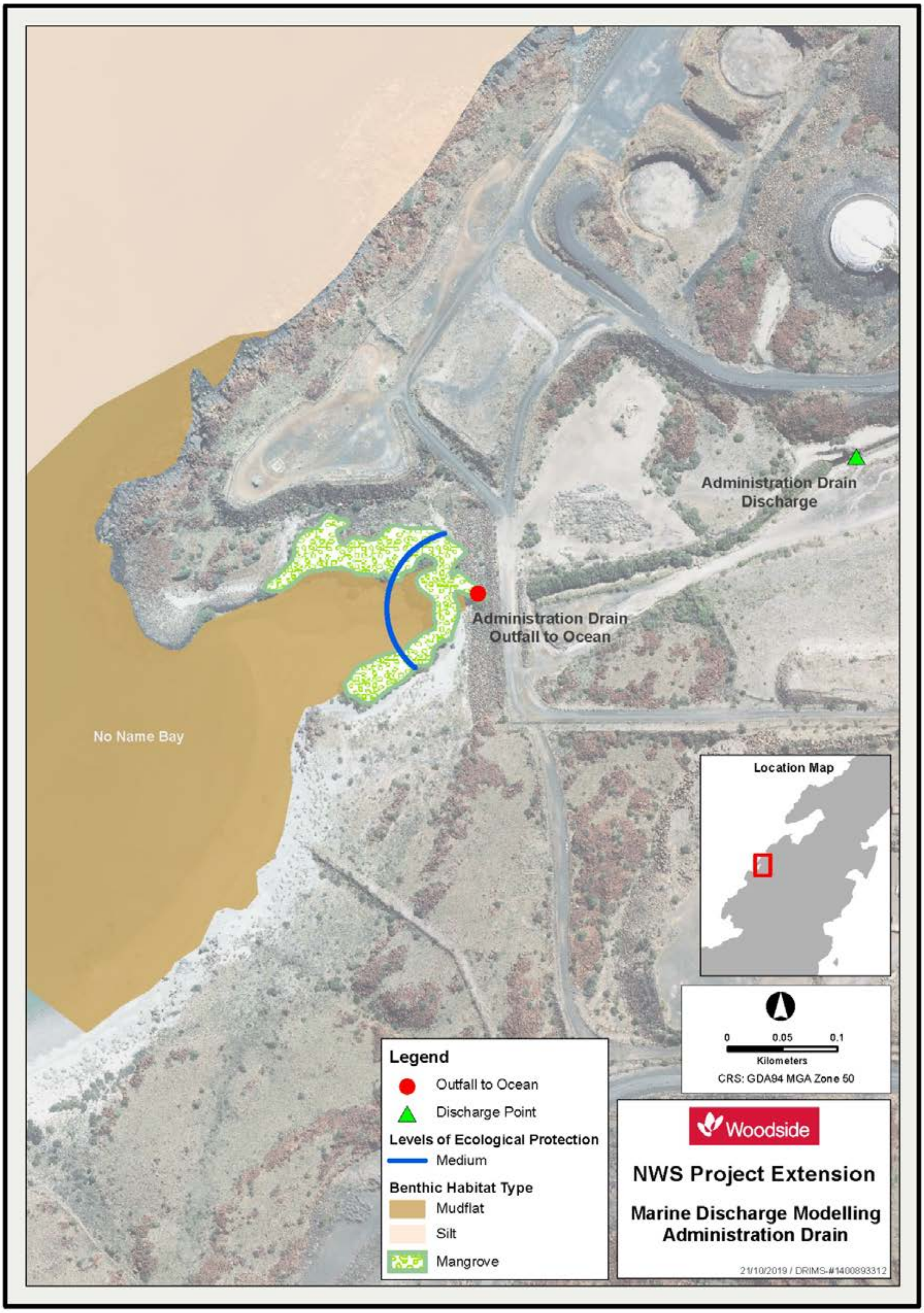

Figure 5-3: Habitat types and ecological protection area surrounding the KGP Administration Drain discharge point

5.2 Environmental Quality Criteria

Environmental quality criteria (EQC) represent scientifically based limits of acceptable change to a measurable environmental quality indicator that is important for the protection of the associated environmental value. The sources of potential impact to marine environmental quality are outlined in **Section 4.1**.

The EQC provide the benchmarks against which environmental quality is measured. Unlike the EVs and EQOs, which are largely qualitative and described narratively, the EQC are more quantitative and are described numerically. The EQC define the limits of acceptable change to the measured environmental quality indicators. They are not compliance limits. The key to successful marine environmental performance under the EQMF is to maintain environmental quality within the bounds of the EQC. If the EQC are met, then it is assumed that the EQOs are met and EVs are protected

There are two levels of EQC:

- EQGs - These are relatively simple and easy-to-measure triggers that, if met, indicate a high degree of certainty that the associated EQO was achieved. If the EQG is not met, there is uncertainty as to whether the associated EQO was achieved and a more detailed assessment against the EQS is required.
- EQSs - These are numerical values or narrative statements that, if not met, indicate a significant risk that the associated EQO has not been achieved and a management response is required. The management response focuses on identifying the cause (or source) of the exceedance and then reducing the loads of the contaminant of concern.

5.2.1 Environmental Quality Guidelines for discharges from the Jetty Outfall

The Jetty Outfall receives wastewater from the KGP process water and site run-off. Potential cause–effect pathways of impacts on marine environmental quality are associated with emissions from the production of gas and fluids by KGP processes. EQC are centred around identifying and managing contaminants (particularly hydrocarbons) in the wastewater (**Table 5-2**).

Table 5-2: Environment quality guidelines identified as relevant to the Jetty Outfall

Potential Impact	Source of Impact	Environmental Quality Guideline
Bioaccumulation of toxicants in biota	Discharge of bioaccumulating toxicants	Concentrations of contaminants in the waste stream will not exceed the ANZG (2018) 80% species protection guideline
Toxic effect of toxicants/stressors on biota	Discharge of non-bioaccumulating toxicants and stressors	95%ile of annual concentrations of contaminants in the waste stream will not exceed specified values
Accumulation of toxicants in sediments	Discharge of toxicants	Sediment total contaminant concentration of specified toxicants immediately beyond the Moderate Ecological Protection Area boundary will not exceed the specified values.

5.2.2 Environmental Quality Guidelines for discharges to No Name Bay from the Administration Drain

The Administration Drain receives wastewater from the STP, DWP, and site run-off. Potential cause–effect pathways of impacts on marine environmental quality are associated with emissions from the production of gas and fluids by the KGP processes, nutrients/organic matter in discharge from the STP, and concentration of salts or solids by the reverse osmosis process. EQC are centred around identifying and managing contaminants (particularly hydrocarbons), nutrients, and organic matter in the wastewater (**Table 5-3**).

Table 5-3: Environment quality guidelines identified as relevant to the Administration Drain

Potential Impact	Source of Impact	Environmental Quality Guideline
Bioaccumulation of toxicants in biota	Discharge of bioaccumulating toxicants	Concentrations of specified bioaccumulating contaminants in the waste stream will not exceed the ANZG (2018) 80% species protection guideline.
Toxic effect of toxicants/stressors on biota	Discharge of non-bioaccumulating toxicants and stressors	Concentrations of contaminants in the waste stream will not exceed specified values.
Accumulation of toxicants in sediments	Discharge of toxicants	Sediment total contaminant concentration immediately beyond the MEPA boundary will not exceed the specified values.
Nutrient enrichment and algal growth	Discharge of nutrients	Nutrient concentrations in the discharge will not exceed the exceed the specified values.

5.3 Rationale for Provisions

Formal management provisions (e.g. EQC) have yet to be established for the Pilbara region (DoE, 2006). In the absence of regionally specific EQC, those described here are based on those in the Environmental Quality Criteria Reference Document for Cockburn Sound (EPA, 2017). The framework adopted for applying EQC to Cockburn Sound is consistent with the approach applied to WA coastal waters generally (EPA, 2016b) and the National Water Quality Management Strategy (ANZG, 2018).

6. Management Provisions

For each environmental indicator monitored, the relevant EQC serve as a benchmark against which the monitoring data can be compared to determine whether the EQO has been achieved. If an EQG is exceeded, assessment against the EQS will commence. If an EQS is exceeded, a management response is required to ensure the EQO continues to be achieved. These responses are specific to maintaining the relevant EQO that is at risk of not being met. The response after triggering EQG/EQS typically requires reporting to the relevant agency (WA Department of Water and Environmental Regulation [DWER]). Responses include further investigations to determine the extent and source of the environmental impact and/or applying management options to reduce the impact.

Table 6-1: Outcomes-based provisions for planned discharges from the Jetty Outfall and Administration Drain to the marine environment

Environment Quality Objective	Monitoring Target	Monitoring	Environment Quality Guidelines	Management Response / Reporting	Environment Quality Standards	Management Response / Reporting
Maintenance of ecosystem integrity	Bioaccumulating toxicants	Monitoring discharges from the Jetty Outfall for dissolved cadmium and mercury	**EQG 1** Annual 95th percentile concentrations of contaminants in the waste stream will not exceed the ANZG (2018) 80% species protection guideline for bioaccumulating toxicants listed in Column 2 of **Table 7-2**.	Report the exceedance to DWER in the Annual Environment Report. Assessment against EQS 1 will then commence.	**EQS 1** Median concentrations of cadmium and mercury in oyster tissue from sites near the boundary of the Moderate Ecological Protection Area are ≤80th percentile of tissue concentrations from a suitable reference site.	Any exceedance of the EQS will be reported to the DWER within five working days of determining that this has occurred. The significance of the exceedance and any required investigation/action will be determined following communication with the DWER.
Maintenance of ecosystem integrity	Non-bioaccumulating toxicants and stressors	Monitoring discharges from the Jetty Outfall for toxicants and stressors of concern, as listed in Column 2 of **Table 7-7**.	**EQG 2** Annual 95th percentile concentrations of contaminants in the waste stream will not exceed values listed in Column 2 of **Table 7-7**.	Report the exceedance to the DWER in the Annual Environment Report. Assessment against EQS 2 will then commence.	**EQS 2** The EQS will be exceeded where modelled dilution expected at either the LEPA and MEPA boundaries are lower than the number of dilutions required to achieve 90% and 99% species protection, respectively determined through whole effluent toxicity testing.	Any instances of an exceedance of the EQS will be reported to the DWER within five working days of determining that this has occurred. The significance of the exceedance and any required investigation/action will be discussed with the DWER.

Environment Quality Objective	Monitoring Target	Monitoring	Environment Quality Guidelines	Management Response / Reporting	Environment Quality Standards	Management Response / Reporting
Maintenance of ecosystem integrity	Sediment contamination	Five-yearly monitoring of sediments	**EQG 3** A) Median sediment total contaminant concentration at the HEPA boundaries will not exceed the ANZG (2018) default guideline values (DGVs) as specified in **Section 7.3.2.1** B) Total contaminant concentration at individual sample sites will not exceed the ANZG (2018) high guideline value (GV-high).	Report the exceedance to DWER in the Annual Environment Report. An investigation against EQS 3 will then be conducted, in accordance with the framework developed in the Environmental Quality Criteria Reference Document for Cockburn Sound (EPA, 2017).	**EQS 3** A) The 80th percentile of bioavailable metal or metalloid concentrations in sediments from the defined sampling area will not exceed the ANZG (2018) default guideline values (DGVs) as specified in **Section 7.3.2.1.** B) The median bioavailable concentration for non-metallic contaminants from the defined sampling area will not exceed ANZG (2018) default guideline values (DGVs) as specified in **Section 7.3.2.1**. C) The median tissue concentration of chemicals that can adversely bioaccumulate or biomagnify will not exceed the 80th percentile of tissue concentrations from a suitable reference site.	The management response based on an exceedance of the EQS is: Management measures to reduce the contaminant(s) of concern will be implemented, along with monitoring to confirm that the required results are being achieved. The monitoring could include wastewater characterisation, further WET tests, and in situ monitoring, subject to further consultation with the DWER.
Maintenance of ecosystem integrity	Bioaccumulating toxicants	Monthly monitoring of Administration Drain discharges for dissolved cadmium and mercury	**EQG 4** Annual 95th percentile concentrations of contaminants in the waste stream will not exceed the ANZG (2018) 90% species	Report the exceedance to the DWER in the Annual Environment Report. Assessment against EQS 4 will then commence.	**EQS 4** Median concentrations of metals that may bioaccumulate (cadmium and mercury) in oyster tissue from sites near the boundary of the MEPA are lower than or equal to the	Any instances of an exceedance of the EQS will be reported to the DWER within five working days of determining that this has occurred. The significance of the

Environment Quality Objective	Monitoring Target	Monitoring	Environment Quality Guidelines	Management Response / Reporting	Environment Quality Standards	Management Response / Reporting
			protection guideline for bioaccumulating toxicants, as listed in Column 3 of **Table 7-12**. 80% species protection values applies for Zinc.		80th percentile of tissue concentrations from a suitable reference site.	exceedance and any required investigation/action will be discussed with the DWER.
Maintenance of ecosystem integrity	Non-bioaccumulating toxicants	Monitoring of Administration Drain discharges for toxicants listed in **Table 7-6**.or pH	**EQG 5** Annual 95th percentile concentrations of contaminants in the waste stream will not exceed the site-specific triggers as listed in Column 3 of **Table 7-7**.	Report the exceedance to the DWER in the Annual Environment Report. Assessment against EQS 5 will then commence.	**EQS 5** The EQS will be exceeded where modelled dilution expected at the MEPA and boundary are lower than the number of dilutions required to achieve 99% species protection, determined through whole effluent toxicity testing.	Any instances of an exceedance of the EQS will be reported to the DWER within five working days of determining that this has occurred. The significance of the exceedance and any required investigation/action will be discussed with the DWER.
Maintenance of ecosystem integrity	Nutrients as stressors	Monitoring of Administration Drain discharges for total nitrogen and phosphorus	**EQG 6** Annual 95th percentile concentrations in the discharge will not exceed the values specified in **Table 7-11**.	Report the exceedance to the DWER in the Annual Environment Report Assessment against EQS 6 will then commence.	**EQS 6** No increases in sediment organic enrichment (total nitrogen & total phosphorus) that can be attributed to wastewater nutrients beyond the MEPA boundary.	Any instances of an exceedance of the EQS will be reported to the DWER within five working days of determining that this has occurred. The significance of the exceedance and any required investigation/action will be discussed with the DWER.

7. Monitoring

7.1 Bioaccumulating Toxicants

7.1.1 Timing

Measurement of bioaccumulating toxicants in the Jetty Outfall discharge will be undertaken each time water is discharged to the marine environment (EQG 1).

Measurement of bioaccumulating toxicants in the Administration Drain discharge will be undertaken monthly (EQG 4).

7.1.2 Environmental Quality Criteria

EQGs and EQSs have been defined for bioaccumulating toxicants (**Table 7-1**). Only relevant contaminants of concern (as per **Section 4.2.4** and **Section 4.3.5**) are subject to the EQC.

Table 7-1: Environmental Quality Criteria for bioaccumulating toxicants

Environmental Quality Guideline	Environmental Quality Standard
EQG 1 and EQG 4 Annual 95th percentile concentrations of contaminants that may bioaccumulate (cadmium and mercury) in the waste stream will not exceed their ANZG (2018) 80% species protection guideline (EQG1) or 90% species protection guidelines (EQG4).	**EQS 1 and EQS 4** Median concentrations of metals that may bioaccumulate (cadmium and mercury) in oyster tissue from sites near the boundary of the Jetty Outfall MEPA (EQS 1) / Admin Drain MEPA (EQS 4) are lower than or equal to the 80th percentile of tissue concentrations from a suitable reference site.

7.1.2.1 Environmental Quality Guideline

The wastewater characterisation sample used to compare water quality against the EQG will be a sample of wastewater collected prior to discharge (for EQG 1) or of a representative stream during continuous discharge (EQG 4).

Samples will be collected, stored and handled using appropriate techniques. All analyses will be undertaken by NATA-accredited laboratories.

Given the nature of these discharges and the receiving environment, a one-off exceedance of the EQG trigger value does not present an immediate risk to exceeding the EQS or associated EQO. Compliance with the EQG will be assessed annually. However, sampling results will be reviewed quarterly and trends compared to guideline values as an early warning indicator of potential exceedances. Any trigger values that are not achieved will be identified through this quarterly discharge review process.

This EQG applies to the concentration in contaminants within the waste streams only when discharged to the environment but prior to dilution occurring (i.e. end of pipe concentrations).

Table 7-2: 80% species protection guideline for bioaccumulating toxicants of concern (ANZG, 2018)

Parameter	Jetty EQG[1] (mg/L)	Administration Drain EQG[2] (mg/L)
Cadmium	0.036	0.014
Mercury	0.0014	0.007

Note 1: Value for protection of 80% of species stated in ANZG (2018), consistent with requirements for Low Ecological Protection Areas.

Note 2: Value for protection of 90% of species stated in ANZG (2018), consistent with requirements for Moderate Ecological Protection Areas.

7.1.2.2 Environmental Quality Standard

Oysters will be investigated for contamination if wastewater characterisation indicates that the concentrations of bioaccumulating contaminants exceed ANZG (2018) 80% species protection guidelines prior to dilution (i.e. EQG 1 and EQG 4).

Naturally occurring shellfish will be collected in situ, from sites as close to the relevant management boundaries as practicable. The numbers of individuals collected at each site will depend on availability but will be enough to account for variability between individuals. A random selection of live adult shellfish of the relevant species will be collected from the nearest suitable surface (e.g. rock ledges, wharf pylons, channel markers) to each sampling site. The animals will be bagged and stored on ice/frozen before being transported to the laboratory. Appropriate handling practices will be used to minimise the risk of contamination.

Although seafood is not permitted to be collected and consumed by the public from within the MEPA, as it is within the KGP maritime exclusion zone, the risk of bioaccumulating toxicants to marine ecosystem health will be assessed by comparing the median concentration of toxicants in the oyster flesh collected from this region with the maximum safe eating levels provided by the Australia New Zealand Food Standards Code (ANZ FS Code) – Standard 1.4.1 – Contaminants and natural toxicants (**Table 7-3**).

Table 7-3: Environment quality standard for bioaccumulating toxicants in Oysters

Parameter	EQS (mg/kg)[1]
Cadmium	2
Mercury	0.5

Note 1: Sourced from Australia New Zealand Food Standards Code.

7.2 Non-bioaccumulating Toxicants

7.2.1 Timing

Measurement of non-bioaccumulating toxicants in the Jetty Outfall will be undertaken each time water is discharged to the marine environment (EQG 2).

Measurement of non-bioaccumulating toxicants in the Administration Drain will be undertaken monthly (EQG 5).

7.2.2 Environmental Quality Criteria

EQGs and EQSs have been defined for toxicants (**Table 7-4**).

Table 7-4: Environmental quality criteria for non-bioaccumulating toxicants

Environmental Quality Guidelines	Environmental Quality Standards
EQG 2 and EQG 5 Annual 95th percentile concentrations of contaminants in the waste stream will not exceed the site-specific triggers listed in **Table 7-7**. These are derived from the ANZG (2018) 90/99% species protection guidelines or existing internal monitoring limits where guidelines are unavailable, corrected for dilution after discharge and accounting for background levels.	**EQS 2 and EQS 5** The EQS will be exceeded where modelled dilution expected at either the LEPA and/or MEPA boundary are lower than the number of dilutions required to achieve 90 and 99% species protection (as relevant), determined through whole effluent toxicity testing.

7.2.2.1 Environmental Quality Guideline

Sampling protocol

The wastewater characterisation sample will be a representative sample of wastewater collected prior to discharge (for EQG 2) and of a representative stream during continuous discharge (EQG 5).

Samples will be collected, stored and handled using appropriate techniques. All analyses will be undertaken by NATA-accredited laboratories. Samples for bioavailable metals will be passed through a 0.45 µm filter before analysis.

Derivation of EQG values

Where possible the EQGs are based on the default ANZG (2018) marine guidelines for maintaining the associated level of ecological protection, scaled to account for dilutions achieved at the edge of the management zone boundary (the number of dilutions were determined by modelling), as per a modified formula in Zaker et al. (2001) (which also factors in background concentrations):

$$Trigger\ value = \left(Dilution\ x\ (guideline - background)\right) + background$$

where 'background' is the background concentration of the contaminant in seawater and 'dilution' is the modelled dilution at the relevant ecological protection boundary.

Section 4.5 of this MEQMP describes the dilution modelling that was conducted for wastewater discharges. The modelled dilution at the edge of the Jetty Outfall LEPA was 1:100. Dilutions required to achieve a high level of ecological protection were 280, which was reliably achieved within 400 m the discharge point, well within the MEPA boundary specified in the EQP. The achieved dilutions at the edge of the Administration Drain low ecological protection area were modelled to be a minimum of 1:150. These dilution values were utilised for deriving discharge specific EQG values.

EQG for maintaining both a high and moderate level of ecological protection (99 and 90% species protection levels, respectively) were calculated for the Jetty Outfall (**Table 7-5**) and high level of ecological protection for the Administration Drain (**Table 7-6**). The most conservative (i.e. lowest) was selected as the site-specific trigger value, with a listed of compiled triggers for each discharge point shown in **Table 7-7**.

For contaminants where no ANZG (2018) trigger is available, long-term internal criteria were adopted. For all internally derived triggers, EQG values ensure that, after dilution, values at the edge of the MEPA are at or near laboratory limits of detection. These internal working targets have been in place for a considerable time, with no evidence observed of associated adverse environmental effects.

The area immediately (i.e. within 70 m) around the Jetty Outfall has been afforded a low level of ecological protection (DoE, 2006). The Jetty Outfall low ecological protection area is contained within a broader moderate ecological protection area surrounding the shipping infrastructure. The Administration Drain moderate ecological protection area is within a surrounding high level of ecological protection area.

Table 7-5: Published environmental guideline values and derived EQG values for non-bioaccumulating toxicants relevant to Jetty Outfall discharges

Parameter	Guideline Value (µg/L)[1]	Background (µg/L)	Derived EQG (µg/L)	Derived EQG (mg/L)
Moderate Protection (ANZG 90% Species Protection Value)				
Ammonia-N	1,200	9.8[1]	119,030	119
Copper	3	0.165[2]	284	0.28
Lead	6.6	0.01[2]	659	0.66
Zinc	23	0.14[2]	2,286	2.3
High Protection (ANZG 90% Species Protection Value)				
Ammonia-N	500	9.8[1]	137,266	137
Copper	0.3	0.165[2]	38	0.38
Lead	2.2	0.01[2]	613	0.61
Zinc	7	0.14[2]	1,921	1.9

Note 1: From Pearce et al (2003)

Note 2: From Table 15 of Wenziker et al (2006)

Table 7-6: Published environmental guideline values and derived EQG values for non-bioaccumulating toxicants relevant to Admin Drain discharges

Parameter	Guideline Value (µg/L)[1]	Background (µg/L)	Derived EQG (µg/L)	Derived EQG (mg/L)
Moderate Protection (ANZG 90% species protection value)				
Ammonia-N	1,200	9.82[2]	14,292	14
Copper	3	0.165[3]	34	0.03
Lead	6.6	0.013[3]	79	0.08
Zinc	43[1]	0.14[3]	514	0.5
High Protection (ANZG 99% species protection value)				
Ammonia-N	500	9.8[2]	73,540	74
Copper	0.3	0.165[3]	20	0.02
Lead	2.2	0.01[3]	329	0.33
Zinc	7	0.14[3]	1,029	1.0

Note 1: The 80% species protection value has been applied for zinc. Elevated levels of zinc have occasionally been detected in the Admin Drain runoff.

Note 2: Sourced from Pearce et al (2003)

Note 3: Sourced from Table 15 of Wenziker et al (2006)

Table 7-7: Site specific (compiled) triggers for toxicants in Jetty Outfall and Administration Drain discharge

Parameter	Jetty Outfall EQG triggers (mg/L)	Admin Drain EQG triggers (mg/L)
Non-bioaccumulating toxicants with trigger values derived from ANZG (2018)[1]		
Ammonia-N	119	14
Copper	0.28	0.02
Lead	0.61	0.08
Zinc	1.9	0.5
Non-bioaccumulating toxicants with internally determined trigger values[2]		
Anionic surfactants	150	150
aMDEA	15	15
Total petroleum hydrocarbons	10	10
Tri-ethylene glycol	100	100
Sulphide	1	1
Stressors		
pH	6 to 9	6 to 9
COD	200	200

Note 1: Derived using methodology described in **Section 7.2.2.1**.

Note 2: See below for an explanation as to the suitability of these limits.

Given the nature of these discharges and the receiving environment, a one-off exceedance of the EQG trigger value does not present an immediate risk to exceeding the EQS or associated EQO. Compliance against the EQG will be assessed annually. However, sampling results are reviewed quarterly and trends compared to guideline values as an early warning indicator of potential exceedances. Any trigger values that are exceeded can be identified through this quarterly discharge review process.

Internally derived trigger values

Where approved guideline values were not available in published literature, the internally determined trigger values currently in place at KGP were utilised. These values have been the discharge limits applicable to the two licenced discharge points for many years. In the case of the Jetty Outfall discharges, internally derived trigger values are complemented by the completion of three yearly whole effluent toxicity testing to determine a 99% species protection value that considers the acute and chronic toxicity of the waste stream. The results of this WET testing are reviewed against modelled dilution values to confirm ensure that the relevant MEPA/HEPA boundaries continue to be achieved. These results are supported by the results of the ecological monitoring program which continue to demonstrate impacts from these discharges in aligned to the relevant ecological protection target levels.

In relation to the Administration Drain, these parameters are not expected to be present in the discharge but EQG values have been set consistent with the Jetty Outfall.

7.2.2.2 Environmental Quality Standard

Whole Effluent Toxicity (WET) testing is a direct indicator of toxicity and involves exposing organisms to dilutions of wastewater and determining its impact on their health, growth or reproduction over a selected period. The full suite of WET testing measures the responses of several biota (from a number of trophic levels) to a range of salt-adjusted wastewater solutions. The number and type of tests will be determined at the time and will include at least five species from at least four taxonomic groups. Previous WET testing results and associated methods are described in Jacobs 2018. Data generated are used to calculate the toxicity of wastewater required to protect 90 - 99% of species and this will be done using the BurrliOZ 2.0 software or equivalent relevant statistical package. The samples used to conduct WET testing are grab samples of wastewater collected prior to discharge.

Dilutions required to be protective of the environment are expected to be lower than modelled dilutions at the relevant management zone boundary - these are 1:100 at the boundary of the Jetty Outfall LEPA/MEPA and a minimum of 1:500 at the MEPA/HEPA boundary, however detailed modelling results should be consulted when interpreting compliance with the Jetty Outfall EQC. A minimum dilution of 1:150 is achieved at the boundary of the Administration Drain MEPA/HEPA. Dilutions achieved within the No Name Creek channel are approximately 12.5, between the licenced discharge point and entry into the No Name Bay MEPA.

7.3 Sediments

7.3.1 Timing

Sediments at the boundary of the Jetty Outfall MEPA and Administration Drain MEPA will be sampled every five years. Sediment sampling will also be conducted in the year following an exceedance of EQG 1 or EQG 4.

7.3.2 Environmental Quality Criteria

An EQG and EQS have been defined for toxicants in sediment (**Table 7-8**).

Table 7-8: Environmental Quality Criteria for sediments

Environmental Quality Guidelines	Environmental Quality Standards
EQG 3 A) Median sediment total contaminant concentration at the HEPA boundaries will not exceed the ANZG (2018) DGVs as specified in **Section 7.3.2.1** B) Total contaminant concentration at individual sample sites will not exceed the ANZG (2018) GV-high. If so, repeat sampling will be conducted to define the extent of the contamination, which will be assessed as in point A.	**EQS 3** Depending on the contaminant exceeding the EQG, either of the following EQS may apply; A) The 80th percentile of bioavailable metal or metalloid concentrations from the defined sampling area should not exceed the EQG. B) The median bioavailable concentration for non-metallic contaminants from the defined sampling area should not exceed the EQG. C) The median tissue concentration of chemicals that can adversely bioaccumulate or biomagnify will not exceed the 80th percentile of tissue concentrations from a suitable reference site.

7.3.2.1 Environmental Quality Guideline

Sediment contaminant concentrations in areas beyond the Jetty Outfall MEPA or Administration Drain MEPA will be compared directly to the DGVs listed in ANZG (2018). The use of these values as EQGs is consistent with the DEC (2006) recommendations. The concentrations of total petroleum hydrocarbons (TPH) will be normalised to 1% total organic carbon (TOC) before comparison with the guidelines. For TOC contents of less than 0.2% or greater than 10%, multiplication factors of 5 and 0.1 will be used for normalisation, respectively.

If an individual site exceeds the GV-high trigger for contaminants in sediments, additional sampling will be conducted to define the spatial extent of the contamination; this sampling will be assessed against the DGV. Where applicable, only bioavailable concentrations of contaminants will be compared to guideline values.

Table 7-9: Environmental Quality Guideline values for sediments (ANZG, 2018)

Potential Contaminant	DGV (mg/kg dry weight)	GV-high (mg/kg dry weight)
Cadmium	1.5	10.0
Chromium	80	370
Copper	65	270
Lead	50	220
Mercury	0.15	1.0
Zinc	200	410
TPH	280	550
PAH	4000	4500

There are currently no formally recognised screening levels for PFOA, PFOS or PFAS in any media for use in Australia. As an interim measure, DER have recommended screening values in the Interim Guideline on the Assessment and Management of Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS) (DWER, 2017). These are shown in **Table 7-10** below and will be used to assess impacts from firefighting foam in sediments. These substances are not routinely used on site and would only be discharged in emergency circumstances.

Table 7-10: Interim screening values to be utilised for sediment EQG relating to PFOS/PFOA (DWER, 2017)

Potential Contaminant	Guideline Value[1]
PFOA	40 mg/kg
PFOS / PFHxS	100 mg/kg

Note 1: Values for soil have been assumed relevant, in the absence of authorised sediment guideline values.

7.3.2.2 Environmental Quality Standard

An investigation against the EQSs will be conducted in accordance with the framework developed in the Environmental Quality Criteria Reference Document for Cockburn Sound (EPA, 2017). These EQSs are adapted from the risk-based approach recommended in ANZG (2000), which is:

- if the contaminant of concern is a metal or metalloid, adopt EQS 3A.
- if the contaminant of concern is an organometallic or organic contaminant, adopt EQS 3B.
- if the contaminant of concern has the potential to bioaccumulate, adopt EQS 3C.

7.4 Nutrients

7.4.1 Timing

Wastewater characterisation for nutrients in discharges from the Administration Drain will be undertaken monthly.

7.4.1.1 Environmental Quality Criteria

An EQG and EQS have been defined for nutrients (**Table 7-11**). These EQC only apply to discharge from the Administration Drain.

Table 7-11: Environmental Quality Criteria for nutrients in discharges from the Administration Drain

Environmental Quality Guidelines	Environmental Quality Standards
EQG 6 Annual 95th percentile concentrations in the discharge will not exceed the values specified in **Table 7-12**.	**EQG 6** No increases in sediment organic enrichment (total nitrogen & total phosphorus) that can be attributed to wastewater nutrients beyond the MEPA boundary.

7.4.1.2 Environmental Quality Guideline

The wastewater characterisation sample will be a grab sample of water collected from the Administration Drain discharge stream during continuous discharge using appropriate collection techniques. All analyses will be undertaken by NATA-accredited laboratories. The EQGs for nutrients are summarised in **Table 7-12**. Annual 95th percentile nutrient concentrations will be compared to these values.

Table 7-12: Wastewater discharge guideline values for nutrients in discharges from the Administration Drain

Parameter	EQG trigger values (mg/L)
Total phosphorus	5
Total nitrogen	30

7.4.1.3 Environmental Quality Standard

The EQS is based on an assessment of sediment nutrient and organic carbon concentrations to identify potential enrichment. Concentrations for total nitrogen and total phosphorous at sides immediately beyond the MEPA will be compared directly to 80th percentile values in unimpacted reference areas. This is consistent with the methodology applied in EPA (2017), as relevant to High Ecological Protection Areas which is the classification of region immediately beyond the Administration Drain MEPA.

8. Adaptive Management and Review of the EMP

8.1 Adaptive Management

Recognising that the nature of the discharge, the environment, and the science underpinning environmental impact assessment is not static, adaptive management also allows monitoring programs to feed back into the management processes so that environmental management continues to be fit-for-purpose. The EQMF that underpins this MEQMP is inherently an adaptive management framework.

In line with the concept of adaptive management, the management actions presented in this MEQMP shall be monitored, reviewed, evaluated and updated, as required, considering:

- Persistent exceedances, systematic changes to the discharge/environmental conditions, and/or changes to the science underpinning the monitoring and management of marine discharges
- There are material updates to the scientific literature supporting the guideline values or management framework underpinning this MEQMP
- A comparison of monitoring data that shows unexpected results, which vary significantly from previous and baseline results or predictions
- The results of annual chemical characterisation or WET testing that indicate changes that warrant remodelling of the mixing zone, which could result in a change to the existing LEP established in the marine environment adjacent to the KGP
- The results of annual chemical characterisation testing detects contaminants in the waste stream at levels where guideline values may be exceeded if discharged, specifically reviewing the concentrations of BTEX and PAH in the waste stream.

With relevant updates included in a revised MEQMP. In addition, this MEQMP may be reviewed:

- Changes in State or Commonwealth legislation or policy.
- Based on EPA and decision-making authorities (DMAs) comments during the Environmental Review Document (ERD) approval process
- After any new or revised operating licence is issued under Part V of the *Environmental Protection Act 1986 (WA)*
- If a significant environmental incident occurs related to the protection of ambient air quality and human health
- If a new process or activity is proposed to be introduced that has the potential to alter the emissions from the Proposal (and that is not in accordance with this AQMP)

Technical review and evaluation of the management actions outlined in this MEQMP will be conducted every five years[1] (if not initiated prior to that time) to ensure the management actions are adequately addressing the key risks and meeting EPA objectives. If, as a result of any review, any significant changes are required to be made to this MEQMP, a revised MEQMP will be provided to the EPA for approval.

When the five-yearly review cycle is triggered, or if a significant change to either the facility, activity, or risk is identified, a revised MEQMP will be submitted to the EPA. When approved, the revised plan will be made publicly available.

[1] Frequency no more than annually.

9. Stakeholder Consultation

Comprehensive public consultation was undertaken by the DoE to develop EVs, EQOs, and LEPs for the greater Pilbara coast, including the waters of Mermaid Sound (DoE, 2006). This process resulted in a robust and publicly approved basis for establishing an interim Environmental Quality Plan (EVs, EQOs, and LEPs) for the waters of Mermaid Sound surrounding the NWS infrastructure. The EQP remains a key guideline for managing potential impacts to the marine environment in Northern WA and has been identified as the EPA as being the formal EQP for management of the marine environment in this region.

This MEQMP is included as an Appendix to the ERD for the Proposal (Woodside, 2019) and therefore is reviewed by the EPA, key decision-making authorities (DMAs), and the general public as part of the assessment process for the ERD. Relevant comments received from the EPA and DMAs during the initial review are incorporated into this MEQMP before publication of the ERD (and associated management plans) for public review and comment. All comments received during the public review period that relate to this MEQMP are considered, and changes made to this MEQMP where required.

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11. Terms

Terms	Definitions
~	Approximately
<	Less/fewer than
>	Greater/more than
≤	Less than or equal to
µg	Microgram
µm	Micrometre
µS	micro Siemens
1TL, 2TL	Subsea trunklines
aMDEA	Activated methyl diethanolamine
ANZECC	Agriculture and Resource Management Council of Australia and New Zealand
ARMCANZ	Australian and New Zealand Environment and Conservation Council
CFU	Colony-forming unit; used to estimate the number of viable bacteria or fungal cells in a sample
cm	Centimetre
COD	Chemical oxygen demand
DGV	Default Guideline Value
DMA	Decision-making Authority
DoE	Former Western Australian Department of Environment
Domgas	Domestic Gas
DWER	Western Australian Department of Water and Environmental Regulation
DWP	Demineralisation Water Plant
EC_{10}	A concentration or dose that yields biological effects in 10% of test animals/species
EC_{50}	A concentration or dose that yields biological effects in 50% of test animals/species
EMP	Environmental Management Plan
EP	Environmental Plan
EP Act	Western Australia *Environmental Protection Act 1986*
EPA	Western Australian Environmental Protection Authority
EQC	Environmental Quality Criteria
EQG	Environmental Quality Guidelines
EQS	Environmental Quality Standard
EQMF	Environmental Quality Management Framework
EQO	Environmental Quality Objective
ERD	Environmental Review Document
EV	Environmental Value
GV-high	Guideline Value (high)

Terms	Definitions
HEPA	High Ecological Protection Area
KBSB	King Bay Supply Base
kg	Kilogram
KGP	Karratha Gas Plant
L	Litre
LEP	Level of Ecological Protection
LEPA	Low Ecological Protection Area
LNG	Liquefied Natural Gas
LOR	Limit of Reporting
m	Metre
m3	Cubic metres
MEPA	Moderate Ecological Protection Area
MEQMP	Marine Environmental Quality Management Plan
mg	Milligram
mL	Millilitre
NATA	National Association of Testing Authorities
NTU	Nephelometric Turbidity Unit
NWS	North West Shelf
NWS Project	The North West Shelf (NWS) Project is one of the world's largest liquefied natural gas producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. The NWS Project is owned by the NWSJV participants and since the 1980s, it has been Western Australia's largest producer of domestic gas. The NWS Project currently processes resources owned by the NWSJV and CNOOC NWS Private Limited and is proposed to also process third-party gas and fluids as part of the NWS Project Extension Proposal.
NWSJV	North West Shelf Joint Venture. A joint venture comprising six companies; Woodside Energy Ltd. (Operator), BHP Billiton Petroleum (North West Shelf) Pty Ltd, BP Developments Australia Ltd, Chevron Australia Pty Ltd, Japan Australia LNG (MIMI) Pty Ltd, and Shell Australia Pty Ltd. The North West Shelf Joint Venture owns the infrastructure used as part of the North West Shelf Project and, together with CNOOC NWS Private Limited, the North West Shelf Joint Venture owns the resources processed as part of the NWS Project.
OC	Organic Content
OCW	Oil-contaminated Water
PC	Protection Concentration; e.g. PC99 is 99% protection concentration, PC95 is 95% protection concentration etc.
pH	Measure of acidity or basicity in a solution
Proposal	NWS Project Extension Proposal. The Proposal as described in the NWS Project Extension Section 38 Referral Supporting Information (Woodside, 2018) to continue to use the Existing NWS Project facilities for the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities; and ongoing operation of the NWS Project to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070.

Terms	Definitions
State Waters EP	North West Shelf Trunklines State Waters Operations Environment Plan
STP	Sewage Treatment Plant
TL	Trunkline
TOC	Total Organic Carbon
TWW	Treated waste water
WA	Western Australia
WET	Whole Effluent Testing
Woodside	Woodside Energy Ltd

North West Shelf Project Extension Marine Environmental Quality Management Plan

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APPENDIX E NORTH WEST SHELF PROJECT EXTENSION AIR QUALITY IMPACT ASSESSMENT

Revision 1

Woodside

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NWS Project Extension

Woodside Energy Ltd.

Air Quality Impact Assessment

Final Report | Revision 4

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Air Quality Impact Assessment

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NWS Project Extension

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Executive Summary

This report details the results of air quality modelling conducted to support the environmental approvals for the North West Shelf (NWS) Project Extension Proposal (the Proposal). As a part of this assessment, the existing air emissions scenario, and potential future air emissions scenarios, were developed for the Burrup Peninsula. Air dispersion modelling was undertaken to determine how emissions from all identified sources may impact on sensitive receptors on the Burrup Peninsula. The model predictions were assessed against air quality assessment standards, to gauge potential future (cumulative) air quality impacts on human health and 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, efficiency and the ability to simulate the effects of long-term variations in meteorological conditions. Model input emissions inventories were developed in consultation with Woodside, 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. To confirm that TAPM-GRS performance was fit for purpose, modelled results were compared to measured results from Woodside ambient air monitoring programs. When compared to ambient air monitoring results for Nitrogen Dioxide (NO_2) and Ozone (O_3) from 2014, when the North West Shelf (NWS) Project: Karratha Gas Plant (KGP) and Pluto Liquified Natural Gas Development began operating together at or near capacity, model results were found to support actual results and the TAPM-GRS model was therefore deemed suitable and with an accuracy appropriate for the assessment of the Proposal.

The scope of this air quality impact assessment included modelling NO_2, O_3 and Sulfur Dioxide (SO_2) for assessment against National Environmental Protection (Ambient Air Quality) Measure (NEPM [Ambient Air Quality]). 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.

Monitoring of hydrocarbons undertaken during 2009-2015 showed that emissions of Benzene, Toluene and Xylenes (BTX), as indicators of all Volatile Organic Compounds (VOCs), had insignificant air quality effects at the monitoring locations of Dampier, Karratha, and Burrup Road. For most of the time, monitored BTX concentrations were nil at those locations. From a risk assessment it was concluded that formaldehyde would have low concentrations similar to those of benzene. As such individual VOCs such as benzene and formaldehyde were excluded from the assessment. However, estimates for emissions of VOCs were included in the modelling as part of photochemical model input requirements to obtain results for NO_2 and O_3.

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

Key results for the Proposal's air quality impact assessment were that:

- There were no predicted exceedances of NEPM (Ambient Air Quality) standards for NO_2, O_3, and SO_2 for any of the emission scenarios that were investigated as part of this assessment. All results for these pollutants were well below NEPM (Ambient Air Quality) standards.
- There were no predicted exceedances of European Union (2008) air quality standards for oxides of nitrogen (NO_x) and SO_2 for the protection of vegetation, for any of the emission scenarios.

In conclusion, there is a low risk of air quality impact on human health and vegetation from the Proposal, where "low risk" has been defined from predicted concentrations well below relevant air quality standards.

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 North West Shelf Project Extension Proposal 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 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, 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.

This report has been prepared on behalf of, and for the exclusive use of Woodside Energy Ltd and is subject to, and issued in accordance with, the provisions of the contract between Jacobs and Woodside Energy Ltd. Jacobs accepts no liability or responsibility whatsoever for, or in respect of, any use of, or reliance upon, this report by any third party.

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Abbreviations and Definitions

Abbreviation	Expansion / Definition
ABS	Australian Bureau of Statistics
BAAMP	Burrup Ambient Air Monitoring Program
BoM	Bureau of Meteorology
CBM	Current Baseline
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DANHP	Dampier Archipelago National Heritage Place
EPA	Environmental Protection Authority (Government of Western Australia)
FBSIA E&A	Future Burrup Strategic Industrial Area State – existing and approved development, representing Current Baseline and the NWS Extension Project with implementation of improvement opportunities
FBSIA-KIO	Future Burrup Strategic Industrial Area (State) with KGP Improvement Opportunities
FEED	Front-End Engineering and Design
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).
Jacobs	Jacobs Group (Australia) Pty. Limited
KGP	Karratha Gas Plant
KIO	CBM with KGP Improvement Opportunities
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
NWS Project	The existing NWS Project including the existing Karratha Gas Plant
PAQS	Pilbara Air Quality Study
PLP	Pluto on-shore LNG Plant
$PM_{2.5}$	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.
The Proposal	The North West Shelf Project Extension Proposal
SIA	(Burrup) Strategic Industrial Area
SKM	Sinclair Knight Merz

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Abbreviation	Expansion / Definition
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
WEL	Woodside Energy Limited
FBSIA E&A	Woodside Future SIA State – NWS Extension Project including KGP Improvement Opportunities

1. Introduction

1.1 Overview

Woodside Energy Ltd (Woodside), as operator for and on behalf of the North West Shelf Joint Venture (NWSJV), is proposing to continue and extend the operating life of the North West Shelf (NWS) Project through the long-term processing of third-party gas and fluids and the long-term processing of existing and future NWSJV field resources. This proposal is referred to as the NWS Project Extension Proposal (the Proposal).

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 long-term processing of third-party gas and fluids, and the long-term processing of existing and future NWSJV field resources.

1.2 Project Background

The NWS Project is one of the world's largest liquefied natural gas (LNG) producers, supplying oil and gas to Australian and international markets from offshore gas, oil, and condensate fields in the Carnarvon Basin off the north-west coast of Australia. For more than 30 years, it has been Western Australia's largest producer of domestic gas. The associated gas processing plant is located on the Burrup Peninsula, Western Australia (WA), approximately 6 km from Dampier.

1.3 Scope

This report provides an air quality impact assessment of the Proposal. The following items are within the scope of this report:

- Modelling of air emissions associated with the proposed future operations of the Proposal.
- Demonstration of cumulative air quality impacts associated with the best case, realistic worst case and most likely future emission scenarios for Burrup Peninsula.

1.4 Geographical Summary

The Proposal is located on the central Burrup Peninsula on a lease area of approximately 200 ha. 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 m above sea level.

The towns of Dampier and Karratha are located approximately 15 km and 30 km, respectively, from the Proposal.

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.

Vegetation with heritage value is also found on the Burrup Peninsula. Ethnographic studies have identified two bush-medicine plants growing at Withnell Bay—one is used as a healing balm for physical injuries and colds, and is also a spiritual protection for people visiting country; the other is used to settle the stomach which is also a source of food (Integrated Heritage Services, 2018). The Murujuga Cultural Management Plan (MAC, 2016) also places emphasis on the heritage value of vegetation on the Burrup Peninsula. Some trees provide medicine for colds and flus, shade for shelter and ceremonial tools. *Jami* bush is used to treat aches, pains and cuts. Mangroves are used for fishing and spinifex seeds are used to make damper.

The location of the Proposal in relation to the towns of Dampier and Karratha is shown in Figure 1-1.

Figure 1-1 NWS Project Extension 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 Proposal.

2.2 Ambient Air Quality Standards – Criteria Pollutants

The WA Environmental Protection Authority (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, have been established through monitoring and accepted proxy data.
- Whether analysis of potential health and amenity impacts have 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 Proposal, modelled predictions were assessed against the relevant NEPM (Ambient Air Quality) standards shown in Table 2-1.

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

Air pollutant	Averaging period	Maximum concentration standard	Maximum allowable exceedances
Nitrogen dioxide (NO_2)	1 hour 1 year	120 ppb 30 ppb	1 day a year None
Ozone (O_3)	1 hour 4 hours	100 ppb 80 ppb	1 day a year 1 day a year
Sulfur dioxide (SO_2)	1 hour 1 day 1 year	200 ppb 80 ppb 20 ppb	1 day a year 1 day a year 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 NSW EPA assessment criteria (NSW EPA, 2016) are two relevant frameworks.

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 the Proposal 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 and were used to assist with

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interpretation of measured hourly average concentrations. (Information is lost if only assessing longer term averages). The NSW EPA (2016) assessment criteria relevant to the Proposal are also shown in Table 2-2.

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

Pollutant	NEPM 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, 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 enable comparison with 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°C was used for this conversion, which is a typical ambient temperature relevant to the Proposal. Note that SKM (2006) used zero degrees Celsius for the conversion calculations (that is, at standard temperature and pressure).

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 °C
NO_x	30 µg/m^3, annual	16.2 ppb at 30 °C

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

Aside from particulate matter, there are no accepted or commonly applied standards for assessing deposition of air pollutants on land surfaces, such as Burrup Peninsula Aboriginal rock art. 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, or 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. Local meteorology is important for developing an understanding of air quality on the Burrup Peninsula and the surrounding region; a review is provided in Appendix B. Local Meteorology.

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 these more recent monitoring programs, the Pilbara Air Quality Study (PAQS) was undertaken by the Government of Western Australia (GWA) in the early 2000s (GWA, 2004), which included investigations of monitoring data. CSIRO (2006) reported on monitoring undertaken specifically to assess the potential for air pollutant impacts on petroglyphs, including measurements of gaseous and particulate pollutants, deposited dust, meteorological parameters, rainwater composition, and the deposition of nitrogen and sulfur.

The PAQS established a baseline for future assessments such as the Burrup Peninsula air pollution study by CSIRO Marine and Atmospheric Research (CSIRO, 2008), and air dispersion modelling studies to investigate the potential for air quality impacts; e.g., SKM (2009), and Air Assessments (2010b). Other similar air quality studies, and their supporting studies and reports, were completed around the same time.

The purpose of this section is to set out existing air quality for the Burrup Peninsula, with a focus on results from more recent monitoring programs that are most closely associated with current air pollution sources. More information about sources of air pollution on the Burrup Peninsula ('air emissions inventory'), and the outcomes of a risk assessment of those emissions, is provided in Section 4.2. A review of the modelling methods used to assess the emissions is provided in Section 5.2.

In summary, the review of the more recent (Woodside) air quality monitoring data for the Burrup Peninsula study area showed that NO_2, O_3, PM_{10} and $PM_{2.5}$ are the highest risk air quality indicators. While NO_2, O_3 and SO_2 concentrations have not exceeded NEPM (Ambient Air) standards, PM_{10} and $PM_{2.5}$ concentrations have exceeded the NEPM (Ambient Air) standards on several occasions each year, primarily due to dust storms or bushfires.

3.2 Air Quality Effects from Fires

There are a number of air quality reports that suggest bush fires noticeably influence 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. Golder (2014) suggested that the highest O_3 levels detected at Karratha in 2012 may have been caused by fires rather than industrial sources (see next section).

3.3 Nitrogen Dioxide and Ozone

NO_x and O_3 are key pollutants associated with the Proposal. Whilst NO_x is emitted from the Proposal, 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 (Seinfeld and Pandis, 2016). More information about O_3 is provided in the last paragraph of this section.

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

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results showed that O_3 is a higher risk air pollutant for the Burrup Peninsula based on relative 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, 2014) 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 (2014) 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 determined from 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). The statistics determined from the hourly averages are: maximum, 99.9th percentile, etc., down to the median and annual averages.

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 the Pluto LNG Development Plant (PLP) had ramped up to full production, and the

Karratha Gas Plant (KGP) at the NWS Project was operating to capacity. 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 2009-2015.

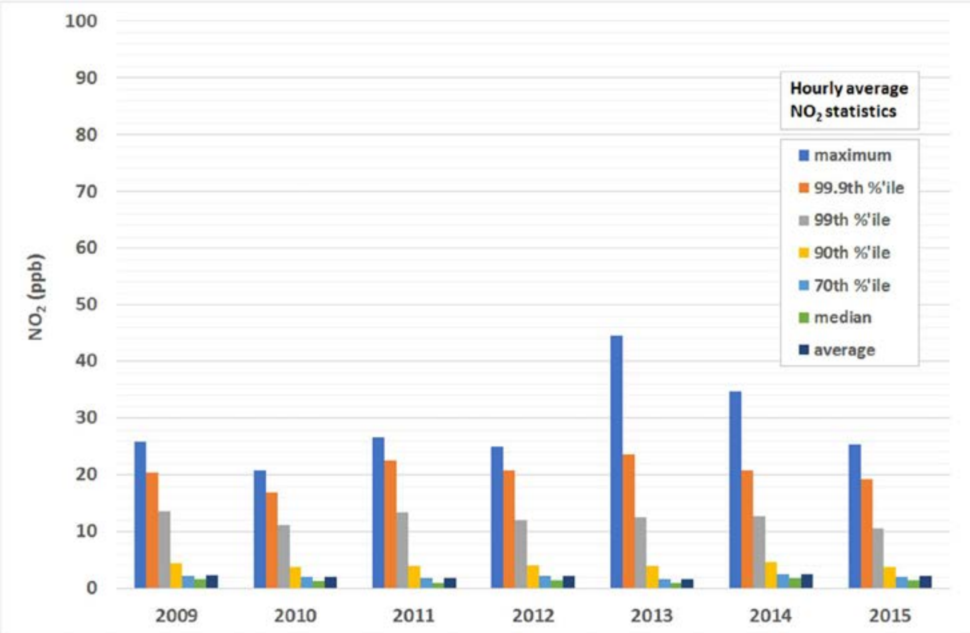

Figure 3-1: Woodside Air Quality Monitoring Results 2009-2015: Karratha NO_2

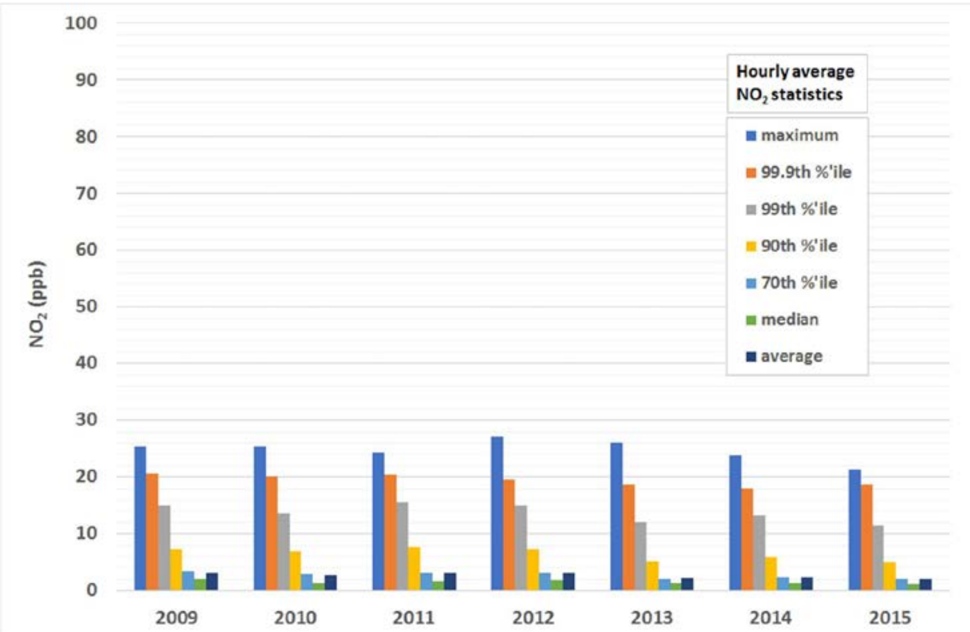

Figure 3-2: Woodside Air Quality Monitoring Results 2009-2015: Dampier NO_2

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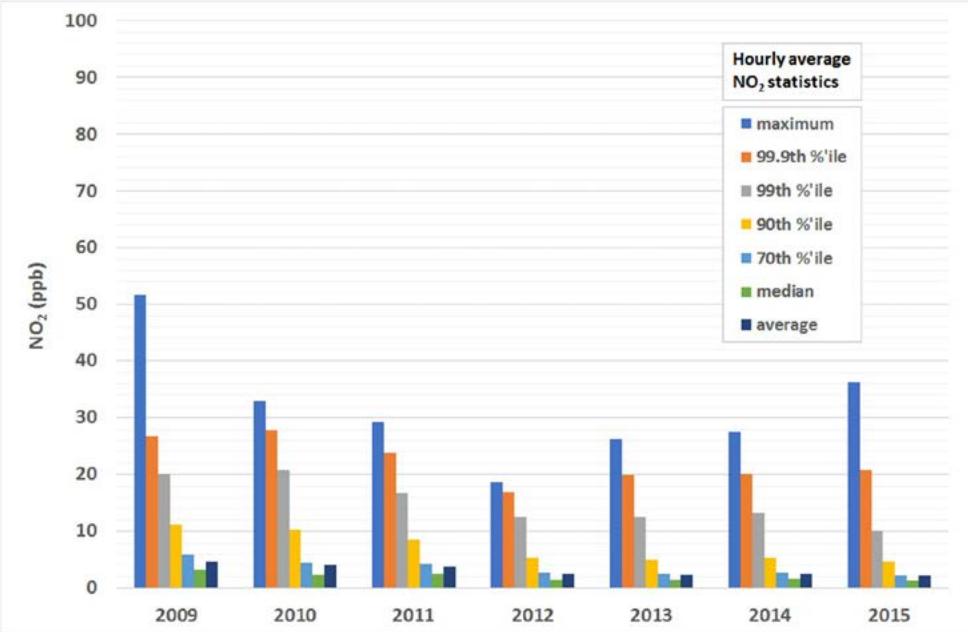

Figure 3-3: Woodside Air Quality Monitoring Results 2009-2015: Burrup NO_2

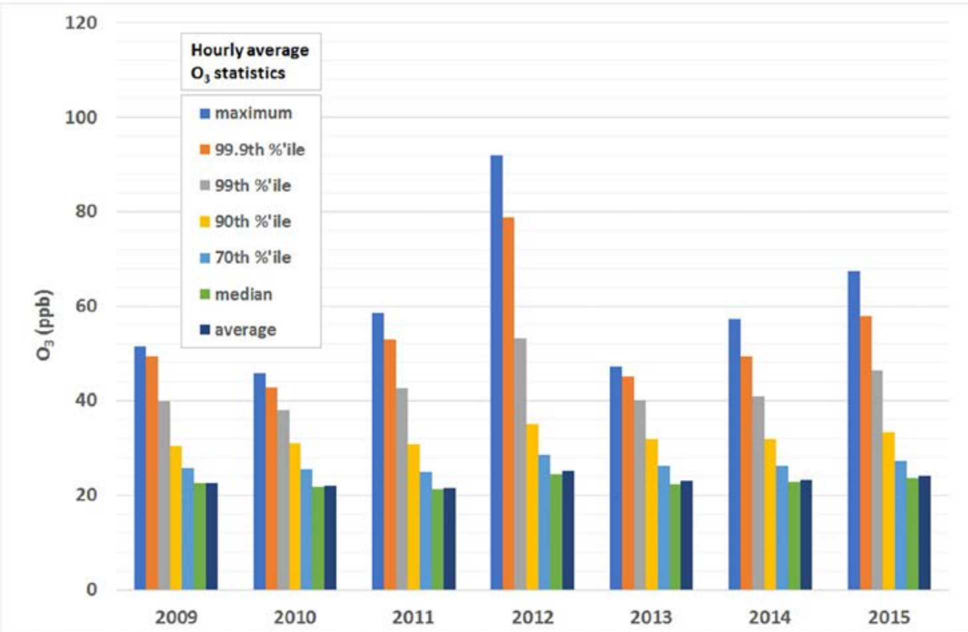

Figure 3-4: Woodside Air Quality Monitoring Results 2009-2015: Karratha O_3

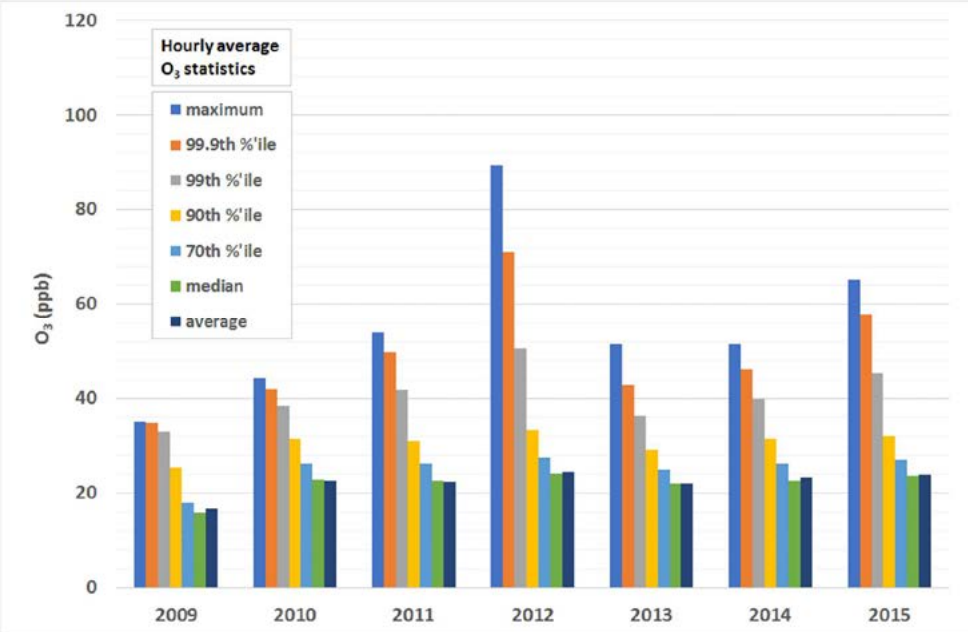

Figure 3-5: Woodside Air Quality Monitoring Results 2009-2015: Dampier O_3

Some additional commentary is provided about the O_3 observations. In the Burrup region, which is exposed to prevailing westerly winds from over the Indian Ocean, large fractions of the measured O_3 would be of marine (oceanic) origin, with some of this O_3 brought down to sea level due to mixing of air from the free troposphere into the marine boundary layer; e.g., see Ayers et al. (1992). For example, at Cape Grim in north-west Tasmania, during marine baseline conditions when the air is almost purely of Southern Ocean origin, the O_3 concentrations range from approximately 15-20 ppb in summer to 30-35 ppb in winter (Galbally et al., 1986; Oltmans et al., 2006). Emissions of NO_x over land has the effect of destroying O_3 near the NO_x sources, lowering its concentrations there; e.g., Galbally et al. (1986). From a review of the literature, Pilbara air at sea level should contain baseline (oceanic) O_3 ranging from approximately 15 ppb to 30 ppb, depending on the season. This means that approximately 25%-50% of the higher O_3 concentrations observed on the peninsula would have been due to natural, background levels. Isolated, elevated levels of short-term average O_3 concentrations would be due to contributions from a combination of NO_x, hydrocarbon and other emissions from bushfires and controlled burns, and industrial sources, with emissions from shipping and road vehicles contributing also.

3.4 Hydrocarbons – Benzene, Toluene, and 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); see Section 2.2 for more detail on relevant assessment criteria. The measured 90th percentile hourly average benzene concentrations at both locations was 0.1 ppb. 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 and 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' (i.e. no data).

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
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.

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, relative to other emissions, the existing environment is characterised by high levels of PM, relative to air quality standards, 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 online and can be used for assessment (Pilbara Iron, 2019). On the 9th 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 strong correlation between these measurements, taken by several monitors on this day, suggests 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. The record provides information about the clean-air background and air quality impacts, with the latter likely 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 ranged from 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, as the small particle fraction is higher in smoke emissions.

The review by Air Assessments (2010a) indicated that measurements of PM_{10} at Dampier tend to be high, and "exceed the NEPM (Ambient Air Quality) standard". Air Assessments (2010a) 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 (2014) 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 (2014) 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 exceedences 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 to several 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 engine exhausts on ships, the most significant source in the region. The comparable maximum hourly average NEPM (Ambient Air Quality) standard is 200 ppb.

3.7 Deposition Fluxes 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. 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 CSIRO carried out a study to determine the nitrogen deposition flux (between February 2012 and June 2014) on and around the Burrup Peninsula before and after the commissioning of the Pluto 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. Emissions Sources and Estimates

4.1 Overview

The principal emissions from the LNG process arise from combustion of natural gas. The most significant products of gas combustion include: carbon dioxide (CO_2), NO_x, carbon monoxide (CO) and unburnt hydrocarbons (VOCs). There may also be traces of particulate and SO_2 but such emissions are generally considered negligible due to the firing of very low sulfur content natural gas in a controlled environment. NO_x will be the predominant pollutant of interest.

To determine what the key air pollutants and sources are for the Proposal, in terms of potential impacts, a broad-level risk assessment was conducted. The purpose of the assessment was to determine the relative risk of air pollutants and emission sources in proximity to the Proposal, with a focus on the Burrup Strategic Industrial Area and the surrounding region. This assessment reviewed 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 identified what facilities should be included in the modelling and what substances should be modelled.

Emission inventories were developed in consultation with Woodside, based on reasonable and conservative emission estimates, consideration of available datasets, design data, and monitoring data for the Proposal. Representative third-party emissions were based on consideration of publicly available literature and input following consultation with some external parties.

4.2 Outcomes of Risk Assessment

A risk assessment based on a broad survey of Burrup Peninsula air quality studies, emission inventories and other information, was conducted to determine key air pollutants and their sources. The assessment determined that the key substance for assessment was NO_x, with the highest NO_2 and O_3 concentrations to be determined using photochemical modelling.

An early aggregated air emissions inventory for the Pilbara region was developed by SKM (2003) for the WA Department of Environmental Protection. The inventory included emissions from facilities with stacks not reportable to the National Pollutant Inventory (NPI), biogenic emissions of NO_x from soils, hydrocarbons from vegetation, and PM_{10} from a variety of natural sources. As mentioned in Section 3.1, the GWA (2004) PAQS objectives included developing understanding of air quality in the Karratha-Dampier coastal areas and the meteorology affecting air quality. These earlier air quality surveys were the foundation for many modelling studies; e.g., SKM (2009), with the elaborate review and modelling by Air Assessments (2010b) capping this first assessment phase for Burrup Peninsula. Further details about a string of previous modelling studies used as the basis for this project are provided in the review of modelling (Section 5.2).The major sources of airborne particulate matter in the region are smoke from bushfires and dust raised during high winds. Particulate emissions from the Proposal are negligible and unlikely to cause measurable air quality effects. As such, the particulate assessment parameters PM_{10} and $PM_{2.5}$ were excluded from the modelling study.

Based on the risk assessment, VOCs were excluded from the assessment for the Proposal. Monitoring undertaken during 2009-2015 showed that emissions of BTX, as an indicator of VOCs, had insignificant air quality effects at the sensitive receptor locations of Dampier and Karratha. For most of the time, BTX concentrations were nil at those locations. It was concluded that formaldehyde would have low concentrations that were approximately the same as benzene. However, estimates for total VOC emissions were included in the modelling as a part of the input for the photochemical modelling.

None of the previous air quality studies had identified H_2S as an elevated-risk pollutant, therefore it was eliminated as a substance of interest from this assessment.

Regional (beyond the Burrup Peninsula) emission sources were excluded from the air quality assessment because previous modelling studies demonstrated that while there may be some transfer of air pollutants, these would be minimal, given the distance. The Air Assessments (2012) results clearly show that air quality effects on the Burrup Peninsula are primarily due to sources on the Burrup Peninsula. 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 for the dispersed pollutants to make a significant contribution to ambient levels around the Burrup Peninsula; e.g. beyond approximately 50 km from Dampier and Karratha.
- Substances emitted not associated with air quality effects caused by emissions from the Proposals processing facilities; e.g. NH_3 and particulate matter from ship-loading.

The risk assessment also demonstrated that emissions from regional shipping have the potential to make a significant contribution to ambient NO_x levels and need to be considered in the modelling.

Based on the findings of the risk assessment, 94 existing air pollutant “point” sources (stack) on the Burrup Peninsula were identified to be included in the modelling. A summary of these point sources, with total NO_x emissions (g/s), is presented in Table 4-1. Emission source locations are shown in Figure 4-1.

Table 4-1: Summary of Current Air Emissions Sources Considered in the Modelling Assessment

Industrial Facility	Number of Emission Sources	Total NO_x Emission Rate (g/s)
Karratha Gas Plant	44	281
Pluto LNG Plant	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

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Figure 4-1 Locations of Modelled Emissions sources

4.3 Model Scenarios

The Proposal does not include the material additional or additive processing or power generation equipment with respect to emissions rates. Therefore, emissions are expected to be similar to or less than that from the Existing NWS Project. However, as the Proposal is implemented Woodside has proposed emission reduction opportunities to reduce NOx emissions from the Proposal. Therefore, modelled scenarios are based on cumulative impacts and emissions reduction scenarios.

Five air emissions scenarios were tested by modelling to support the Proposal. These scenarios are detailed in Table 4-2; further details about specific sources for modelling are set out in the following sub-sections.

Table 4-2: NWS Extension Air Emissions Scenarios for Assessment

Scenario	Description and Emission Sources
(1) Current Baseline (CBM) Near-term, most likely	The CBM scenario represents all current air pollutant sources,. There are existing air quality effects that are demonstrated by the current phase. CBM represents the existing air emissions scenario mostly applicable to the BSIA and the region to use as a baseline for assessment, including air emissions estimates for these facilities currently operating: • 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 • All shipping berths at Cape Lambert CB represents a current and near-term operating scenario and could be described as the near term 'most likely' case (EPA, 2019).
(2) CBM with KGP Improvement Opportunities (KIO) Best-case	The purpose of the KIO scenario was to illustrate the potential future effects of the Proposal in the frame of current emissions in the region, with no other expansion of industry on Burrup Peninsula. The KGP data for modelling were modified to reflect likely improvement opportunities representing feasible and significant NO_x reduction options. The KIO scenario could be described as a 'best case' considering emissions reduction opportunities, and there is no cumulative effects from proposed future developments.
(3) Future SIA State – Existing and Approved (FBSIA E&A) Long-term, most likely	The purpose of FBSIA- E&A is to illustrate the potential future effects of the existing and approved sources, in the frame of current emissions in the region. FBSIA E&A represents Current Baseline, NWS Extension Project with implementation of improvement opportunities, expansion of Pluto (Train 2), however excludes recently referred Urea and Methanol proposals (which are currently proposed but not referred) The FBSIA E&A is the most likely long term.
(4) Future Burrup Strategic Industrial Area State (FBSIA) Worst-case	FBSIA represents the future state aligned with current operations, but with the proposed Burrup SIA future Pluto Expansion, and indicative representation of Urea and Methanol proposals. The FBSIA scenario represents best estimates of potential future worst-case air quality on Burrup Peninsula.

Scenario	Description and Emission Sources
	Assumes all future developments approved and NWS operating at current levels.. The FBSIA scenario could be described as a 'worst case' (EPA, 2019).
(5) Future Burrup Strategic Industrial Area (State) with KGP Improvement Opportunities ('FBSIA-KIO') Long-term, possible	The FBSIA-KIO scenario represents KGP Improvement Opportunities, inclusive of indicative expansion on the Burrup Peninsula. FBSIA-KIO represents a realistic, cumulative scenario of the Proposal including implementation of KGP improvement opportunities, future developments represented by the Pluto expansion initial design, and indicative representation of Urea and Methanol proposals, and continuing operation of other current facilities. The FBSIA-KIO scenario could be described as a 'most likely' (EPA, 2019) air emissions scenario for the longer term.

4.4 Existing Emission Sources

4.4.1 Karratha Gas Plant

The existing key 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 emission parameters for the KGP sources are listed in Table 4-3. The existing KGP emissions data are relevant for the scenarios CBM and FBSIA.

Table 4-3: NWS Karratha Gas Plant Air Emissions Parameters

Emissions Source	Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Domgas GTC 1	24.0	0.98	42.3	815	0.01	3.81	0.12	0.01
Domgas GTC 2	24.0	1.40	43.4	764	0.01	12.02	0.25	0.01
Domgas GTC 3	24.0	0.98	42.3	815	0.01	3.81	0.12	0.01
Domgas GTC 4	24.0	1.40	43.4	764	0.01	12.02	0.25	0.01
TRAIN 1 – GTC 1	40.0	1.94	19.5	777	0.01	10.15	0.27	0.01
TRAIN 1 – GTC 2	40.0	1.94	19.5	782	0.01	9.68	0.27	0.01
TRAIN 1 – GTC 3	40.0	1.80	22.7	767	0.01	9.81	0.27	0.01
TRAIN 1 – GTC 4	40.0	1.80	21.7	771	0.01	9.19	0.27	13.5
TRAIN 1 – GTC 5	40.0	1.36	18.9	795	0.01	3.55	0.12	0.01
TRAIN 2 – GTC 1	40.0	1.94	19.5	777	0.01	10.15	0.27	0.01
TRAIN 2 – GTC 2	40.0	1.94	19.5	782	0.01	9.68	0.27	0.01

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Emissions Source	Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
TRAIN 2 – GTC 3	40.0	1.80	22.7	767	0.01	9.81	0.27	0.01
TRAIN 2 – GTC 4	40.0	1.80	21.7	771	0.01	9.19	0.27	13.5
TRAIN 2 – GTC 5	40.0	1.36	18.9	795	0.01	3.55	0.12	0.01
TRAIN 3 – GTC 1	40.0	1.94	19.5	777	0.01	10.15	0.27	0.01
TRAIN 3 – GTC 2	40.0	1.94	19.5	782	0.01	9.68	0.27	0.01
TRAIN 3 – GTC 3	40.0	1.80	22.7	767	0.01	9.81	0.27	0.01
TRAIN 3 – GTC 4	40.0	1.80	21.7	771	0.01	9.19	0.27	13.5
TRAIN 3 – GTC 5	40.0	1.36	18.9	795	0.01	3.55	0.12	0.01
TRAIN 4 – GTC 2	40.1	3.00	23.8	811	0.01	5.79	0.64	0.01
TRAIN 4 – GTC 1 WHRU1	40.1	1.45	50.9	588	0.01	3.13	0.29	0.01
TRAIN 4 – GTC 1 WHRU2	40.1	1.45	50.9	521	0.01	3.13	0.29	0.01
TRAIN 5 – GTC 2	40.1	3.01	23.7	811	0.01	7.18	0.64	0.01
TRAIN 5 – GTC 1 WHRU 1	40.1	1.45	50.9	523	0.01	3.11	0.29	0.01
TRAIN 5 – GTC 1 WHRU 2	40.1	1.45	50.9	483	0.01	3.11	0.29	0.01
Stabiliser 2 Furnace Stack	33.0	0.73	39.2	699	0.01	2.56	0.01	0.01
Stabiliser 4 Furnace Stack	33.0	0.73	39.2	668	0.01	2.17	0.01	0.01
Stabiliser 5 Furnace Stack	33.0	0.73	39.2	659	0.01	2.23	0.01	0.01
Stabiliser 6 Furnace Stack	32.6	0.73	39.2	630	0.01	1.98	0.01	0.01
Power Generation GTG 1	40.0	1.98	20.4	681	0.01	11.58	0.24	0.01
Power Generation GTG 2	40.0	1.98	21.5	681	0.01	12.21	0.24	0.01
Power Generation GTG 3	40.0	1.98	20.4	675	0.01	8.63	0.24	0.01
Power Generation GTG 4	40.0	1.98	21.5	681	0.01	12.21	0.24	0.01
Power Generation GTG 5	40.0	1.98	20.4	675	0.01	8.63	0.24	0.01
Power Generation GTG 6 + AGRU 4 & 5 Vent	40.0	1.98	20.4	675	0.02	8.63	0.24	40.6
Power Generation GTG 7	40.0	1.79	22.2	751	0.01	3.00	0.22	0.01
Power Generation GTG 8	40.0	1.79	17.7	751	0.01	2.66	0.22	40.6
Power Generation GTG 9	40.0	1.79	34.6	751	0.01	4.45	0.22	0.01
Power Generation GTG 10	40.0	1.79	31.3	745	0.01	3.64	0.22	0.01
Domgas-E Flare	128.5	0.51	20.0	1273	0.05	0.28	0.001	0.58
LNG Emergency Flare (representative)	145.3	3.26	20.0	1273	1.95	11.32	0.044	23.42
LNG-SL Flare	56.9	0.28	20.0	1273	0.01	0.08	0.0003	0.17
LPG-SL Flare	56.5	0.21	20.0	1273	0.01	0.05	0.0002	0.10

Emissions Source	Stack Height (m)	Stack Radius (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Operations Flare	46.8	0.73	20.0	1273	0.10	0.56	0.002	1.17
Emissions Totals (g/s)					2.5	281.1	9.2	147.5

#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 flarepoints.

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.

4.4.2 Woodside Pluto Onshore LNG Plant

The Pluto gas field was discovered in April 2005 and is located on the North West Shelf of WA, approximately 190 km north-west of Dampier. The associated gas processing plant is located on the Burrup Peninsula, approximately 6 km from Dampier.

The Pluto LNG Development was approved by the State and Commonwealth governments following public environment review of the proposal in 2006. The original proposal included the construction, commissioning and operation of the Pluto LNG Development with two LNG processing trains. However, only one train was built, commissioned and operated.

The Woodside PLP air emissions parameters are listed in Table 4-4.

Table 4-4: Pluto Onshore LNG Plant Air Emissions Parameters

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
PLP Train 1 – GTC 1 WHRU 1	40.0	2.90	39.2	531.2	0.01	5.63	0.37	0.01
PLP Train 1 GTC 1 WHRU 2	40.0	2.90	41.2	527.2	0.01	5.10	0.38	0.01
PLP Train 1 – GTC 2	40.0	6.01	28.0	824.2	0.01	10.20	0.37	0.01
PLP GTG 1	40.0	3.11	28.0	868.2	0.01	3.27	0.25	0.01
PLP GTG 2	40.0	3.86	23.0	874.2	0.01	3.36	0.24	0.01
PLP GTG 3	40.0	2.80	30.1	879.2	0.01	3.22	0.16	0.01
PLP GTG 4	40.0	2.80	29.5	883.2	0.01	1.82	0.33	0.01
PLP Train 1 - Regenerative Thermal Oxidiser	40.0	2.80	17.7	394.2	0.01	0.08	0.42	0.01
Flare Cold Dry	139.5*	1.34	20.0	1273.0	0.08	0.49	0.002	1.01
Flare Warm Wet	139.5*	1.34	20.0	1273.0	0.08	0.49	0.002	1.013
Storage and Loading Flare	64.3*	1.28	20.0	1273.0	0.08	0.45	0.002	0.923
Emissions Totals (g/s)					0.32	34.1	2.53	3.03

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

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

4.4.3 Other Relevant Emission Sources

The risk assessment determined that point source (stack) emissions of NO_x, VOCs and other substances from the following facilities have the potential to make a significant contribution to the ground level concentrations and therefore needed to be considered in any air quality assessment:

- Yara Pilbara Fertilisers and Yara Pilbara Nitrates Technical Ammonium Nitrate (TAN)
- Pilbara Iron Yurralyi Maya Power Station
- Santos Devil Creek Power Station
- ATCO Karratha Power Station
- West Kimberley Power Plant

The Yara Pilbara Fertilisers and Yara Pilbara Nitrates TAN air emissions parameters are listed in Table 4-5.

Table 4-5: Yara Pilbara Fertilisers and Yara Pilbara Nitrates TAN Air Emissions Parameters

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
TAN Plant Stack	54.0	1.4	27.5	423.0	0.00	4.2	0.0	0.0
TAN power generation	30.0	2.6	16.9	450.0	0.06	2.1	0.0	0.0
Fertiliser Reformer	35.0	3.5	15.0	413.0	0.91	17.1	0.23	0.0
Fertiliser Boiler	30.0	3.0	4.1	450.0	0.36	6.9	0.13	0.0
Emissions totals (g/s)					1.33	30.3	0.36	0.0

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 4-6.

Table 4-6: Yurralyi Maya Power Station Emissions Data

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	40.0	3.57	25.7	722.0	1.0	5.63	4.0	0.04
GTG 2	40.0	3.57	25.7	722.0	1.0	5.63	4.0	0.04
GTG 3	40.0	3.57	25.7	722.0	1.0	5.63	4.0	0.04
GTG 4	40.0	3.57	25.7	722.0	1.0	5.63	4.0	0.04
GTG 5	40.0	3.57	25.7	722.0	1.0	5.63	4.0	0.04
Emissions totals (g/s)					5.0	28.2	20.0	0.20

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 emission sources for the BHSM were:

- two Solar Taurus 60 gas turbine generators 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;
- waste gas incinerator.
- and an elevated flare and ground flare.

The associated air emissions parameters are listed in Table 4-7.

Table 4-7: Devil Creek Gas Plant Air Emissions Parameters

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	13.0	1.6	23.5	783.0	0.004	0.75	0.0	0.005
GTG 2	13.0	1.6	23.5	783.0	0.004	0.75	0.0	0.005
GTC 1	13.0	1.6	16.0	633.0	0.004	0.75	0.0	0.005
GTC 2	13.0	1.6	16.0	633.0	0.004	0.75	0.0	0.005
Waste Gas Incinerator	21.0	1.8	14.0	1073.0	0.004	0.00	11.0	0.005
Elevated Flare	48.0	1.6	20.0	1273.0	0.004	0.77	0.0	0.005
Ground Flare	20.0	1.6	20.0	1273.0	0.004	0.77	0.0	0.005
Emissions totals (g/s)					0.028	4.54	11.0	0.035

The West Kimberley Power Station, operated by EDL Energy, is located approximately 25 km south-west of the Burrup Hub site. Air emissions parameters for the three gas turbines, are listed in Table 4-8.

Table 4-8: West Kimberley Power Project Emissions Data

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	10.0	1.2	26.5	700.0	0.002	0.385	0.0006	0.0025
GTG 2	10.0	1.2	26.5	700.0	0.002	0.385	0.0006	0.0025
GTG 3	10.0	1.2	26.5	700.0	0.002	0.385	0.0006	0.0025
Emissions totals (g/s)					0.006	1.155	0.002	0.0075

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 4-9.

Table 4-9:Karratha Power Station Emissions Data

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 1	18.2	3.57	26.0	723.0	0.04	6.0	0.01	0.043

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Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
GTG 2	18.2	3.57	26.0	723.0	0.04	6.0	0.01	0.043
Emissions totals (g/s)					0.08	12.0	0.02	0.086

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 all these berths with ancillary engines running continuously; i.e. 24 hours per day, every day of the year. The air emissions parameters assigned for each of the total of 18 berth locations are listed in Table 4-10.

Table 4-10: Air Emissions Data for Shipping

Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10}	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
35.0	0.5.0	11.9	673.0	0.25	2.0	2.0	0.12
Burrup Peninsula shipping berths: emissions totals (g/s)				3.25	26.0	26.0	1.56
Cape Lambert shipping berths: emissions totals (g/s)				1.25	10.0	10.0	0.60

4.5 Future Emission Sources

Modelling conducted for the "future" scenarios included emissions from:

- KGP with improvement assumptions
- Pluto LNG Development (Train 1 existing, and proposed Train 2 expansion (preliminary design 2019))
- other current relevant sources, without any expansion
- proposed new facilities (Urea Plant and Methanol Plant).

4.5.1 Future Relevant Developments

Woodside, as operator of the Pluto LNG Development, proposes a brownfield expansion as part of the Pluto LNG Development (Pluto Expansion Project). This includes the construction and commissioning of a second LNG processing train, Pluto Train 2.

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

Table 4-11: Pluto LNG Development – Train 2 Air Emissions Parameters (and Train 1 power assumption minor change)

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	2.80	29.1	821.0	2.98	0.07	0.01
Train 1 – GTG 4	40.1	2.80	29.5	823.0	3.53	0.06	0.01
Train 2 – GTC 1	50.7	3.06	29.6	741.0	4.55	0.002	0.01
Train 2 – GTC 2	50.7	3.06	29.6	741.0	4.55	0.002	0.01

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 2 – GTC 3	50.7	3.6	2.4	741.0	4.55	0.002	0.01
Train 2 – GTC 4	50.7	3.06	29.6	584.0	4.55	0.002	0.01
Train 2 – GTC 5	50.7	3.6	2.4	741.0	4.55	0.002	0.01
Train 2 – GTC 6	50.7	3.06	29.6	584.0	4.55	0.002	0.01
PLP GTG 5	30.0	5.7	38.3	787.0	4.88	0.003	0.01
PLP Train 2 - AGRU Thermal Oxidiser	16.0	0.84	13.2	962.0	0.69	0.141	0.01
PLP Train 2 - NRU Thermal Oxidiser	30.5	1.07	31.0	700.0	0.70	0.040	0.01
Emissions Totals (g/s)					40.1	0.33	0.11

Pluto Train 2 emission characteristics are based on early FEED concept reports and subject to change as design matures.

& Emissions parameters add and/or replace equivalent sources of existing air emissions scenario (Section 4.4).

While the modelling scenarios include emissions from the other relevant current emissions, future developments at these industrial facilities are excluded. The scenarios do, however, include two new representative facilities located within the Burrup Strategic Industrial Area, near the Proposal:

- a urea plant with a production capacity of approximately 2 Mtpa
- a methanol plant with production capacity of approximately 5,000 tpd

Air emissions parameters used in the modelling for the Urea Proposal are set out in Table 4-12, and for the Methanol Proposal in Table 4-13.

Table 4-12: 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	75.0	2.5	15.3	423.0	6.68	0.04	0.02
GTG 1	30.0	3.0	20.8	378.0	2.25	0.07	0.01
Urea Train 1 Absorber vent	40.0	6.5	19.6	320.0	0.0	0.0	0.0
Urea Train 2 Absorber vent	40.0	6.5	19.6	320.0	0.0	0.0	0.0
Emissions Totals (g/s)					8.93	0.11	0.03

Table 4-13: 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	35.0	3.7	20.0	433.0	20.8	0.001	0.01
Process Condensate Stripper	8.3	0.5	20.0	343.0	0.0	0.001	0.01
Flare Stack (with effective diameter)	35.0	1.4	20.0	1273.0	0.03	0.001	0.01
Gas Turbine Stack	20.0	3.0	8.0	753.0	0.83	0.001	0.01

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)
Auxiliary Boiler Stack	30.0	3.7	6.0	463.0	6.39	0.001	0.01
Emissions Totals (g/s)					28.05	0.005	0.05

4.5.2 Karratha Gas Plant – Improvement Opportunities

The NWS Project Extension Proposal includes a staged reduction of NOx emissions. The improvement opportunities modelling scenario emissions estimates listed in Table 4-14 were based on representative concepts of feasible and significant NO_x reductions as determined by Woodside engineering investigations. These KGP data were relevant for the scenarios: KIO, FBSIA-KIO, and FBSIA E&A.

Table 4-14: Changes to Karratha Gas Plant emissions to reflect potential improvement opportunities

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
Domgas GTC 1	24.0	1.0	42.3	815.0	0.01	3.81	0.12	0.01
Domgas GTC 2	24.0	1.4	43.4	764.0	0.01	4.47	0.25	0.01
Domgas GTC 3	24.0	1.0	42.3	815.0	0.01	3.81	0.12	0.01
Domgas GTC 4	24.0	1.4	43.4	764.0	0.01	4.47	0.25	0.01
TRAIN 1 – GTC 1	40.0	1.9	23.1	764.0	0.01	4.47	0.27	0.01
TRAIN 1 – GTC 2	40.0	1.9	23.1	764.0	0.01	4.47	0.27	0.01
TRAIN 1 – GTC 3	40.0	1.8	26.9	764.0	0.01	4.47	0.27	0.01
TRAIN 1 – GTC 4	40.0	1.8	26.9	764.0	0.01	4.47	0.27	0.01
TRAIN 1 – GTC 5	40.0	1.4	18.9	795.0	0.01	3.55	0.12	0.01
TRAIN 2 – GTC 1	40.0	1.9	23.1	764.0	0.01	4.47	0.27	0.01
TRAIN 2 – GTC 2	40.0	1.9	23.1	764.0	0.01	4.47	0.27	0.01
TRAIN 2 – GTC 3	40.0	1.8	26.9	764.0	0.01	4.47	0.27	0.01
TRAIN 2 – GTC 4	40.0	1.8	26.9	764.0	0.01	4.47	0.27	0.01
TRAIN 2 – GTC 5	40.0	1.4	18.9	795.0	0.01	3.55	0.12	0.01
TRAIN 3 – GTC 1	40.0	1.9	23.1	764.0	0.01	4.47	0.27	0.01
TRAIN 3 – GTC 2	40.0	1.9	23.1	764.0	0.01	4.47	0.27	0.01
TRAIN 3 – GTC 3	40.0	1.8	26.9	764.0	0.01	4.47	0.27	0.01
TRAIN 3 – GTC 4	40.0	1.8	26.9	764.0	0.01	4.47	0.27	0.01
TRAIN 3 – GTC 5	40.0	1.4	18.9	795.0	0.01	3.55	0.12	0.01
TRAIN 4 – GTC 2	40.1	3.0	23.8	811.0	0.01	5.79	0.64	0.01
TRAIN 4 – GTC 1 WHRU1	40.1	1.5	50.9	588.0	0.01	3.13	0.29	0.01
TRAIN 4 – GTC 1 WHRU2	40.1	1.5	50.9	521.0	0.01	3.13	0.29	0.01

Emissions Source	Stack Height (m)	Stack Diameter (m)	Exit Velocity (m/s)	Temp. (K)	PM_{10} (g/s)	NO_x (g/s)	SO_2 (g/s)	VOC (g/s)
TRAIN 5 – GTC 2	40.1	3.0	23.7	811.0	0.01	7.18	0.64	0.01
TRAIN 5 – GTC 1 WHRU 1	40.1	1.5	50.9	523.0	0.01	3.11	0.29	0.01
TRAIN 5 – GTC 1 WHRU 2	40.1	1.5	50.9	483.0	0.01	3.11	0.29	0.01
Stabiliser 2 Furnace Stack	33.0	0.7	39.2	699.0	0.01	2.56	0.01	0.01
Stabiliser 4 Furnace Stack	33.0	0.7	39.2	668.0	0.01	2.17	0.01	0.01
Stabiliser 5 Furnace Stack	33.0	0.7	39.2	659.0	0.01	2.23	0.01	0.01
Stabiliser 6 Furnace Stack	32.6	0.7	39.2	630.0	0.01	1.98	0.01	0.01
Power Generation GTG1	40.0	2.0	17.1	814.0	0.01	2.01	0.24	0.01
Power Generation GTG2	40.0	2.0	17.1	814.0	0.01	2.01	0.24	0.01
Power Generation GTG3	40.0	2.0	17.1	814.0	0.01	2.01	0.24	0.01
Power Generation GTG4	40.0	2.0	17.1	814.0	0.01	2.01	0.24	0.01
Power Generation GTG5	40.0	2.0	17.1	814.0	0.01	2.01	0.24	0.01
Power Generation GTG6	40.0	2.0	17.1	814.0	0.02	2.01	0.24	40.61
Power Generation 7	40.0	1.8	22.2	751.0	0.01	3.00	0.22	0.01
Power Generation 8	40.0	1.8	17.7	751.0	0.01	2.66	0.22	40.60
Power Generation 9	40.0	1.8	34.6	751.0	0.01	4.45	0.22	0.01
Power Generation 10	40.0	1.8	31.3	745.0	0.01	3.64	0.22	0.01
Domgas-E Flare	128.5	0.5	20.0	1273.0	0.05	0.28	0.00	0.58
LNG Emergency Flare (representative source)	145.3	3.3	20.0	1273.0	1.95	11.32	0.04	23.42
LNG-SL Flare	56.9	0.3	20.0	1273.0	0.01	0.08	0.00	0.17
LPG-SL Flare	56.5	0.2	20.0	1273.0	0.01	0.05	0.00	0.10
Operations Flare	46.8	0.7	20.0	1273.0	0.10	0.56	0.00	1.17
Emissions Totals (g/s)					2.5	153.3	9.2	107.0

Emissions parameters add and/or replace equivalent sources of existing air emissions scenario (Section 4.4).

5. Modelling Methodology

5.1 Overview

The modelling used the CSIRO-developed 'TAPM' meteorological and air dispersion model (Hurley, 2008a; Hurley et al., 2008). The model was chosen for consistency with previous air quality modelling studies for the Burrup Peninsula completed by CSIRO atmospheric scientists; 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 Services air quality specialists prior to the commencement of modelling (Jacobs, 2019b). At the EPA Services meeting, it was proposed to use TAPM for the project primarily due to the legacy of TAPM modelling for the Pilbara environment and simulating the potential effects of annual variations in meteorology. Subsequent meetings to discuss methodology model development findings, and preliminary outcomes were held with EPA Services and DWER between on 28 March and 13 May 2019. Several aspects about the model were raised including which version of the model to use for the project, and alternative modelling options were discussed; however, TAPM has been found, from the current and historical modelling, to provide an accuracy appropriate for the assessment of the Proposal.

5.2 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 WA 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 Proposal detailed in the next section.

5.3 Model configuration

5.3.1 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 Proposal 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 one month 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 data were obtained from Geoscience Australia’s gridded 9-second DEM data (approximately 250 m).

For the Proposal, sensitivity tests were undertaken by comparisons of TAPM-predicted winds at Karratha Aerodrome with the Bureau of Meteorology (BoM) measurements of wind speed and wind direction at Karratha Aerodrome and Roebourne. Inclusion of an additional grid with finer horizontal resolution of 400m 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 several 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 the current Proposal assessment, a balance between computing speed and accuracy of results was achieved using the TAPM settings set out in Table 5-1.

Table 5-1: 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	Nil
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 a back-up year due good examples of NO_2 and O_3 measurements, and typical wind pattern.
Vertical Layers (m)	25 vertical layers including: 10, 50, 100, 150, 200, 300, 400, 500, 750, 1000, 1250, 1500, 2000… up to 8000 m.	Not fully operational

5.3.2 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 parameters important 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.

Parameters for vegetation types defined in the TAPM model are set out in Table 5-2 (Hurley 2008a).

Table 5-2: TAPM Vegetation Characteristics

Type	Height (m)	Surface fraction (•$_f$)	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 1km 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 5-1.

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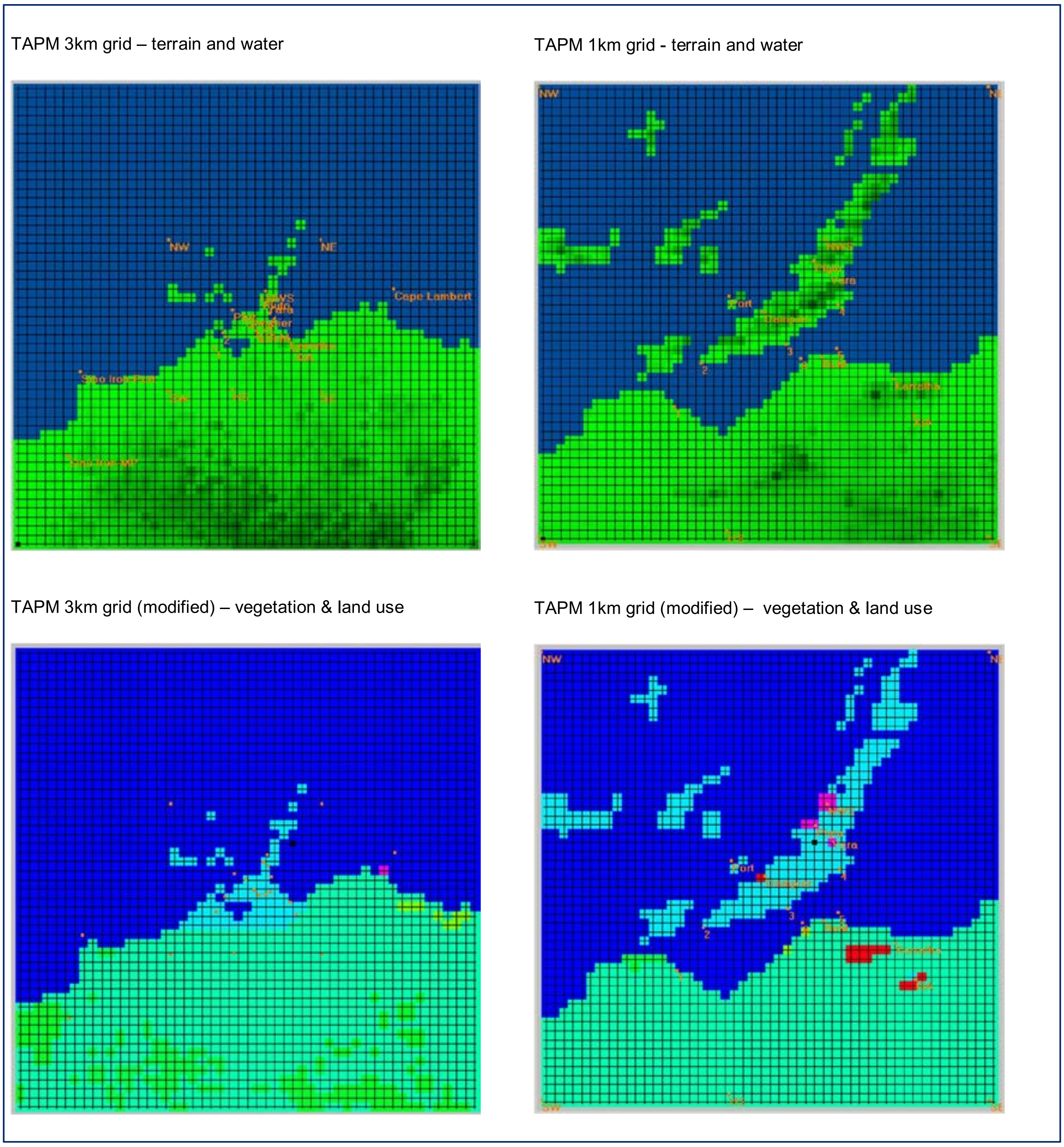

Figure 5-1: TAPM 3km and 1km Grids – Terrain, Vegetation and Land Use

5.3.3 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 5-2 .

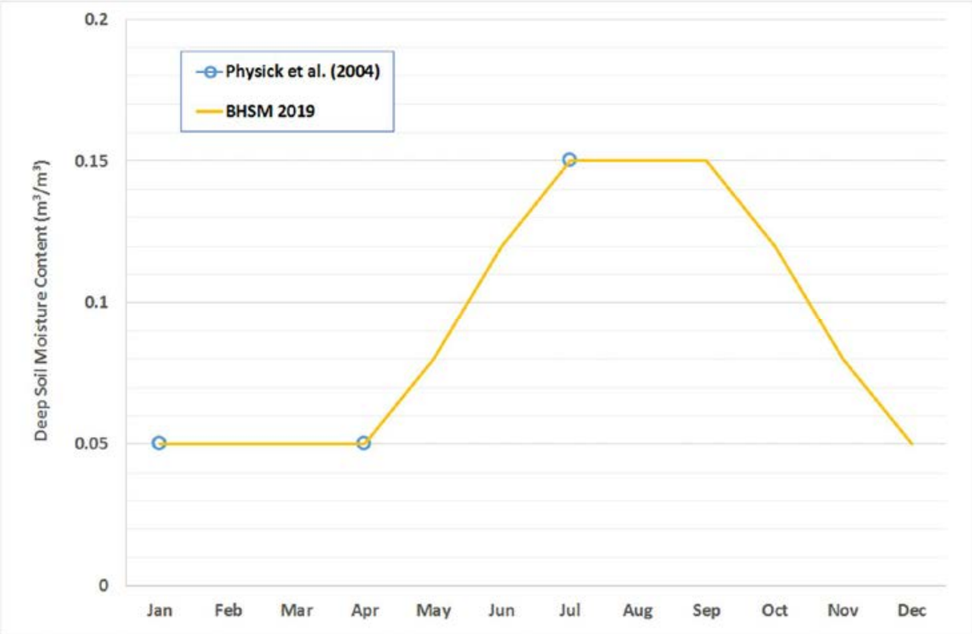

Figure 5-2: Deep Soil Moisture Content Settings

5.3.4 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), NO_2, 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),

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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 5-3 (NO_x), and Figure 5-4 (R_{smog}). The figures are overlaid on the base map image of the Burrup Peninsula study area, representing the TAPM inner-grid.

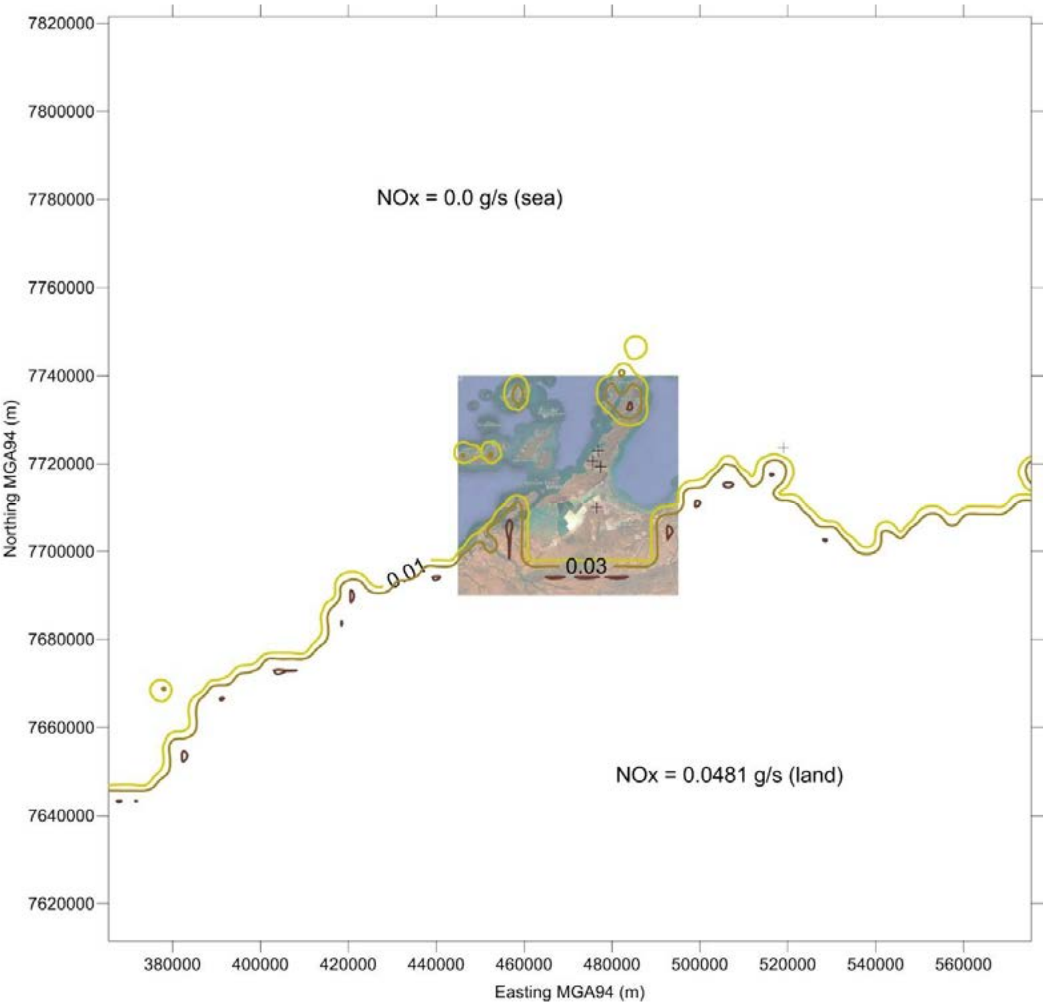

Figure 5-3: CSIRO Biogenic NO_x Area Emissions Database and Current Study Area (Inset)

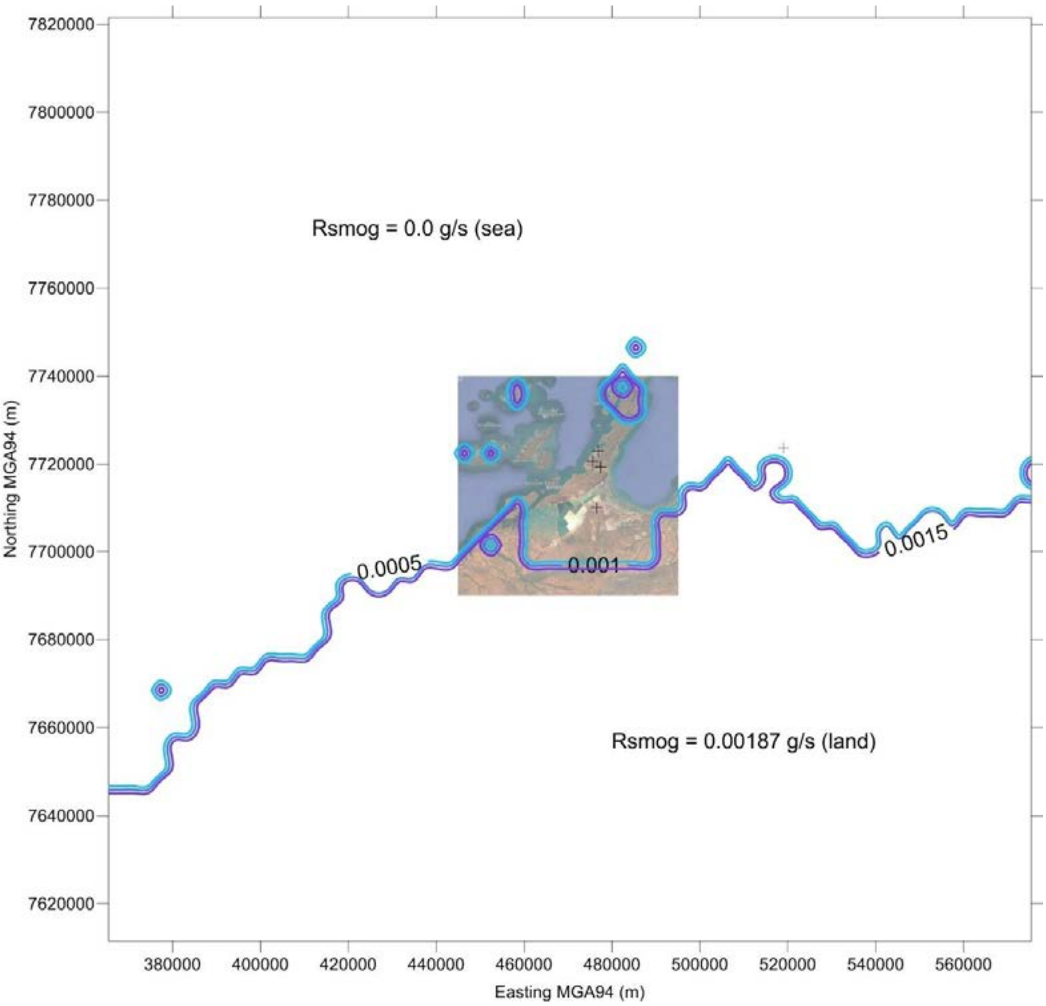

Figure 5-4: CSIRO Biogenic Area R_{smog} Emissions Database and Current Study Area (Inset)

Another area source file used with previous TAPM modelling included emissions from shipping and the relatively small townships of Dampier (population approximately 1,100), and Karratha (population approximately 15,800). A weakness of this database was overestimating the effects of the shipping emissions by excluding the effects of hot (buoyant) exhausts from ship engines. This weakness in the emissions estimates was recognised by Air Assessments (2010). For this project, the effects of shipping were modelled by including ship engines running continuously throughout a year at every available berth in the Burrup Peninsula and 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, O3, particles and hydrocarbons in the modelling, the emissions from Dampier and Karratha were included implicitly.

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

The deposition flux of nitrogen and sulfur on Burrup Peninsula may be relevant for effects on rock art, and a summary of results for the NO_2 and SO_2 deposition components obtained from measurements was set out in Section 3.7. TAPM-GRS modelling outputs were obtained for the NO_2 and SO_2 deposition components of these

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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., Gillet (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 (2014). 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. Variability 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.

5.3.6 Selection of Year for Modelling

The TAPM meteorological simulation year 2014 was selected as the basis for the air quality assessment supporting the Proposal. 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 C. Results – Meteorological Modelling).

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.

PLP 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. Results – Meteorological Modelling.

5.3.7 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.

6. 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 5.3.6.

Comparisons of the TAPM results for hourly average NO_2 GLCs (ppb) with monitoring data are set out in Table 6-1. The plots provide statistical summaries of the 8760 one-hour average NO_2 GLCs predicted by TAPM-GRS 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 6-2 for O_3–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, 99.9^{th} percentile, 99^{th} percentile, 70^{th} percentile, 50^{th} percentile (i.e. median), and annual average. An analysis of the comparisons is provided below each chart.

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 measured by Woodside at the Burrup, Dampier and Karratha monitoring stations.

Table 6-1: Comparisons of TAPM Results with 2014 Monitoring Results for Hourly Average NO_2

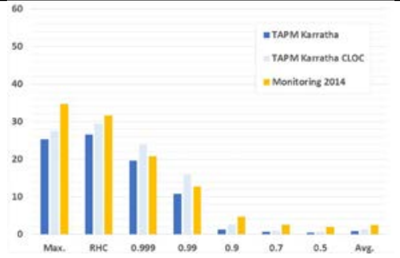	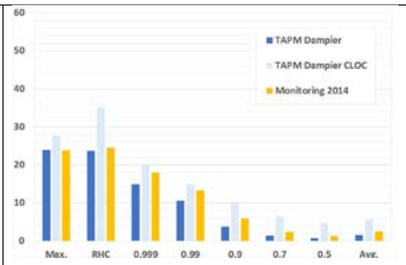	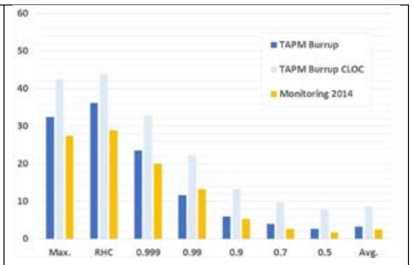
• Karratha 2014: 1-Hour Average NO_2 (ppb) • TAPM (blue) and monitoring (yellow) • Plotted range is 0-60 ppb • NEPM (Ambient Air Quality) standard 120 ppb	• Dampier 2014: 1-Hour Average NO_2 (ppb) • TAPM (blue) and monitoring (yellow) • Plotted range is 0-60 ppb • NEPM (Ambient Air Quality) standard 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).

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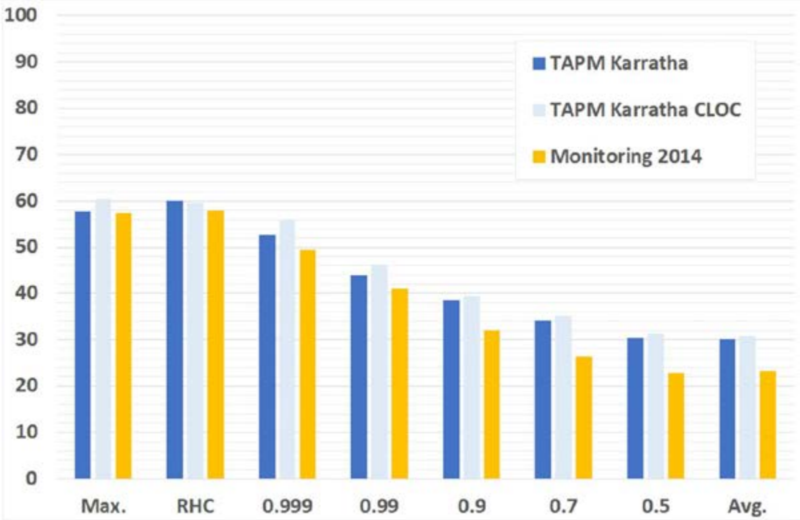
Table 6-2: Comparisons of TAPM Results with 2014 Monitoring Results for Hourly Average O_3

<table>
<tr>
<td>
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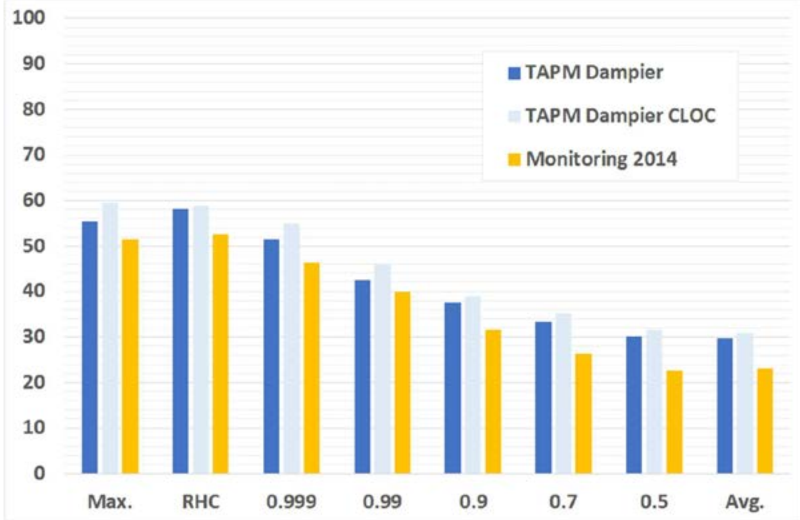
<td>
</td>
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<tr>
<td>• Karratha 2014: 1-Hour Average O_3 (ppb)
• TAPM (blue) and monitoring (yellow)
• Plotted range is 0-100 ppb
• NEPM (Ambient Air Quality) standard 100 ppb</td>
<td>• Dampier 2014: 1-Hour Average O_3 (ppb)
• TAPM (blue) and monitoring (yellow)
• Plotted range is 0-100 ppb
• NEPM (Ambient Air Quality) standard 100 ppb</td>
</tr>
<tr>
<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 are aligned, 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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7. Results

7.1 Overview

Modelled concentrations of pollutants of concern are presented in the following sections. Contour plots for each species and averaging period provide comparison between the modelled scenarios and give indications of the concentration trends over the wider region.

7.2 NO_2 Concentrations

The maximum 1-hour averaged NO_2 GLCs for the five modelled air emissions scenarios at the three sensitive receptor locations, Karratha, Burrup and Dampier, and the maxima anywhere on the grid, are presented in Table 7-1. Contour plots of the GLCs are provided in Figure 7-1 (Current Baseline) through to Figure 7-5 (scenario FBSIA E&A). There were no predicted exceedances of the corresponding NEPM standard of 120 ppb for any of the five air emissions scenarios tested by modelling.

Table 7-1: Maximum 1-hour Average NO_2 Concentrations (ppb)- Grid Receptors

Receptor	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
Karratha	24.8	16.1	28.3	20.9	17.5
Burrup	33.4	22.4	34.2	25.4	22.9
Dampier	24.8	18.2	25.8	19.5	19.0
Maximum on Grid	42.6	29.1	43.9	32.4	30.7
NEPM Standard	**120**	**120**	**120**	**120**	**120**

The modelled maxima of the annual average NO_2 concentrations for the air emissions scenarios at the sensitive receptor locations, and the grid receptor maxima, are presented in Table 7-2. Contour plots of the GLCs are provided in Figure 7-6 (Current Baseline) through to Figure 7-10 (scenario FBSIA E&A). There were no predicted exceedances of the corresponding NEPM standard of 30 ppb for any of the five air emissions scenarios tested by modelling.

Table 7-2: Annual Average NO_2 concentrations (ppb)- Grid Receptors

Receptor	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
Karratha	0.9	0.8	1.0	0.9	0.8
Burrup	3.2	3.0	4.0	3.8	3.3
Dampier	1.7	1.6	1.8	1.7	1.6
Maximum on Grid	5.0	4.9	5.6	5.7	5.0
NEPM Standard	**30**	**30**	**30**	**30**	**30**

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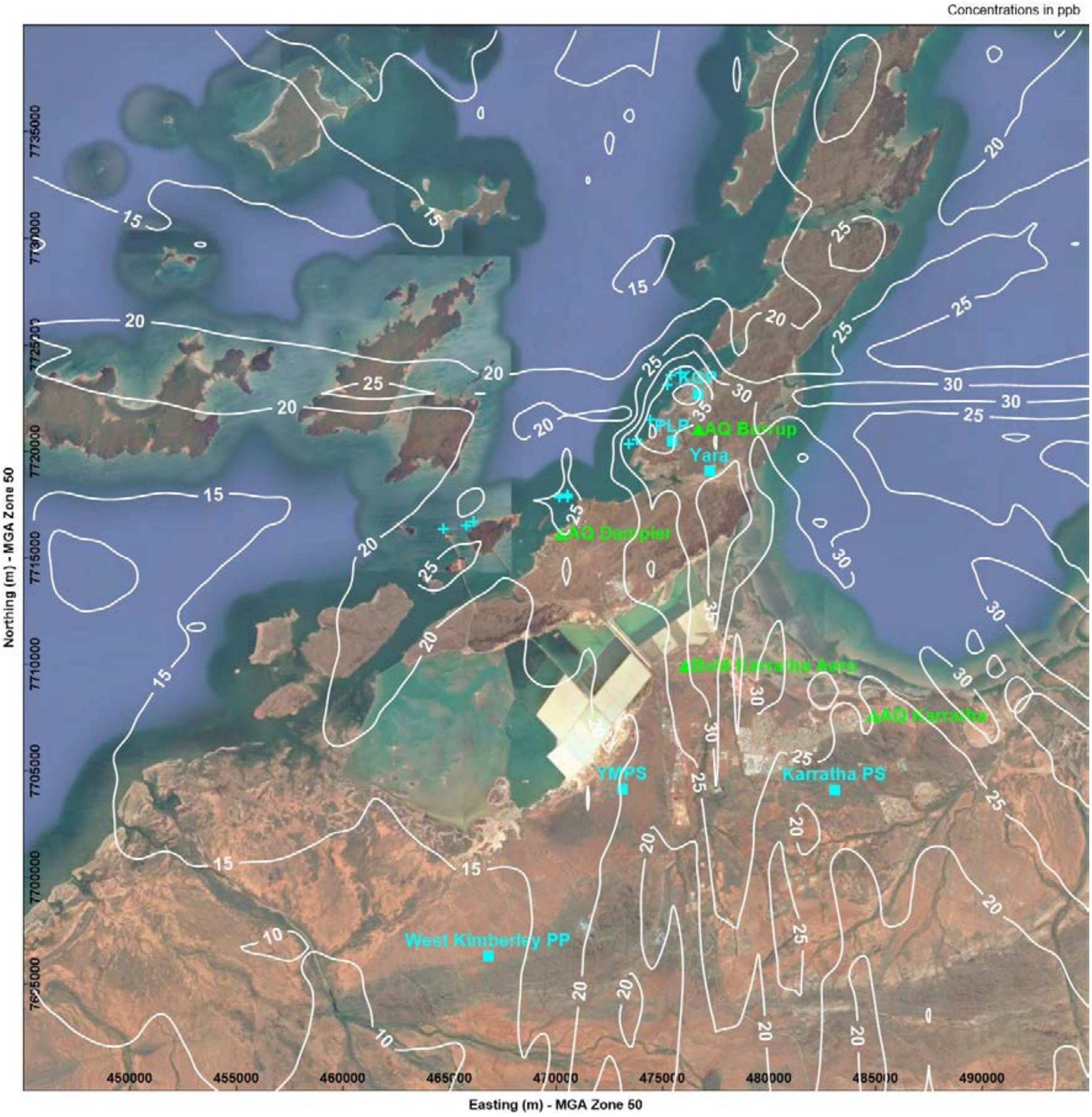

Figure 7-1: CBM – Maximum 1h NO_2 concentrations (ppb)

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

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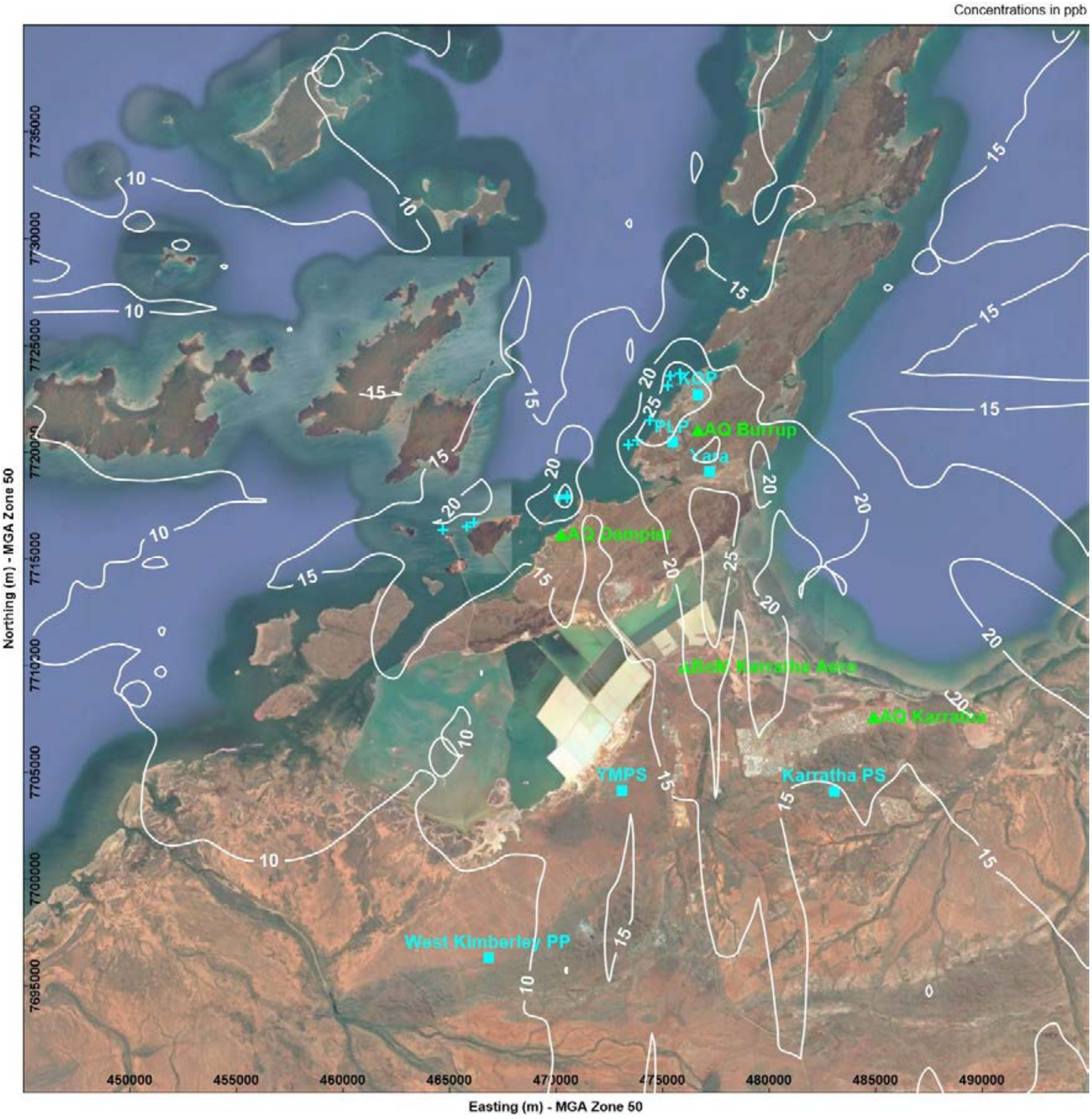

Figure 7-2: KIO – Maximum 1h NO_2 concentrations (ppb)

- Maximum grid receptor concentration, 29.1 ppb.
- NEPM (Ambient Air Quality) standard, 120 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

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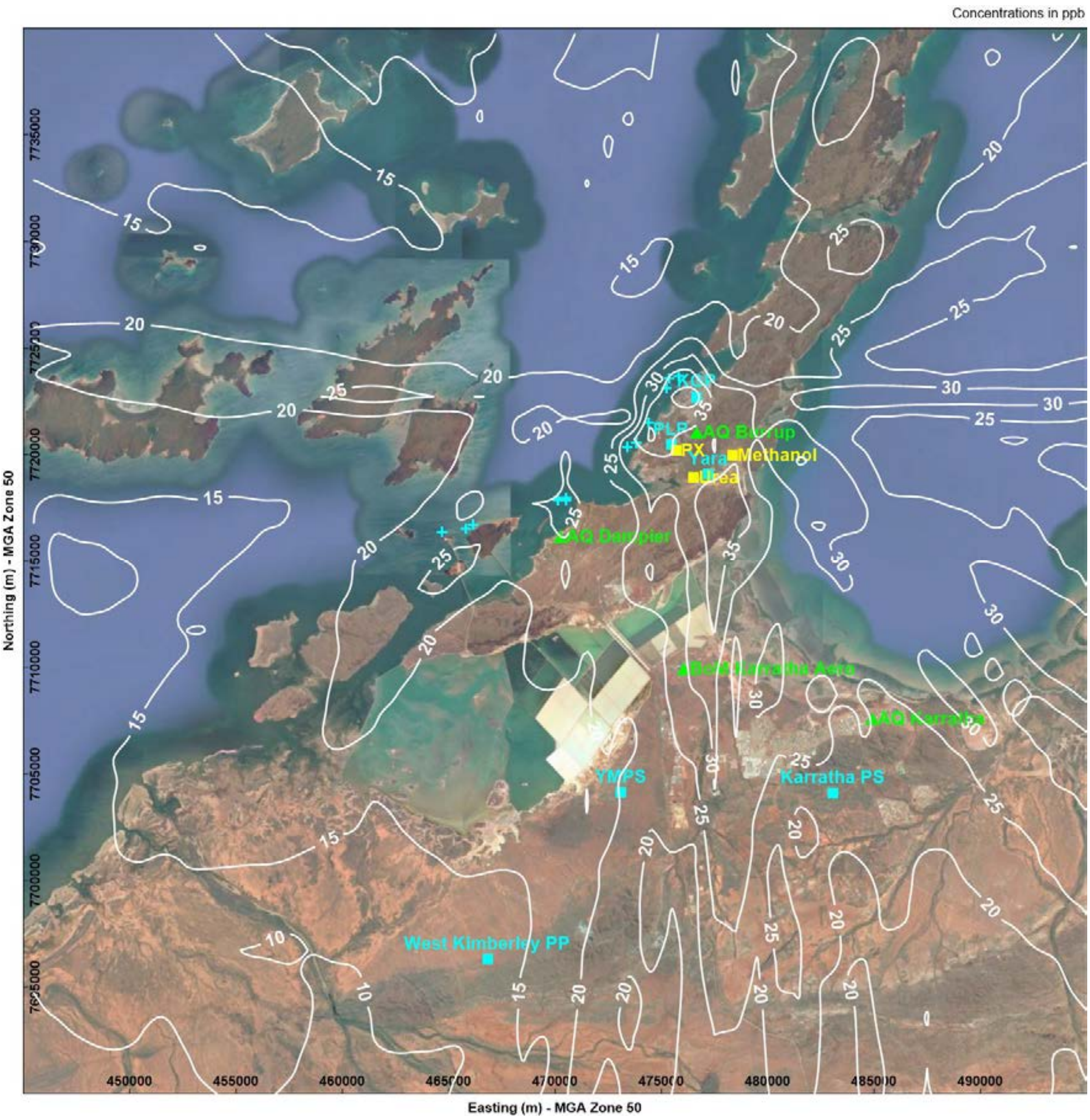

Figure 7-3: FBSIA – Maximum 1h NO_2 concentrations (ppb)

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

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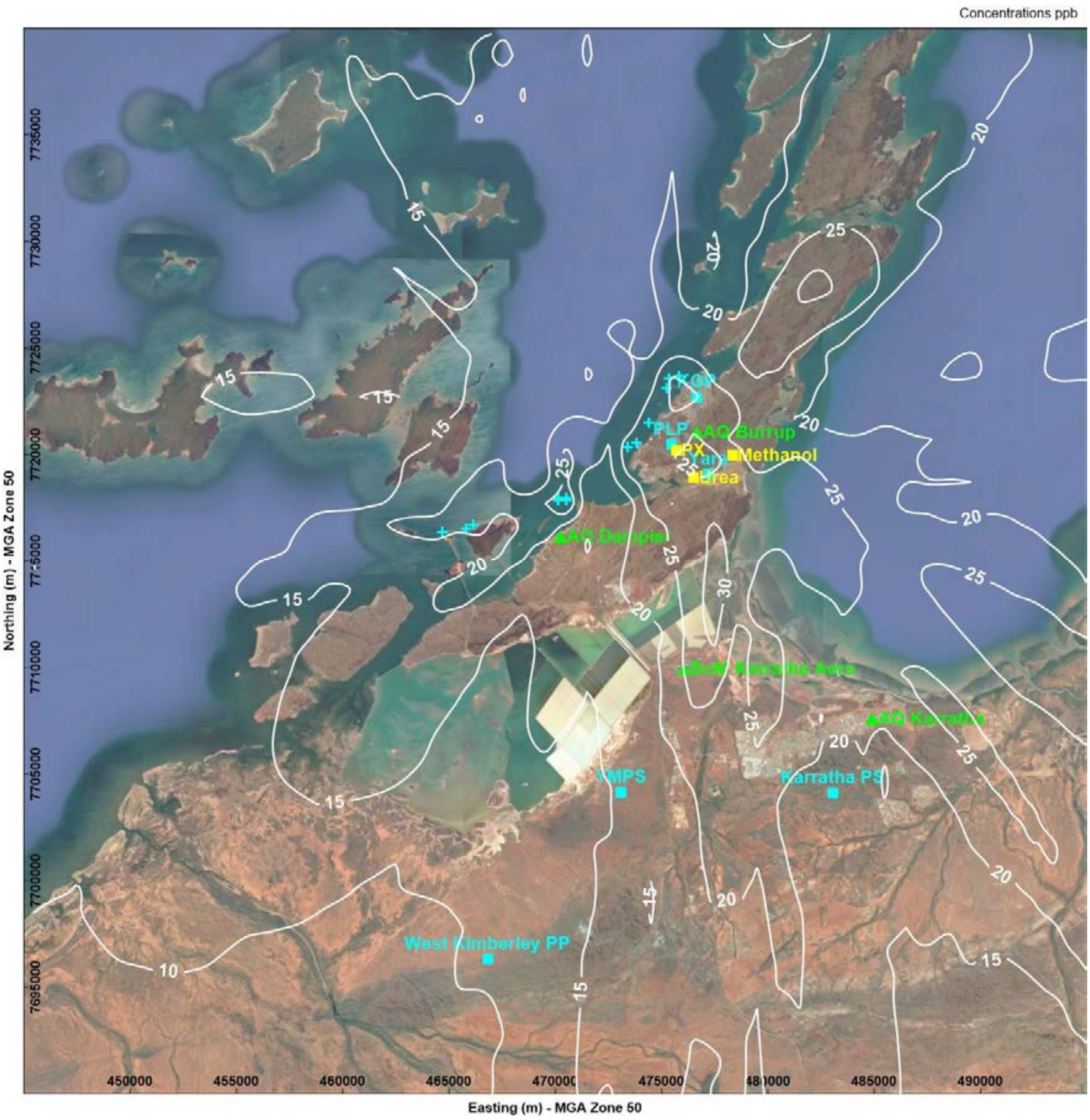

Figure 7-4: FBSIA-KIO – Maximum 1h NO_2 concentrations (ppb)

- Maximum grid receptor concentration, 32.4 ppb.
- NEPM (Ambient Air Quality) standard, 120 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

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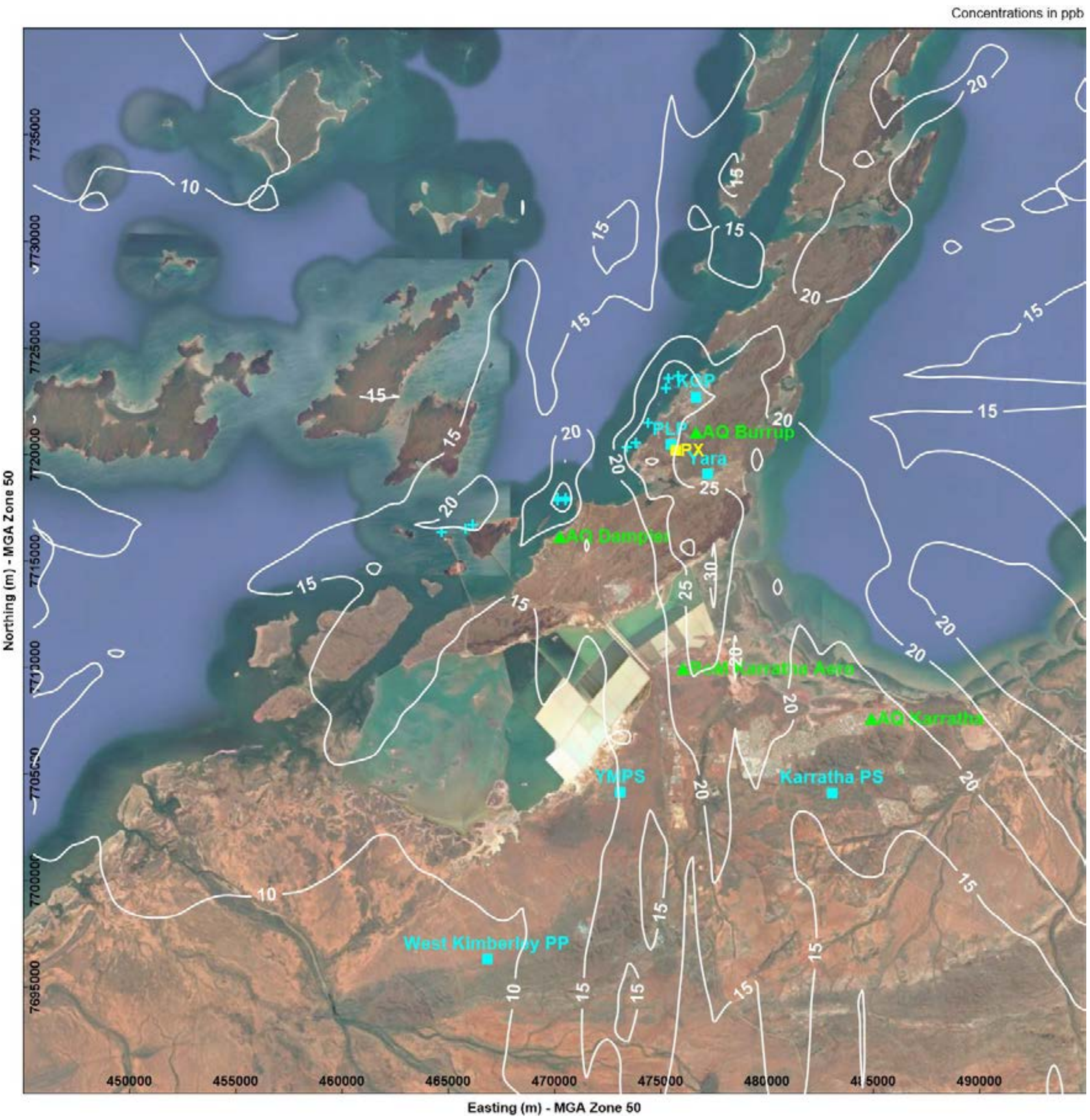

Figure 7-5: FBSIA E&A – Maximum 1h NO_2 concentrations (ppb)

- Maximum grid receptor concentration, 30.7 ppb.
- NEPM (Ambient Air Quality) standard, 120 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

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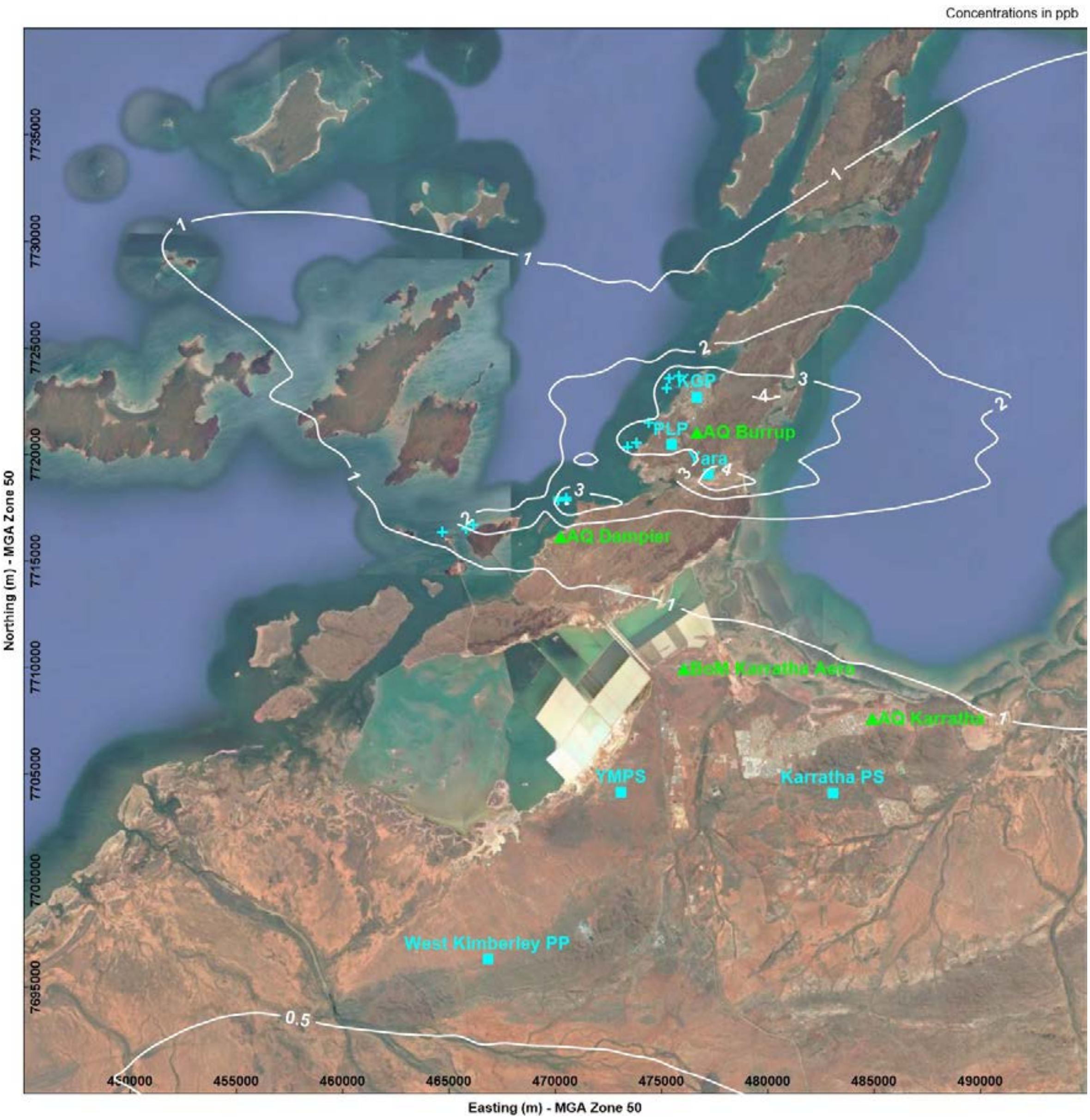

Figure 7-6: CBM – Annual Average NO_2 concentrations (ppb)

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

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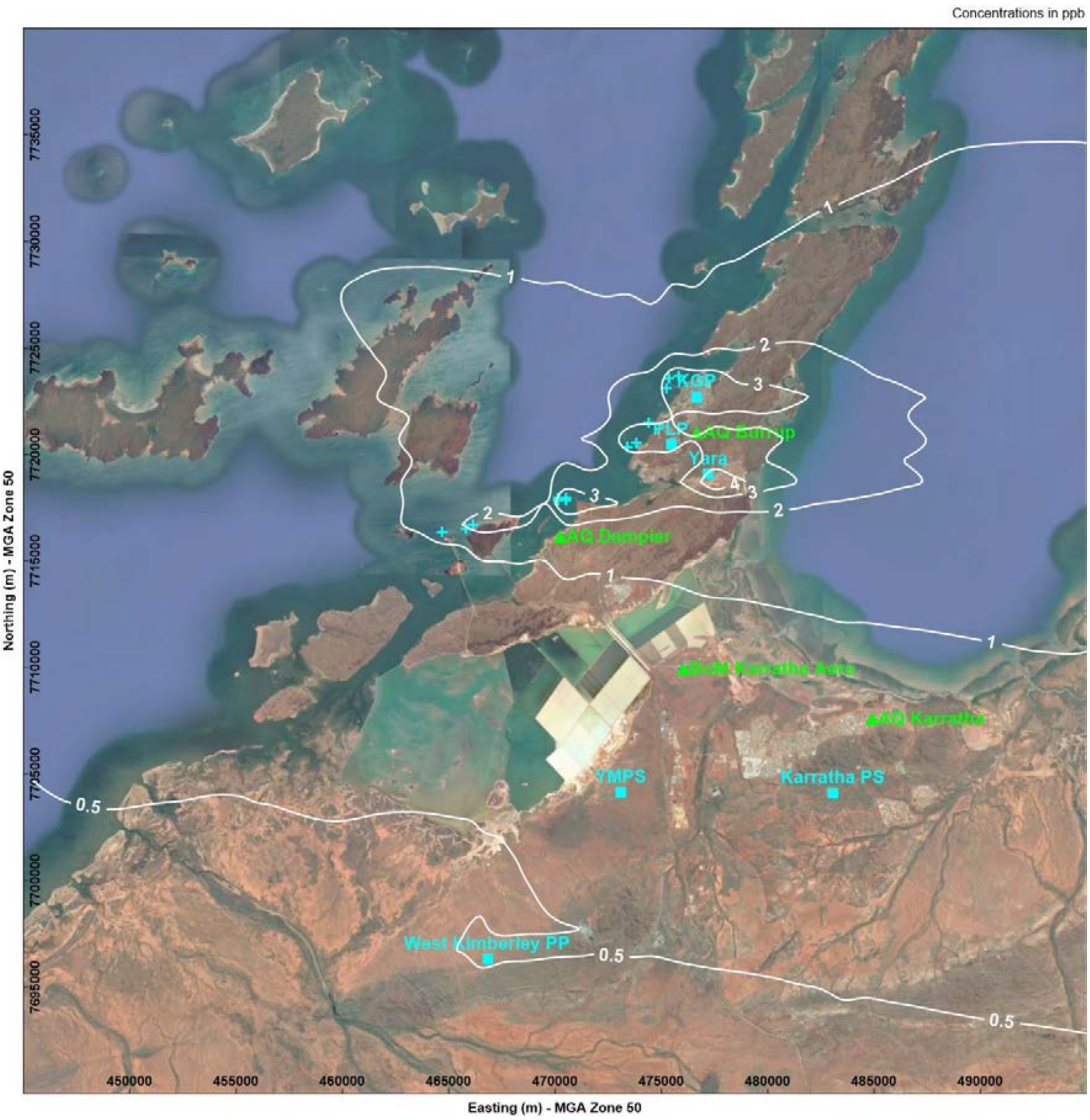

Figure 7-7: KIO – Annual Average NO_2 concentrations (ppb)

- Maximum grid receptor concentration, 4.9 ppb.
- NEPM (Ambient Air Quality) standard, 30 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

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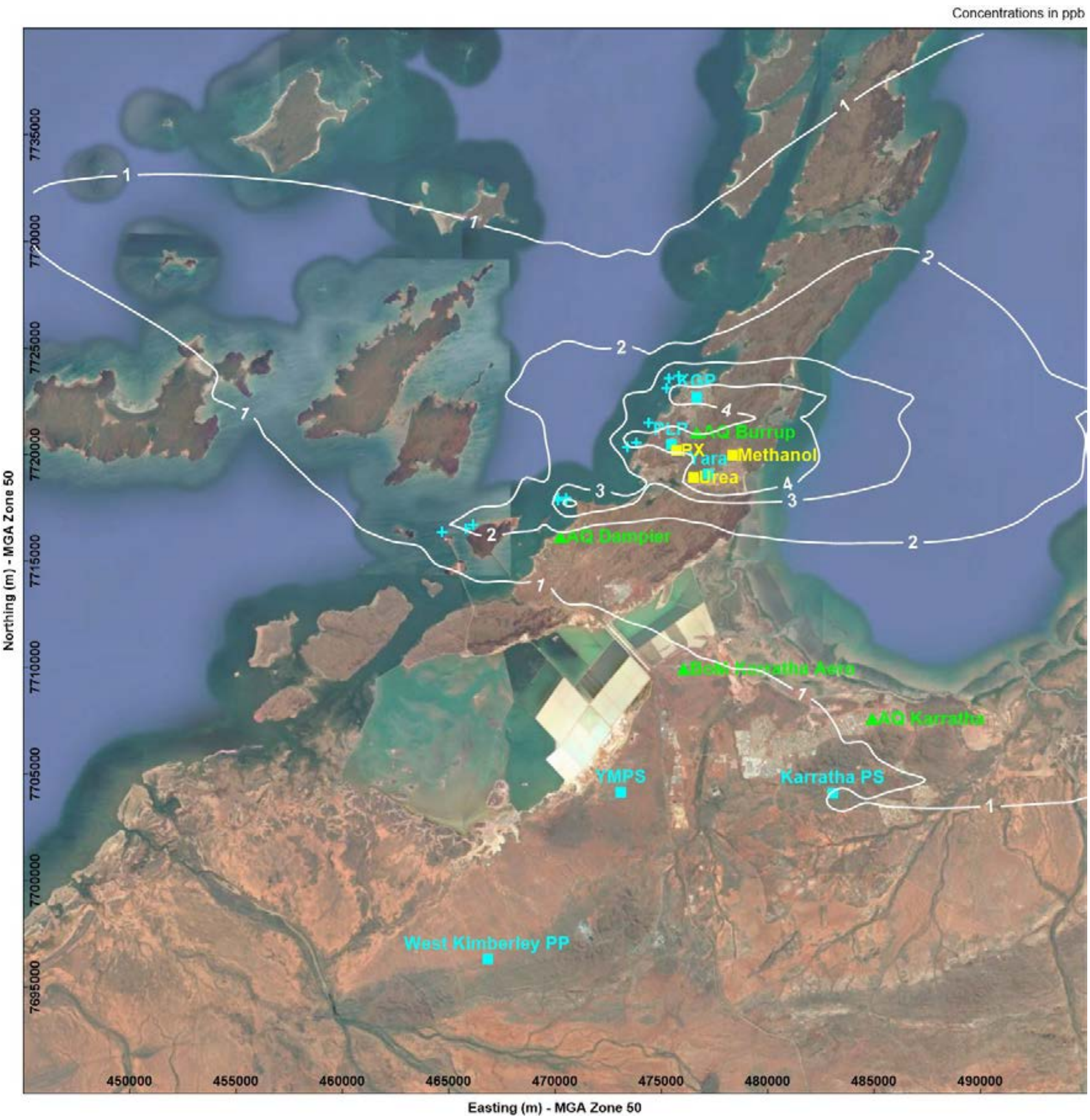

Figure 7-8: FBSIA – Annual Average NO_2 concentrations (ppb)

- Maximum grid receptor concentration, 5.6 ppb.
- NEPM (Ambient Air Quality) standard, 30 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

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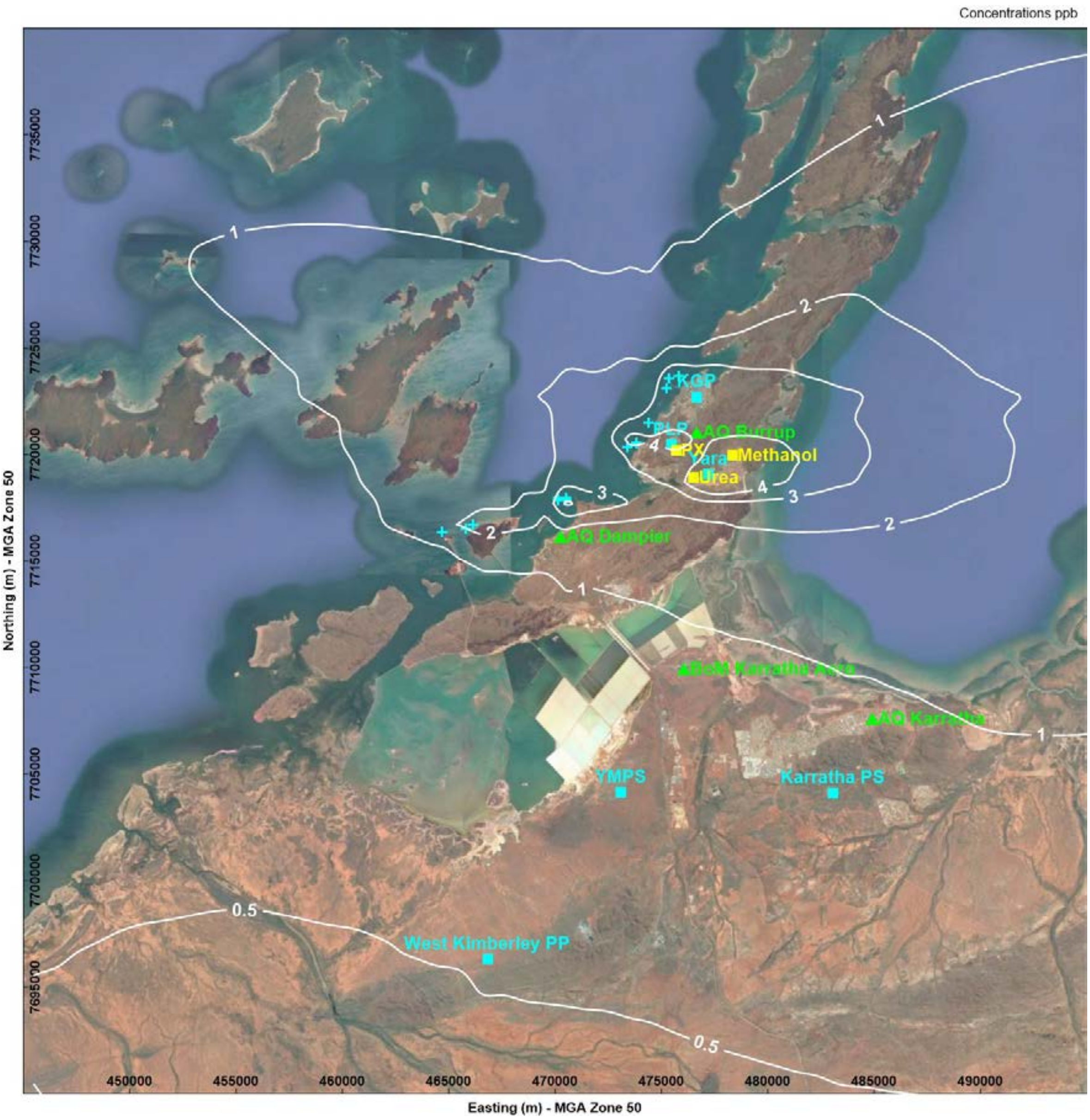

Figure 7-9: FBSIA-KIO – Annual Average NO_2 concentrations (ppb)

- Maximum grid receptor concentration, 5.7 ppb.
- NEPM (Ambient Air Quality) standard, 30 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

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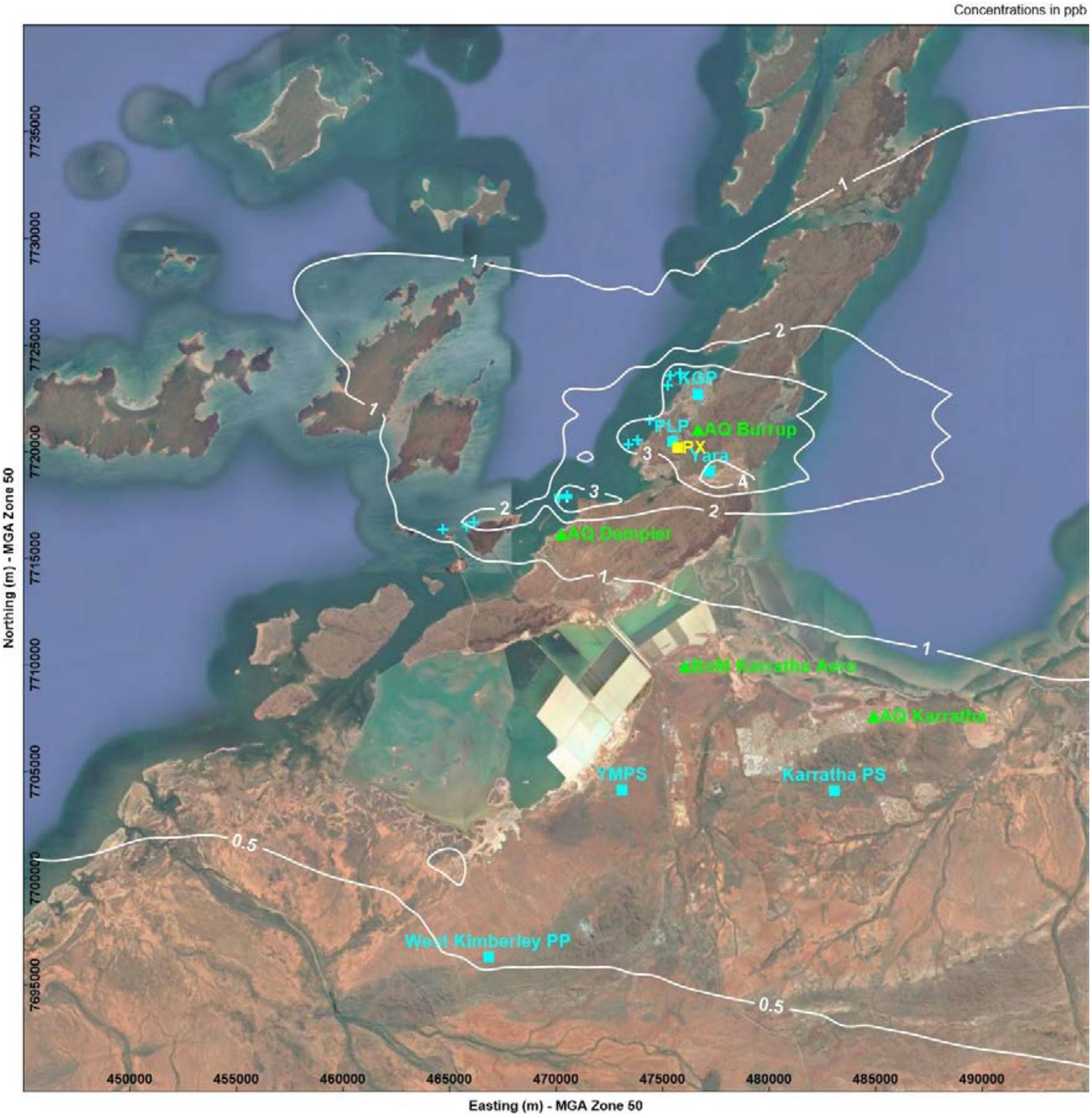

Figure 7-10: FBSIA E&A – Annual Average NO_2 concentrations (ppb)

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

7.3 O_3 Concentrations

The maximum 1-hour average O_3 concentrations for the five modelled air emissions scenarios at the sensitive receptors, and the grid maxima, are presented in Table 7-3. Contour plots of the maximum hourly average O_3 GLCs for the five scenarios are provided in Figure 7-11 (Current Baseline) through to Figure 7-15 (FBSIA E&A). All the results are less than the corresponding NEPM standard of 100 ppb.

Table 7-3: Maximum 1-hour Average O_3 Concentrations (ppb)- Grid Receptors

Receptor	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
Karratha	57.9	55.0	61.2	55.8	55.2
Burrup	58.7	55.4	58.4	55.6	55.6
Dampier	55.4	53.2	56.5	54.4	53.7
Maximum on Grid	61.8	59.2	63.0	61.0	60.0
NEPM Standard	**100**	**100**	**100**	**100**	**100**

It is noted the TAPM output for 4-hour average O_3 is not the 'rolling average' needed for assessment against the relevant NEPM standard (80 ppb). Therefore the 4-hour average results provided here are indicative. However, the step-wise 4-hour average O_3 results; i.e., the standard TAPM output, should provide a reasonable indication of the rolling 4-hour averages. The maximum 4-hour average O_3 concentrations for the three modelling scenarios at the sensitive receptors and anywhere on the grid are presented in Table 7-4.

Table 7-4: Maximum 4-hour Average O_3 Concentrations (ppb)- Grid Receptors

Receptor	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
Karratha	56.3	51.2	59.1	53.8	51.8
Burrup	54.3	51.7	53.7	51.7	51.9
Dampier	52.5	50.5	53.6	51.8	51.0
Maximum on Grid	58.2	55.3	59.7	57.4	56.1
NEPM Standard	**80**	**80**	**80**	**80**	**80**

The results for maximum 1-hour and maximum 4-hour average O_3 GLCs show relevant NEPM standards are unlikely to be exceeded anywhere in the study area; at least in relation to the industrial NO_x sources. Other 'natural' sources of O_3, such as bushfires, were not included in the modelling, and potentially these could cause exceedances of O_3 standards.

Air Quality Impact Assessment

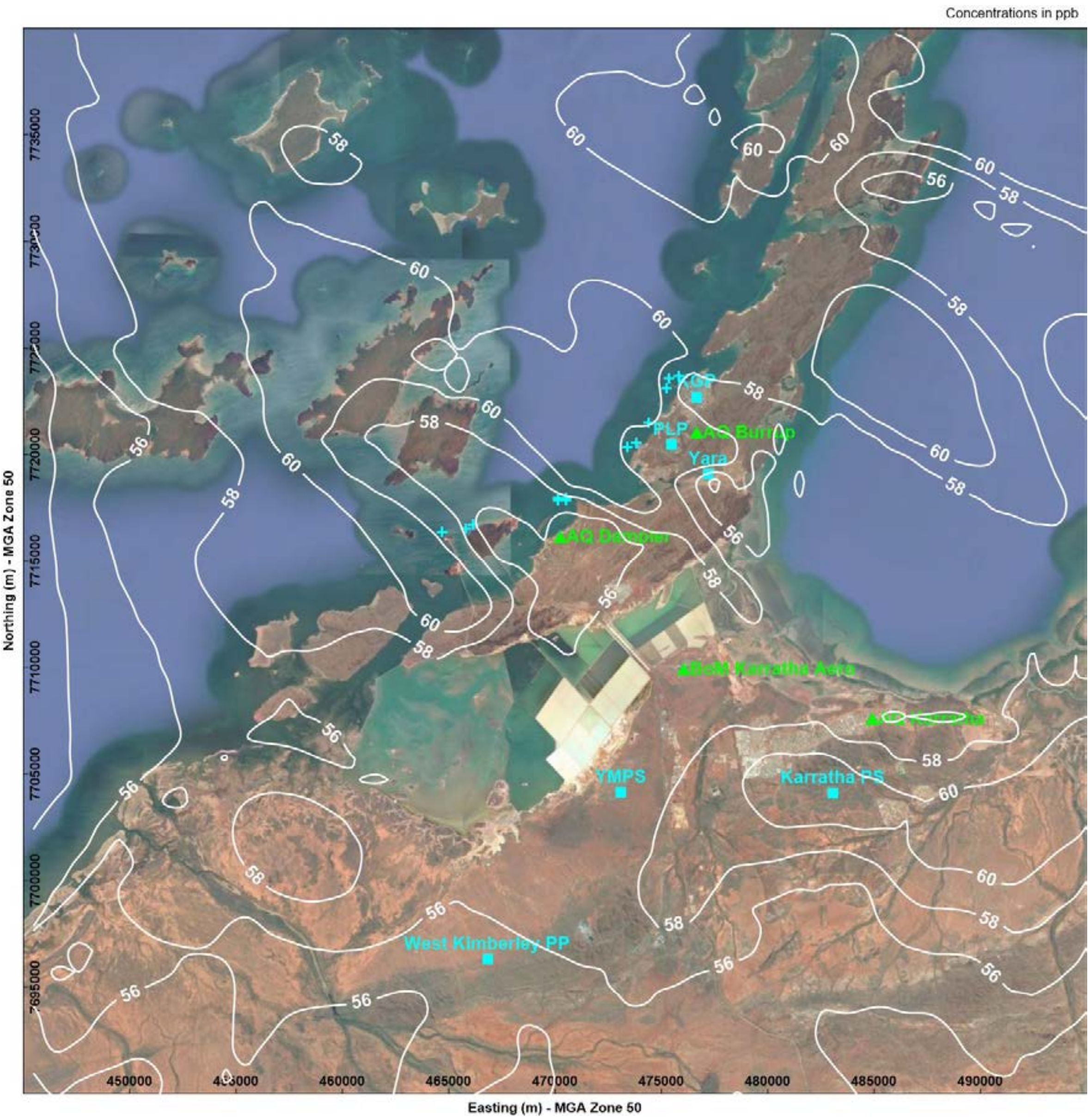

Figure 7-11: CBM – Maximum 1-hour Average O_3 Concentrations (ppb)

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

Air Quality Impact Assessment

Figure 7-12: KIO – Maximum 1-hour Average O_3 Concentrations (ppb)

- Maximum grid receptor concentration, 59.2 ppb.
- NEPM (Ambient Air Quality) standard, 100 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

Air Quality Impact Assessment

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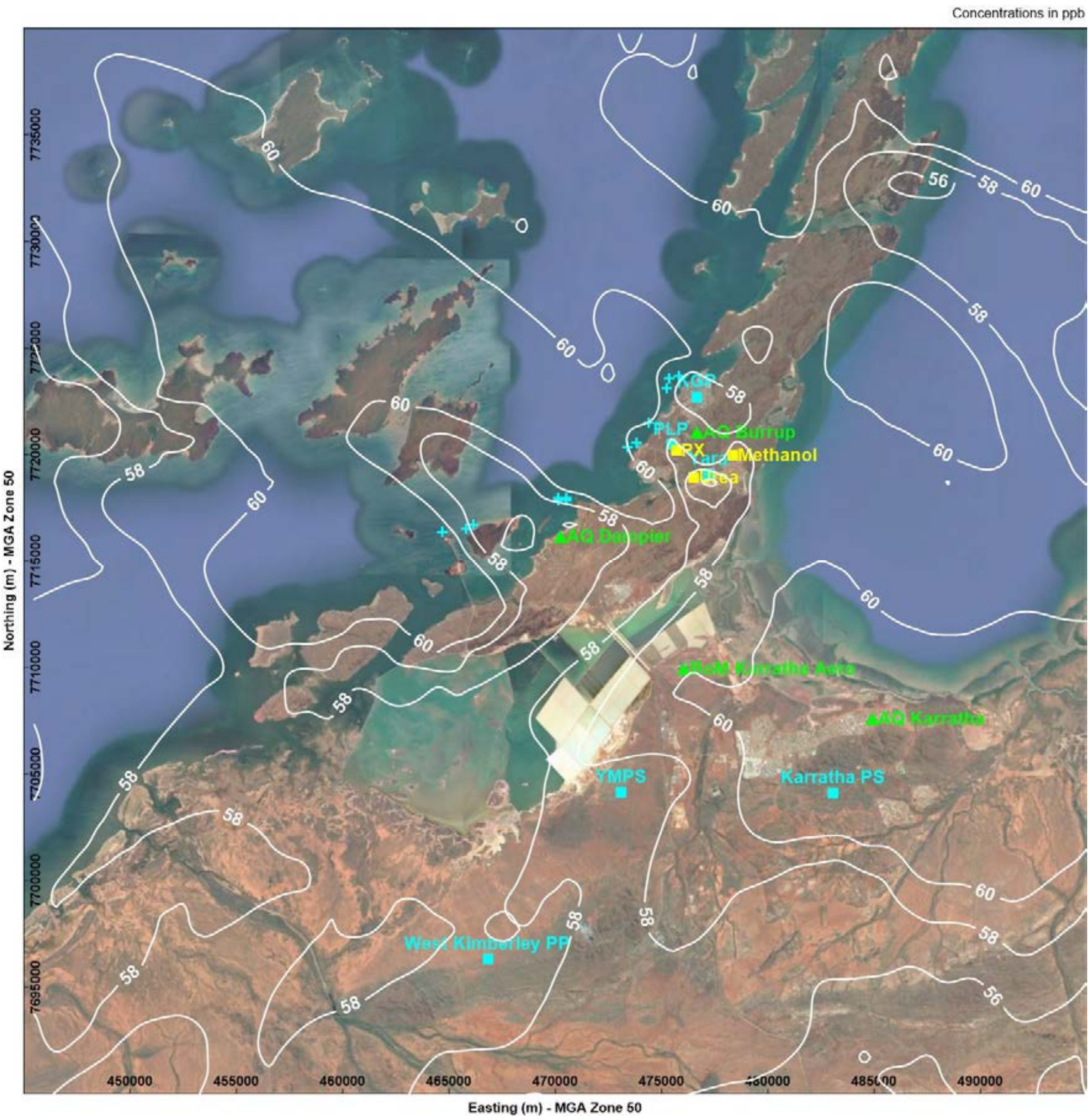

Figure 7-13: FBSIA – Maximum 1-hour Average O_3 Concentrations (ppb)

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

Air Quality Impact Assessment

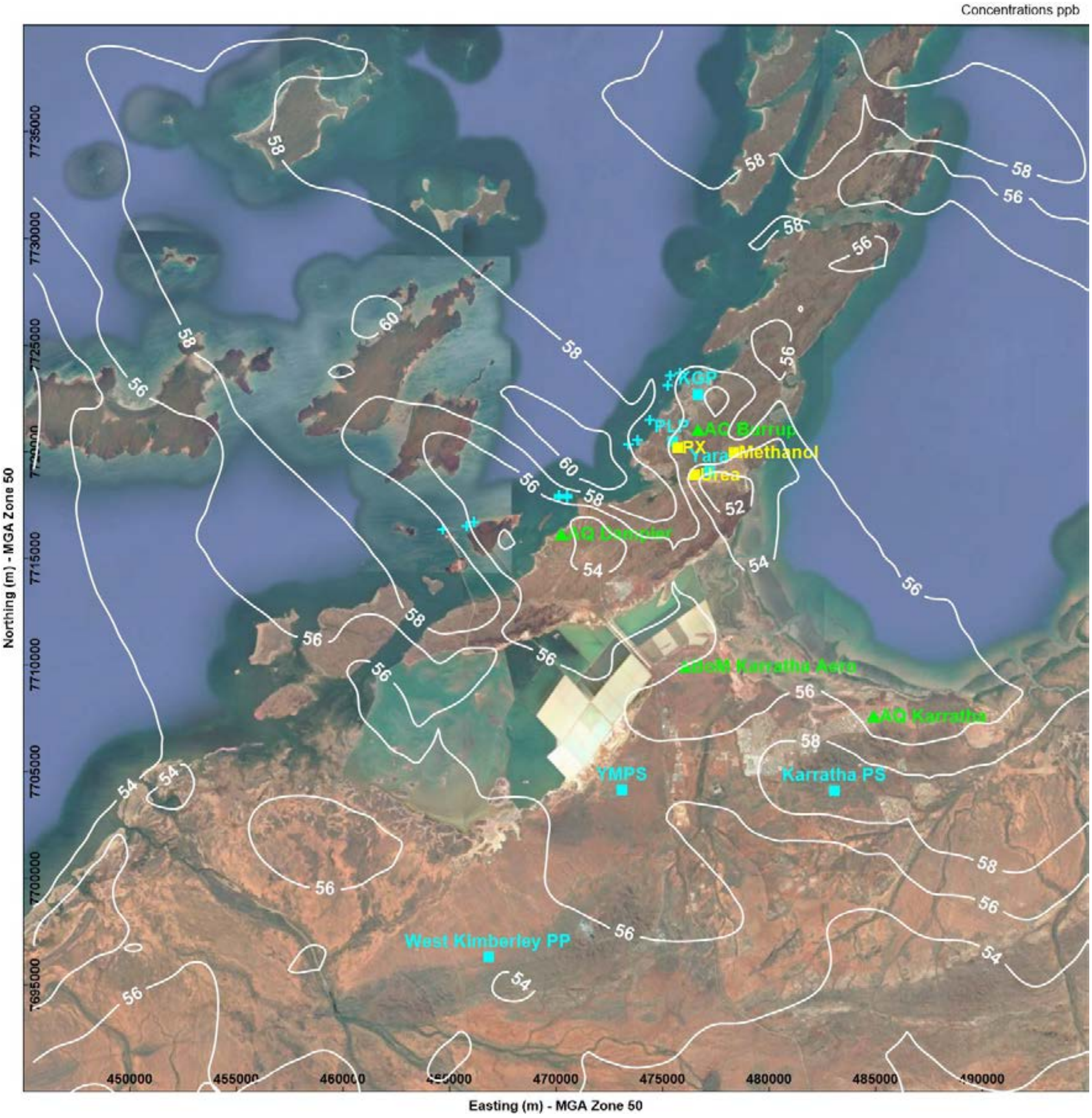

Figure 7-14: FBSIA-KIO – Maximum 1-hour Average O_3 Concentrations (ppb)

- Maximum grid receptor concentration, 61.0 ppb.
- NEPM (Ambient Air Quality) standard, 100 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

Air Quality Impact Assessment

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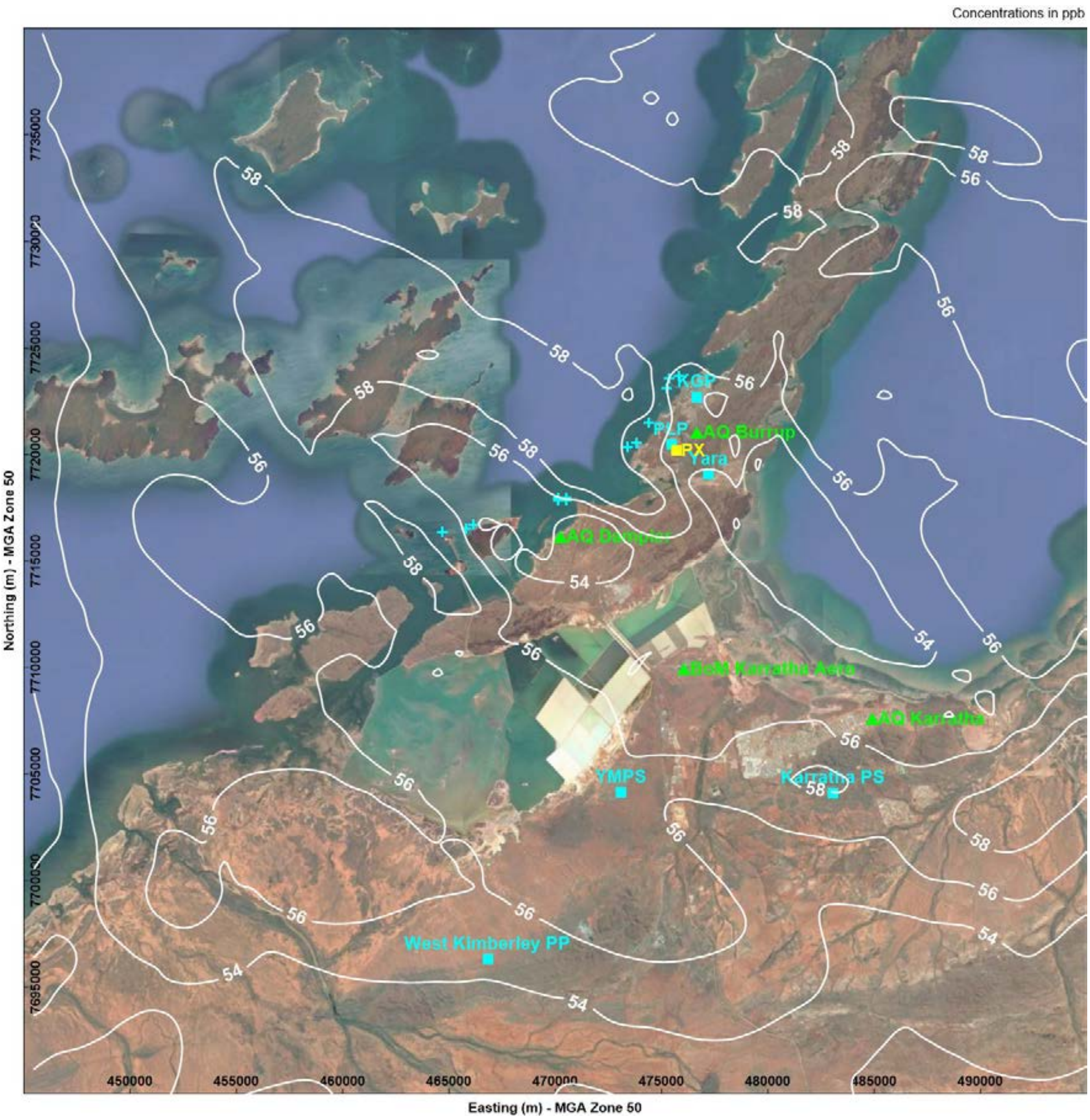

Figure 7-15: FBSIA E&A – Maximum 1-hour Average O_3 Concentrations (ppb)

- Maximum grid receptor concentration, 60.0 ppb.
- NEPM (Ambient Air Quality) standard, 100 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.4 SO_2 Concentrations

The model results for the SO_2 GLCs for the five modelled air emissions scenarios at the three sensitive receptor locations, Karratha, Burrup and Dampier, and the grid maxima, are presented in Table 7-5 (maximum 1-hour averages), Table 7-6 (maximum 24-hour averages), and Table 7-7 (annual averages). These results show that the relevant NEPM standards are not expected to be exceeded anywhere in the study area. It is noted that SO_2 concentrations are expected to decrease from 1 January 2020 with the introduction of low sulfur fuel requirements for ships by the International Maritime Organization (IMO) (section 7.5). However, this emissions reduction was not factored into the modelling scenarios.

Table 7-5: Maximum 1-hour Average SO_2 Concentrations (ppb)

Receptor	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
Karratha	3.6	3.6	3.6	3.6	3.6
Burrup	11.3	11.2	11.4	11.3	11.3
Dampier	12.9	13.3	12.9	13.3	13.3
Maximum on Grid	18.1	18.2	18.1	18.2	18.2
NEPM Standard	**200**	**200**	**200**	**200**	**200**

Table 7-6: Maximum 24-hour Average SO_2 Concentrations (ppb)

Receptor	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
Karratha	1.7	1.7	1.7	1.7	1.7
Burrup	4.7	4.7	4.8	4.7	4.7
Dampier	4.6	4.5	4.6	4.5	4.5
Maximum on Grid	7.0	7.0	7.0	7.0	7.0
NEPM Standard	**80**	**80**	**80**	**80**	**80**

Table 7-7: Annual Average SO_2 Concentrations (ppb)

Receptor	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
Karratha	0.9	0.9	0.9	0.9	0.9
Burrup	2.0	2.0	2.0	2.0	2.0
Dampier	1.6	1.6	1.6	1.6	1.6
Maximum on Grid	4.5	4.5	4.5	4.5	4.5
NEPM Standard	**20**	**20**	**20**	**20**	**20**

The SO_2 emission rates varied by very little between the scenarios. As such, only one set of contour plots is provided for the Current Baseline scenario, which is representative of all five model scenarios. The results are provided in Figure 7-16 (maximum 1-hour average SO_2), Figure 7-17 (maximum 24-hour average SO_2), and Figure 7-18 (annual average SO_2).

Air Quality Impact Assessment

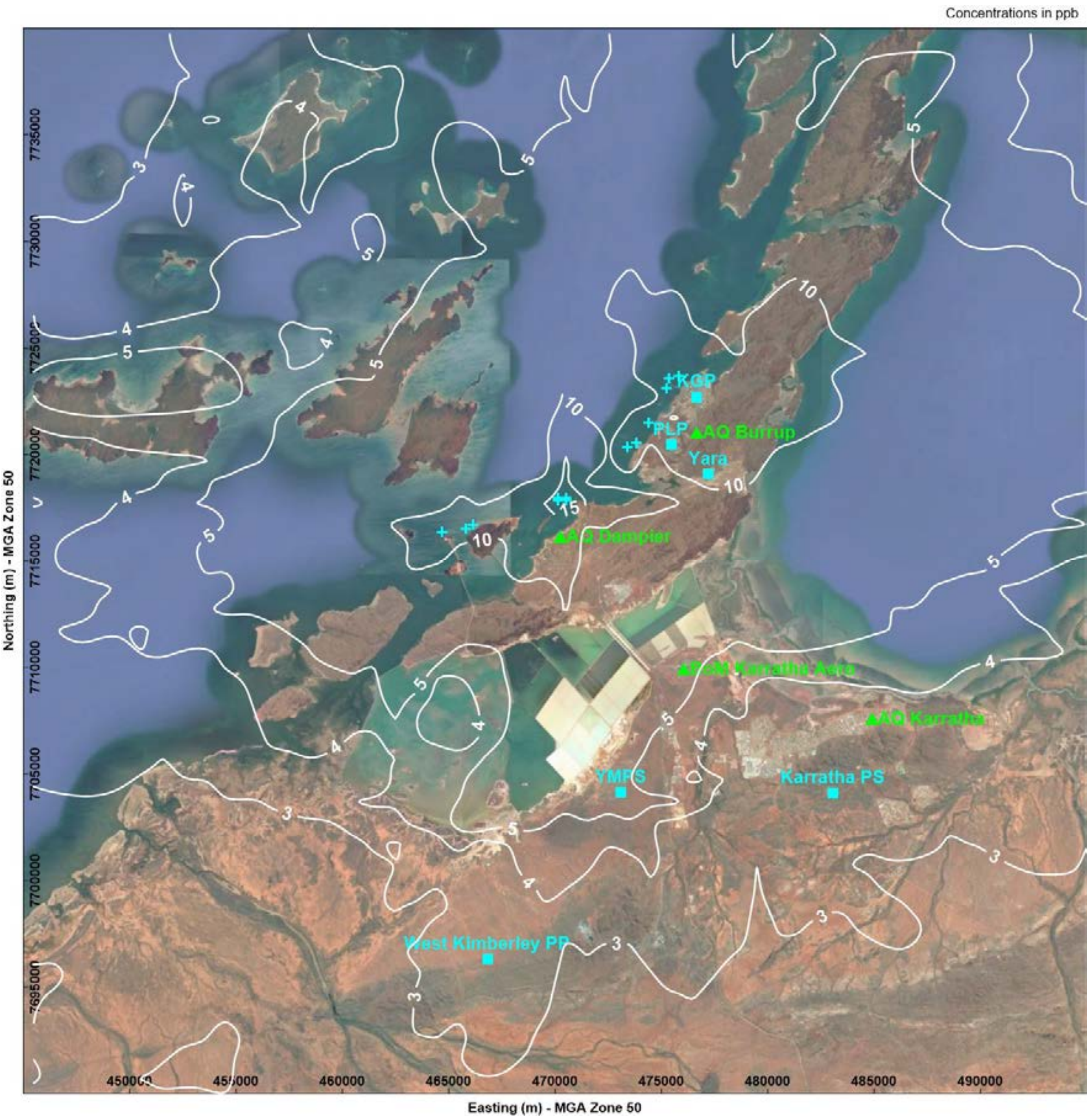

Figure 7-16: CBM – Maximum 1-hour Average SO_2 Concentrations (ppb)

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

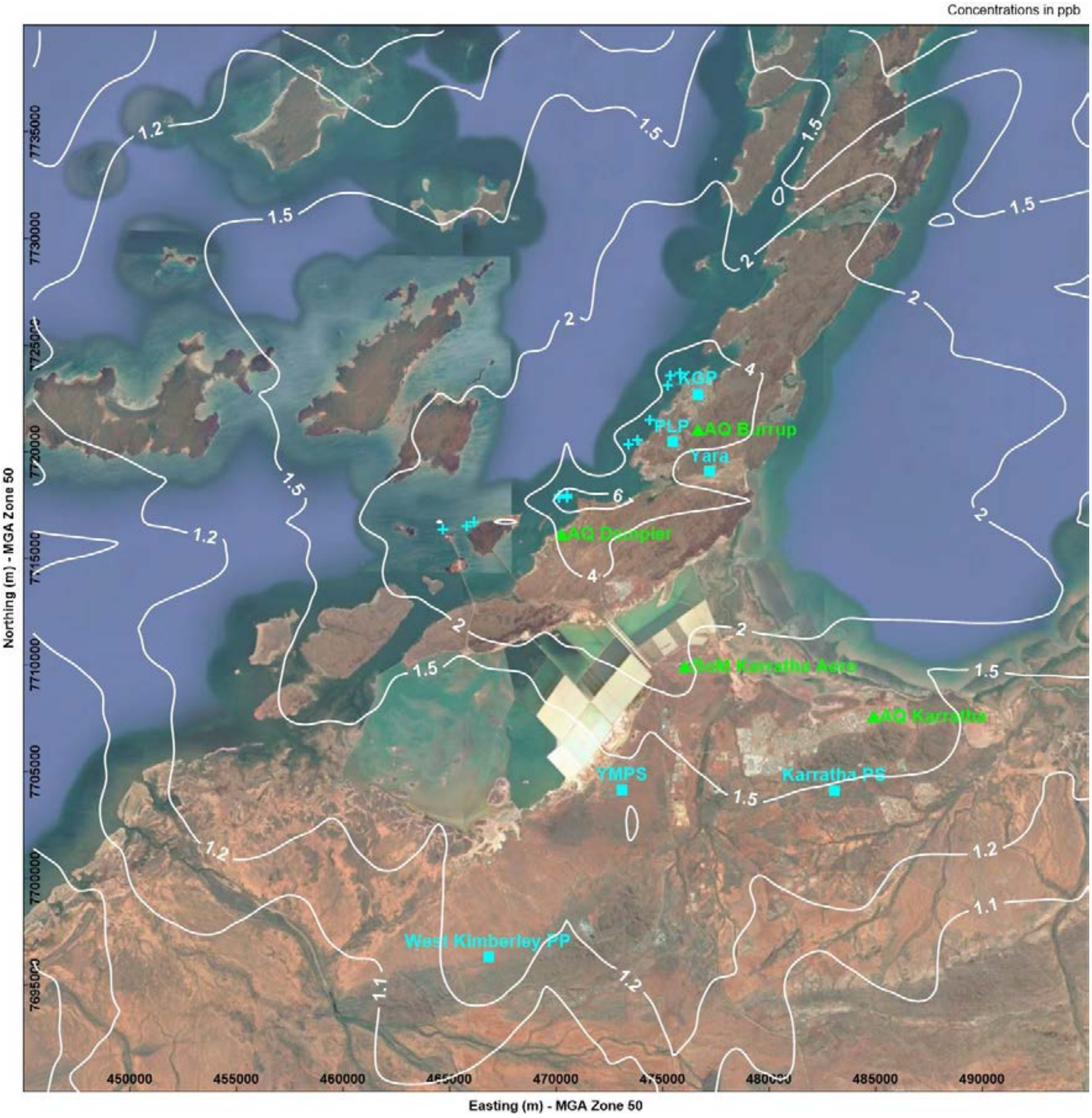

Figure 7-17: CBM – Maximum 24-hour Average SO_2 Concentrations (ppb)

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

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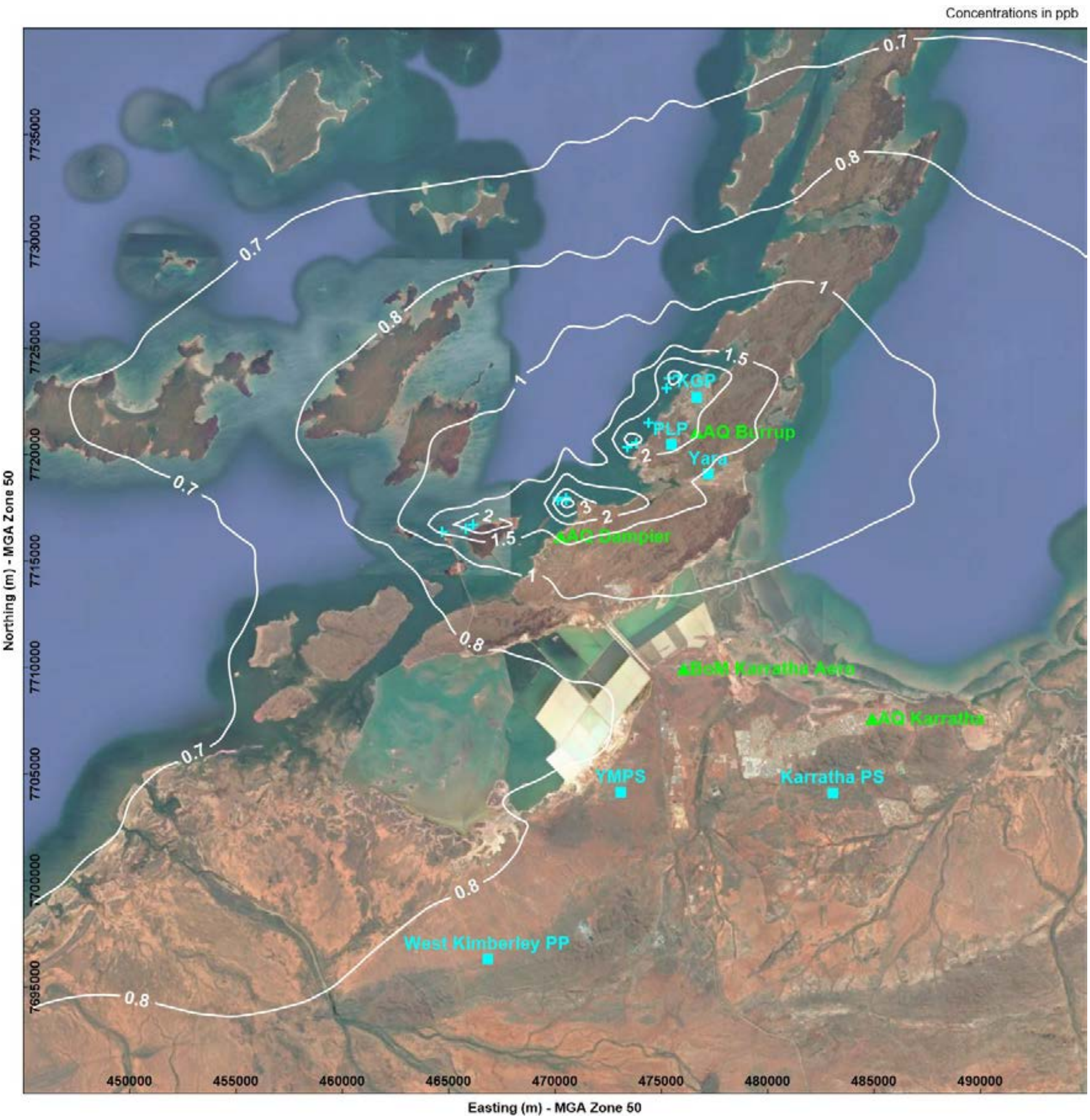

Figure 7-18: CBM – Annual Average SO_2 Concentrations (ppb)

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

7.5 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 2.4; these are also listed in Table 7-8.

The maximum annual average NO_x results (ppb) for each of the five scenarios are provided in Table 7-8. All values are less than 16 ppb, which is well below the relevant EU (2008) standard of 16 ppb (we have converted the EU standard of 20 µg/m^3 to 16 ppb using the temperature 30°C).

Also, the maximum annual average SO_2 results (ppb) for each of the five scenarios are provided in Table 7-8. All values are less than 5 ppb, which is well below the relevant EU (2008) standard of 8 ppb. For all five scenarios, the highest concentrations were predicted for locations adjacent to the shipping berths, which were conservatively modelled as continuous sources; e.g., see Figure 7-18, provided in the preceding Section 7.4. It is noted that the future IMO requirements to reduce the sulfur content of fuel for shipping (Section 7.4), is likely to lower the future risk of impact on vegetation from SO_2 emissions (AMSA, 2018). However, this emissions reduction was not factored into the modelling scenarios.

Results for the two new Proposal scenarios for annual NO_x are provided in Figure 7-22 (FBSIA-KIO) and Figure 7-23 (FBSIA E&A); for annual SO_2 results, see the CBM results in Figure 7-18.

Table 7-8: Maximum Grid concentrations for the three scenarios for Assessment of Vegetation Effects

Assessment Parameter	EU 2008 Veg. Standard (ppb)	CBM (ppb)	KIO (ppb)	FBSIA (ppb)	FBSIA-KIO (ppb)	FBSIA E&A (ppb)	Max. Fraction of Standard
Annual average NO_x	16.2 ppb (from 30 µg/m^3 as NO_2 at 30°C)	7.7	7.4	9.0	8.8	7.7	56%
Annual average SO_2	7.8 ppb (from 20 µg/m^3 at 30°C)	4.5	4.5	4.5	4.5	4.5	58%

Air Quality Impact Assessment

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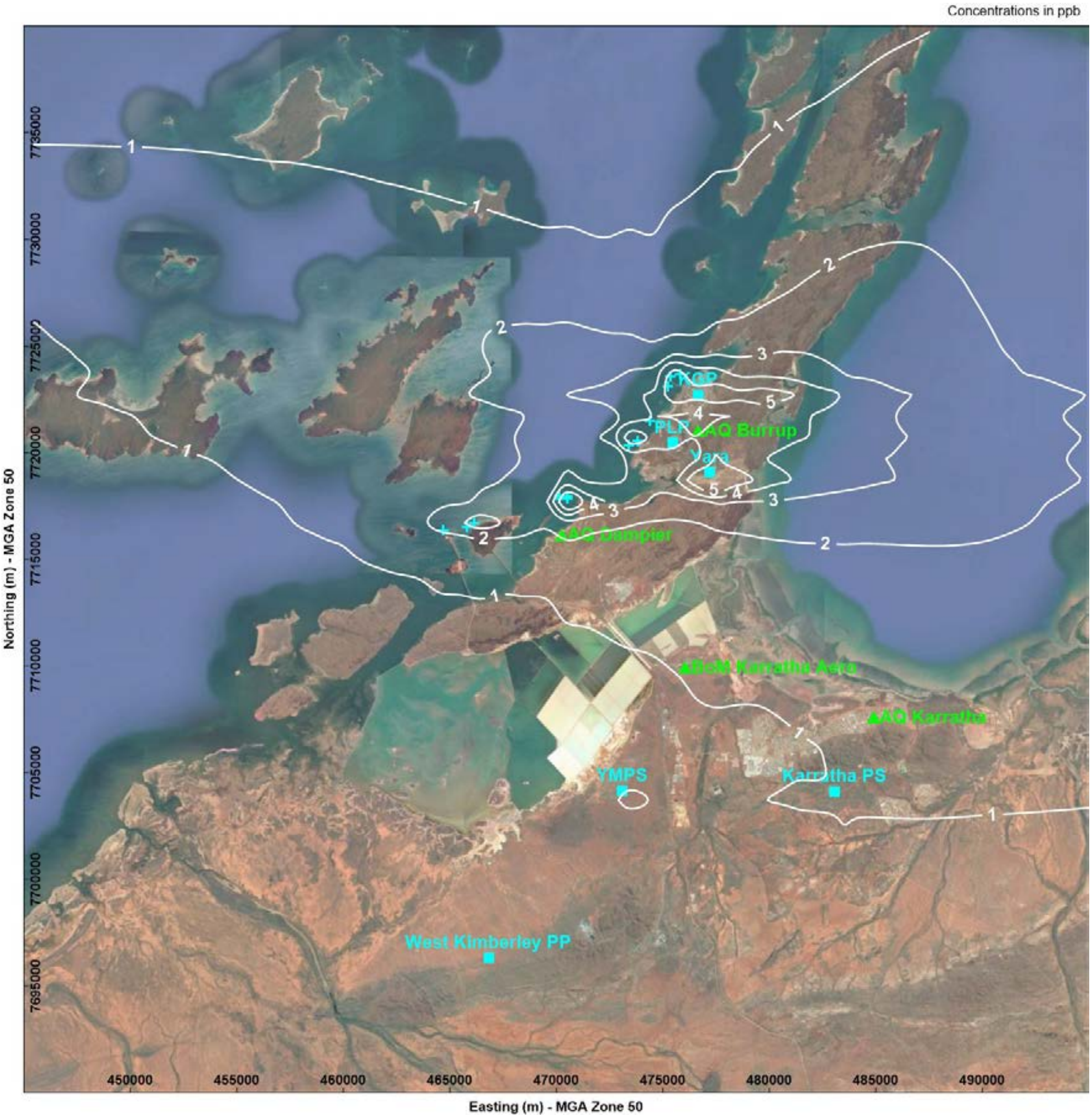

Figure 7-19: CBM- Annual Average NO_X Concentrations (ppb)

- Maximum grid receptor concentration, 7.7 ppb.
- EU (2008) standard for protection of vegetation, 16.2 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

Air Quality Impact Assessment

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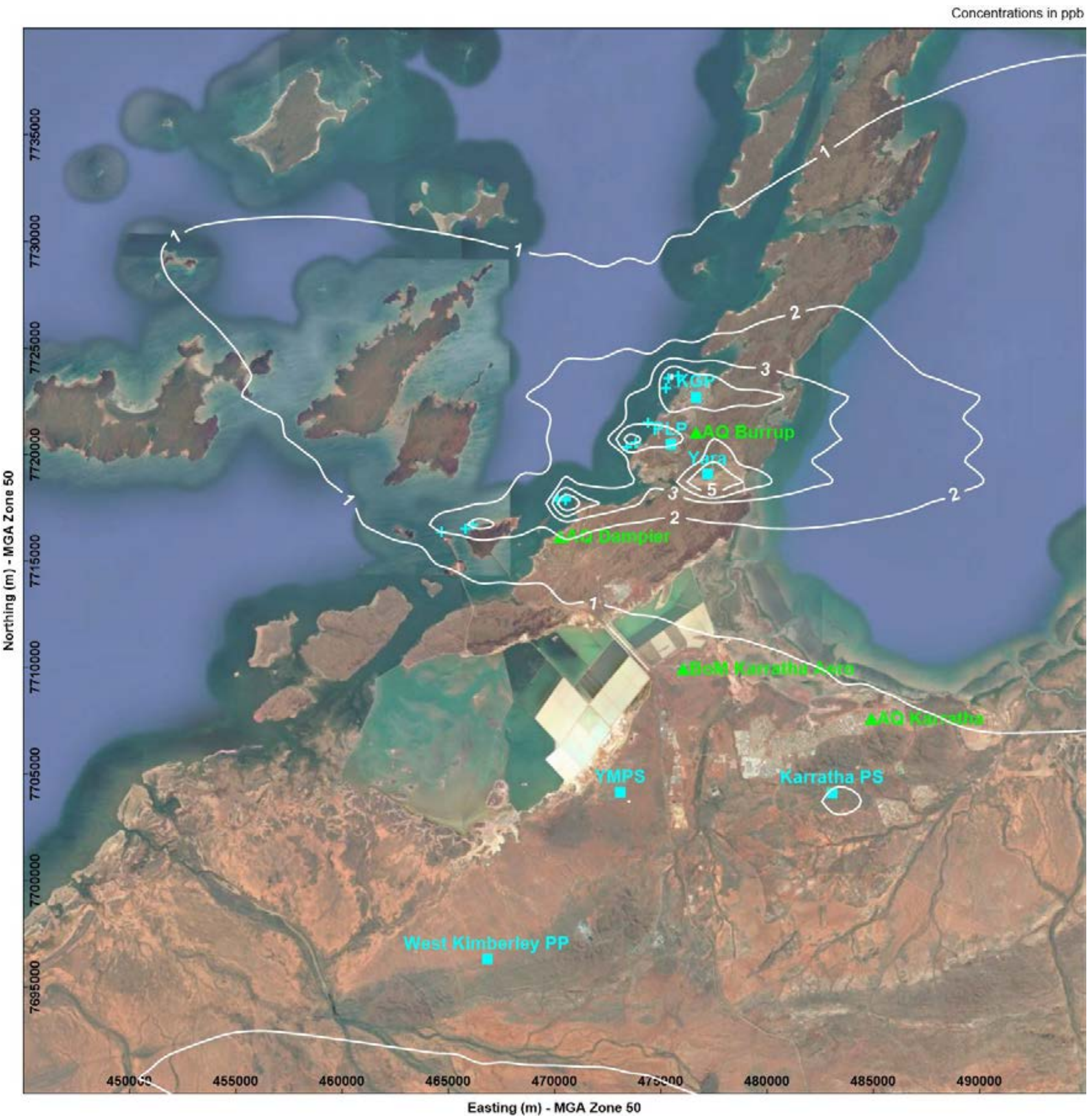

Figure 7-20: KIO- Annual Average NO_X Concentrations (ppb)

- Maximum grid receptor concentration, 7.4 ppb.
- EU (2008) standard for protection of vegetation, 16.2 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

Air Quality Impact Assessment

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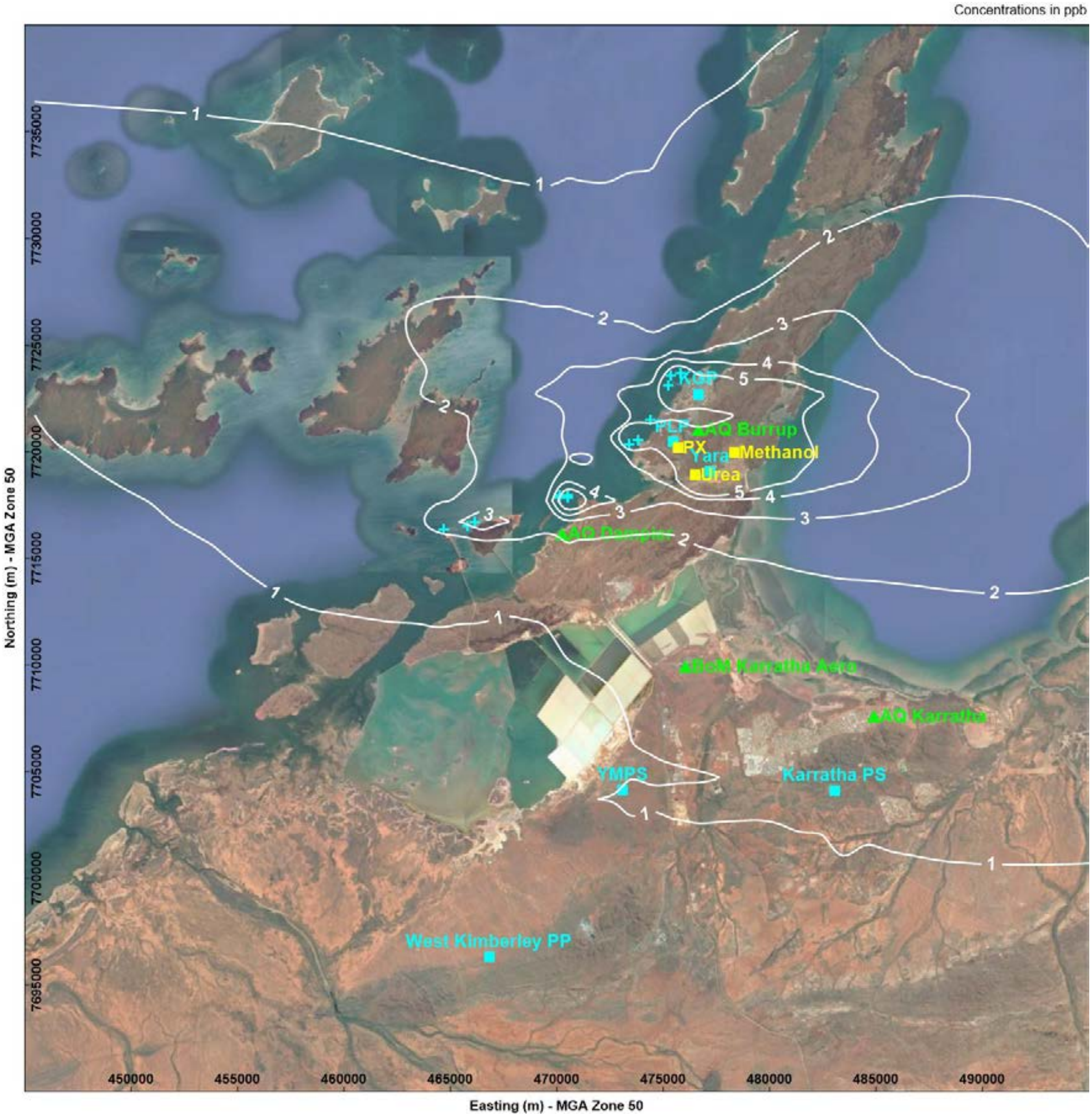

Figure 7-21: FBSIA- Annual Average NO_X Concentrations (ppb)

- Maximum grid receptor concentration, 9.0 ppb.
- EU (2008) standard for protection of vegetation, 16.2 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

Air Quality Impact Assessment

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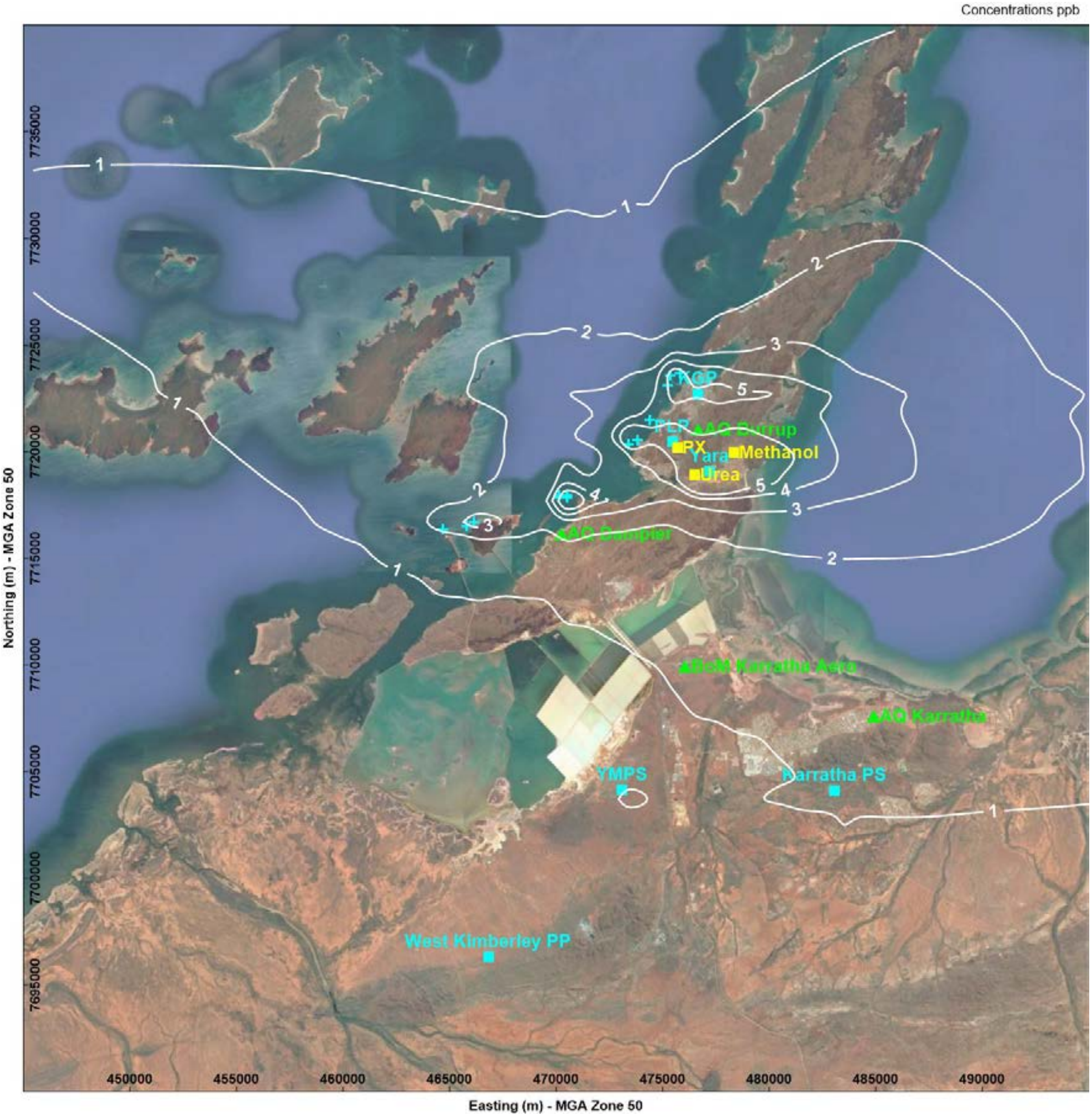

Figure 7-22: FBSIA- KIO- Annual Average NO_X Concentrations (ppb)

- Maximum grid receptor concentration, 8.8 ppb.
- EU (2008) standard for protection of vegetation, 16.2 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

Air Quality Impact Assessment

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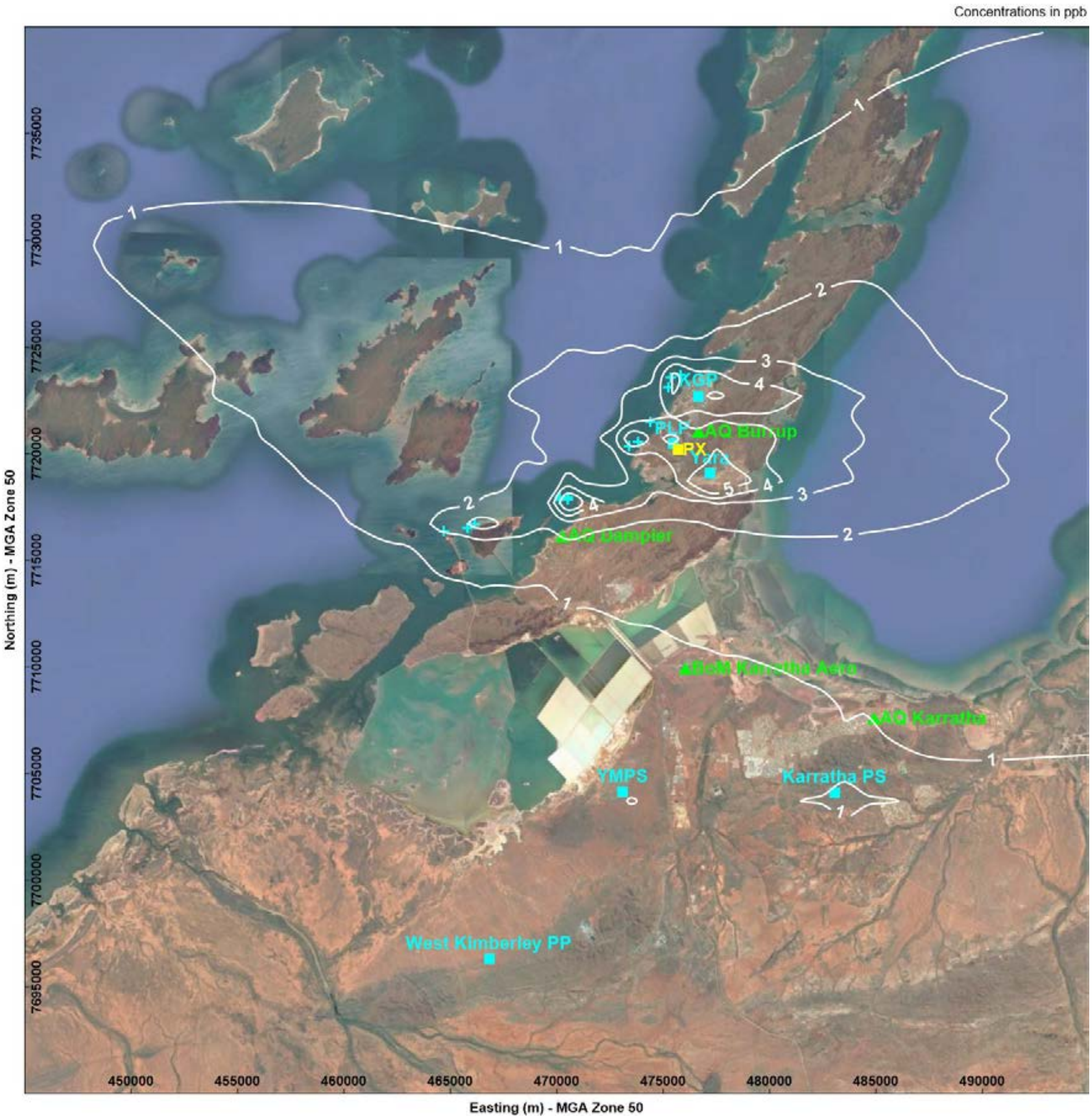

Figure 7-23: FBSIA E&A- Annual Average NO_X Concentrations (ppb)

- Maximum grid receptor concentration, 7.7 ppb.
- EU (2008) standard for protection of vegetation, 16.2 ppb.
- Result of cumulative air quality impact assessment: no exceedances.

7.6 Deposition of NO_2 and SO_2

This section provides a summary of modelling results for the deposition of NO_2 and SO_2. The scope of works excludes an impact assessment or analysis of these results as there are no approved deposition standards for the assessment of environmental impacts on land surfaces. (For the assessment of effects on vegetation health, see the results for annual average NO_x and SO_2 provided in the previous section).

Results for modelled deposition for the five air emissions scenarios are provided in the following series of plots:

- Annual average NO_2 deposition (kg/ha/year); Figure 7-24 through to Figure 7-28.
- Annual average NO_2 deposition (meq/m^2/year); Figure 7-29 through to Figure 7-33.
- Annual average SO_2 deposition (kg/ha/year); Figure 7-34. It is relevant to note that the SO_2 deposition rates varied by very little between the scenarios. As such, only one set of contour plots is provided for the Current Baseline scenario, which is representative of all five model scenarios.

Air Quality Impact Assessment

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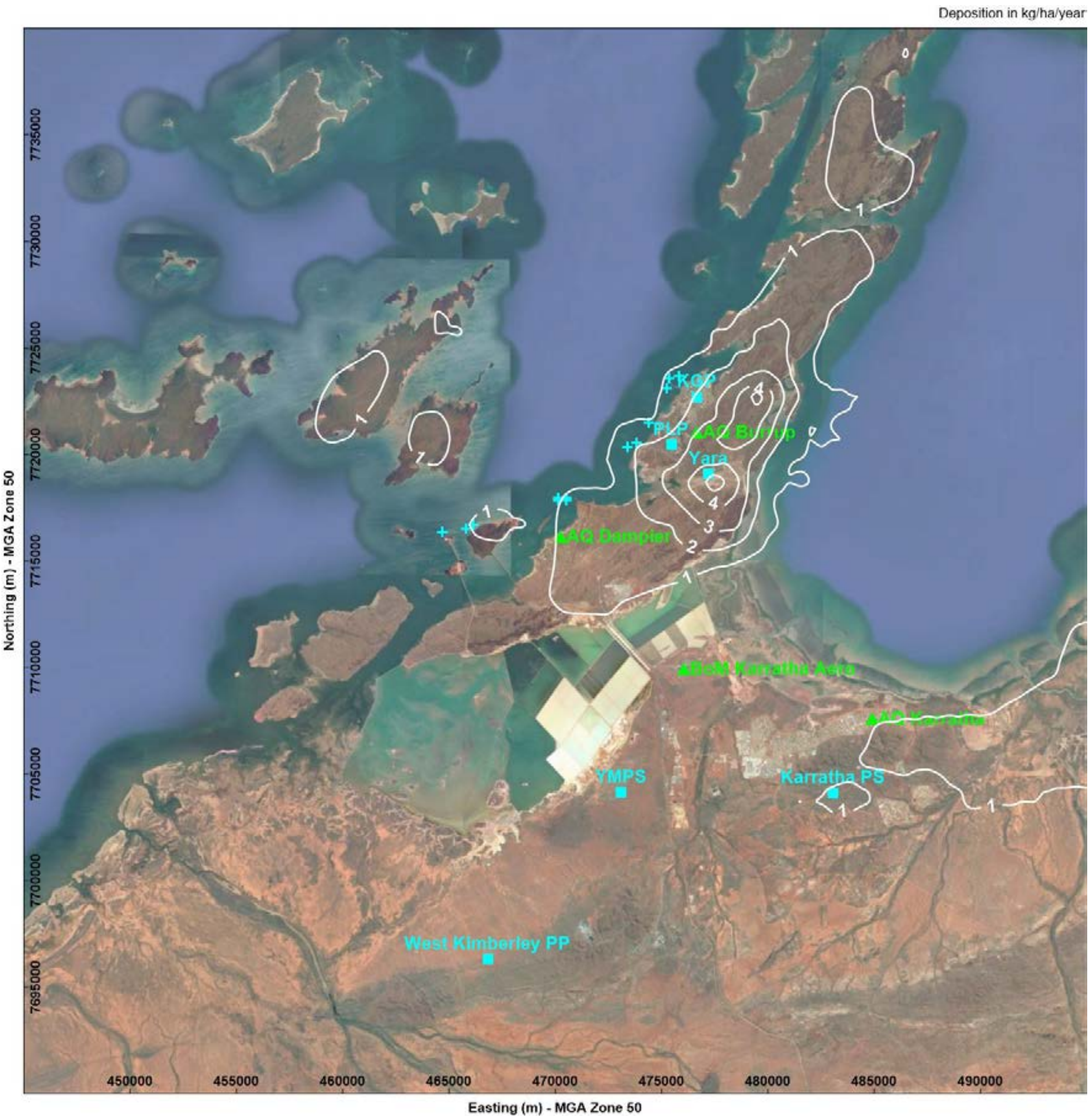

Figure 7-24: CBM – NO_2 deposition (kg/ha/year)

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

Air Quality Impact Assessment

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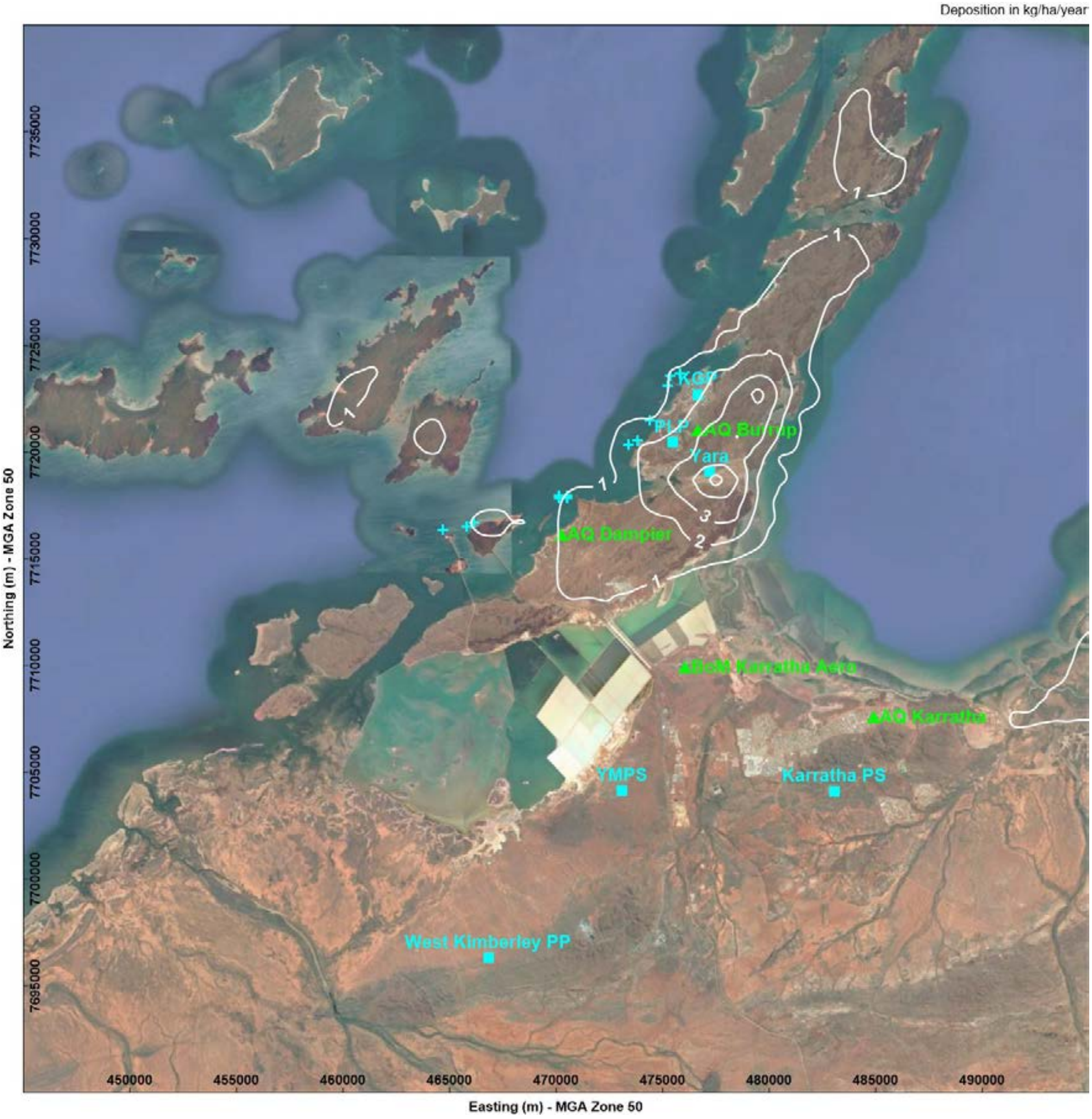

Figure 7-25: KIO – NO_2 deposition (kg/ha/year)

- Maximum grid receptor deposition, 5.5 kg/ha/year.
- For assessment of effects on vegetation health; see annual average NO_x.

Air Quality Impact Assessment

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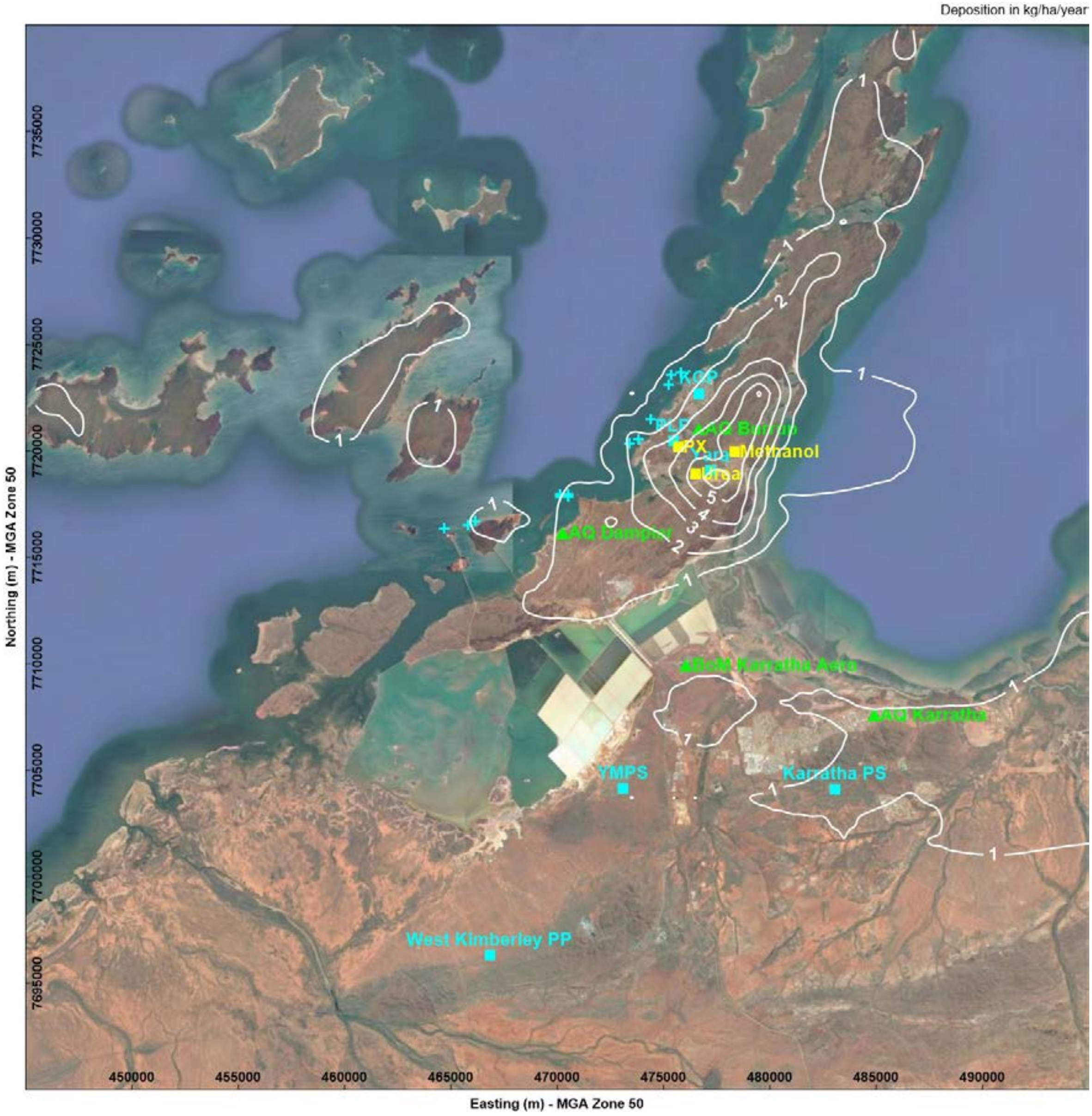

Figure 7-26: FBSIA – NO_2 deposition (kg/ha/year)

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

Air Quality Impact Assessment

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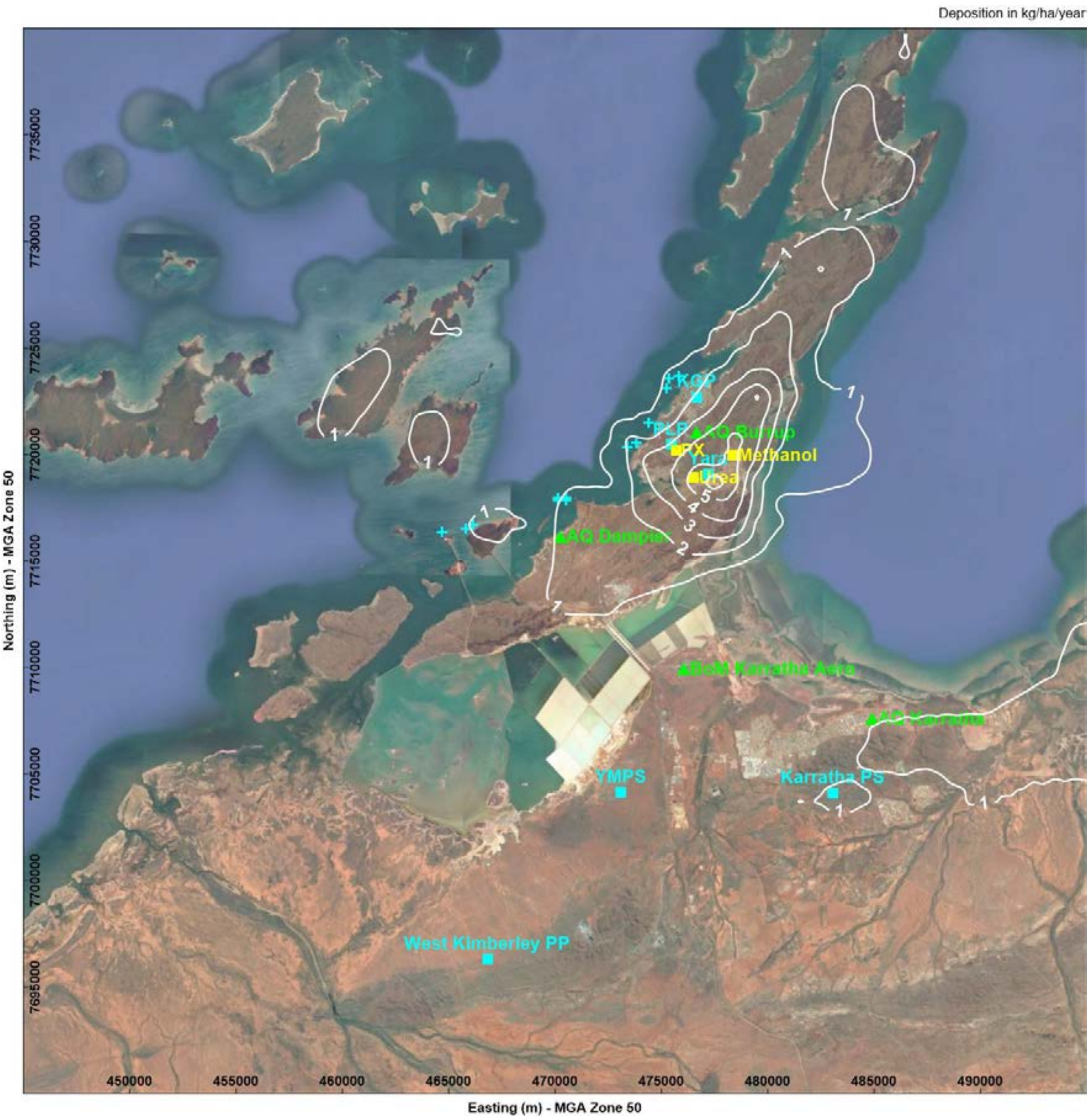

Figure 7-27: FBSIA-KIO – NO_2 deposition (kg/ha/year)

- Maximum grid receptor deposition, 6.6 kg/ha/year.
- For assessment of effects on vegetation health; see annual average NO_x.

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Deposition in kg/ha/year

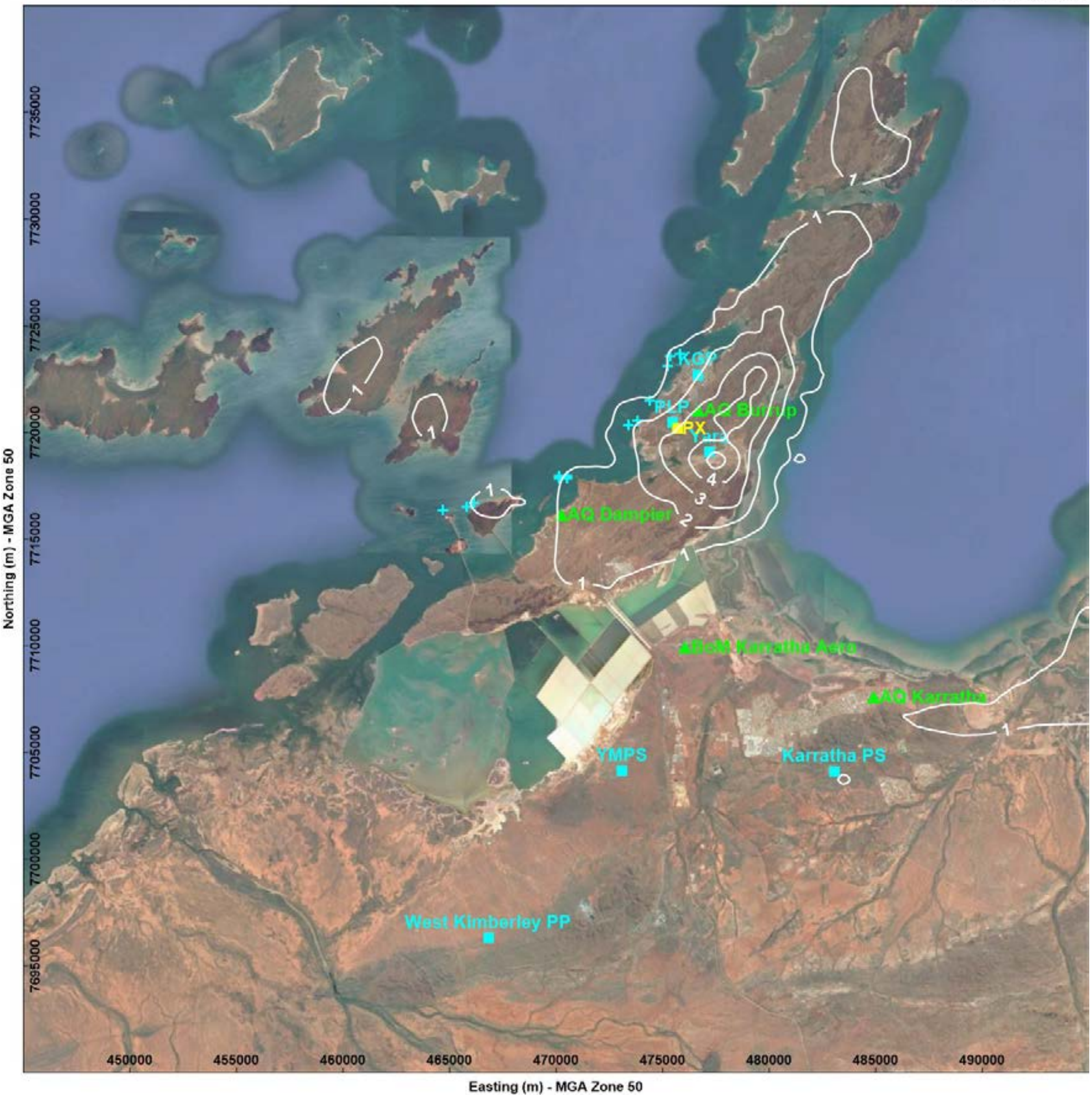

Figure 7-28: FBSIA E&A – NO_2 deposition (kg/ha/year)

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

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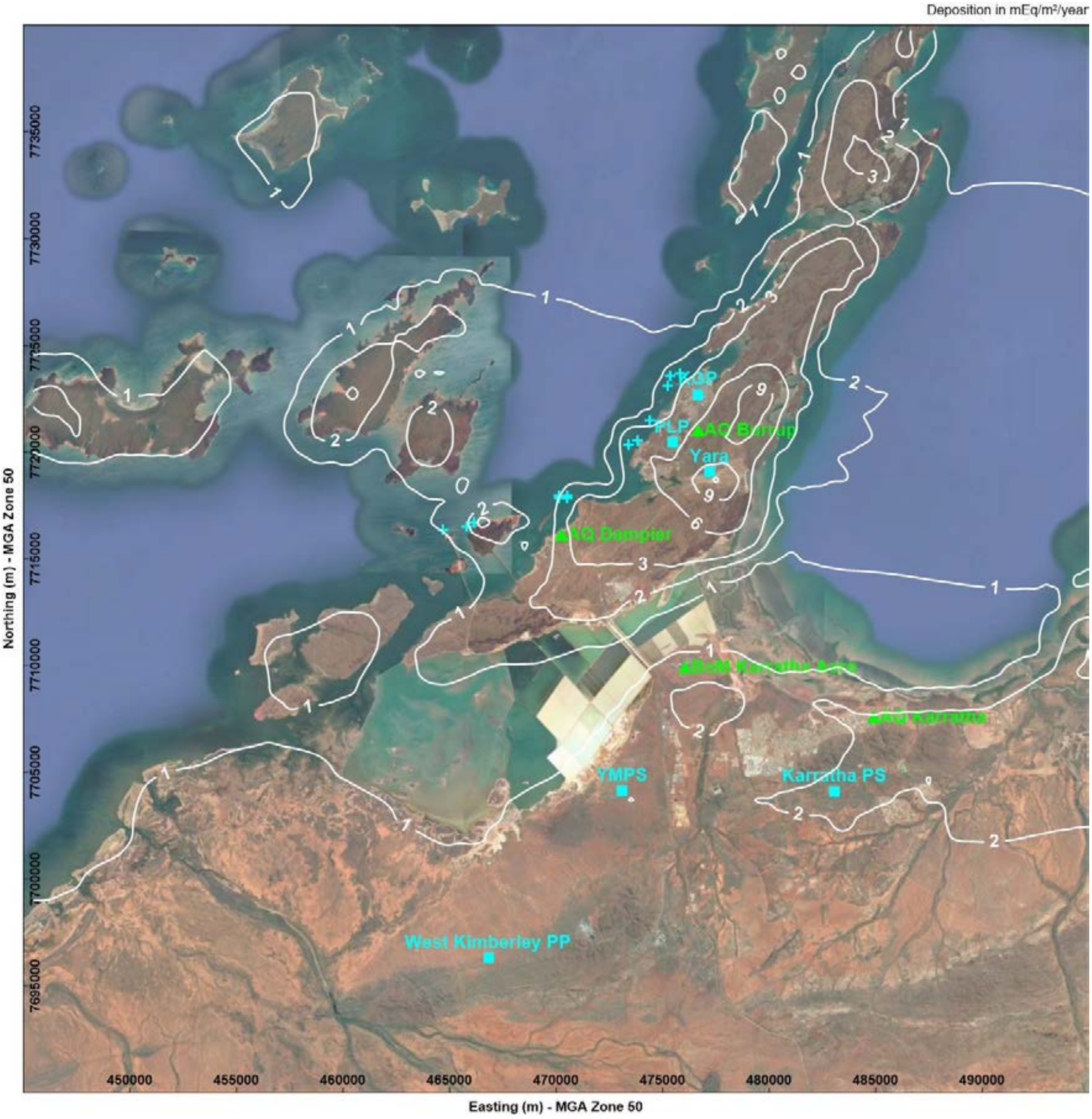

Figure 7-29: CBM – NO_2 deposition (meq/m²/year)

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

Air Quality Impact Assessment

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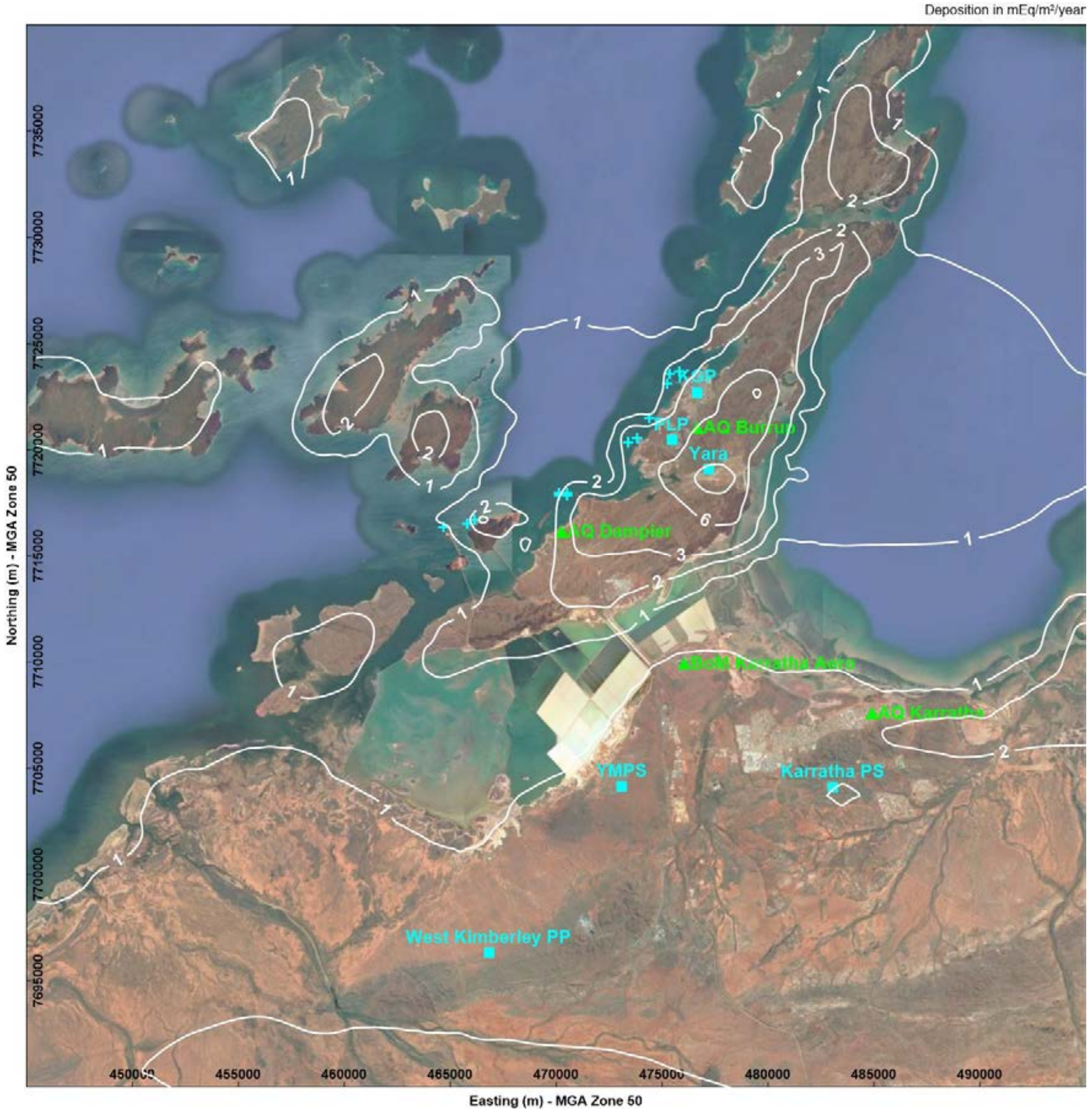

Figure 7-30: KIO – NO_2 deposition (meq/m²/year)

- Maximum grid receptor deposition, 11.9 meq/m^2/year.
- For assessment of effects on vegetation health; see annual average NO_x.

Air Quality Impact Assessment

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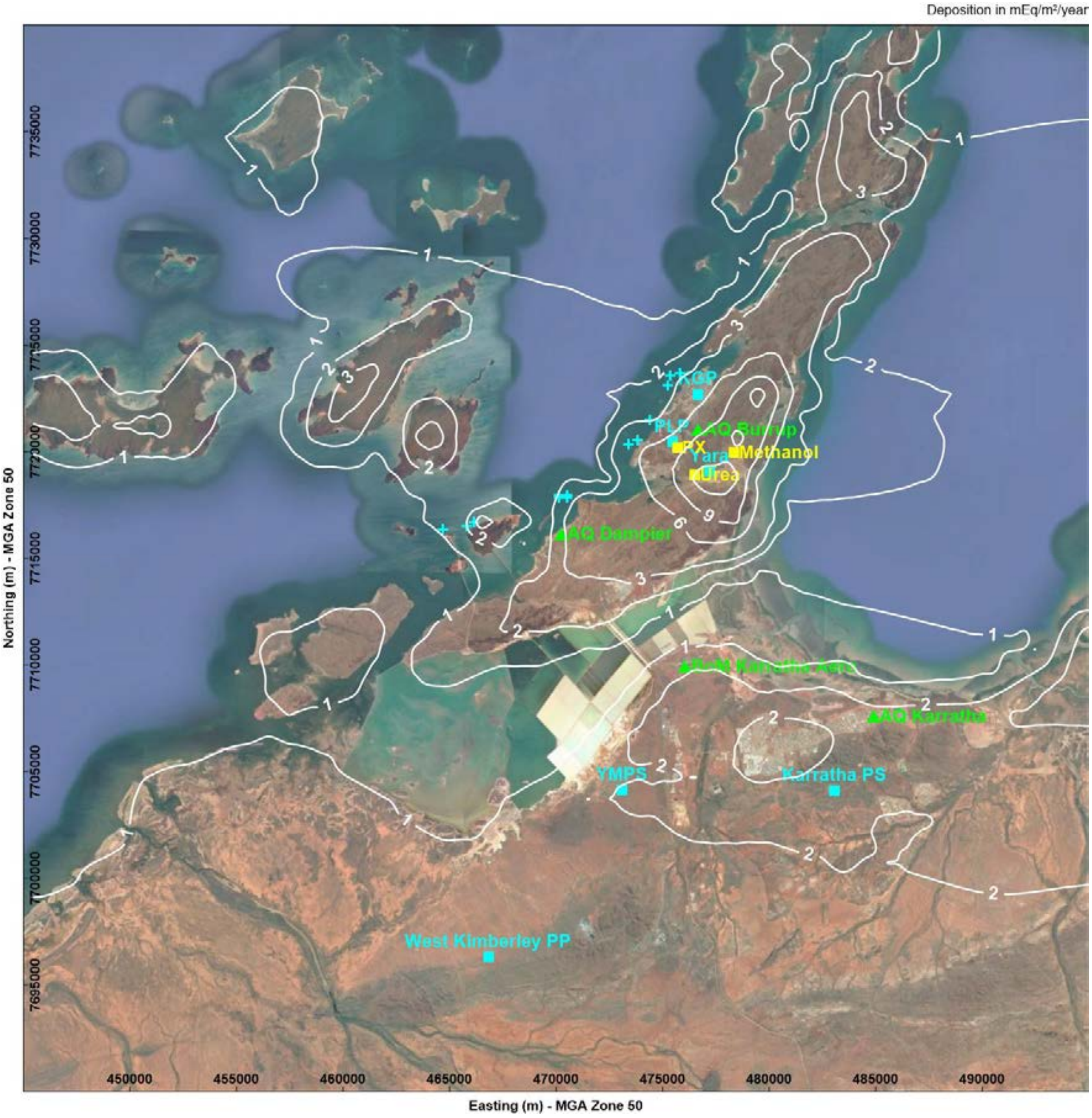

Figure 7-31: FBSIA – NO_2 deposition (meq/m²/year)

- Maximum grid receptor deposition, 14.8 meq/m²/year.
- For assessment of effects on vegetation health; see annual average NO_x.

Air Quality Impact Assessment

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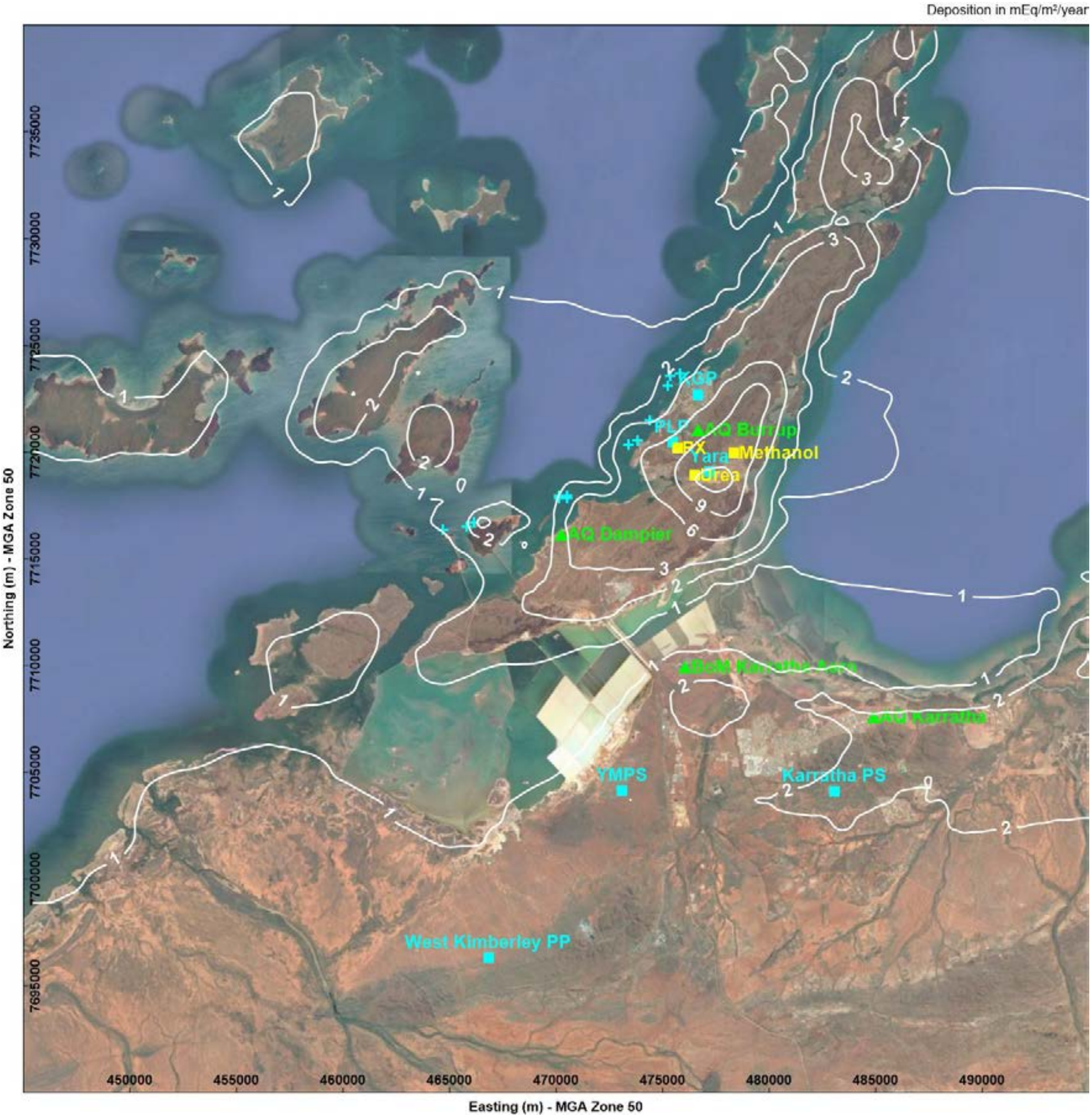

Figure 7-32: FBSIA-KIO – NO_2 deposition (meq/m²/year)

- Maximum grid receptor deposition, 14.3 meq/m²/year.
- For assessment of effects on vegetation health; see annual average NO_x.

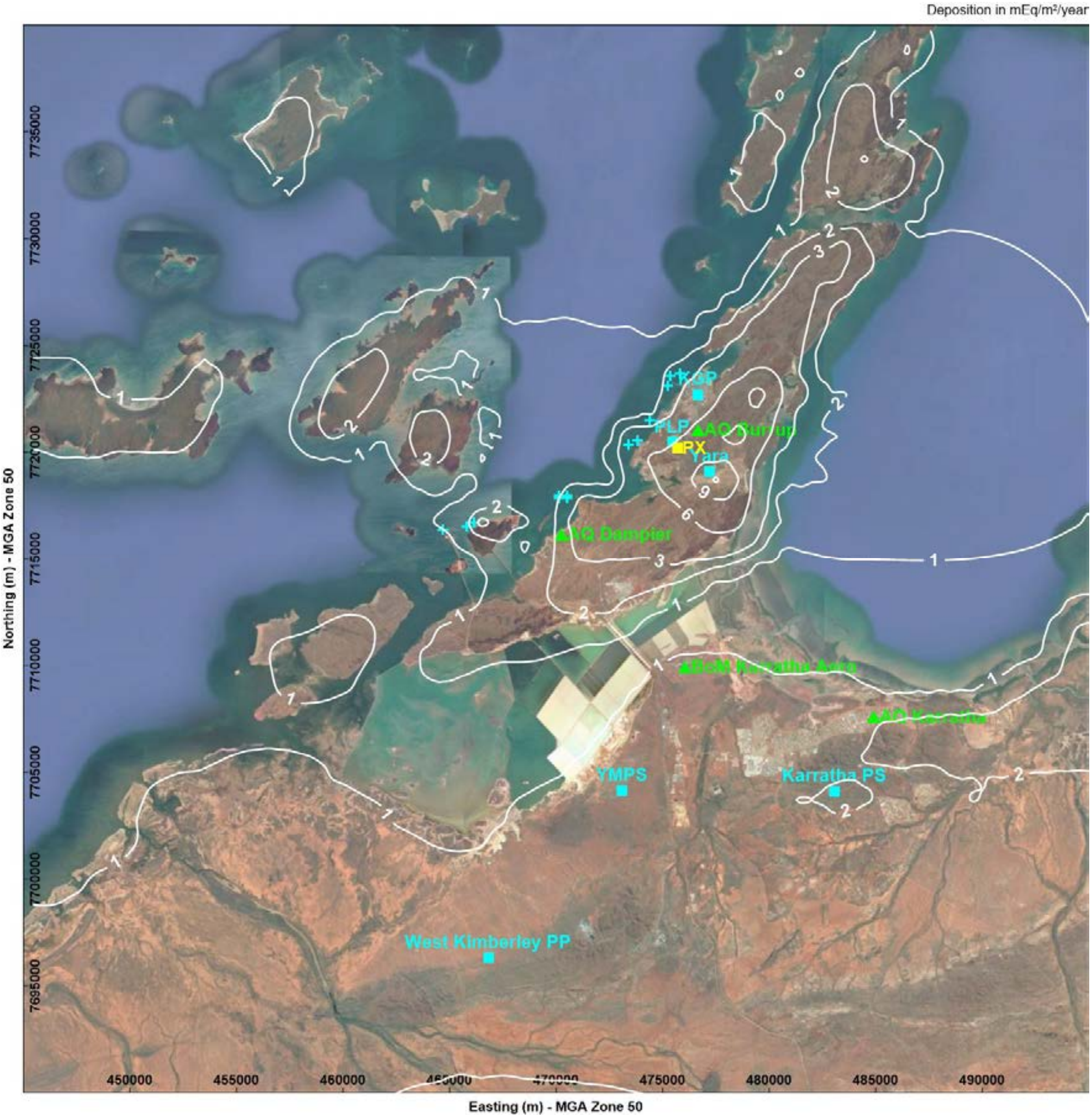

Figure 7-33: FBSIA E&A – NO_2 deposition (meq/m²/year)

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

Air Quality Impact Assessment

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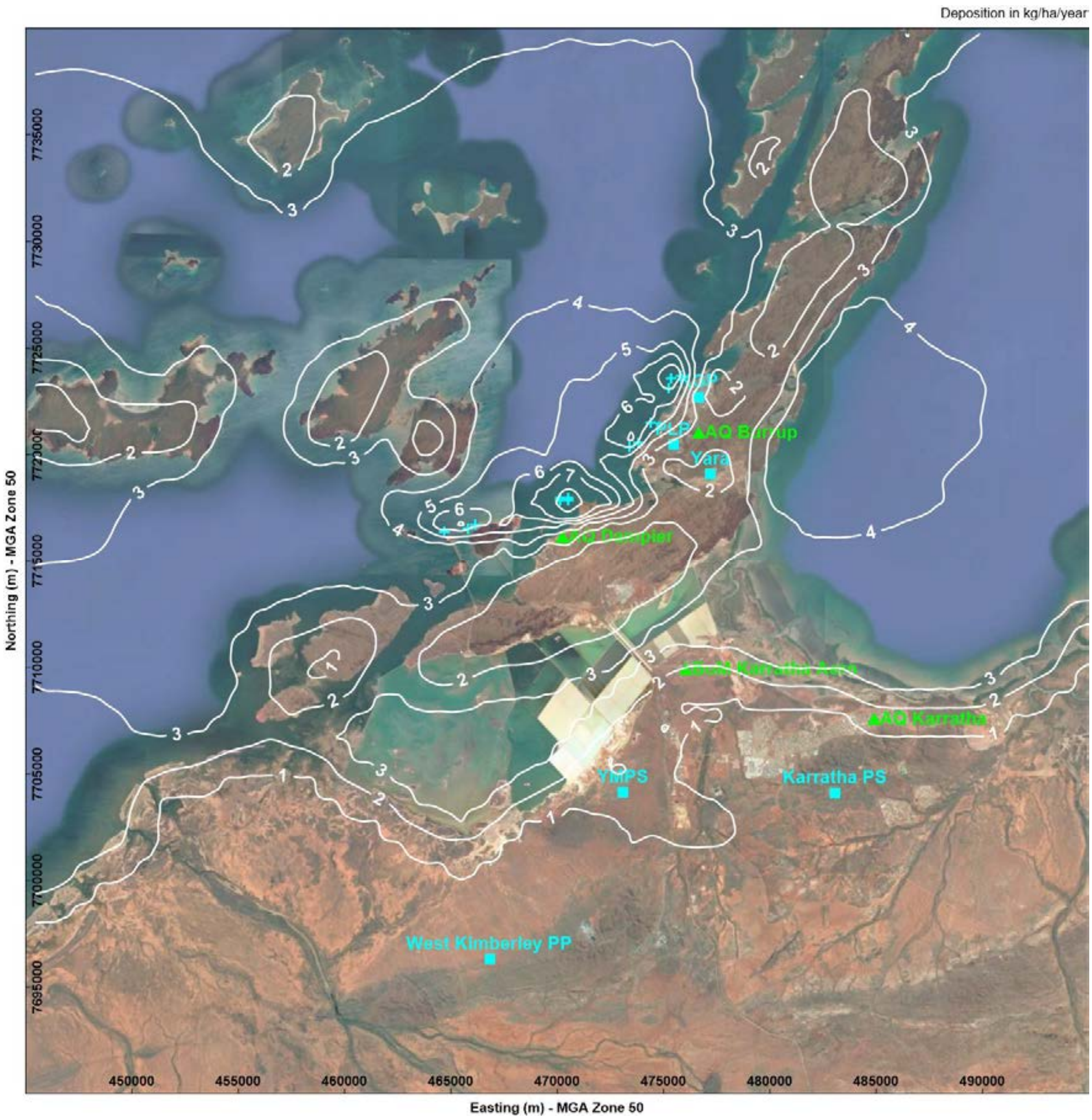

Figure 7-34: CBM – SO_2 deposition (kg/ha/year)

- Maximum grid receptor deposition, 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.

7.7 Summary of Results

7.7.1 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 (Ambient Air Quality) Standards

Assessment Parameter (units)	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A	NEPM (Ambient Air Quality) Standard
max 1h NO_2 (ppb)	42.6	29.1	43.9	32.4	30.7	120
annual NO_2 (ppb)	5.0	4.9	5.6	5.7	5.0	30
max 1h O_3 (ppb)	61.8	59.2	63.0	61.0	60.0	100
max 4h O_3 (ppb)	58.2	55.3	59.7	57.4	56.1	80
max 1h SO_2 (ppb)	18.1	18.2	18.1	18.2	18.2	200
max 24h SO_2 (ppb)	7.0	7.0	7.0	7.0	7.0	80
annual SO_2 (ppb)	4.5	4.5	4.5	4.5	4.5	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 for Protection of Vegetation

Assessment Parameter	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A	EU 2008 Standard
annual NO_x (ppb)	7.7	7.4	9.0	8.8	7.7	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	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 deposition is provided in Table 7-11, which does not include the effects of future reductions in shipping fuel sulfur content. For completeness, refer to Section 8.1.1 and Figure 8-1, Figure 8-3, Figure 8-4, Figure 8-5 and Figure 8-6.

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

Deposition Parameter	CBM	KIO	FBSIA	FBSIA-KIO	FBSIA E&A
annual NO_2 deposition (kg/ha/year)	5.7	5.5	6.8	6.6	5.7
annual NO_2 deposition (meq/m^2/year)	12.4	11.9	14.8	14.3	12.4
annual SO_2 deposition (kg/ha/year)	13.6	13.7	13.7	13.7	13.7

Air Quality Impact Assessment

7.7.2 Summary of Results – Discrete Receptors

A summary of the TAPM-GRS results for the discrete (sensitive) receptor locations Karratha, Burrup and Dampier, for assessment against the 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	KIO	FBSIA	FBSIA-KIO	FBSIA E&A	NEPM (Ambient Air Quality) Standards
Maximum 1 hour average NO_2 (ppb)						
AQ Karratha	24.8	16.1	28.3	20.9	17.5	120
AQ Burrup	33.4	22.4	34.2	25.4	22.9	120
AQ Dampier	24.8	18.2	25.8	19.5	19.0	120
Annual average NO_2 (ppb)						
AQ Karratha	0.9	0.8	1.0	0.9	0.8	30
AQ Burrup	3.2	3.0	4.0	3.8	3.3	30
AQ Dampier	1.7	1.6	1.8	1.7	1.6	30
Maximum 1 hour average O_3 (ppb)						
AQ Karratha	57.9	55.0	61.2	55.8	55.2	100
AQ Burrup	58.7	55.4	58.4	55.6	55.6	100
AQ Dampier	55.4	53.2	56.5	54.4	53.7	100
Maximum 4 hour average O_3 (ppb)						
AQ Karratha	56.3	51.2	59.1	53.8	51.8	80
AQ Burrup	54.3	51.7	53.7	51.7	51.9	80
AQ Dampier	52.5	50.5	53.6	51.8	51.0	80
Maximum 1 hour average SO_2 (ppb)						
AQ Karratha	3.6	3.6	3.6	3.6	3.6	200
AQ Burrup	11.3	11.2	11.4	11.3	11.3	200
AQ Dampier	12.9	13.3	12.9	13.3	13.3	200
Maximum 24 hour average SO_2 (ppb)						
AQ Karratha	1.7	1.7	1.7	1.7	1.7	80
AQ Burrup	4.7	4.7	4.8	4.7	4.7	80
AQ Dampier	4.6	4.5	4.6	4.5	4.5	80
Annual Average SO_2 (ppb)						
AQ Karratha	0.9	0.9	0.9	0.9	0.9	20
AQ Burrup	2.0	2.0	2.0	2.0	2.0	20
AQ Dampier	1.6	1.6	1.6	1.6	1.6	20

8. Testing of Model Results for Deposition

8.1.1 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 Gillett (2014) monitoring locations and compared with the measurements of dry deposition of NO_2 (meq/m^2/year), and total nitrogen and sulfur deposition (also expressed in units of meq/m^2/year); the results are listed in Table 8-1. 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 8-1 are also plotted in Figure 8-1.

Table 8-1: 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) – all units are meq/m^2/year						
Total nitrogen flux	25.5	23.9	28.8	17.9	17.1	9.8
Dry NO_2 deposition	4.4	4.0	7.7	4.4	5.8	1.3
Model results (this report) – all data are NO_2 deposition (meq/m^2/year)						
CBM	1.8	8.5	5.0	5.7	6.2	approx. 1.0
KIO	1.6	7.8	4.7	5.2	5.9	approx. 1.0
FBSIA	2.0	11.6	5.8	6.8	8.8	approx. 1.0
FBSIA-KIO	1.8	10.9	5.6	6.4	8.5	approx. 1.0
FBSIA E&A	1.7	8.8	4.9	5.7	7.0	approx. 1.0

- Superscript ‘B’ denotes 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 due to modelled biogenic NO_x emissions over land (nil emissions modelled over water).

Some further analysis of the model results for NO_2 deposition was undertaken in an attempt to tease out differences between CBM and the other modelled scenarios, 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.

Histograms of the model results for NO_2 deposition (meq/m^2/year) were created for the model grid points within the DANHP boundaries (Figure 8-2), to illustrate the differences between CBM and each of the other scenarios.

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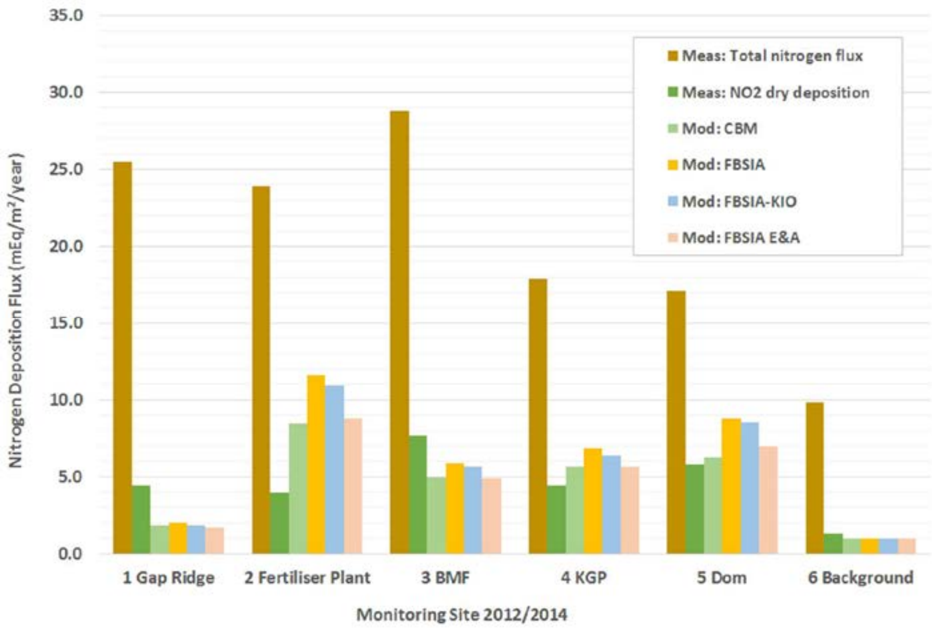

Figure 8-1: Measured and Modelled Nitrogen Fluxes (meq/m²/year)

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

Model results comparing NO_2 deposition between CBM and each of the other modelled scenarios are provided in the following series of histograms:

- Frequency Distributions of Model Results for CBM and KIO NO_2 Deposition Within DANHP (Figure 8-3)
- Frequency Distributions of Model Results for CBM and FBSIA NO_2 Deposition Within DANHP (Figure 8-4)
- Frequency Distributions of Model Results for CBM and FBSIA-KIO NO_2 Deposition Within DANHP (Figure 8-5)
- Frequency Distributions of Model Results for CBM and FBSIA E&A NO_2 Deposition Within DANHP (Figure 8-6)

For all scenarios, the majority of the NO_2 deposition results for the grid receptors within the DANHP fall within the range of 1-4 meq/m^2/year. There are slightly fewer modelled scenario results in the lower deposition range of 1-4 meq/m^2/year when compared to CBM results with the exception of KIO and FBSIA E&A; whereas there are slightly fewer CBM results in the range of 5-14 meq/m^2/year when compared to the modelled scenario results. The highest deposition rate of 14 meq/m^2/year (Figure 8-4) was observed in the scenario comparing CBM and FBSIA.

To summarise – for comparative analysis of modelled NO_2 deposition values as a sub-component of overall nitrogen and sulfur deposition:

- KIO generally shows an observable relative reduction of deposition frequencies above 2 meq/m^2/year compared with CBM;
- FBSIA E&A (current and approved (Pluto Train 2) with KGP Improvement Opportunities) shows a nominally consistent and slightly lower deposition frequencies than CBM above 2 meq/m^2/year; and
- FBSIA and FBSIA-KIO show relative marginal increases in deposition frequencies above 3 meq/m^2/year.

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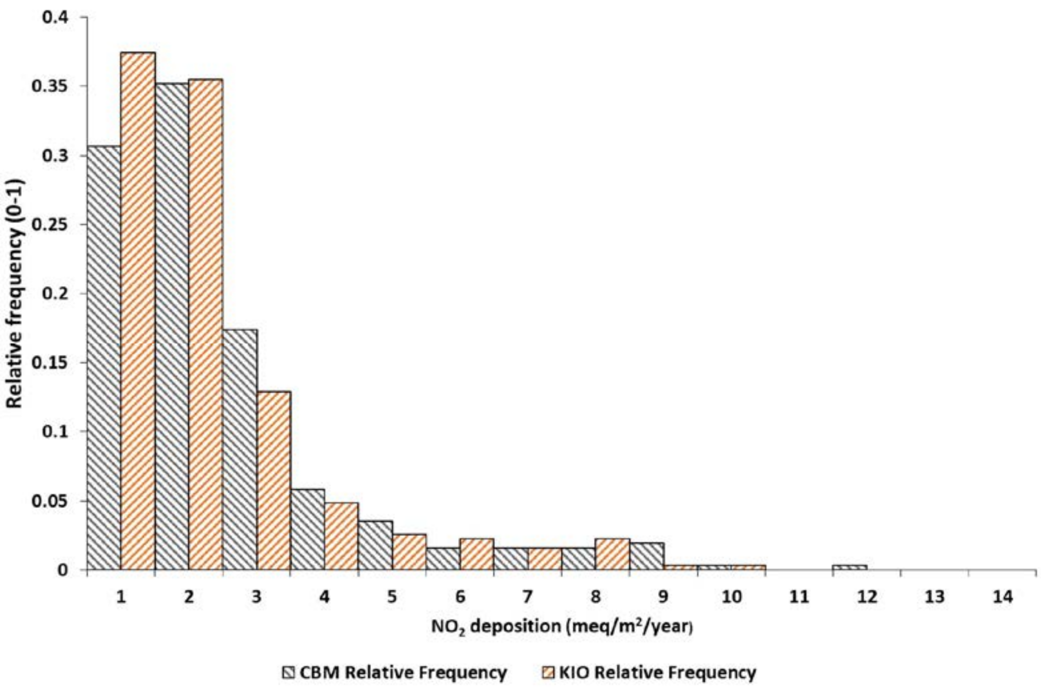

Figure 8-3: Frequency Distributions of Model Results for CBM and KIO NO_2 Deposition Within DANHP

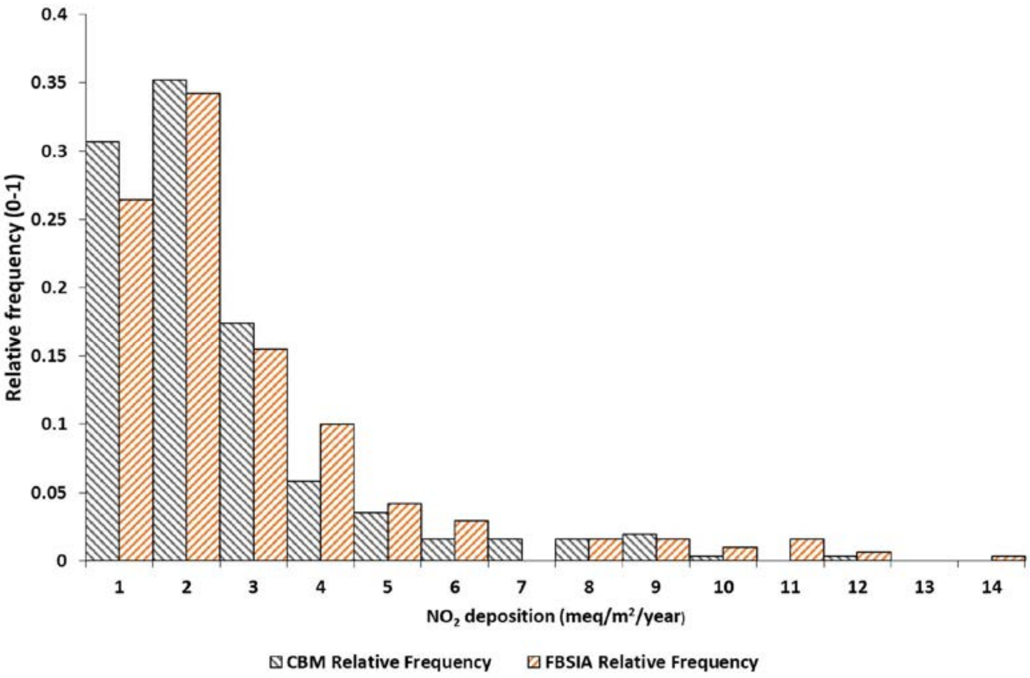

Figure 8-4: Frequency Distributions of Model Results for CBM and FBSIA NO_2 Deposition Within DANHP

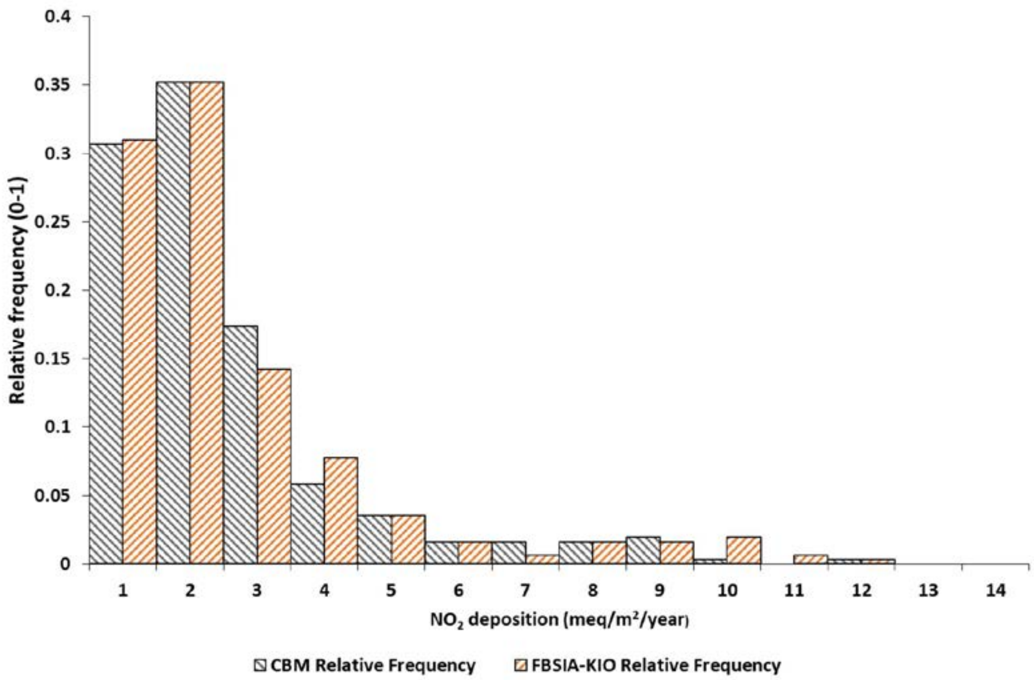

Figure 8-5: Frequency Distributions of Model Results for CBM and FBSIA-KIO NO_2 Deposition Within DANHP

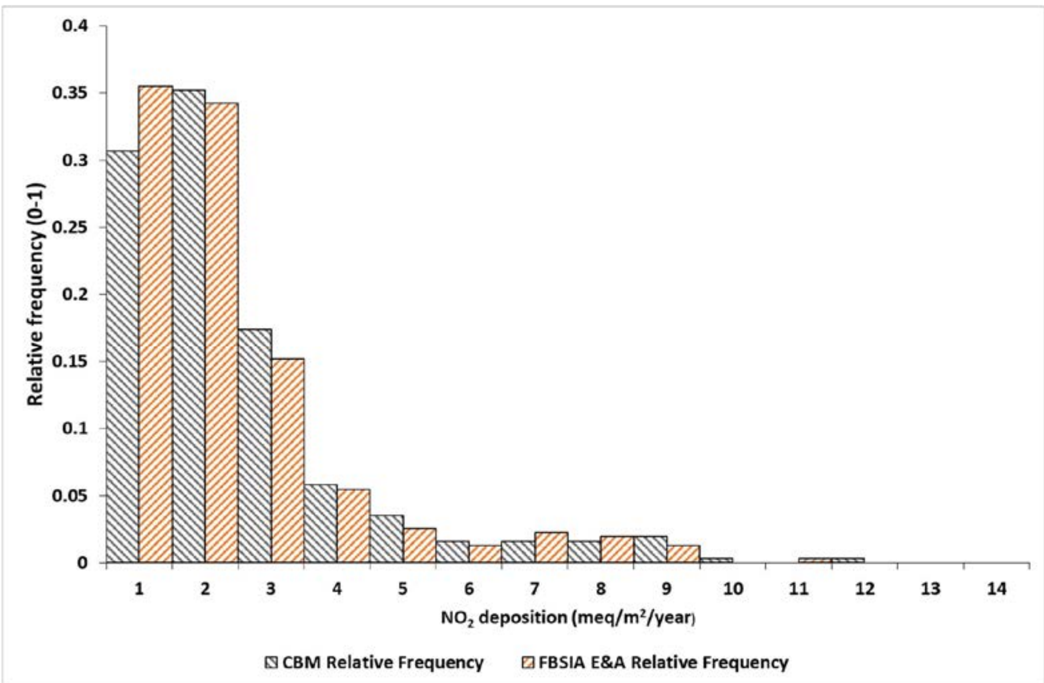

Figure 8-6: Frequency Distributions of Model Results for CBM and FBSIA E&A NO_2 Deposition Within DANHP

8.1.2 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 all emissions scenarios were almost identical, showing only a very small effect on the baseline due to the Proposal. 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. Conclusion

This report details the results of air quality modelling to support the Proposal. As a part of this assessment the existing air emissions scenario, Current Baseline, and potential future air emissions scenarios, were developed for the Burrup Peninsula. The results of modelling were set out to determine how the current emissions are affecting existing air quality. Potential future air emissions scenarios were modelled to increase our understanding of potential future best case, most likely, and worst-case air quality effects for the Burrup Peninsula.

The modelling methodology was set out based on a literature review that included several key CSIRO papers from the 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 Services 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 measurements at three monitoring stations on or adjacent the Burrup Peninsula: Burrup Road, Dampier and Karratha. The comparisons of modelling results with monitoring indicated TAPM-GRS was performing very well in terms of being able to accurately predict a variety of statistical results for NO_2 and O_3.

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 as applied to the Burrup Peninsula, produced results that agreed very well with monitoring data from 2014 when KGP and PLP were operating at or near capacity.

Key results from the air quality impact assessment were:

- 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 set for the protection of human health.
- 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, based on assessments using NEPM and EU (2008) standards, there is a low risk of impact to human health and vegetation due to air emissions from the Proposal. In this context, “low risk” has been defined from predicted concentrations well below relevant air quality standards.

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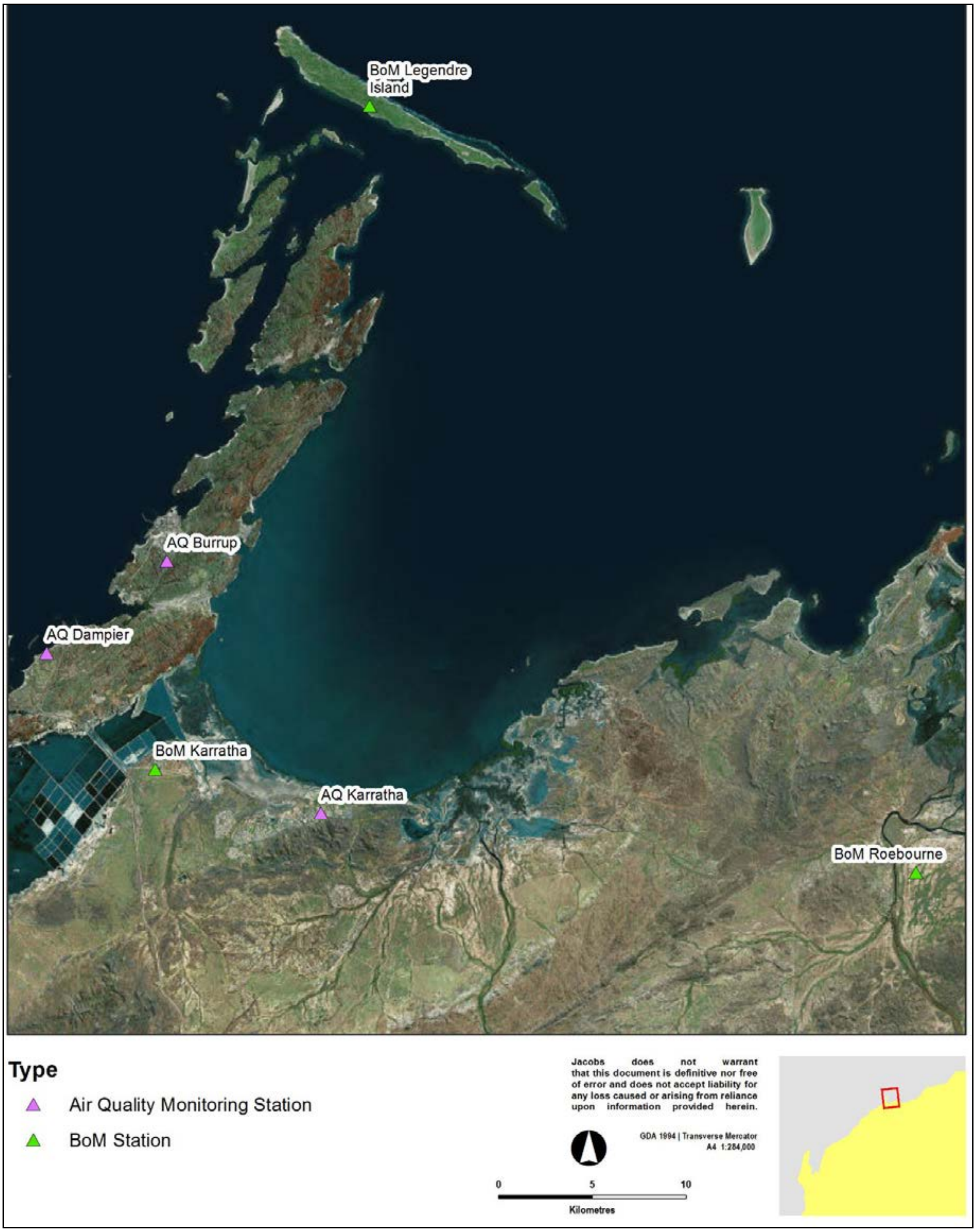
Appendix A. Location Map and Monitoring Stations



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 Proposal 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 Proposal. 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 48°C in the wet season to only 7°C in the dry season, from 1993 to 2018.

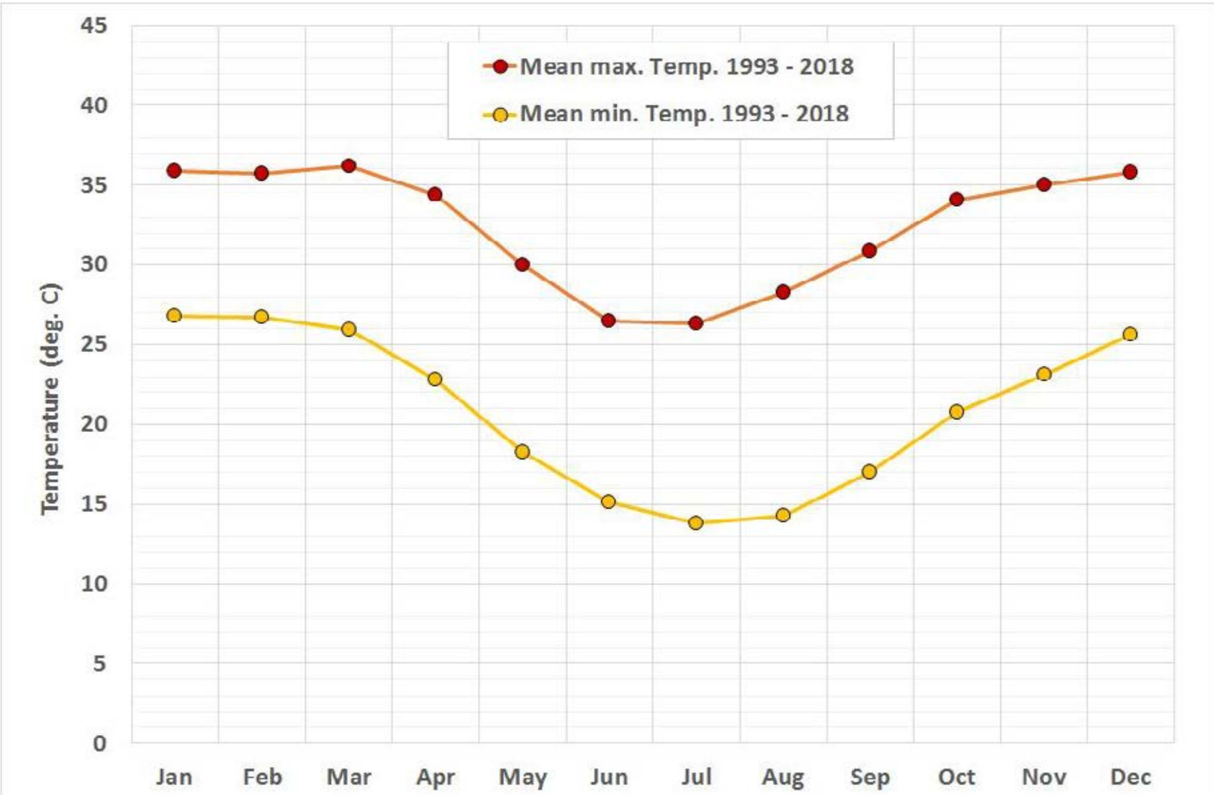


Figure B- 1: Monthly Mean-Maximum and Minimum Temperature – Karratha Aerodrome 1993-2018

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.

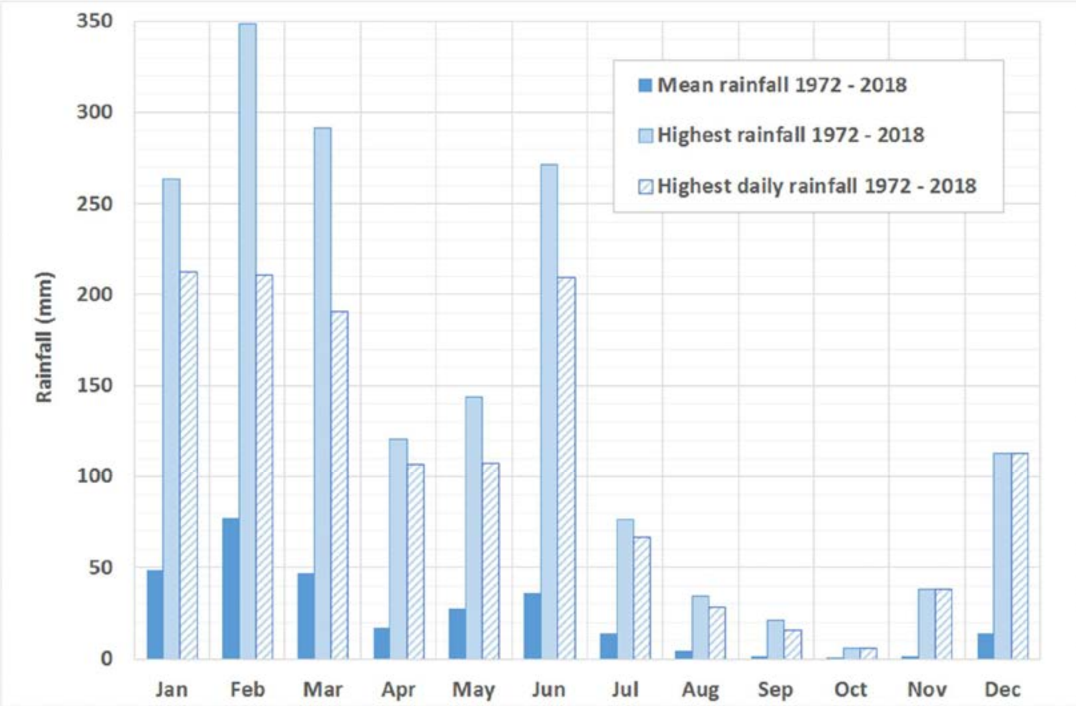


Figure B- 2: Monthly Rainfall – Karratha Aerodrome 1972-2018

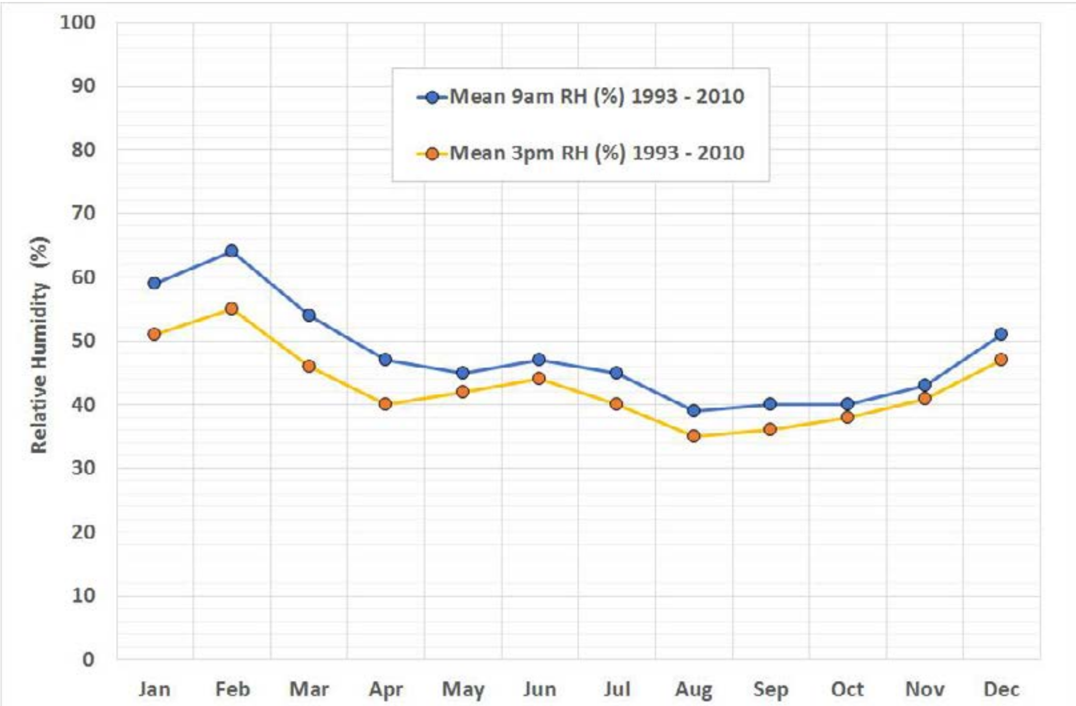


Figure B- 3: Monthly 9am and 3pm Relative Humidity – Karratha Aerodrome 1972-2018

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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.

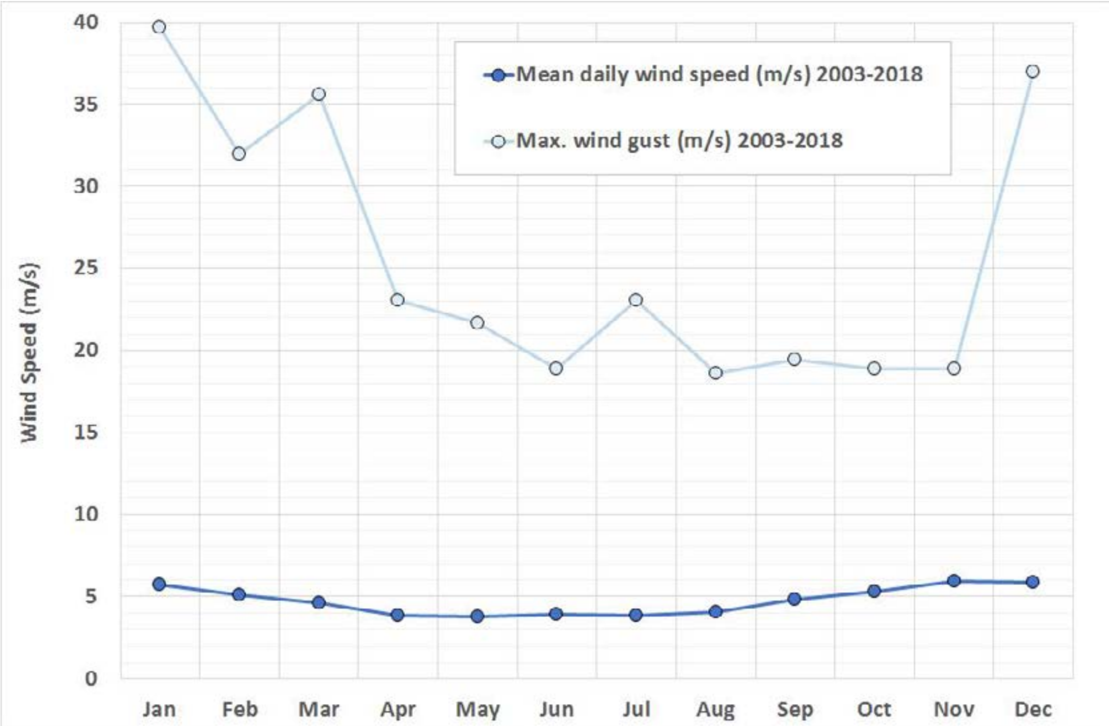

Figure B- 4: Mean Daily Wind Speed and Maximum Wind Gust – Karratha Aerodrome 1993-2018

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
90^{th} percentile (m/s)	8.0	7.8	9.7
70^{th} percentile (m/s)	6.2	5.7	7.1
Average (m/s)	5.0	4.5	6.0

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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.

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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).

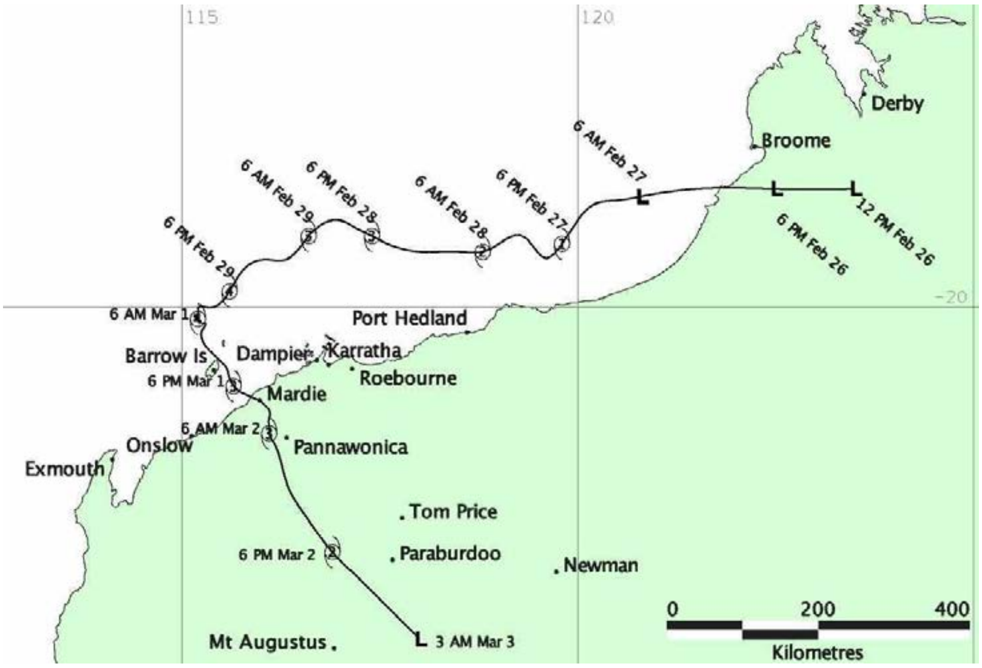

Figure B- 6: Track of Tropical Cyclone Monty 2004 (BoM, 2019b)

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 Proposal's 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.

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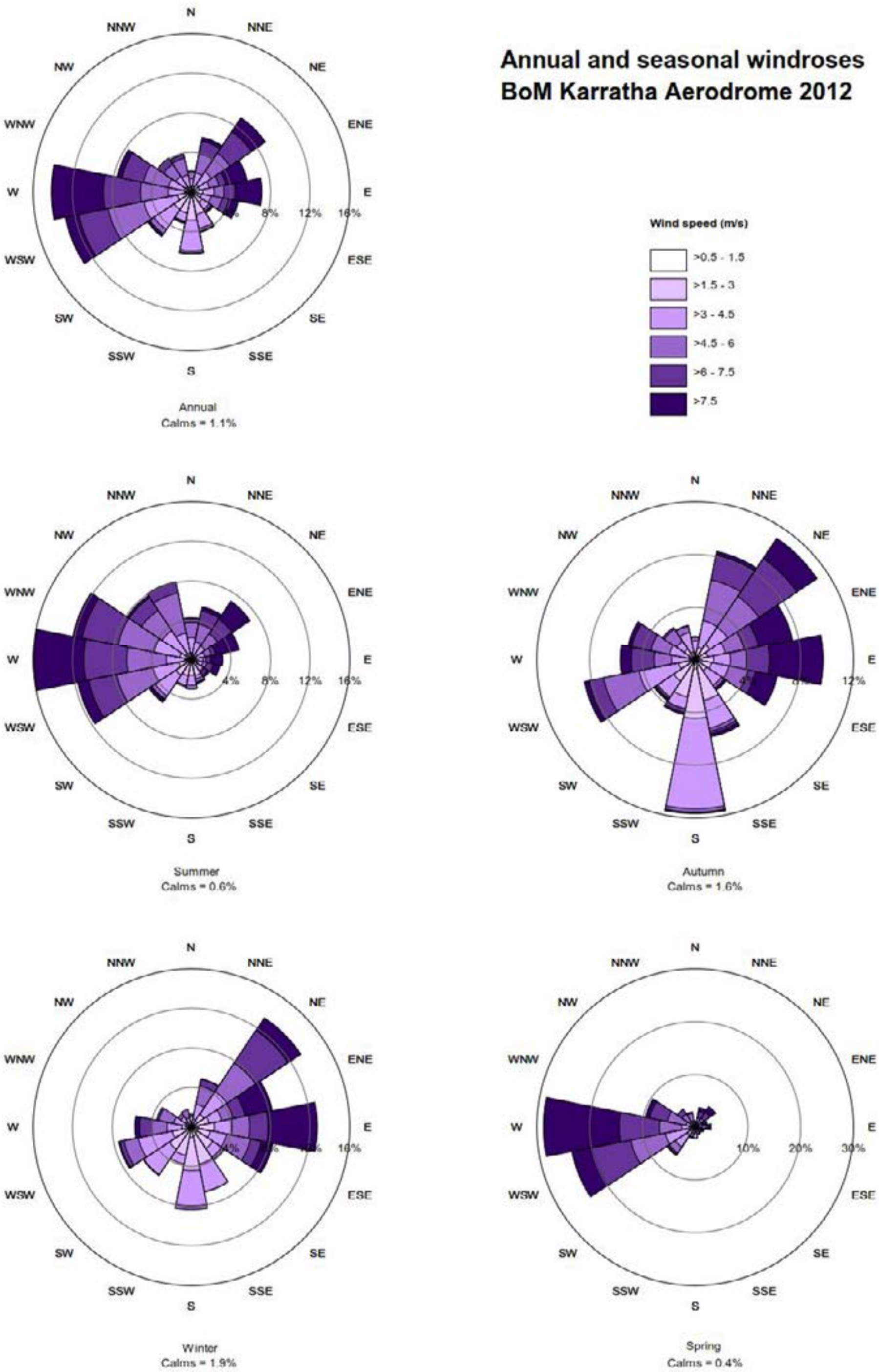
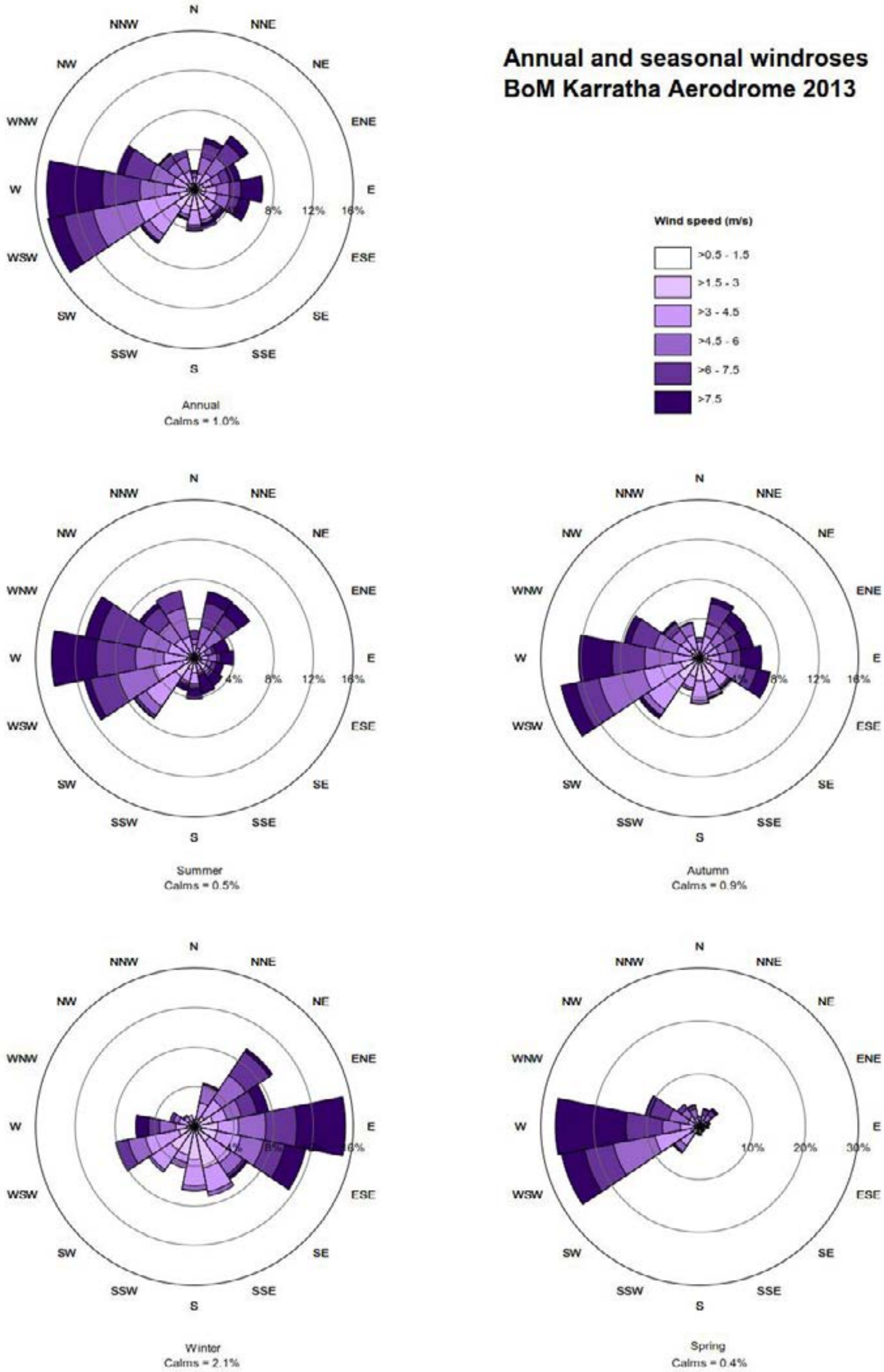

Annual and seasonal windroses
BoM Karratha Aerodrome 2012
Wind speed (m/s)
>0.5 - 1.5
>1.5 - 3
>3 - 4.5
>4.5 - 6
>6 - 7.5
>7.5
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
4%
8%
12%
16%
10%
20%
30%
Annual
Calms = 1.1%
Summer
Calms = 0.6%
Autumn
Calms = 1.6%
Winter
Calms = 1.9%
Spring
Calms = 0.4%


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
Annual
Calms = 1.0%
Summer
Calms = 0.5%
Autumn
Calms = 0.9%
Winter
Calms = 2.1%
Spring
Calms = 0.4%

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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 Proposal). The modelled predictions for wind patterns matched the observations reasonably well; annual wind roses generated from hourly data are compared in Figure C- 1.

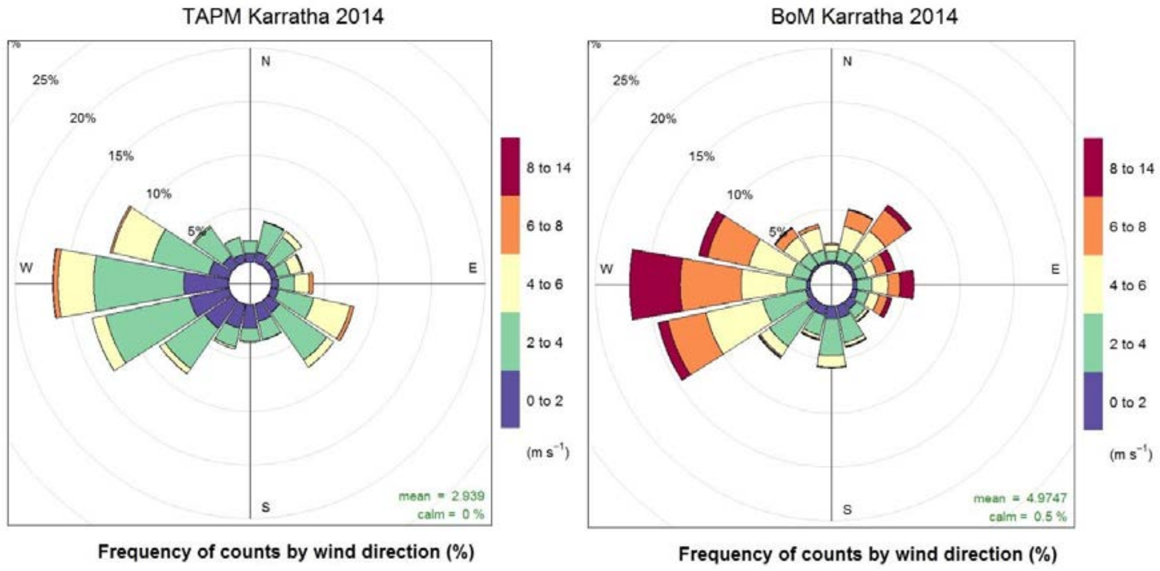

Figure C- 1: Annual Wind Roses Karratha 2014: TAPM (Left) and BoM Measurements (Right)

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

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Station	Karratha Aero.		Roebourne		Legendre Is.	
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

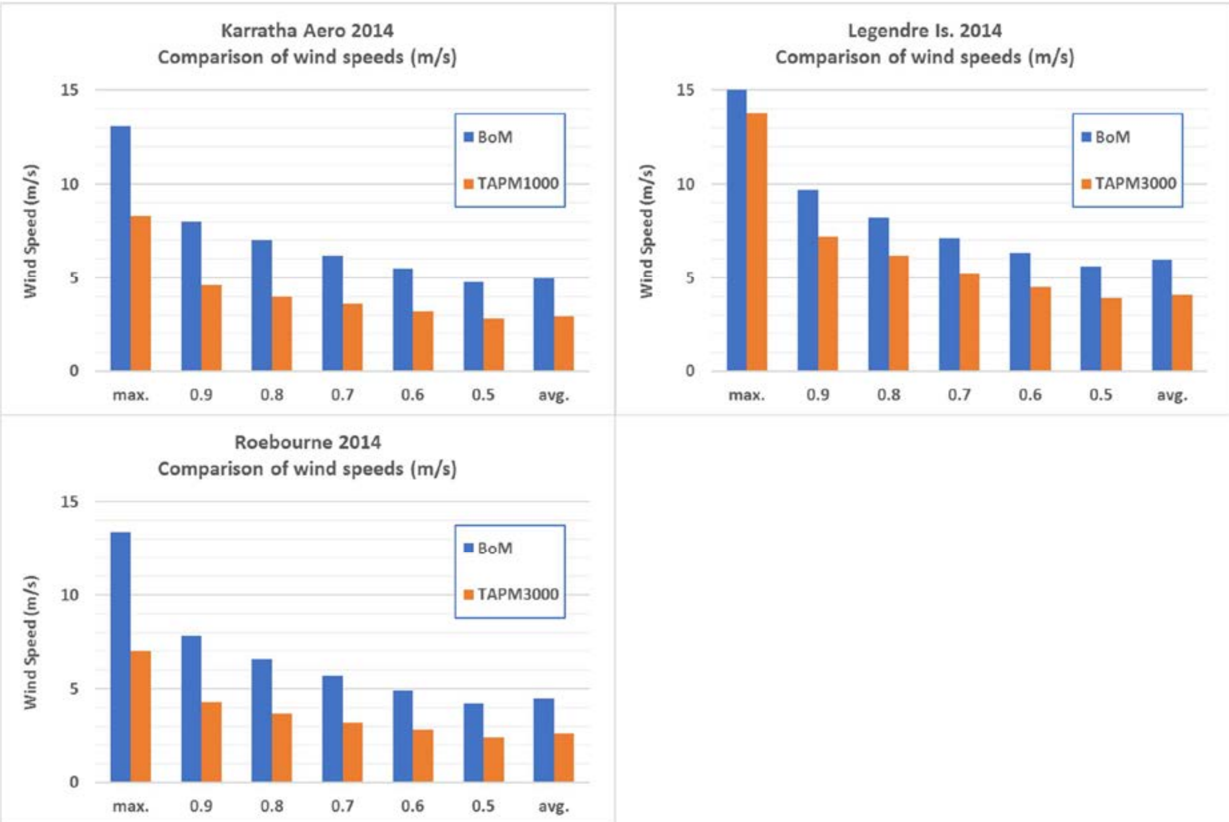

Figure C- 2: Model Results for Wind Speed Compared with 2014 Observations

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 F NORTH WEST SHELF PROJECT EXTENSION GREENHOUSE GAS BENCHMARKING REPORT

Revision 1

Woodside

Appendix F

NWS Project Extension Proposal

Woodside Energy Ltd

Greenhouse Gas Benchmarking

| Revision 4

October 17, 2019

Greenhouse Gas Benchmarking

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NWS Project Extension Proposal

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4	17 Oct 2019	For Client	M Hall	L Boulden	M Goodwin

Greenhouse Gas Benchmarking

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Greenhouse Gas Benchmarking

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1. Introduction

1.1 Background

Woodside Energy Ltd (Woodside), as operator for and on behalf of the North West Shelf Joint Venture (NWSJV), is proposing to continue and extend the operating life of the North West Shelf (NWS) Project through the long-term processing of third-party gas and fluids. This proposal is referred to as the NWS Project Extension Proposal (the Proposal).

This greenhouse gas (GHG) benchmarking study has been prepared to support the environmental approvals for the Proposal which includes the following:

- Emissions of up to 7.7 million tonnes per annum (mtpa) of carbon dioxide equivalent (CO_2-e);
- Potential changes to feed gas composition including changed content of inerts, hydrocarbons and other components;
- Changes to the composition of environmental discharge and emissions, although annual volumes of emissions and discharges are expected to be in line with current levels;
- Modifications to the onshore receiving facilities to accommodate third-party gas and fluids; and
- Potential construction of additional operational equipment to accommodate changes to feed gas composition or management of environmental discharge and emissions.

The Proposal requires environmental approval under the *Environmental Protection Act 1986* (WA) (EP Act) and *Environment Protection and Biodiversity Act 1999* (Commonwealth) (EPBC Act).

This GHG benchmarking assessment has been prepared in accordance with the NWS Project Extension Proposal Environmental Scoping Document (Woodside, 2019) to support the development of the NWS Project Extension Proposal Environmental Review Document.

1.2 Objective

The objective of this report is to benchmark the GHG emissions performance of the Karratha Gas Plant (KGP) (which is a component of the Proposal) against that of other comparable Australian and international Liquified Natural Gas (LNG) facilities. This information will assist in assessing the performance of the Proposal in accordance with Woodside’s Climate Change Policy.

1.3 Scope of this Assessment

The scope of this benchmarking assessment is Scope 1 emissions, as defined by the NGER Regulations (AG, 2018) definition[1], from the KGP and associated utilities.

The following are out of scope:

- GHG emissions from upstream operations associated with the extraction and compression of raw gas, i.e. upstream of the Trunkline Onshore Terminals (TOT1 and TOT2)
- Scope 2 emissions
- Scope 3 emissions.

Emissions associated with handling, transport and use of gas product downstream of the fiscal product meter are excluded from the benchmarking scope.

[1] NGER Regulation 2008 (AG, 2018) definition: Scope 1 emission of greenhouse gas, in relation to a facility, means the release of greenhouse gas into the atmosphere as a direct result of an activity or series of activities (including ancillary activities) that constitute the facility.

2. Overview of Approach

A benchmark is a standard of performance that is used to inform trends and typical conditions in a given industry, for the purposes of assessing relative impact. For GHG assessments, benchmarking is a tool which can compare the performance of activities or facilities within the same industry, using the same assessment parameters and boundaries. For the benchmarking of LNG facilities, the comparison parameter most commonly used is 'GHG intensity'; this term is defined as the tonnes of GHG emitted per tonne (t) of LNG produced and has been applied to this GHG benchmarking assessment. GHG emissions are expressed in t CO_2-e, where the CO_2-e emissions are an aggregate of GHG emissions including carbon dioxide, methane and nitrous oxide, calculated as an equivalent CO_2 emission by factoring in the global warming potential (GWP) of each constituent gas.

The CO_2-e estimates are required to reflect the GWP values at the time of reporting, as specified in the *National Greenhouse and Energy Reporting* (NGER) *Regulations 2008* (AG, 2018). In 2015-16, the GWP values were amended based on the findings of the Intergovernmental Panel on Climate Change's Fourth Assessment Report. A summary of the changes to the GWP as applied in the NGER calculations for the key gases (CO_2, methane and nitrous oxide) are shown in Table 2-1. For the KGP benchmarking data, both the maximum capacity data and the current operational data as per the NGER report data for 2017-18 were included and the amended (i.e. post 2015-16) GWP values were used for each.

Table 2-1: Changes in GWP for Scope 1 emission calculations (CER, 2019c)

Greenhouse gas	GWP pre 2015-16	GWP 2015-16 onwards
Carbon dioxide	1	1
Methane	21	25
Nitrous oxide	310	298

2.1 Selection of Facilities for Comparison

The selection of LNG facilities for comparison with the NWS Project Extension Proposal was based on:

- Location – LNG facilities in Australia as well as selected facilities internationally were selected to represent comparable operating conditions (including climatic conditions) and facility designs.
- Age – the most recent LNG facilities, planned or recently started up, have been included in the assessment as these plants are more likely to have the most recent energy efficient technology and designs, thereby are expected to have the lowest emissions intensity associated with the liquefaction process.
- Capacity – the LNG production capacity of a facility will impact the type of equipment used and the energy efficiency achievable. Including facilities in the benchmarking with a similar capacity to the KGP is important to ensure comparison of facilities with the same or similar ability to achieve energy efficiency savings. The KGP is considered a large facility with annual LNG production in FY2017/18 of 16.6 mt and maximum capacity of 18.5 mtpa.
- Available data – to enable assessment of the GHG intensity, sufficient emissions and production data must be available, including details of emission sources (e.g. upstream, liquefaction facility, etc.) in the public domain. To this end, the majority of data used has been obtained from publicly available environmental impact assessments (EIA), or similar. This is acknowledged to be a short-coming (see Section 5.2) as the data is representative of expected emissions for full planned LNG capacity as determined during the design phase, and not current operational rates.

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In total, 10 Australian and 8 international LNG facilities were selected for benchmarking and comparison with the KGP. These facilities are shown in Table 2-2. The table includes individual LNG trains (T) for KGP and some other facilities where data was available, enabling a more detailed comparison of emissions.

Table 2-2: Summary of Benchmarked LNG Facilities

LNG facility	Location	Year commissioned	LNG production (mtpa)[1]	Reservoir CO_2 content (mol%)[1]
Australian facilities				
Barossa-Caldita LNG	Offshore Northern Territory (NT)	Design phase. Expected to commence operation in 2023	3.6	16 - 20
Prelude LNG	Offshore WA	2018	3.6	9
Ichthys LNG	Offshore WA, with 890 km pipeline to Darwin, NT	2016	8.4	Brewster: 8, Plover: 17
Gorgon LNG	WA	2016	15.6	Gorgon 15, Jansz 0.5
KGP T1 – T3	WA	1989-92	8.2	2.4
Darwin LNG	NT	2006	3.6	6
KGP T1 – T5	WA	1989-2004	18.5 [3] Current operation: 16.6	2.4
Wheatstone Project	WA	2017	25 [4] Current capacity: 8.9	"low" [2]
Pluto LNG	WA	2012	4.8	2
KGP T4 and T5	WA	2004	8.4	2.4
Gladstone LNG	Queensland	2015	10	0.3
Australia-Pacific LNG (APLNG)	Queensland	2016	18 [4] Current capacity: 9.0	1
Queensland Curtis LNG	Queensland	2015	11	< 1
International facilities				
Cove Point	Maryland, USA	2017	5.75	Not applicable
Qatargas 1 (T1 – T3)	Qatar	1997	10	2.1

LNG facility	Location	Year commissioned	LNG production (mtpa)[1]	Reservoir CO_2 content (mol%)[1]
Qatargas 2 (T4 and T5)	Qatar	2009	15.6	2.1
Qatargas 3 (T6)	Qatar	2010	7.8	2.1
Qatargas 4 (T7)	Qatar	2011	7.8	2.1
Qatargas TOTAL	Qatar	1997 - 2011	41.2	2.1
RasGas	Qatar	1999	6.4	2.3
PNG LNG	Papua New Guinea	2014	6.3	0.7 - 2.0
Nigeria LNG	Nigeria	2000	6.1	1.8
Snohvit LNG	Norway	2007	4.3	8
Oman LNG	Oman	2001	6.9	1.0
Sabine Pass	Louisiana, USA	2016	16	0.1 - 4.8

1. Production rates are as reported in publicly available information, typically environmental approval documentation, and therefore represent planned rates, i.e. those expected at the time of the preparation of approval documentation. For the Australian LNG facilities, the current capacities from the Australian Government Resources and Energy Quarterly, March 2019 (AG, 2019), are also shown.
2. The publicly available reservoir CO_2 content reported in the Draft Environmental Impact Statement for the Wheatstone Project (Chevron, 2010) is described as 'low' and no CO_2 mol% is provided.
3. The LNG production rate for KGP T1 – T5 of 18.5 mtpa is the current maximum production rate.
4. Planned capacity.

2.2 Basis of Comparison

In addition to using the same parameters for comparison of LNG facility GHG emissions performance, i.e. the GHG intensity (t CO_2-e / t LNG), emissions within the same 'boundaries' have been used for each facility to ensure meaningful comparison. The emission source information and data for LNG facilities is often not transparent within environmental assessment reports available in the public domain and this introduces uncertainty to the comparisons.

Although the standard benchmarking parameter, GHG intensity, is based on the production rate of LNG, it is acknowledged that data provided also include emissions associated with other co-produced products such as LPG and condensates. This has the potential to introduce differences in the basis of comparison of emissions intensity data for the benchmarked facilities.

Typically, the numerator in benchmarking LNG facility emissions intensity will include only emissions associated with the gas processing facility, e.g. emissions from the acid gas removal unit (AGRU), combustion for fuel gas, flaring and venting at the LNG production plant. These are Scope 1 emissions for the processing facility, i.e. downstream of the raw gas extraction and transfer operations, and upstream of the product custody transfer points. Scope 2 emissions are excluded from this assessment. Emissions from the upstream processing operations, e.g. production wells and platforms, and downstream operations, i.e. piping, distribution, transport, and third-party consumption (Scope 3) are also excluded from the calculations. This approach has been applied for the current benchmarking.

Although the intent of defining the emissions boundary is to achieve a 'like for like' comparison of facility performance, this is not always possible due to the variation in design and operation of LNG facilities. For example, the extent of processing raw gas upstream from an LNG plant, i.e. at or near the point of extraction, will impact the magnitude of the emissions attributable to the LNG plant. A number of the facilities included in the benchmarking utilise subsea production systems. This tends to increase the GHG emissions at the gas processing plant site, making direct comparisons of actual emission intensity of the LNG processing operations more difficult.

As discussed in Section 2.1, publicly available data for other Australian and international LNG facilities is largely representative of planned maximum capacity. Operational data, i.e. LNG production and associated GHG emissions following approval and commissioning, is not typically available. The benchmarking comparisons have therefore included the KGP planned capacity data, as well as the current operational data.

3. Overview of KGP GHG Emissions

3.1 Introduction

The primary CO_2-e emissions from a typical LNG facility are shown in Table 3-1.

Table 3-1: Key GHG Emission Sources associated with LNG Production [1]

Process area	Typical CO_2-e emission sources (API, 2015)
Upstream – gas extraction and production	Flaring Fuel use for compression Fuel use (gas and diesel) for power generation Fugitive emissions Minor process venting, e.g. from tanks Electricity purchase
LNG liquefaction plant – gas treatment, liquefaction and storage	Flaring Fuel use for refrigeration compressors Fugitive losses (leaks from equipment, including tanks and pipelines) Fuel use for power generation Fuel use for any fired process heat generators Venting from AGRU Nitrogen venting (containing methane)
Downstream – transport of facility products (pipeline, shipping, etc.)	Fuel use for compression Fugitive emissions Flaring due to ship gas up and cool down Boil-off gas

1. The emissions shown represent the key emissions which are expected as part of a typical LNG facility. There will be other minor emissions which are dependent of the gas quality, e.g. condensate stabilisation after separation from the gas phase.

The emissions from each of the three process areas shown in Table 3-1 can fall into Scope 1, Scope 2 or Scope 3 emission categories, depending on the facility operation. Typically, the ‘upstream’ and ‘LNG liquefaction plant’ emissions will be predominantly Scope 1 emissions. However, at some sites, Scope 2 emissions may also be relevant, e.g. if electricity is imported. In addition, if raw gas is imported from another facility (owned and operated by others), then these emissions may be considered Scope 3. The ‘downstream’ processes typically constitute Scope 3 emissions as they are indirect emissions which occur outside of the gas processing premises. The most significant of these are emissions from product combustion by end users. For the GHG intensity benchmarking assessment, Scope 1 emissions associated with the LNG liquefaction plant are compared.

The break-down of the CO_2-e emissions for the KGP for year 2017-18 is shown in Table 3-2. These represent Scope 1 emissions, consistent with reporting requirements under NGER Regulations (AG, 2018). The largest sources of GHG emissions at KGP is from the fuel gas consumed for driving the refrigeration compressors, followed by the CO_2 released via the AGRU vents. The category ‘fuel gas use – other stationary’ includes fuel consumed in furnaces, non-LNG related compressors and the combustion of non-LNG products (Liquified Petroleum Gas [LPG], greases, oils, etc.). ‘Other’ includes fugitive leaks from tanks and pipeline, diesel combustion (vehicle transport, electricity generation) and emissions associated with wastewater treatment at site.

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Table 3-2: Indicative Break-down of CO_2-e emissions for KGP

KGP CO_2-e emission source	Indicative % of total CO_2-e emissions
Fuel gas use – electricity generation	15%
Fuel gas use – refrigerant compressor gas turbines	55%
Fuel gas use – other stationary	< 1%
AGRU	22%
Venting and flaring	7%
Other	< 1%
Total, KGP	100%

3.2 Emissions Related to Design

GHG emissions are influenced by the design of the LNG facility and selection of equipment. Key technology and process factors which influence GHG intensity are:

- Selection of liquefaction technology
- Choice of power generation equipment and configuration
- Use of waste heat recovery
- Acid gas removal process.

3.2.1 Liquefaction technology and power generation

Typically, the largest source of emissions at an LNG facility is from the fuel consumption associated with the operation of the refrigeration compressor and power generator drivers. There are two main options for selection and design of the drivers:

- Direct drive – These are the most common type used in liquefaction plants. Natural gas being delivered to the site is used to fuel gas-turbine driven compressors. The gas turbines can be conventional heavy-duty industrial or aeroderivative types. Aeroderivative gas turbines usually have higher efficiencies than conventional gas turbines, resulting in lower GHG emissions intensity per MWhr of energy produced. For some LNG facilities, aeroderivative gas turbines are used for both the refrigerant compressors and power generation.
- Electric drive – These systems use an electric motor to drive the compressors, which are less common, but can achieve higher efficiencies and hence lower GHG emissions (Kleiner, 2005). If the electricity is from renewable or low-emissions sources, then this can offer a lower intensity method of driving the compressors. In some cases, electricity is provided within the LNG facility by combined cycle gas turbine (CCGT) plants using natural gas at the site. These use waste heat effectively to achieve high thermal efficiencies.

With any drive type (for both liquefaction and power generation), it is important to match the design and selection of the drivers with the production rates and operating conditions to maximise operating efficiency (GPN, 2014). Operating equipment items at sub-optimal performance levels can result in poor reliability and reduced energy efficiency.

As part of the KGP Expansion Project, Train 4 (T4) was implemented in 2004 and Train 5 (T5) in 2008 with new high-efficiency Frame 7 gas turbine with power recovery via hydraulic turbines, as well as four new aeroderivative gas turbines (Frame 7) for electrical power generation. The power generation turbines have higher efficiency (i.e. lower GHG emissions per unit energy output) than the older industrial gas turbines which are also used for power generation at KGP. The electrical power system is integrated and therefore the more efficient aeroderivative turbines are loaded preferentially to industrial turbines.

3.2.2 Waste heat recovery

The use of waste heat recovery at an LNG facility can offer significant reductions in fuel use and GHG emissions. This technology is currently used at several of the newer LNG facilities, including each of the five trains (T1 – T5) at the KGP. Waste heat from the gas turbine compressor drivers is used to supply process heat to other areas of the plant, e.g. via a heated water system. Recovered process heat means that the need to generate heat via fuel fired burners is reduced, thereby reducing GHG emissions. The process items which require the highest amount of heat within an LNG facility are often the AGRU and dehydration media regeneration. For sites where the reservoir CO_2 levels are low, the process heat requirements for the AGRU is also relatively low. For such sites, the potential savings in GHG emissions are lower than those which have higher reservoir CO_2 levels.

At KGP, waste heat recovery units (WHRUs) use the exhaust stream from the gas turbines driving the propane compressors to provide process heating via the heated water system. The WHRUs also provide process heat to a slipstream of dried feed gas to regenerate the molecular sieve adsorber beds used for dehydration of the feed gas. Waste heat is also shared with the Domgas unit.

3.2.3 Acid gas removal

CO_2, as well as other co-absorbed substances, including a small amount of methane, is removed from the liquefaction plant inlet gas stream via the AGRU to avoid it freezing at low temperatures. As the stripped gases are typically vented to atmosphere, minimising the non-CO_2 components released, including methane, is important. Most recent LNG facilities use the solvent, activated methyldiethanolamine (aMDEA), for absorption of CO_2 in the AGRU. The use of aMDEA has been demonstrated to reduce co-absorption of hydrocarbons which may otherwise be vented to atmosphere and is used at the KGP for CO_2 removal at the AGRU.

3.2.4 Other process design options

Other process designs which can influence GHG emissions are:

- Routing gas vents from start-up operations to the flare system, instead of direct venting to atmosphere.
- Use of dry gas seals on gas turbine compressors which have been intrinsically designed for minimal venting.
- Avoiding flare emissions by ensuring adequate boil-off gas compressor capacity (and redundancy) is incorporated in the design.
- The design and selection of process items with high reliability to minimise the number of shut-downs and process upsets, during which gas streams are released to atmosphere (via flare or venting).
- Flash gas streams, e.g. from the AGRU, are recovered back in to the process instead of venting to atmosphere.
- Combustion of co-absorbed hydrocarbons in the AGRU vent stream via a regenerative or recuperative thermal oxidiser.

- The extent of process integration, i.e. the efficient use of hot and cold process streams across different processing areas, to reduce the amount of fuel use at the site can reduce the site's GHG emissions. This is most applicable to larger scale plants which have more stable energy requirements and flexibility in design.

3.3 Emissions Related to External Factors

In addition to the impact of the design of the LNG facility, 'external' factors, i.e. inherent to the site location, also have the potential to affect the environmental performance of a facility. Common external factors which affect the level of GHG emissions are discussed in the following sections.

3.3.1 Ambient temperatures

The ambient temperature at the LNG facility location will impact the system energy demand and subsequent GHG emissions. For sites with cooler ambient temperatures, less energy is required for liquefaction, as the efficiency of the gas turbines (for refrigeration compressor and power generation drivers) increases at lower temperatures, reducing fuel use and GHG emissions per unit of power output. For every one-degree Celsius reduction in ambient operating temperature, LNG process capacity increases by approximately 0.6% (Chevron, 2015).

3.3.2 Reservoir gas composition

The concentration of CO_2 and other inert gases in the reservoir will affect the GHG emissions for the LNG facility. CO_2 needs to be removed from the raw gas stream as it will freeze at the low operating temperatures in the liquefaction process. If the CO_2 concentration is high, this translates directly to high emissions of CO_2 (with small amounts of methane) which are vented to atmosphere at the AGRU, upstream of the liquefaction process. Emissions from fuel combustion associated with energy use at the AGRU will also occur. These incremental GHG emissions can be reduced by the use of waste heat for power generation.

3.3.3 Geosequestration Opportunities

Geosequestration offers opportunities to capture the CO_2 vented to atmosphere from the AGRU. Geosequestration, whereby the CO_2 gas stream stripped from the natural gas feed stream to the liquefaction plant is injected into an underground reservoir (such as the Dupuy Formation underneath Barrow Island), has been incorporated into the design and construction of the Gorgon LNG facility in Western Australia. Reinjection of CO_2 has recently (August 2019) commenced. The Ichthys LNG facility has been designed as "CCS (carbon capture and storage) ready" meaning that provisions have been made in the design to be able to retrofit the facility with CCS capability in the future (APPEA, 2018). The Snohvit LNG facility in Norway reduces its CO_2 emissions by injecting the CO_2 stream into an offshore reservoir (see Section 5.3.2).

4. NWS Project Extension Proposal GHG Emissions

As part of the Proposal, the feed gas composition to the KGP may change as a result of third-party gas and liquids and changing NWSJV field resources. However, importantly, there will be no change to the current and future projected level of GHG emissions and/or the LNG production capacity at the KGP. Although the future projected GHG emissions and LNG production rates are expected to vary from year to year, and consequently the GHG intensity will also be variable, the changes to the plant inlet gas under the Proposal will not alter the projected GHG intensity for the Proposal.

A summary of the NWS Project Scope 1 CO_2-e emissions (including upstream emissions), production rates and calculated emission intensities for the last four years is provided in Table 4-1. The table shows the calculated GHG intensity representing the KGP LNG plant GHG emissions as part of the NWS Project, i.e. excluding upstream operations. This metric is used for benchmarking with other LNG facilities (see Section 5). The highest GHG intensity over the last 4 years has been 0.41 t CO_2-e / t LNG.

Table 4-1: Summary of NWS Project GHG Emissions and LNG Production for the KGP LNG plant, FY2015-2018[1]

NWS GHG parameter	Units	FY2014/15	FY2015/16	FY2016/17	FY2017/18
CO_2-e emissions					
Fuel combustion[2]	t CO_2-e / yr	5,162,500	4,986,900	5,188,600	5,165,700
Venting	t CO_2-e / yr	1,520,400	1,477,500	1,563,000	1,685,300
Other[3]	t CO_2-e / yr	100	100	100	100
Total KGP LNG plant CO_2-e (excluding upstream)	t CO_2-e / yr	6,683,000	6,464,500	6,751,700	6,851,100
LNG production rate	mtpa	16.29	15.95	17.35	16.62
GHG intensity (Scope 1 KGP only)	t CO_2-e / t LNG	0.41	0.41	0.39	0.41

1. The NWS Project emissions and LNG production data shown is based on the supporting data from the annual NGERs submissions to the Clean Energy Regulator.
2. Fuel combustion includes flaring emissions.
3. 'Other' emissions include those associated with wastewater handling and emissions of hydrofluorocarbons and sulphur hexafluoride gases.

5. Benchmarking Results and Discussion

5.1 Overview

Figure 5-1 provides a summary and comparison of the GHG intensities for various Australian and international LNG facilities (selected as described in Section 2.1).

The total column for each facility depicts the GHG intensity for the emissions attributable to the LNG plant. As detailed in Section 1.3, emissions from upstream processing associated with gas extraction and off-shore processing are not included. Similarly, Scope 2 and Scope 3 emissions are excluded.

Within the LNG plant emissions, the graph shows the distinction between the emissions released via the AGRU which are directly related to the reservoir CO_2 concentration, and the remaining emissions attributable to the LNG plant, i.e. emissions from refrigeration compressors, power generation, flaring, fugitive emissions, etc. The amount of CO_2 removed at the LNG facility may not be representative of the total reservoir CO_2; some may be removed upstream. Additionally, emissions data is inclusive of the processing of other products in addition to LNG due to limitations of available data.

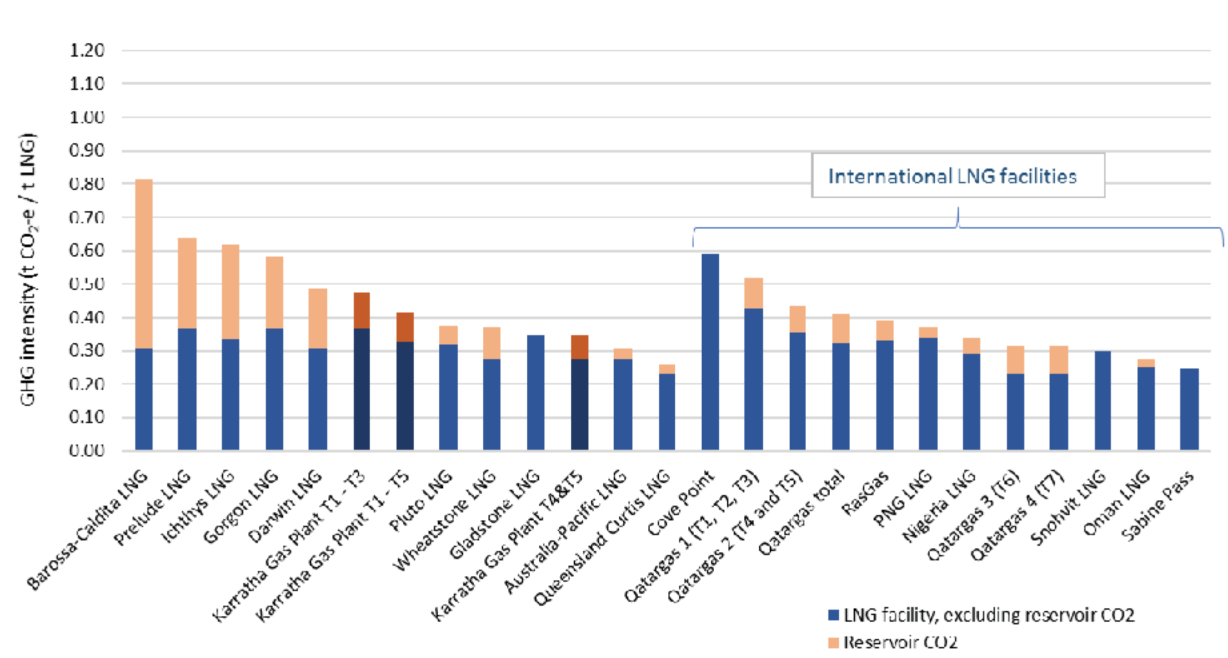

Figure 5-1: GHG Intensity of Australian and International LNG Facilities (KGP facilities shown in darker colour)

For the KGP LNG and Pluto LNG facilities, the maximum approved CO_2-e emission rates and LNG production data have been applied in Figure 5-1. The following are relevant to the interpretation of Figure 5-1:

1. The Barossa-Caldita LNG is a proposed off-shore floating production storage and offloading (FPSO) facility. The data shown includes emissions associated with CO_2 removal (reservoir CO_2) at the FPSO. The LNG facility emissions, excluding reservoir CO_2, have been assumed to be the same as the downstream Darwin LNG facility where the gas will be processed.

2. For the Gladstone LNG facility, the GHG emissions attributable to reservoir CO_2 are not provided in available data and are instead included in the total for the LNG facility. However, the CO_2 reservoir content for the Gladstone feed gas is very low at 0.3 mol%. As a result, the associated CO_2-e emissions are expected to also be low.

3. The CO_2-e emissions attributable to reservoir CO_2 are not available for the Snohvit LNG facility. Several previous assessment reports have stated a GHG intensity of 0.22 t CO_2-e / t LNG. However, a study undertaken for the Government of British Columbia, Canada (Delphi Group, 2013) highlighted that this figure is a 'pre-production' estimate as the Snohvit facility was then currently under construction. This report provided a newer estimate of 0.3 – 0.35 t CO_2-e / t LNG due to problems with geosequestration. The reservoir CO_2 content is 8 mol%.

4. The CO_2-e emissions attributable to reservoir CO_2 for the Sabine Pass LNG are very low due to CO_2 removal undertaken as part of upstream processing (see further information below).

GHG intensities calculated using the 2017/18 NGER data have been provided in Table 5-1 for comparison.

Table 5-1: KGP LNG facility GHG intensity data for current operations

LNG facility	LNG production rate (2017-18), mtpa	GHG intensity (t CO_2-e / t LNG)		
		Reservoir CO_2	LNG facility, excluding reservoir CO_2	Total LNG facility
Karratha Gas Plant T1 - T5	16.6[2]	0.09	0.32	0.41
Karratha Gas Plant T1 - T3	8.22	0.09	0.40	0.49
Karratha Gas Plant T4 -T5	8.40	0.09	0.26	0.35

5.2 Limitations

For the non-Woodside operated facilities, the emissions data has been obtained from publicly available information. The majority of this information has been extracted from EIA reports and for some cases there is limited amount of data break-down and definition of reporting boundaries. Uncertainties associated with the use of data and information available from these sources include:

- In some cases, the definition of 'LNG production' is not clear. Some reports may also include other co-produced products such as LPG and condensates.
- The extent of processing at the upstream facilities, e.g. at the point of raw gas extraction, varies from site to site. For example, if some CO_2 removal is carried out at upstream facilities instead of at the AGRU within the LNG facility, the CO_2 emissions reported for the LNG liquefaction facility will be reduced accordingly.
- A number of the facilities benchmarked utilise subsea production systems (e.g. Gorgon LNG, Snohvit LNG) and this may inflate the emissions at the gas processing plant site, further obscuring the actual emissions intensity of the LNG processing operations.
- The data available from EIA reports is based on concept or detailed phase designs and not operational data. The emissions data is therefore not based on current operation and would not reflect any plant

[2] Actual KGP capacity is 18.5mpta

modifications or operating condition changes carried out since the EIA. This has the potential to introduce significant variation from actual current operational GHG intensity data.

5.3 Discussion

5.3.1 Benchmarking against Australian LNG facilities

The data for the five KGP LNG trains, T1 – T5 in Figure 5-1, shows the improved performance of train T4 and T5, commissioned in 2004 and 2008, compared to that of the original trains T1, T2 and T3 (commissioned 1989 – 1992), with the GHG intensity decreasing from 0.47 to 0.35 t CO_2-e / t LNG, respectively. This is a result of the following mitigation measures implemented for the newer T4 and T5 LNG trains (Woodside, 2004):

- Use of higher-efficiency Frame 7 gas turbines with power recovery via hydraulic turbines.
- Use of higher-efficiency aero-derivative gas turbines for electrical power generation.
- Routing flash gas from the horizontal three phase separator of the AGRU to the low pressure fuel gas system.
- Routing the start-up vent from the AGRU to the flare system, rather than direct venting of the gas stream to atmosphere.
- Utilisation of dry gas seals, that have minimal venting, or double oil seals, with seal gas losses routed back to compressor suction, to reduce seal gas losses from the gas and refrigerant compressors.

Of the Australian LNG facilities, the emissions for the KGP T4 and T5, and for the entire LNG facility (i.e. T1 – T5), are lower than the average for the Australian facilities analysed of 0.44 t CO_2-e / t LNG [3]. Facilities with GHG intensities lower than KGP T4 and T5 are Australia-Pacific LNG (APLNG) and Queensland Curtis LNG. Wheatstone Project and Gladstone LNG have GHG intensities similar to that of KGP T4 and T5, but slightly lower than KGP T1 – T5. Each of these facilities have relatively high LNG production capacities and have been commissioned recently, i.e. in the last 5 years. Emissions from these facilities are discussed below. Interestingly, the GHG intensities for large and recently commissioned plants, i.e. Ichthys LNG, Prelude LNG and Gorgon LNG, are higher than that of KGP T1 – T5. This indicates that the higher reservoir CO_2 content for these facilities more than off-sets the improvements made by the implementation of more recent LNG technologies.

Comparisons of GHG intensity values which exclude emissions attributable to the reservoir CO_2 content are useful as these emissions are inherent to the fields which supply the facility. The GHG intensity of KGP T4 and T5, excluding CO_2 reservoir emissions, is lower than the average for the Australian facilities analysed of 0.31 t CO_2-e / t LNG, and is comparable to Wheatstone LNG and APLNG. The GHG intensity, excluding CO_2 reservoir emissions, for the entire KGP LNG facility (T1 – T5) is 0.33 t CO_2-e / t LNG which is slightly higher than the average for the Australian facilities.

The KGP has GHG intensity comparable to the Wheatstone Project, which is a new facility. The GHG intensity of the LNG facility, excluding emissions attributable to the CO_2 reservoir, is slightly lower for Wheatstone compared to the KGP (T1 – T5). Influencing factors may be the use of aero-derivative turbines for both the refrigeration process and power generation at Wheatstone (compared to the use of aero-derivative turbines for power generation for the KGP T4 and T5 only) and the use of the Optimised Cascade refrigeration process. The use of this process has been reported to offer efficient liquefaction and operational flexibility (APLNG, 2010) which is supported by its application in recent LNG facility installations.

[3] The calculated average excludes the Barossa-Caldita LNG GHG intensity as the data are preliminary estimates only based on early reservoir modelling and early engineering designs (ConocoPhillips, n.d).

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The Gladstone LNG and APLNG facilities are major Australian facilities, with significant LNG production rates, as reported in the respective environment approval documentation, of 10 mtpa and 18 mtpa, respectively. It is noted however, that the nameplate capacities for these facilities are less than the planned rates shown in the approval documentation (see Table 2-2). The Gladstone LNG facility GHG intensity, excluding CO_2 reservoir emissions, is similar to that for the whole KGP (T1 – T5), and the intensity for APLNG is lower. However, the intensity for the KGP T4 and T5 trains is slightly lower than that of Gladstone LNG and similar to that of APLNG when CO_2 reservoir emissions are excluded. Potential contributors to the APLNG intensity being lower than that of KGP T1 – T5, excluding emissions attributable to CO_2 reservoir venting emissions, are the use of the Optimised Cascade refrigeration process, and reduced energy requirements at the AGRU due to the low reservoir CO_2 levels for APLNG (1 mol%, which islower than 2.4 mol% for KGP).

The Queensland Curtis LNG facility has the lowest GHG intensity of the major Australian facilities, both with and without CO_2 reservoir emissions. The Queensland Curtis LNG facility employs the following design features:

- Aero-derivative gas turbines used within the Optimised Cascade liquefaction process, with inlet air chilling.
- Use of aero-derivative gas turbines for electricity generation.
- Use of waste heat recovery units for process heat requirements.

The use of aero-derivative turbines for both refrigeration compression and power generation contribute to the lower emissions for the Queensland Curtis Island facility. In addition, the lower reservoir CO_2 content means that the power requirements for handling the CO_2 will be lower than that of KGP T1 – T5, although this is a relatively minor influence to total CO_2-e emissions.

All other Australian facilities are more recent installations compared to the KGP. It is therefore expected that these LNG facilities would have more advanced processing equipment and designs which would result in better energy efficiency, thereby resulting in lower GHG intensities. Interestingly, the older KGP LNG facility compares well with the performance of several of the more recent LNG facilities, e.g. Gorgon LNG, Prelude LNG and Ichthys LNG, with and without CO_2 reservoir emissions. This is considered to be a result of the ongoing changes implemented at the site to mitigate emissions as described above, as well as ongoing continuous improvement projects. However, the CO_2 content of the raw gas to KGP may vary in the future and associated variation in GHG emissions may occur.

Of the Australian facilities assessed, the Darwin LNG plant, commissioned in 2006, provides the closest comparison to the KGP in terms of age with KGP T4 and T5 commissioned in 2004 and 2008. The GHG intensity for Darwin LNG is 0.49 t CO_2-e / t LNG which is higher than that of KGP T1 – T5 (0.42 t CO_2-e / t LNG). This is possibly a result of the higher reservoir CO_2 content for Darwin LNG. Excluding emissions attributable to the feed gas CO_2, the GHG intensity for the Darwin LNG is similar to that of the KGP T1 – T5 and higher than that for KGP T4 and T5.

The proposed Barossa-Caldita LNG FPSO has the highest reservoir CO_2 GHG intensity. This is due to the high CO_2 reservoir content of 16 – 20%. It should be noted that the GHG estimates for the facility are preliminary only as the project is currently in the design phase with a final investment decision not due until end 2019.

An Australian LNG facility not included in the assessment is a small facility in Kwinana, Perth. This facility processes 175 t /day LNG (0.064 mtpa) and has an estimated emissions intensity of 0.20 t CO_2-e / t LNG. However, there is insufficient publicly available information to determine the emission sources which are included in the reported emissions. Due to the scale of the facility and the lack of information, this site has therefore not been included in the Australian facilities for benchmarking.

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5.3.2 Benchmarking against international LNG facilities

The Sabine Pass LNG facility in Louisiana, USA, has the lowest GHG intensity, with and without consideration of reservoir CO_2 emissions. This is a large capacity LNG facility (16 mtpa, compared to KGP FY2017/18 LNG production of 16.6 mtpa) which uses the ConocoPhillips Optimised Cascade technology for the liquefaction process. Aeroderivative turbines are used for the refrigeration compressors. Gas is supplied to the LNG facility by a network of pipelines which can deliver gas from various conventional and unconventional gas fields across the United States. In 2010, the most likely sources of gas to the Sabine Pass LNG facility were the Gulf Coast Texas and Louisiana onshore conventional gas fields, the gas fields (Permian, Anadarko, and Hugoton basins), and the emerging unconventional gas fields (Barnett, Haynesville, Eagle Ford, Fayetteville, Woodford, and Bossier basins) (Cheniere, 2013). The pipeline CO_2 concentration for these gas fields varies from 0.1 to 4.8 mol%. Due to the very low reported emissions from the AGRU, previous studies (Delphi Group, 2013) have estimated the pipeline feed CO_2 content at 0.01 mol% and have concluded that the gas delivered to the LNG facility must have already undergone acid gas removal upstream. This low level of CO_2 in the raw gas entering the LNG plant is expected to contribute to the reported low GHG intensity.

Oman LNG has the second lowest GHG intensity of 0.28 t CO_2-e / t LNG, with and without consideration of reservoir CO_2 emissions. A contributor is expected to be the use of water cooling instead of air cooling at the facility. This leads to more efficient heat exchange and more consistent production rates that are less susceptible to variance in ambient air temperature. Another contributor may be the low inlet gas CO_2 content and consequent low power requirements for the AGRU.

The Snohvit LNG project is located in northern Norway, just above the Arctic Circle. A very low GHG intensity of 0.22 t CO_2-e / t LNG has been reported for this facility within various EIA and GHG assessment documents for other projects. However, a study undertaken for the Government of British Columbia, Canada (Delphi Group, 2013) highlighted that this figure is a ‘pre-production’ estimate as the Snohvit facility was then currently under construction. However, the report provided a newer estimate of 0.3 – 0.35 t CO_2-e / t LNG as it appears there have been problems with CO_2 injection at the Snohvit facility due to reservoir pressure buildup, so the plant has not been performing as well as initially planned. In any case, contributing factors to the relatively low GHG intensity for this facility are:

- The GHG intensity is based on the re-injection of reservoir CO_2 into the subsurface
- The cold operating temperatures (compared to the Australian facilities) mean less energy is required for refrigeration and the gas turbines run more efficiently, increasing power and reducing relative fuel gas use.
- The facility is connected to the local electrical grid, removing the requirement for spinning reserve electrical power generation.

It is noted that the Snohvit facility uses subsea production systems, i.e. there is no offshore gas platform. Although there will be no emissions related to gas production, there may be a slight increase in emissions for the onshore facility (Chevron, 2015).

Of the international LNG facilities, the Qatargas facility is most easily compared with the KGP T1 – T5 as it is a large facility of similar age (1997 – 2011 for the progressive implementation of liquefaction trains) and has a similar reservoir CO_2 content. This facility comprises four LNG plants, with a total of 7 liquefaction trains (T1 – T7). The GHG intensity for this facility (combined T1 – T7) is 0.41 t CO_2-e / t LNG which is very similar to that of KGP T1 – T5. When reservoir CO_2 emissions are excluded, the GHG intensities are also similar for the two facilities. Like the KGP, the GHG intensity has decreased progressively as newer liquefaction trains have been added over the years.

Overall, the GHG performance of the KGP is comparable with both Australian and international LNG facilities. The GHG intensity for KGP is lower than the average intensity for the 10 Australian facilities assessed (excluding the Barossa-Caldita LNG FPSO). Excluding CO_2 emissions attributable to reservoir CO_2 content, the GHG intensity for the KGP facility (T1 – T5) is similar to the average intensity for the Australian facilities, and the intensity for T4 and T5 is slightly lower than the average.

When assessed against international LNG facilities, the GHG performance of the KGP was found to be very similar to those facilities located in a similar climate and of similar age.

6. Conclusion

In conclusion this benchmarking study shows that the GHG performance of KGP compares well against other LNG facilities. Although the older infrastructure (T1-T3) contains older technology the overall facility compares well against some of the newest LNG facilities in Australia. Overall, the current and future projected GHG performance of the Proposal is similar to both Australian and international LNG facilities. The GHG intensity for KGP is lower than the average intensity for the ten Australian facilities assessed. When assessed against international LNG facilities, the GHG performance of the Proposal was found to be very similar to those facilities located in a similar climate and of similar age.

Whilst there are a number of limitations associated with this benchmarking study, largely due to the availability of GHG emission data from other facilities, the assessment provides a useful understanding of how the Proposal GHG emissions compare to other facilities for the purpose of supporting the NWS Project Extension Proposal Environmental Review Document.

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7. Terms

Term	Definition
AGRU	Acid gas removal unit
aMDEA	Activated methyldiethanolamine
APLNG	Australia-Pacific LNG
CCGT	Combined cycle gas turbine
CCS	Carbon capture and storage
CO_2-e	Carbon dioxide equivalent emissions
EIA	Environmental impact assessment
FPSO	Floating production storage and offloading facility
GHG	Greenhouse gas
GWP	Global Warming Potential
KGP	Karratha Gas Plant
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
mt	Million tonnes
mtpa	Million tonnes per annum
MWhr	Mega (x10^6) watt hours
NGER	National Greenhouse Energy and Reporting
NT	Northern Territory, Australia
NWS	North West Shelf
NWSJV	North West Shelf Joint Venture
t	Tonnes
T	Train
TOT	Trunkline Onshore Terminal
T1, T2, T3, T4, T5	KGP LNG processing trains #1, #2, #3, #4 and #5
WA	Western Australia, Australia
WHRU	Waste heat recovery unit

Greenhouse Gas Benchmarking

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APPENDIX G
NORTH WEST SHELF PROJECT EXTENSION KARRATHA GAS PLANT WASTEWATER DISCHARGE MODELLING

Revision 1

Woodside

Appendix G

Karratha Gas Plant Wastewater Discharge Modelling

DATE: 1 AUG 2019

PROJECT: J19-003

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Contents

ABBREVIATIONS

ADCIRC	Advanced Circulation Model
C_0	Initial Discharge Concentration
FE	Finite Element
HEPA	High Ecological Protection Area
KGP	Karratha Gas Plant
MEPA	Medium Ecological Protection Area
MSL	Mean Sea Level
m/s	Metres per secod
PSU	Practical Salinity Unit
PW	Produced Water
Woodside	Woodside Energy Ltd.
WW	Wastewater
^{o}C	Degree Celsius

EXECUTIVE SUMMARY

Woodside Energy commissioned Jacobs to develop a dilution model to review mixing zones & discharge concentrations around the Karratha Gas Plant jetty outfall and Admin Drain. For the jetty outfall, stochastic analysis of 150 deterministic model runs was undertaken and the minimum dilution levels for 95% and 99% of tide, wind and phase-of-discharge conditions predicted. Minimum dilutions for 95% of conditions at 100, 250 and 500 m were 1:150, 1:260 and 1:400 respectively. These values decreased to 1:75, 1:100 and 1:200 at the 99% level.

Simulation of the Admin Drain discharge was more experimental and was undertaken to determine whether the current model setup could be applied and what the limitations might be. Results for a single deterministic simulation are presented. The results should be treated with caution as the hydrodynamic model has not been validated in this nearshore area and does not properly resolve the inner creek nor the drainage channel (evident on the satellite image). Further work would be required to simulate the Admin Drain discharge more accurately and may require coupling a one-dimensional model.

1 INTRODUCTION

1.1 Background

Woodside Energy has commissioned Jacobs to develop a dilution model to review mixing zones & discharge concentrations around the Karratha Gas Plant jetty outfall and Admin Drain.

1.2 Objective

The objective of this study is to simulate dispersion of wastewater (WW) discharged from the KGP jetty outfall and Admin Drain (Figure 2-1). For the jetty outfall, stochastic analysis was undertaken to present minimum dilution levels for 95% and 99% of tide, wind and phase-of-discharge conditions.

1.3 Scope of Work

The scope of work is as follows:

Jetty outfall

1) Review previous dilution modelling reports provided by Woodside.
2) Collate and assimilate data, including:
    - discharge parameters (location, flow, diffuser dimensions);
    - tidal current and elevations from hydrodynamic model;
    - measured wind data from Woodside;
    - toxicity data for jetty outfall whole effluent.
3) Near field modelling of the jetty outfall to define the mixing zone under a series of steady state current/wind conditions.
4) Far field modelling to demonstrate fate of discharged plume for various tidal and seasonal wind conditions.
5) Stochastic analysis to present minimum dilutions under 95% and 99% of tide, wind and discharge conditions.

Admin Drain

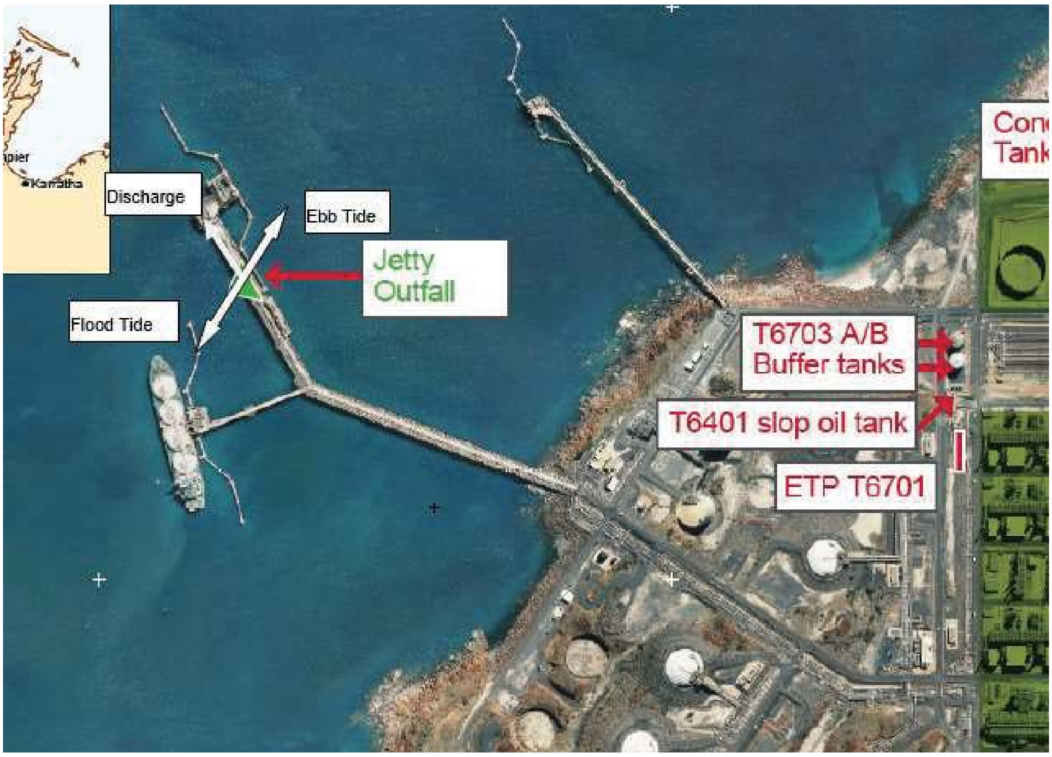
1) Collate and assimilate data, including:
    - discharge parameters (location, flow, hydraulics);
    - tidal current and elevations from hydrodynamic model;
    - measured wind data from Woodside;
2) Far field modelling to demonstrate fate of discharged plume for single tide and wind scenario.

2 KARRATHA GAS PLANT WASTEWATER DISCHARGE

The Jetty Outfall receives wastewater from facility process water, primary and secondary containments, and site run-off. Cause–effect pathways for potential impacts on marine environmental quality are associated with emissions from the production of gas and fluids by KGP processes. Maximum discharge size is limited by the size of the final effluent holding basin, which has a maximum volume of 350m^3. Frequency of discharges varies, but discharges do not typically occur more than twice per week.

The Administration Drain receives wastewater from the STP, reverse osmosis facility, and site stormwater run-off. Cause–effect pathways for potential impacts on marine environmental quality are associated with emissions from the production of gas and fluids by KGP processes, nutrients/organic matter in discharge from the STP, and concentration of contaminants by the reverse osmosis process. Discharges occur in batches, with total daily discharge volumes over the last 10 years of approximately 72m^3/day.

Figure 2-1 Karratha Gas Plant discharge locations



3 MERMAID SOUND RECEIVING WATERS

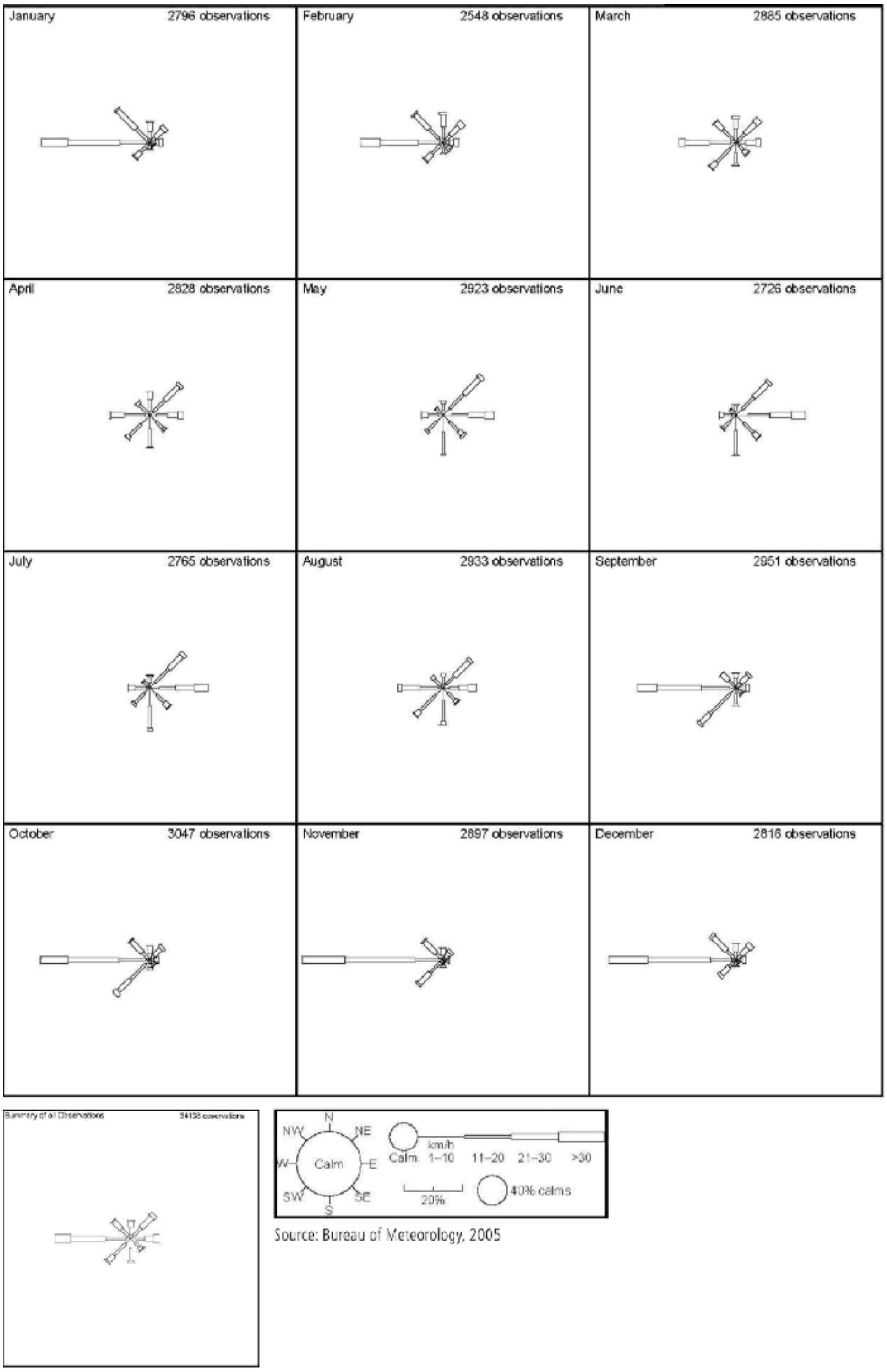
Tides in Mermaid Sound are semi-diurnal giving rise to four current reversals per day. There is a well-defined spring-neap lunar cycle resulting in considerable variation in the speed of the tidal currents over a 14-day period. Tidal currents flood through Mermaid Sound and also from the west (Figure 4-3 (a)). Currents are usually 90° out of phase with tide heights, with maximum speeds occurring at mid-tide and slack water coinciding with high and low waters. The exception to this is where the tidal currents meet adjacent to the intercourse islands where maximum current coincides with high and low water. Ebb currents flow to the northwest out of the sound (Figure 4-3(b)). At the discharge location, peak current speeds range from 0.18 m/s on spring tides to 0.05 m/s on neap tides (Figure 4-4). Wind, wave and density induced currents add a seasonal component to the ambient tidal flows. Net surface drift is dominated by seasonal winds.

Figure 3-1 shows monthly wind roses generated from measured data at Karratha Airport. In summer, (September to March) winds generally blow from the northwest through to the southwest. There is a pattern of daytime sea-breezes and night-time land-breezes. Wind speeds are typically less than 10m/s. In contrast, during winter (May to July), winds blow from the east to southeast. The offshore winds are enhanced by late night to early morning south-easterly land breezes as the land cools and are moderated by afternoon north-westerly sea breezes as the land heats. Winds reach speeds of 10 to 15 m/s inshore and can occasionally peak at over 20 m/s further offshore.

During the transition between the two seasons (April and August) winds tend to be lighter and can blow from either season direction. The typical “rule of thumb” for surface wind driven current flow is 2% to 4% of the wind speed. Surface currents are expected to reflect seasonal wind regimes. Local wind-driven surface currents may attain maximum speeds of 0.7 m/s during extreme wind surges. More typically speeds would be in the range of 0.2 to 0.4 m/s.

Sea surface temperature ranges from 24 – 32°C and salinity is approximately 34 psu. The water column in the Archipelago is essentially well mixed (Mills, 1985).

Figure 3-1 Monthly wind rose for Karratha Airport (from Bureau of Meteorology)



Source: Bureau of Meteorology, 2005

4 MODELLING METHODS

4.1 Overview

The modelling system used in this study is comprised of two components:

- a dispersion module that simulates the near and far field behaviour of the treated waste water; and
- a hydrodynamic module that provides the necessary velocity fields to drive the dispersion models.

4.2 Hydrodynamic Model

Overview

The hydrodynamics applied in the present study were computed using the ADvanced CIRCulation model (ADCIRC). This model is a system of computer programs for solving time dependent, free surface circulation and transport problems in two and three dimensions (Westerink *et al*., 1994). The algorithms that comprise ADCIRC utilise the finite element (FE) method in space and the model can be applied to computational domains encompassing the Deep Ocean, continental shelves, coastal seas and small-scale estuarine systems.

Model Details

Figure 4-1 shows the grid for the Dampier Archipelago. Using the significant flexibility provided by the FE method, grid resolution was increased considerably towards the Mermaid Sound. Node resolution varies from approximately 50km offshore to 40m inshore. The fine nearshore grid spacing was necessary to resolve the complex coastline geometry whilst coarse offshore resolution aids in computational efficiency.

Model bathymetry is shown in Figure 4-2. This was interpolated from the Australian Geological Survey Office database and Admiralty Chart No. AUS58. The model was forced from the open boundary by tidal elevations calculated from the M2, S2, N2, O1 and K1 tidal constituents. Amplitudes and phases for these were taken from the FES-95.2 global ocean model (Le Provost *et al*., 1998).

The model has undergone extensive validation and found to compare favourably against measured currents and tidal elevations in the Dampier Archipelago (Phillips and Luettich 2001).

Figure 4-1: Dampier Archipelago Finite Element Model Grid

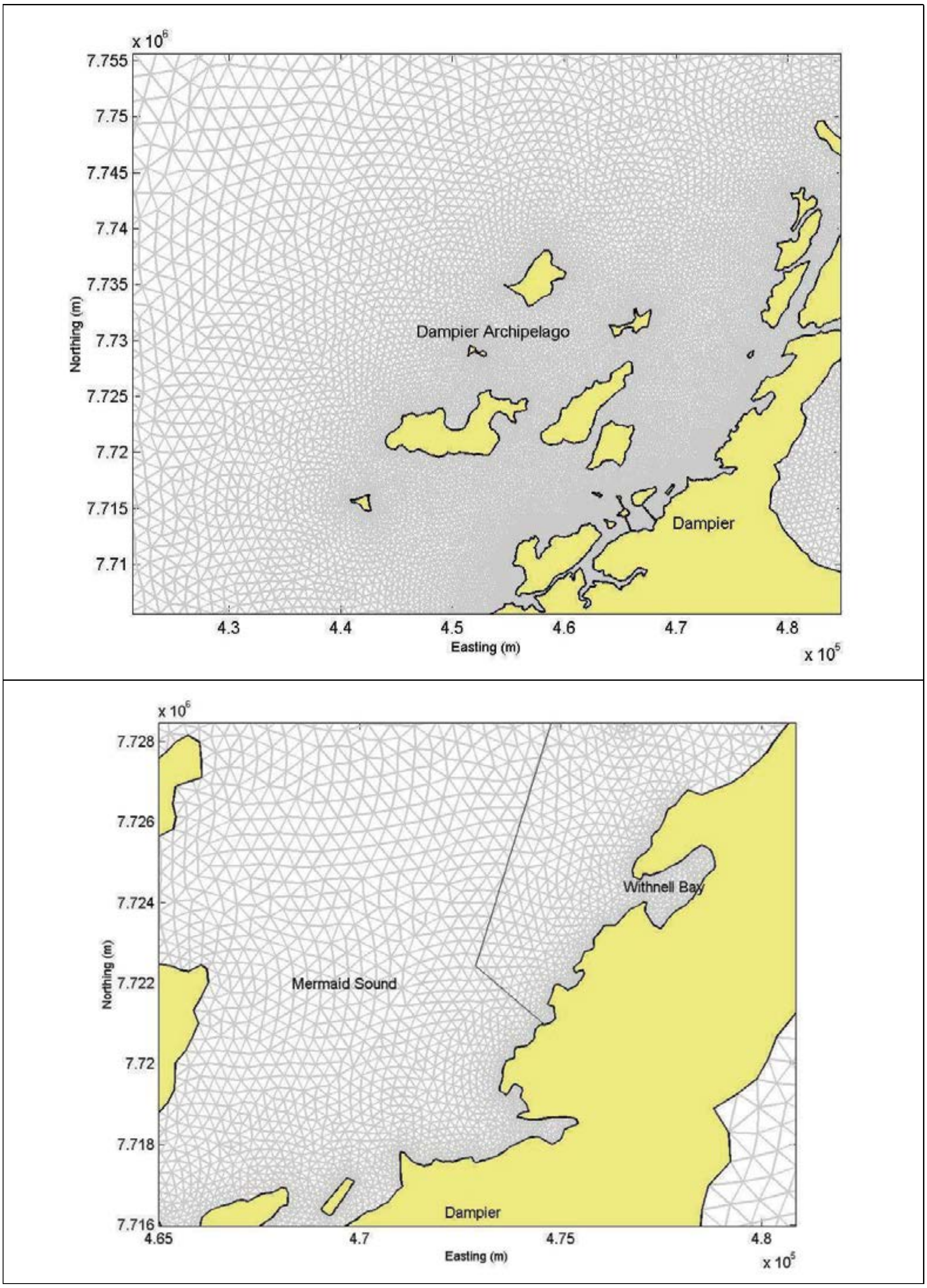


Figure 4-2: Dampier Archipelago Model Bathymetry (m)

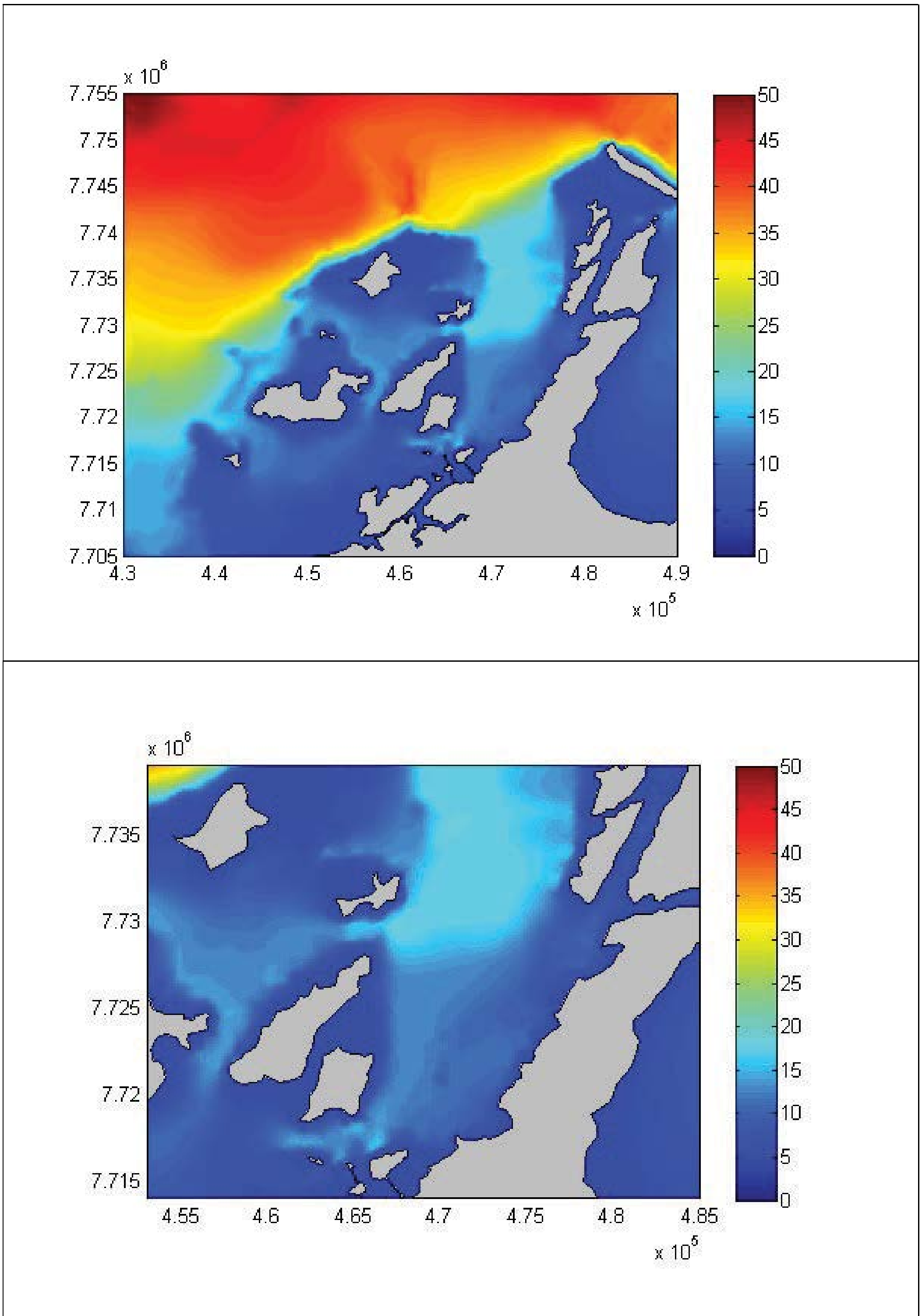
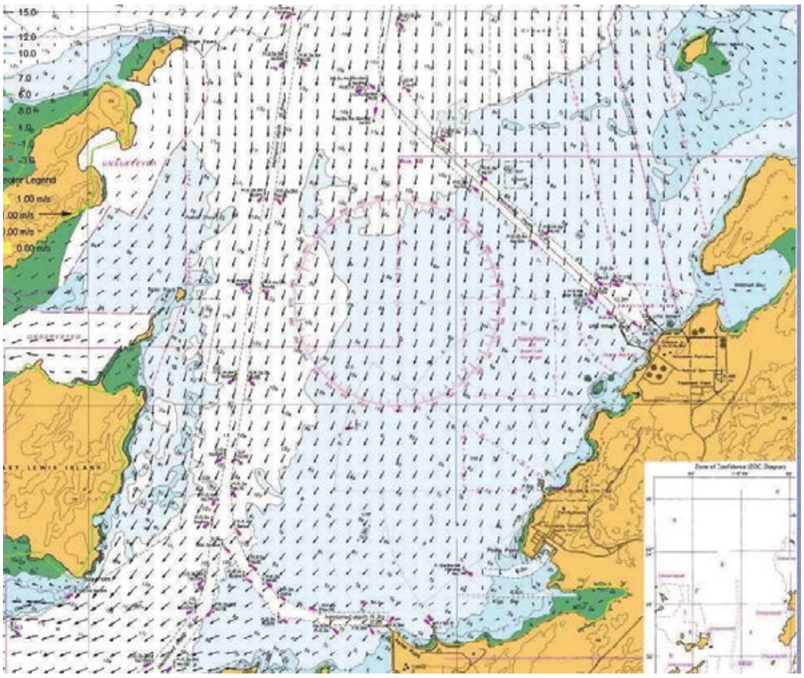


Figure 4-3: Computed currents in the Mermaid Sound

(a) Flood tide



(b) Ebb tide

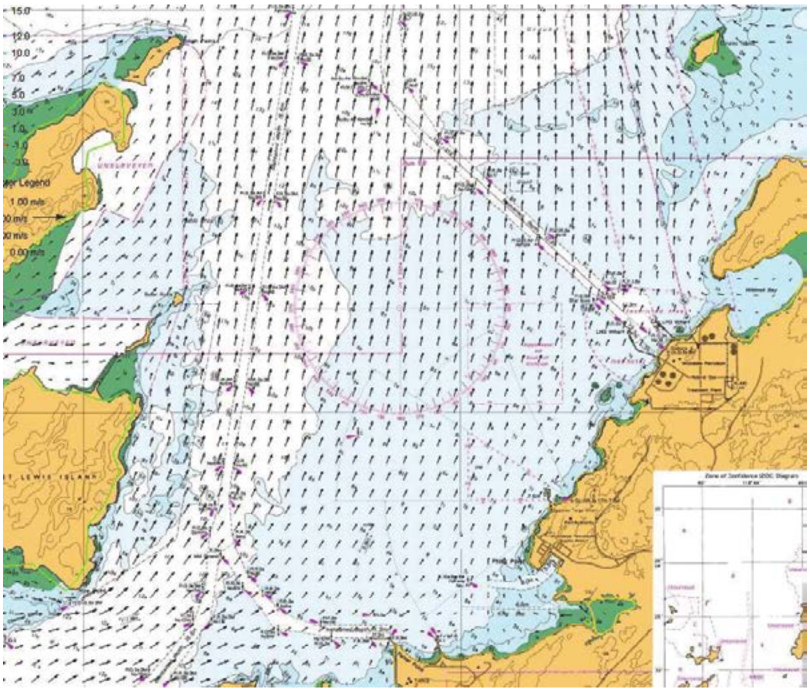
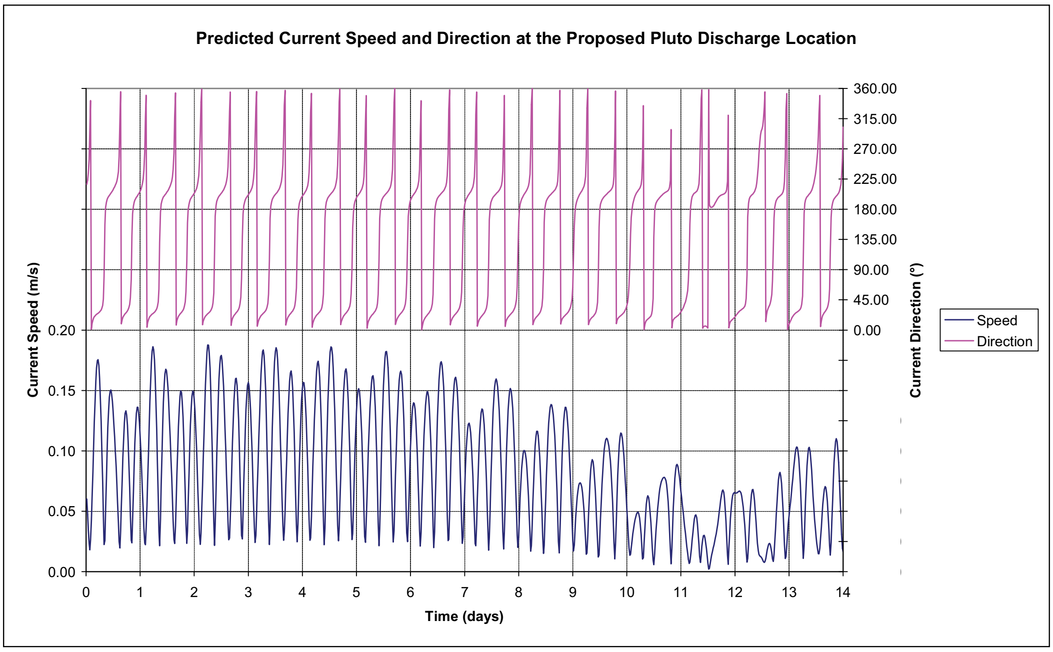


Figure 4-4: Predicted current speeds and directions at the proposed Pluto discharge location



4.3 Dispersion Module

4.3.1 Near field Dispersion

Mixing of a point source discharge is divided into two distinct regions: the near and far fields. The near field is defined as the zone between discharge orifice and impingement on a boundary, either the water surface or a density interface. In the near field, forces are dominated by the momentum and buoyancy of the discharge. Dilution is normally enhanced in this region and is termed ‘initial dilution’.

UM3 was applied to simulate near field mixing. This model is part of the Visual Plumes suite of models maintained by the United States Environmental Protection Agency (Frick, et al. 2003). It has been extensively tested (Roberts and Tian, 2004) and found to provide accurate results for various discharges.

UM3 is a Lagrangian model and solves the three-dimensional hydrodynamic equations governing the conservation of mass and momentum along the curved trajectory of a buoyant jet. To determine the growth of each element, it uses the shear (or Taylor) entrainment hypothesis and projected-area-entrainment hypothesis. The flows begin as round buoyant jets from one side of the diffuser and can merge to a plane buoyant jet (Carvalho et al., 2002). The solution yields values of the trajectory position and of centreline concentrations of pollutant mass, density deficit, temperature and salinity. Dilution is reported as the “effective dilution”, which is the ratio of the initial concentration to the concentration of the plume at a given point (Baumgartner et al., 1994).

4.3.2 Far Field Dispersion Modelling

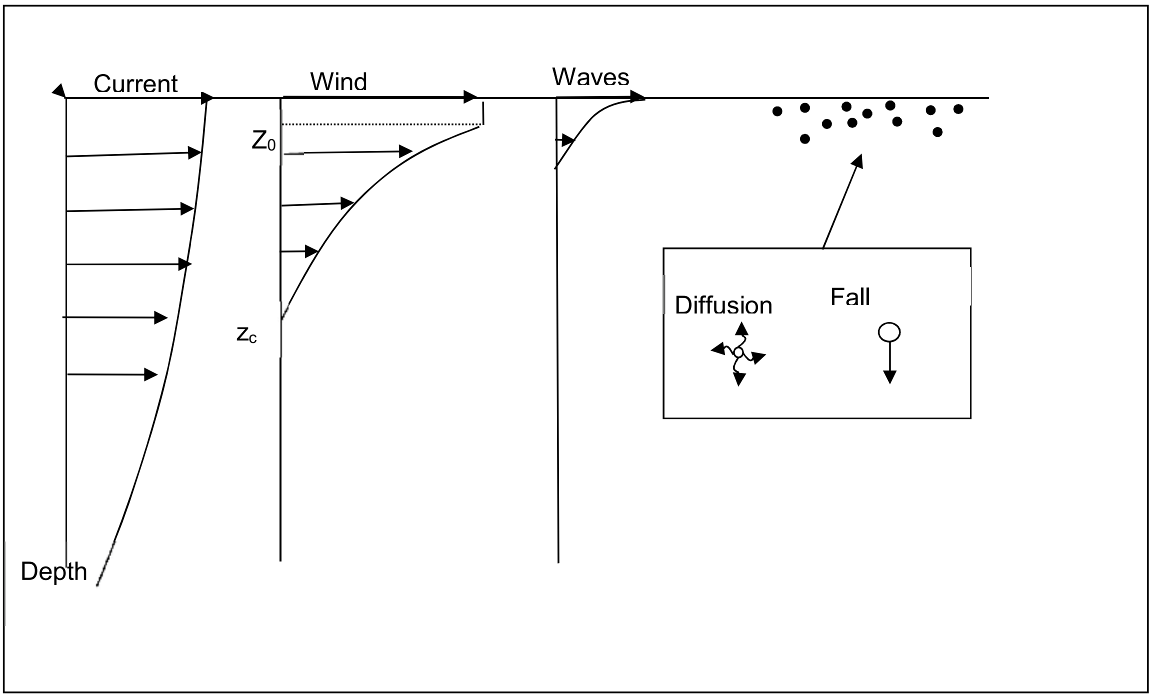
Model Overview

The PW dispersion module is based on the classic random walk particle tracking method (Elliot, 1992) and assumes that the mass of the discharge can be idealised as a large number of particles that move independently under the action of prevailing currents.

Physical mechanisms included in the model are illustrated in Figure 4-5 and include:

- advection by ambient currents (tide, residual, wind and wave); and
- dispersion due to turbulence.

Figure 4-5: Mechanisms included in the three-dimensional model.



Advection is calculated by stepping through the variations in the current field in time. The effects of wind induced surface shear are modelled by the inclusion of a logarithmic velocity profile. It is assumed that the surface layer, of thickness z_0, moves at a velocity U_s (typically 3% of the wind speed) and that the wind induced velocity decays with depth according to:

$$U_z = U_s \left(1 - \frac{\log(z/z_0)}{\log(z_c/z_0)}\right)$$

Where z_c is the depth at which the velocity is zero. It is assumed that z_c scales on the wavelength (L) of the surface waves, $z_c = \mu L$. μ is a free parameter in the model and has been set to 4. z_0 is also a free parameter in the model and has been set to 1 cm.

Waves are accounted for by including the Stokes drift to linear waves:

$$U_z = \frac{\omega k a^2 \cosh(2k(H-z))}{2\sinh^2(kH)}$$

Where a is the wave amplitude, H is the water depth, $\omega = 2\pi/T$ and $k = 2\pi/L$ for waves of period T and wavelength L. Wave height and period are calculated from equations provided in the U.S. Army Corps of Engineers Shore Protection Manual (1984). Local depth and fetch are determined in the model from the grid data. At an open grid boundary, a fetch of 100 km (i.e. virtually non-limiting) is assumed.

Dispersion is included by subjecting each particle to a random displacement at each time step. The dispersive displacement (random step) of each particle at each time step (dt) is scaled by the square root of the increment in the variance of the effluent plume which is given by the product:

(increment in variance) = 2Kdt

where K is the horizontal (Kxy) or vertical (Kz) diffusion coefficient. The actual step length taken by each particle is also determined by a random number selected from a normal distribution with zero mean and unit variance which is scaled by the product (2Kdt). Steps in the x, y and z co-ordinate directions are made independently.

The vertical turbulent diffusion coefficient in the mixed surface layer above the pycnocline is related to the wave conditions following Ichiye (1967):

$$K_z = 0.028\frac{H^2}{T}\exp(-2kz)$$

Below the pycnocline depth, Kz is assumed to be a constant equal to 10^{-4} m^2/s (Kullenberg, 1982).

The model was verified against a dye dispersion study undertaken at the North Rankin facility on 17 May 2006 (Oceanographic Field Services, 2006).

5 JETTY OUTFALL

5.1 Discharge Parameterisation

The existing KGP outfall consists of a 450mm diameter pipe routed along the jetty. Directly above the point of discharge, a 90° elbow directs the pipe vertically downwards to a depth of approximately 7m below MSL. Effluent is discharged through a five port diffuser system. Ports are 150mm diameter, positioned 1m apart and orientated downwards at 45° to the horizontal. The salinity of the effluent is around <2 psu and the discharge rate is given as 180 m^3/hr (0.05 m^3/s) over 116 mins. These and other discharge parameters are summarised in Table 5-1.

Table 5-1: Summary of KGP discharge parameters

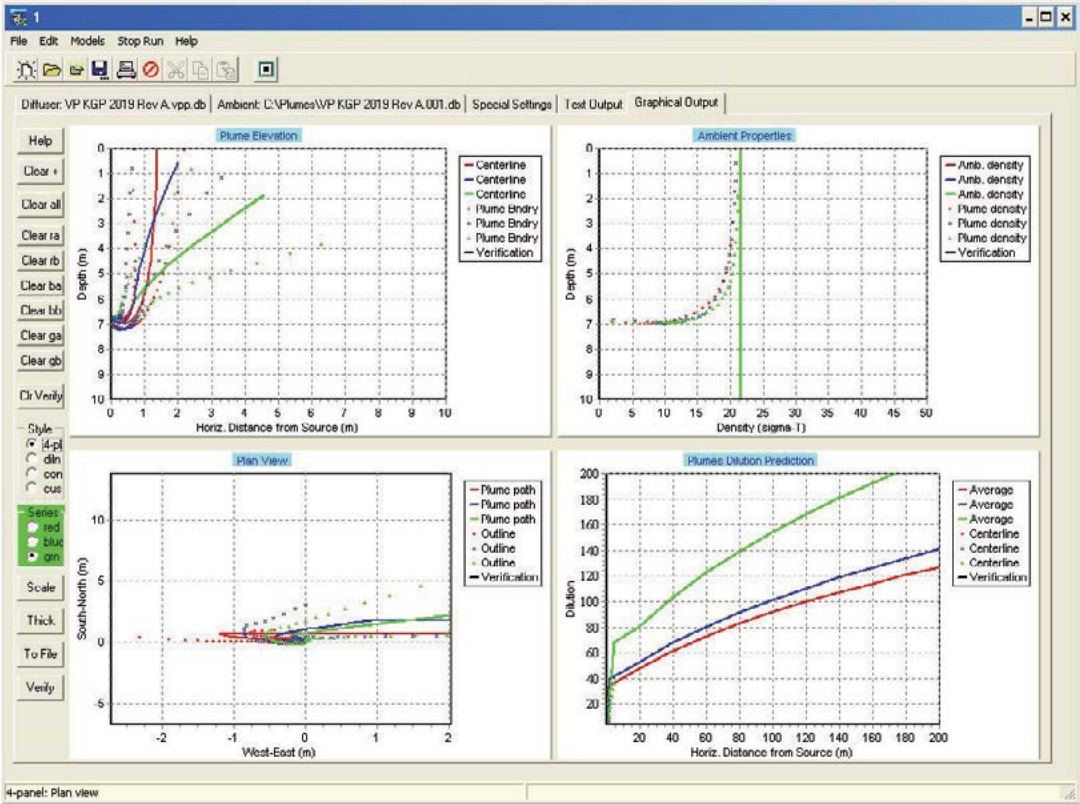
Parameter	Description
Water Depth	7.78m (relative to MSL)
No of Ports	5
Internal Diameter of Ports	150mm
Discharge orientation	45° below the horizontal
Port Spacing	1m
Depth	6.78m rel MSL
Discharge	350m^3 batch discharged over 116 minutes twice a week
Maximum effluent discharges	0.05 m^3/s
Salinity	1psu
Initial Discharge Concentration (C_0)	100% wastewater

5.2 Initial Dilution

Figure 5-1 presents the predicted initial dilution trajectory and dilution for spring tide at low water slack, mid tide (maximum currents) and high tide slacks. The effluent exits the five ports, initially directed downwards at 45° to the horizontal before rising under their own buoyancy. The plumes merge before they reach the surface, bending towards the north on the ebb tide and south on the flood tide. At the surface the plume spreads laterally forming a lens of less dense water. Ambient currents advect the plume away from the source, whilst turbulent diffusion entrains seawater, eroding the density difference and reducing plume concentration.

On the spring tide, dilutions at the end of the near field range from 1:34 at low water slack tide to 1:68 at mid tide (Figure 5-1). On the neap tide, dilutions range from 1:34 at low water slack tide to 1:39 at mid tide.

Figure 5-1: Predicted initial dilutions for Spring tide at low water slack (red), mid tide (green) and high tide slacks (blue)



5.3 Stochastic analysis

5.3.1 Method

For the stochastic analysis, 150 deterministic scenarios were undertaken with wind, tide and phase-of-discharge relative to tide selected randomly for each simulation. Measured winds over a two year period between 2016 and 2017 were applied.

The model was run for 24 hours and predicted concentrations stored every hour over the whole grid. Concentrations were converted to dilutions and the durations that they exceeded 10 levels of dilution (50, 100, 200, 300, 400, 560, 600, 700, 800, 900) calculated for each grid cell.

For the 150 scenarios, probability of dilutions exceeding the 10 dilution levels for one hour or more were calculated. The 5 and 1% probability levels were plotted to provide the minimum dilutions achieved for 95 and 99% of model scenarios (i.e. 5% and 1% of worst-case scenarios were excluded from the plots).

5.3.2 Results

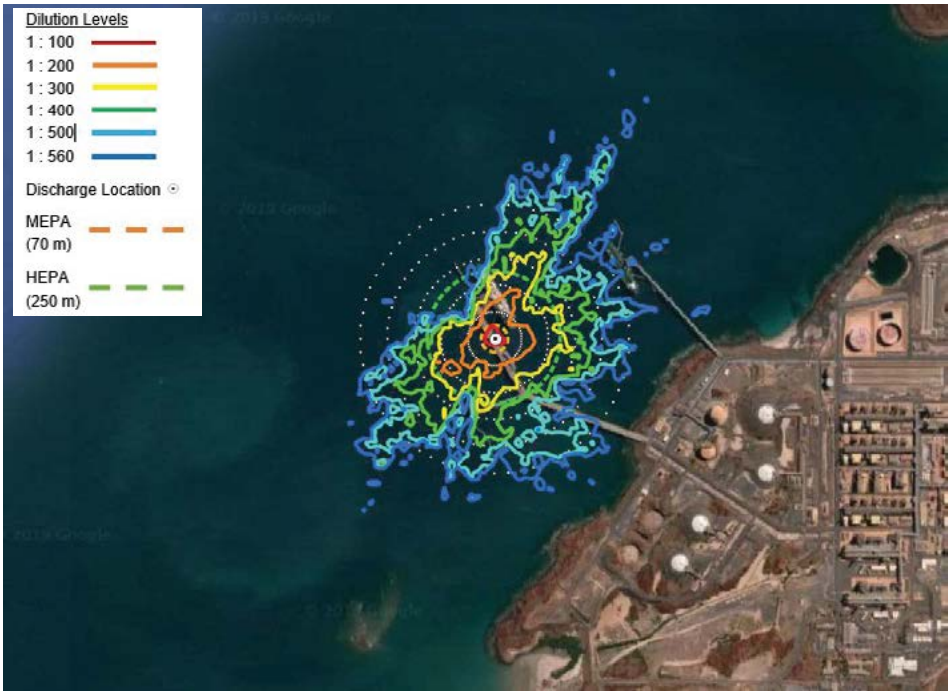
Figure 5-2 shows the minimum dilutions predicted for (a) 95% and (b) 99% of model scenarios. At 100, 250 and 500 m, minimum dilutions at the 95% probability level are 1:150, 1:260 and 1:400 respectively (Table 5-2:). These values decrease to 1:75, 1:100 and 1:200 at the 99% level.

Table 5-2: Minimum dilutions for 95% and 99% of model scenarios.

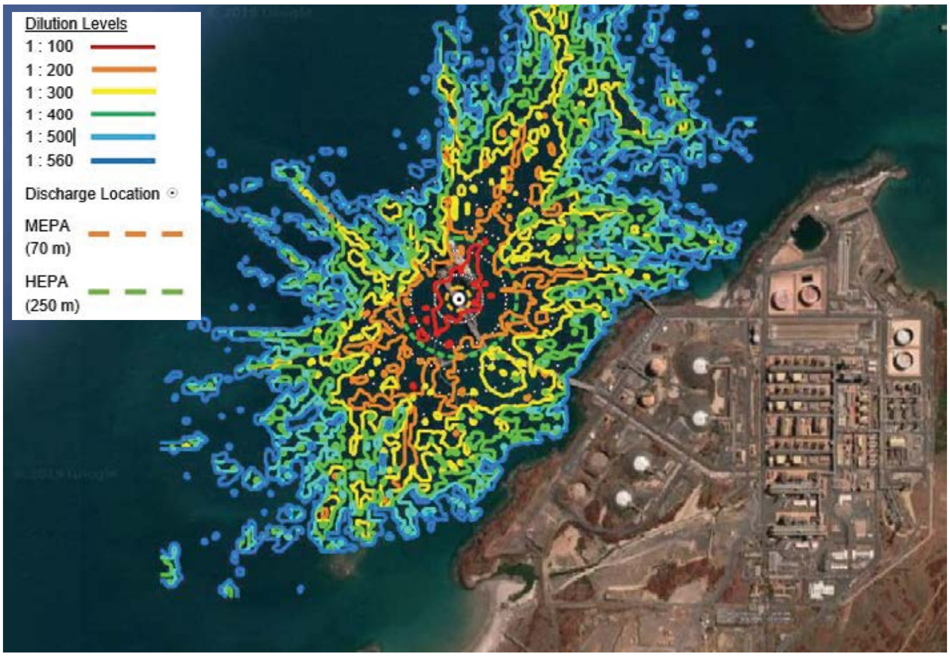
Distance from discharge (m)	Minimum Dilution (95% probability)	Minimum Dilution (99% probability)
100	1:150	1:75
250	1:260	1:100
500	1:400	1:200

Figure 5-2: Karratha Gas Plant jetty discharge: minimum dilutions for (a) 95 and (b) 99% of model scenarios.

(a) 95% probability of occurrence



(b) 99% probability of occurrence



Notes: Flow = $350m^3$/116mins , C_0 = 100%ww, Discharge depth = -6.78m (MSL), PC99(50) = 0.36% (1:280). Range rings (white dots) are drawn at 100m intervals; MEPA (orange dashed ring around the discharge) is the Medium Ecological Protection Area located 70 m from the discharge; HEPA (green dashed ring around the discharge) is Woodside's currently targeted High Ecological Protection Area located 250 m from the discharge.

6 ADMIN DRAIN DISCHARGE

6.1 Discharge parameterisation

Figure 6-1 shows an aerial image of the Admin Drain discharge. The drain discharges into an inner creek and then into No Name Bay. For the purpose of the discharge modelling, it was assumed (Table 6-1):

- A discharge rate (Q1) of 3 m^3/hr (the average discharge rate is 72 m^3/day).
- The creek may be represented by a channel of length 150 m, width 3 m and depth 1m to give a volume of 450 m^3.
- This channel fills on the flood tide into which the Admin Drain effluent mixes and then discharges on the ebb tide.
- On discharge, the inner channel mixes into 'No Name Bay' over a volume of 50m x 50m x 2m depth.
- The discharge profile is distributed over the simple tidal prism shown in Table 6-1.

The mixing volume in No Name Bay was placed on the model boundary and the model ran for 48 hours. Concentrations were calculated over a 25 m regular grid with cell depth of 1 m.

Figure 6-1: Schematic of Admin Drain discharge.

Table 6-1: Discharge load calculations.

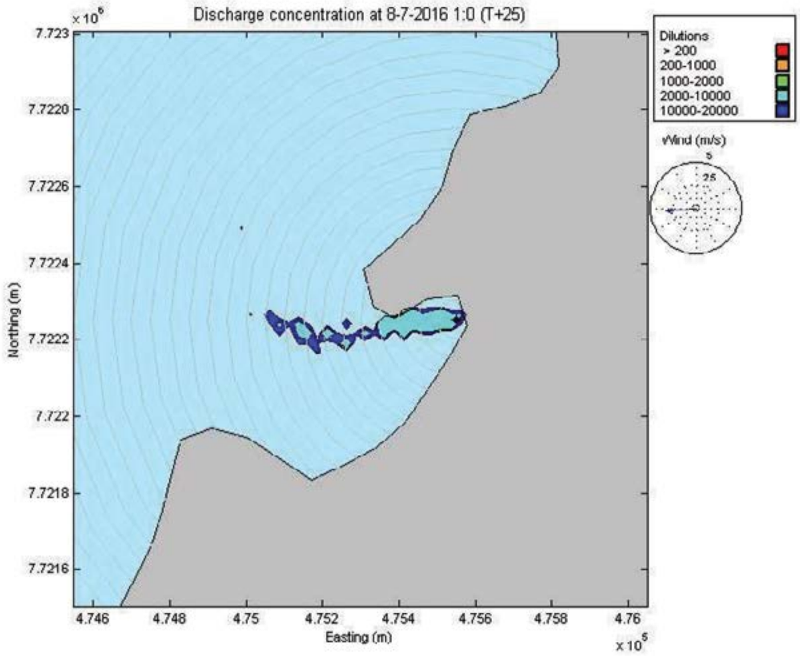
Parameter	Value	Unit
Discharge rate from Drain (maximum discharge scenario)	3	m^3/hr
Volume discharged into Inner Channel over 12 hours	36	m^3
Inner Channel Volume	450	m^3
Dilution in Inner Channel	1 : 12.5	
Distribution of flow from the inner channel into No Name Bay over the ebb tide	Tidal Prism (%)	m^3/hr
HW+1	10	30
HW+2	30	90
HW+3	60	180
HW+4	30	90
HW+5	10	30
HW+6	10	30
Total Volume (m^3)		450

6.2 Results

Figure 6-2 shows the predictions of the drain discharging into No Name Bay during a single ebb tide. The discharge receives approximately 150 to 830 dilutions (including the 12.5 dilutions received in the Inner Channel) when it first enters the Bay (depending on the tidal discharge rate). Thereafter, it is dispersed by tide and wind towards the west. At 70m from the discharge location (in the model) concentrations range from 0% (dilution not applicable) on the flood tide to around 0.08% (1:1,200 dilutions) on the ebb tide (Figure 6-3).

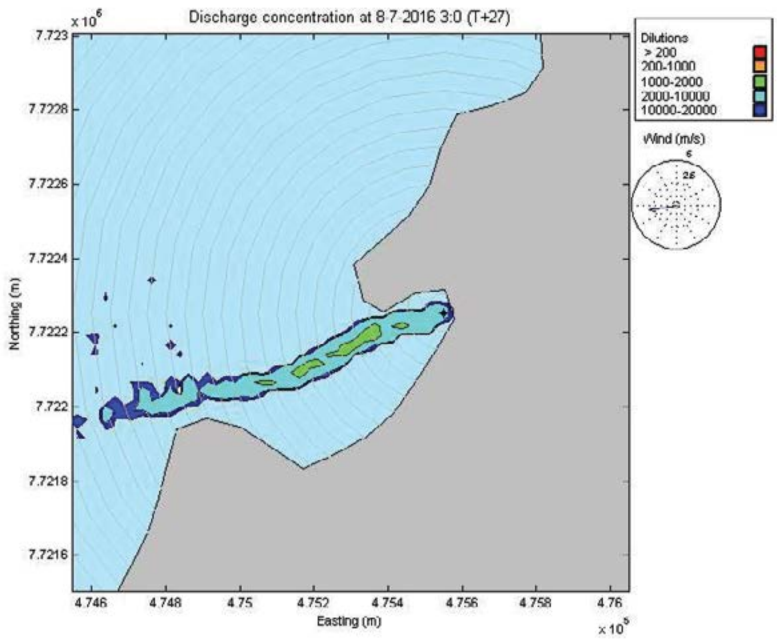
These results should be treated with caution due to the assumptions listed above for the discharge. Also, clearly the model does not properly resolve the inner creek nor the drainage channel, which can be seen on the satellite image. Hence, the discharge location in the model is further into the bay than the actual discharge location shown in Figure 2-1. Further work would be required to simulate the Admin Drain discharge more accurately and may require coupling a one-dimensional model.

Figure 6-2: Predicted dilutions and concentrations for the discharge from the Admin Drain into No Name Bay



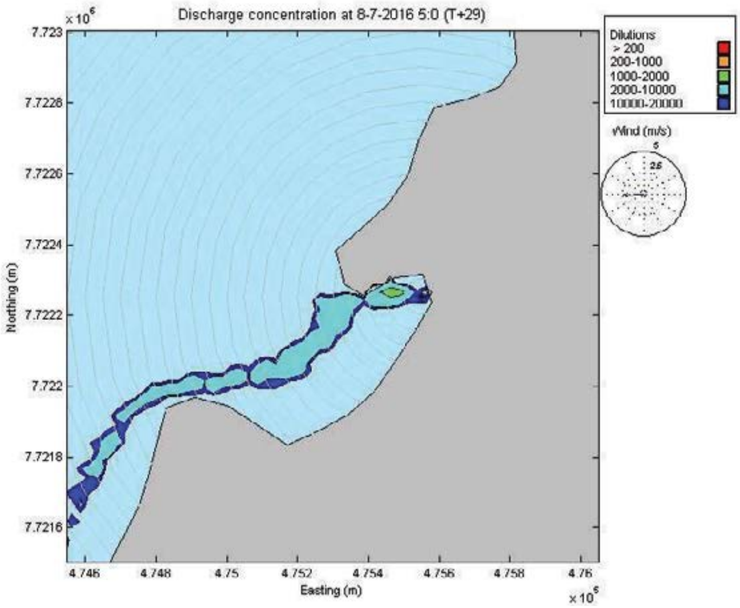
(a) HW+2 hrs

Notes: Flow = 6m^3/hr, Range rings are drawn at 50m intervals;



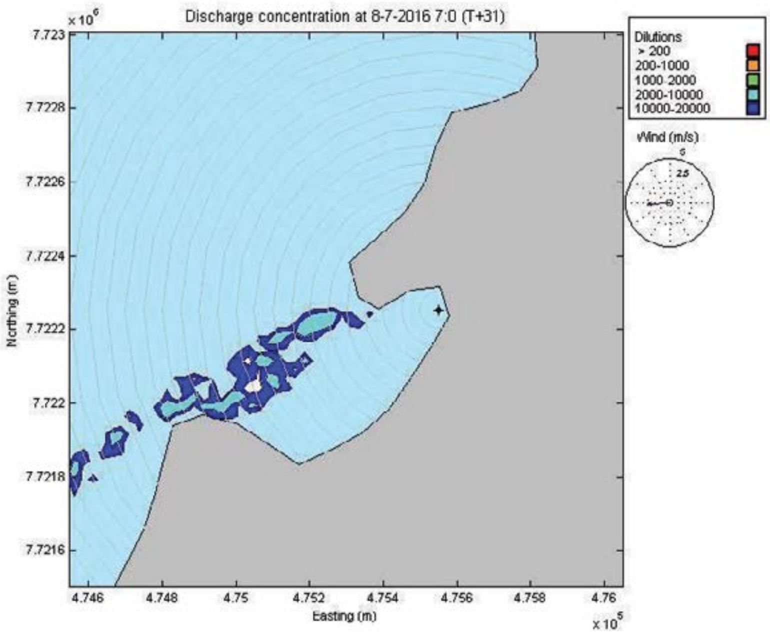
(b) HW +4 hrs

Notes: Range rings are drawn at 50m intervals.



(c) HW +6 hrs

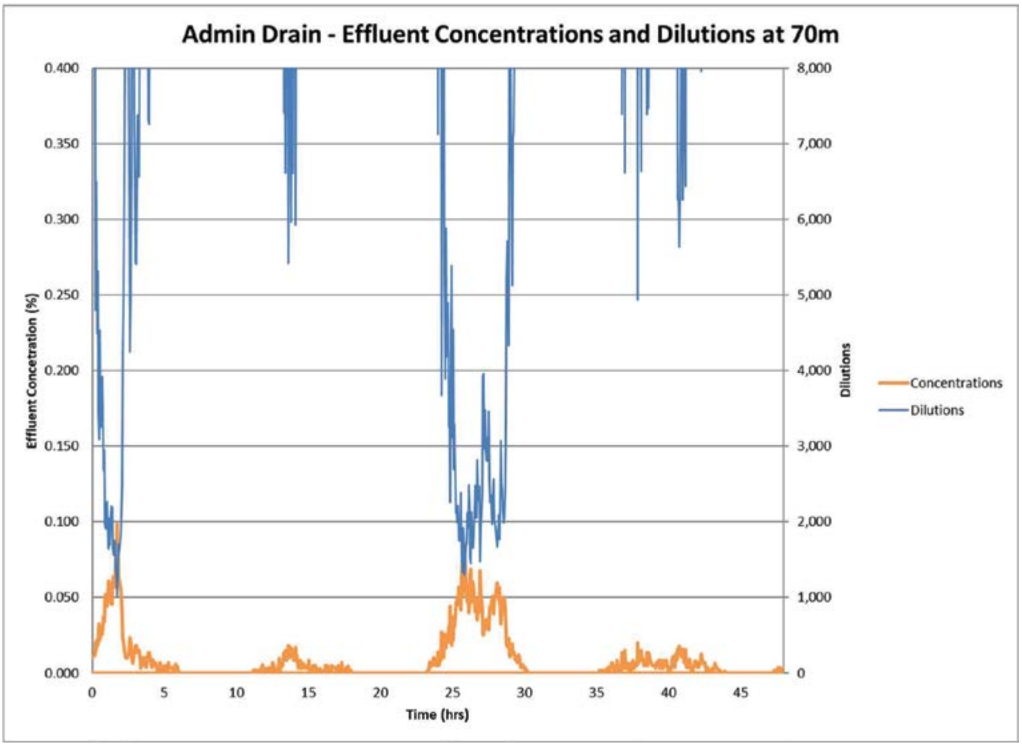
Notes: Range rings are drawn at 50m intervals.



(d) HW +8 hrs

Notes: Range rings are drawn at 50m intervals.

Figure 6-3: Times series of predicted concentrations and dilutions at 70 m from the Admin Drain Discharge.



Notes: These are the predicted concentrations at 70 m from the model discharge location not the actual discharge location at the culverts shown in Figure 2-1 and is a limitation of the model.

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APPENDIX H
A SYNTHESIS OF LITERATURE ON THE POTENTIAL IMPACT OF INDUSTRIAL AIR EMISSIONS ON MURUJUGA ROCK ART

Woodside

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1. EXECUTIVE SUMMARY

The Burrup Peninsula and surrounding islands of the Dampier Archipelago, traditionally referred to as Murujuga, is widely known for its Aboriginal rock art (in the form of engraved petroglyphs). The area hosts one of the largest and most diverse collections of rock art in the world, which have significant cultural value to local Traditional Owner groups and to Aboriginal people more broadly. The presence of heavy industry on the Burrup Peninsula has generated concerns that industrial emissions may lead to an accelerated weathering or deterioration of the rock art. These concerns centre on the issue that deposition of acidic air emissions from anthropogenic sources have the potential to increase the acidity of the rock surface through chemical and/or biological processes. Subsequently, these acidic conditions may then alter the natural state of weathering of the rock, resulting in a deterioration of the colour and depth contrast of the petroglyph image.

Over the past 15 years, a range of government led monitoring programs and independent scientific research has been conducted to investigate the potential for emissions from new and existing industrial development on the Burrup Peninsula to impact on the Murujuga rock art. It is noted that there have been criticisms of the methodologies used and the interpretation of the findings from some of these research studies and monitoring programs. Uncertainties therefore exist regarding techniques for monitoring and detecting change (both natural weathering rates, and potential for accelerated weathering) and the determination of a critical load of acid deposition at which impacts to rock art may occur. This document provides a synthesis of publicly available scientific investigations and monitoring programs that have contributed to the current state of knowledge of the impact of industrial air emissions on the rock art.

2. INTRODUCTION

2.1 Purpose and Scope

This document presents an overview and synthesis of publicly available literature that has contributed to the current state of scientific knowledge on the potential impact of industrial air emissions on the Murujuga rock art. The information summarised in this report has been used to inform the impact assessment undertaken as part of the North West Shelf (NWS) Project Extension environmental approvals, as presented in the NWS Project Extension Environmental Review Document (Woodside, 2019).

2.2 Murujuga Rock Art

The Burrup Peninsula and surrounding islands of the Dampier Archipelago (traditionally referred to as Murujuga) are located on the Pilbara coastline in Western Australia (WA) and contain one of the largest and most diverse collections of rock art in the world (**Figure 2-1**). It is estimated that Murujuga contains over one million rock engravings (in the form of petroglyphs), at a density of around 218 images per km^2 (McDonald, 2015). Although rock art is difficult to date, the petroglyphs images on Murujuga are estimated to range from 4,000 to 30,000 years in age (Mulvaney, 2011; Pillans and Fifield, 2013). The rock art was created with a range of stone tools using various techniques of pecking, pounding, rubbing and scratching (Vinnicombe, 2002). According to Mulvaney (2015), the collection on Murujuga represents one of the longest continual sequences of rock art in the world and has some of the earliest depictions of the human face. The rock art documents the changing environment of Murujuga from when the land was 100 km inland from the sea and include images of terrestrial and marine fauna including extinct species such as the Thylacine (*Thylacinus cynocephalus*; Tasmanian tiger) which has been extinct on mainland Australia for approximately 3,000 years (Bird and Hallam, 2006; Mulvaney, 2011, 2015).

2.2.1 Cultural Significance

The local Aboriginal people of Murujuga (collectively, referred to as Ngarda-Ngarli) have a deep cultural and spiritual connection to the Murujuga rock art as it provides a record of Aboriginal lore, dreamtime stories, customs and local knowledge of the land and its resources (DEC, 2013). The rock art is central to the continuing culture of the Ngarda-Ngarli and showcase the tens of thousands of years of connection between Aboriginal people and country. As outlined in the Murujuga National Park Management Plan, the protection of the rock art and its cultural value are of the highest priority for the Traditional Owners of the area (DEC, 2013).

2.2.2 Formation of Petroglyphs

The geological landscape of the Burrup Peninsula is dominated by large rocky outcrops and distinctive weathered red/brown rock piles (mainly gabbro and granophyre igneous rock types with small granite exposures), providing an ideal canvas for petroglyph carvings (Donaldson, 2011). Over geological time, the surfaces of these rocks have been subject to natural weathering processes and developed a cm-thick layer of pale orange/yellow weathering skin. Overlayed on the weathering skin is a thin dark brown/black coating, typically referred to as a rock 'patina' or 'varnish'. According to Liu and Broecker (2000) the rock patina comprises mainly of clay minerals and manganese and iron oxides, which forms very slowly at an estimated rate of 1 – 10 micrometres (µm) per thousand years, however the mechanisms for this formation are not well understood. For the purpose of this report, the weathered rocks on Murujuga is described as having three distinct layers: (1) fresh parent rock; (2) pale weathering skin; and (3) dark thin surface coating, commonly referred to as the rock patina.

Petroglyphs are created by breaking through the darker rock patina and into the lighter coloured weathering skin, revealing a colour and contour contrast on the rock surface. The preservation of the rock 'patina' is therefore fundamental to maintaining the integrity and condition of the petroglyphs.

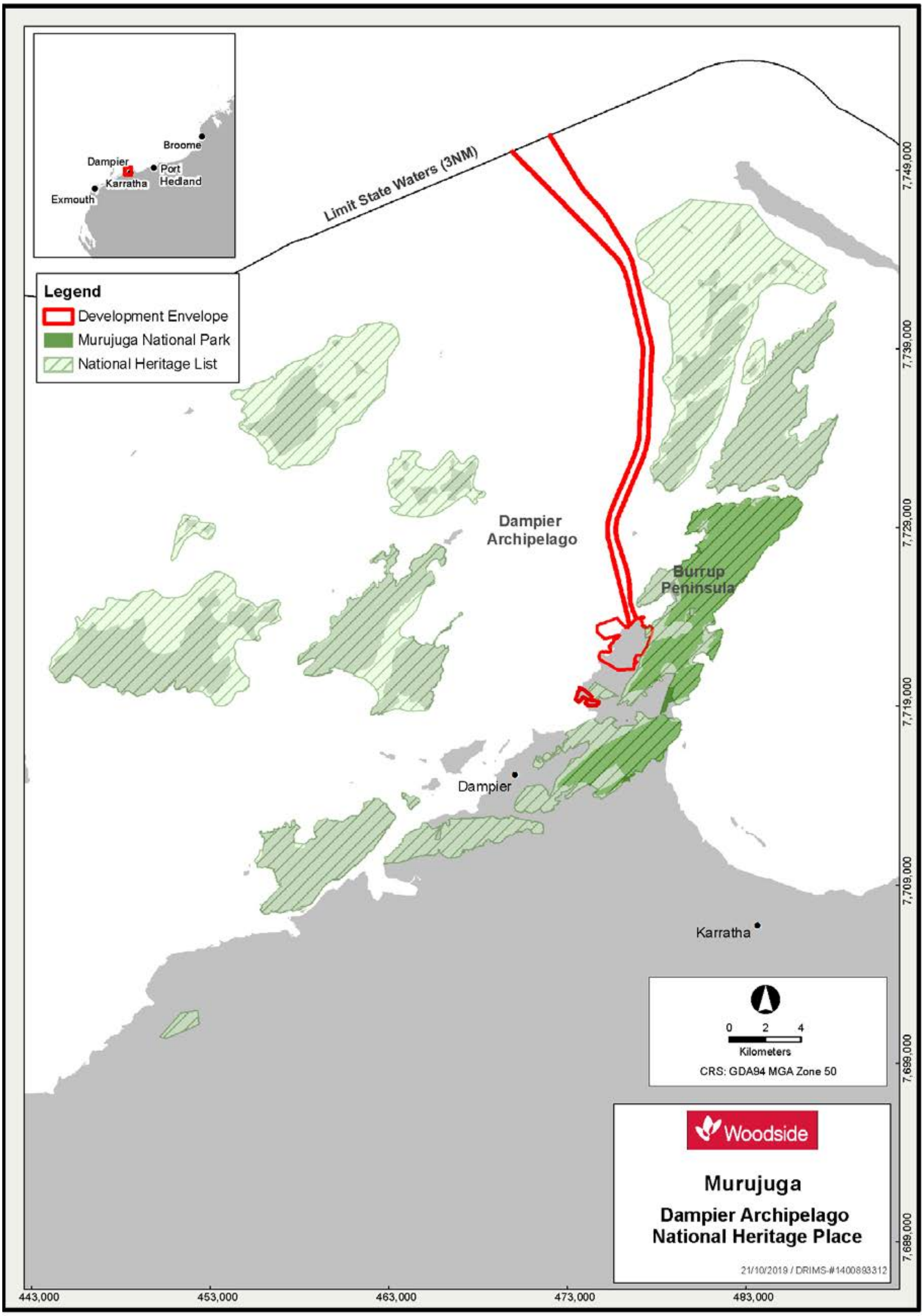

Figure 2-1 Regional Location of Murujuga (Burrup Peninsula and surrounding islands of the Dampier Archipelago)

2.3 Current Protection Status of Murujuga Rock Art

The protection and management of the rock art on Murujuga is covered under a range of State and Commonwealth legislation including:

+ *Aboriginal Heritage Act 1972* (WA)
+ *Aboriginal and Torres Strait Island Heritage Protection Act 1984* (Commonwealth)
+ *Environmental Protection Act 1986* (WA) (EP Act)
+ *Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth) (EPBC Act)
+ *Conservation and Land Management Act 1984* (WA) (CALM Act)

2.3.1 National Heritage Listing

On 3 July 2007, the Dampier Archipelago (including the Burrup Peninsula) was included on the National Heritage List in recognition of Murujuga's unique Aboriginal heritage values, particularly its engraved rock art and stone features (DoEE, 2007). The listing provides robust heritage protection under the Commonwealth EPBC Act.

2.3.2 Murujuga National Park

The Murujuga National Park was established in January 2013 over the northern Burrup Peninsula (**Figure 2-1**) and is jointly managed by the Murujuga Aboriginal Corporation (MAC) and the WA Department of Biodiversity Conservation and Attractions (DBCA) formerly Department of Parks and Wildlife. The Murujuga National Park Management Plan released in 2013 outlines a central objective "to achieve a sustainable coexistence of conservation and industrial development and Aboriginal and other Australian land ownership and use" (DEC, 2013). The plan advocates "protection of the area's internationally important and national heritage listed values, whilst recognising the economic and social benefits of the Burrup Peninsula industries for the people of Western Australia." (DEC, 2013). Classification as a national park ensures further protection for the Murujuga rock art through the application of provisions under the WA CALM Act.

2.3.3 World Heritage Nomination

On 27 August 2018, the Premier of WA, Hon. Mark McGowan, and MAC announced intentions to formally begin the nomination process for UNESCO World Heritage listing. The area is being nominated to be listed specifically for its cultural values. A report by the Australian Heritage Council (AHC) (2011) provides a preliminary assessment of the outstanding universal values of the Dampier Archipelago and any threats to the site. With appropriate management, the WA government considers that industry and tourism can successfully co-exist with the cultural heritage and environmental values of Murujuga (DWER, 2019a).

2.4 Industrial Development on the Burrup Peninsula

Industrial development across the southern half of the Burrup Peninsula began in the early 1960's with the development of deep-water port facilities to support the Pilbara's emerging iron ore industry. In January 2000, the WA government released a notice of intent to acquire land for the construction of heavy industrial estates on the Burrup Peninsula and nearby Maitland Area. On 16 January 2003, the Burrup and Maitland Industrial Estate Agreement (BMIEA) was settled with three local native title claimant groups (the Ngarluma-Yindjibarndi, the Yaburara-Mardudhunera and the Wong-Goo-Tt-Oo).

The agreement allowed for the development of the 'Burrup Strategic Industrial Area' over land across the southern section of the Burrup Peninsula whilst also providing for the development of a new conservation estate (later becoming Murujuga National Park) for the protection of Aboriginal heritage (DWER, 2019a). The BMIEA also led to the formation of the Murujuga Aboriginal Corporation (MAC) in April 2006. MAC represents the five traditional groups in the Murujuga area — the Ngarluma people, the Mardudhunera people, the Yaburara people, the Yindjibarndi people, and the Wong-Goo-Tt-Oo people (MAC, 2016).

The Burrup Peninsula now supports a range of heavy industries and is considered a main export precinct in the North West region (AHC, 2011). Large industrial facilities currently operating on the Burrup Peninsula include Dampier Port and supply base, Yara Pilbara Liquid Ammonium Plant and Technical Ammonium Nitrate Plant, the Karratha Gas Plant, Pluto LNG Plant, Rio Tinto iron ore leases and shipping terminals and Dampier Salt.

3. INDUSTRIAL EMISSIONS AND MURUJUGA ROCK ART

3.1 Theory of industrial related impacts

The rock surface on which petroglyphs are engraved naturally undergo complex physical, chemical and biological weathering processes that alter the mineralogy of the rock surface over time, in turn degrading the colour contrast of the petroglyphs (Ramanaidou and Fonteneau, 2019). In the early 2000's, concerns were raised over potential indirect impacts associated with air emissions from industry and shipping activity, and those emissions having the potential to accelerate the deterioration of the rock art on Murujuga (Bednarik, 2002). Anthropogenic emissions of concern include industrial emissions (namely oxides of nitrogen (NO_X) and oxides of sulphur (SO_X), emissions from shipping, dust from ship loading of iron ore, land clearing and vehicle traffic (DWER, 2019a). These concerns centre on the theoretical potential of SO_X and NO_X increasing the acidity on the rock surface and/or alternatively altering the rock surface microbiology. Subsequently, it is theorised, the natural rates of rock surface weathering are accelerated either through chemical and/or biological processes causing a deterioration in the colour contrast of petroglyphs.

3.2 Government Initiatives

3.2.1 Burrup Rock Art Monitoring Management Committee

The BMIEA Additional Deed[1] included a requirement for the WA government to "organise and fund a minimum four-year study into the effects of industrial emissions on rock art within and in the vicinity of that part of the Industrial Estate that is on the Burrup Peninsula" (DWER, 2019a)

In 2002, the WA government established the independent Burrup Rock Art Monitoring Management Committee (BRAMMC) to oversee a range of scientific studies to address the following research questions:

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

To address these questions, the BRAMMC commissioned a range of independent scientific studies. In the subsequent years, the management, name and scope of these WA government led initiatives have altered and are outlined in **Table 3-1** over the page.

1 The WA Government entered into the Burrup and Maitland Industrial Estates Agreement Implementation Deed (BIMEA) with three Aboriginal groups in January 2003. As part of this agreement an Additional Deed was signed and included requirements under Section 11 to implement a rock art study looking into the effects of industrial emissions on rock art on the Burrup Peninsula. The BIMEA Additional Deed is available from: https://www.dpc.wa.gov.au/lantu/MediaPublications/Documents/Burrup_Additional_Deed.pdf

Table 3-1 List of scientific studies conducted as part of the ongoing state government Murujuga Rock Art Monitoring Initiatives.

Name	Management	Tenure	Scope[1]
Burrup Rock Art Monitoring Management Committee (BRAMMC)	Department of State Development (DSD)	August 2002 - 2010	+ Air Quality + Microclimate + Dust Deposition + Colour Change + Spectral Mineralogy + Microbiological Analyses + Accelerated Weathering Studies + Air Dispersion Modelling
Burrup Rock Art Technical Working Group (BRATWG)	Department of State Development (DSD)	September 2010 – June 2016	+ Colour Change + Spectral Mineralogy
No Formal Group	Department of Environment and Conservation (DER)	July 2016 – June 2017	+ Colour Change + Spectral Mineralogy + Experimental extreme weathering study + Independent reviews
Murujuga Rock Art Strategy	Department of Water and Environmental Regulation (DWERa)	July 2017 - Ongoing	+ To be confirmed

Note 1: The reports from these studies are publicly available on the DWER website (Murujuga Rock Art Monitoring Program).

In 2009, the BRAMMC released a report on the findings of the studies taking into consideration comments received from international peer reviewers and concluded there was no scientific evidence of any measurable impact of industrial emissions on the rate of deterioration of the Rock Art (BRAMMC, 2009). BRAMMC recommended no environmental management measures were necessary at that time to protect the rock art from industrial air emissions (BRAMMC, 2009).

The BRAAMC recommended a technical working group be established to oversee the continuation of the colour contrast and spectral mineralogy monitoring program on an annual basis for ten years. In response, the Burrup Rock Art Technical Working Group (BRATWG) was established on 20 September 2010 to oversee the colour contrast and spectral mineralogy monitoring program and other studies.

The BRATWG completed its five-year term of engagement on 30 June 2016 and provided a draft report to the WA Minister for Environment. The report concluded monitoring results were consistent with earlier findings from BRAMMC (2009) and state that “there is no scientific evidence that indicates any measurable impact of industrial emissions on the rock art on the Burrup over the period 2004 to 2014” (BRATWG, 2015). The report recommended the continuation of the monitoring program on an annual basis to provide an early warning of any possible impacts to rock art from industrial emissions (BRATWG, 2015). At that point oversight passed to the Department of Environment Regulation (DER), which then became DWER on 1 July 2017 (DWER, 2019a).

3.2.2 Senate Inquiry

On the 30 November 2016, the Australian Government Senate referred a range of matters regarding the management and protection of the Murujuga Rock Art to the Senate Environment and Communications References Committee for inquiry (SECRC, 2018). Through this process, concerns were raised relating to the adequacy and accuracy of the methodologies used and interpretation of results from some of the studies undertaken as part of the WA government rock art monitoring program. The Senate Committee’s report, released on 21 March 2018 recommended the development and implementation of a new, fully funded independent monitoring and analysis program (SECRC, 2018).

3.3 Murujuga Rock Art Strategy

On 8 September 2017, DWER released the 'Draft Murujuga Rock Art Strategy' (DWER, 2019a) for public comment. The strategy aims to "build on the previous work on the Burrup Peninsula to deliver a scientifically rigorous, world's best practice monitoring program and risk-based approach to the management of impacts to the rock art, consistent with legislative responsibilities under the EP Act" (DWER, 2019a). The Murujuga Rock Art Strategy will be implemented by DWER in partnership with MAC, representing the Traditional Owner groups of Murujuga. Following consultation and stakeholder feedback the Murujuga Rock Art Strategy was finalised in February 2019. The Murujuga Rock Art Monitoring Program is described further in Section 4 of this document.

3.3.1 Murujuga Stakeholder Reference Group

The Murujuga Rock Art Stakeholder Reference Group was established in September 2018 by the WA Minister for Environment to oversee the finalisation and implementation of the Murujuga Rock Art Strategy and ensure effective engagement between MAC, the WA government and key industry and community representatives (DWER, 2019a). The role of the Murujuga Rock Art Stakeholder Reference Group includes the following:

+ Actively contribute to the monitoring and protection of rock art, being considerate of the views of all stakeholders. This includes the provision of advice to DWER and the Minister for Environment on the design, implementation and analysis of the scientific monitoring and analysis program.
+ Consult, inform and educate other stakeholders on other matters referred by DWER for input or comment, including further development of the strategy, implementation of the strategy and five-yearly reviews.
+ Inform the Government's broader consideration of other strategic issues relating to the protection of the rock art on Murujuga.

The group includes representatives from MAC, the WA museum, research organisations, local and state government departments, industry and the community.

4. PETROGLYPH AND AIR EMISSION STUDIES

4.1 Background

This section of the report provides a synthesis of the scientific investigations and monitoring programs that have been carried out over the last 15 years to understand the potential impact of atmospheric emissions on the Murujuga rock art. The studies summarised in this literature review are listed in **Table 4-1**. Further discussion of each study has been provided including an overview of the study objectives, approach and key findings and a synthesis of how the research has contributed to the current state of scientific knowledge.

Table 4-1 Studies and Reports summarised in this literature review

Subject	Relevant Literature	Section
Air Quality and Deposition Monitoring	+ Pilbara Air Quality Study Summary Report (DoE, 2004). + Burrup Peninsula Air Pollution Study: Report for 2004/2005 and 2007/2008. (Gillet, 2008). + Burrup Peninsula Air Pollution Study: Report for 2004/2005, 2007/2008 and 2008/2009. (Gillet, 2010).	**Section 4.2** **Section 4.4**
Ambient Air Quality Monitoring	+ Burrup Rock Art. Atmospheric Modelling – Concentrations and Depositions (SKM, 2003). + Pluto LNG Development Cumulative Air Quality Study (SKM, 2006). + Burrup Rock Art: Revised Modelling Taking into Account Recent Monitoring Results (SKM, 2009).	**Section 4.3**
Accelerated Weathering Experiments	+ Field Studies of Rock Art Appearance. Final Report: Fumigation and Dust Deposition. (Lau *et al* 2007). + Extreme weathering experiments on the Burrup Peninsula/Murujuga weathered gabbro and granophyre (Ramanaidou *et al* 2017).	**Section 4.5**
Rock Surface Acidity	+ The survival of the Murujuga (Burrup) petroglyphs (Bednarik, 2002). + Effects of moisture, micronutrient supplies and microbiological activity on the surface pH of rocks in the Burrup Peninsula (MacLeod, 2005). + The science of Dampier rock art – part 1 (Bednarik, 2007). + Theoretical effects of industrial emissions on colour change at rock art site on the Burrup Peninsula (Black *et al* 2017).	**Section 4.6**
Microbiological Activity	+ Monitoring the microbial diversity on rock surfaces of the Burrup Peninsula (O'Hara, 2008).	**Section 4.7**
Colour Change and Spectral Mineralogy	+ Burrup Peninsula Aboriginal Petroglyphs: Colour Change and Spectral Mineralogy 2004 – 2016 (Duffy *et al* 2017).	**Section 4.8**

4.2 Air Quality and Deposition Monitoring

To better understand the spatial and temporal composition and concentrations of air contaminants that have the potential to be transferred from the atmosphere to the rock surfaces, a series of air quality and deposition monitoring stations were installed over the last 15 years (see **Table 4-2**). In the early 2000s, the Government of WA implemented the Pilbara Air Quality Study (PAQS), which established important baselines for air quality on the Burrup Peninsula (DoE, 2004). Later, the Government funded the BRAMMC Air Quality Monitoring Program which consisted of three periods of ambient air quality monitoring (2004 – 2005, 2007 – 2008 and 2008 – 2009) on the Burrup Peninsula and the broader region (see Gillet, 2008; 2010). Monitoring stations measured ground level concentrations of air contaminants (nitrogen dioxide (NO_2), nitric acid (HNO_3), ammonia (NH_3), sulphur dioxide (SO_2), micro-climate conditions, rainwater (amount and composition), total suspended particles (TSP) and particulate matter (PM)), which has been a key input into the ambient air quality and nitrogen deposition flux modelling studies (SKM, 2006; 2009).

The BRAMMC Air Quality Monitoring Program was conducted at nine sites, noting not all parameters were measured at every site:

+ five on the southern section of Murujuga (to assess concentrations near the industrial area);
+ two on the northern section of Murujuga (to assess local background concentrations);
+ one at Mardie Station, 81 km southwest of Dampier (to assess background concentrations); and
+ one at Karratha townsite.

More recently (in 2013), Yara Pilbara Nitrates (YPN) Pty Ltd Technical Ammonium Nitrate Plant (TAN Plant) conducted ambient air quality monitoring at three of the original BRAMMC monitoring stations on the Burrup Peninsula as per requirements under Condition 9 of their EPBC Act Approval 2008/4546 (YPN, 2017; Strategen, 2018). The monitoring program includes measurements of ground level concentrations of NO_2, NO_3, NH_3, SO_2, TSP and dust deposition (insoluble and soluble).

Table 4-2 Air Quality and Deposition Monitoring Studies on the Burrup Peninsula

Program	Ownership	Monitoring Period	Reference
Pilbara Air Quality Study	WA Government	1998 – 2000	Pilbara Air Quality Study Summary Report (DoE, 2004)
Burrup Peninsula Air Pollution Study	WA Government	2004 – 2005; 2007 – 2008; and 2008 - 2009	Burrup Peninsula Air Pollution Study (Gillet, 2010)
Yara Ambient Air Quality Monitoring	Yara Pilbara Nitrates Pty Ltd	2013 - Present	Ambient Air Quality Monitoring (Strategen, 2018) Baseline Air Quality Monitoring (YPN, 2017)

4.2.1 Key Findings

Key findings of the Gillet (2010) monitoring program include:

+ Ground level gas concentrations of all measured contaminants were very low in comparison to polluted urban areas
+ Data from the ambient air monitoring showed that NO_2 is typically observed well below the relevant Australian National Environmental Protection Measure (NEPM) (Ambient Air Quality) standard of 120 parts per billion (ppb).
+ There was a small enhancement in SO_2 and HNO_3 ground level concentrations and a larger enhancement in NO_2 at 'industry' sites compared with 'background' sites
+ Annual and monthly averages of NO_2, SO_2 and HNO_3 had little variation across monitoring sites and monitoring periods. The average concentrations of NO_2 at 'background sites' over the three monitoring periods was 0.7 ppb ± 0.1 pbb, whilst at sites closer to industry, average concentrations were slightly higher at 2.1 ppb ± 0.1 pbb.

A report by Strategen (2018) comparing Yara's 'baseline' air quality monitoring program (consisting of data from 2013 – 2017) to their most recent annual monitoring dataset (2017 – 2018) concluded the following:

+ Average ground level concentrations of NO_2 from baseline to 2017/18 are not statistically significant and average concentrations of SO_2 from 2017/18 were lower than baseline
+ TSP concentrations were reasonably consistent across the three sites suggesting an absence of significant direct impacts from individual sources

4.2.2 Discussion

Whilst DWER describes the results from previous air quality monitoring programs as 'reliable and targeted' it is recommended that improvements could be made to inform a detailed cumulative spatial analysis (DWER, 2019a). In response, the WA government is planning to implement a long-term coordinated ambient air quality monitoring network on the Burrup Peninsula and surrounding areas. The Murujuga Rock Art Strategy outlines that the introduction of a centralised, coordinated and independently run monitoring network will help to build a better understanding of the characteristics of the cumulative air shed and enable more informed decision making (DWER, 2019a).

4.3 Air Quality and Deposition Modelling Studies

Air dispersion modelling was conducted by SKM in 2002, and later revised in 2009 to provide insight into the spatial distribution, dispersion and deposition of air pollutants (namely NO_2, SO_2 and NH_3) on the Burrup Peninsula and determine the contribution of specific emissions sources to the airshed (SKM 2003; 2009). Relevant emission sources included contribution from industries as point sources, shipping and area emissions from biogenic and anthropogenic sources. The TAPM model was used to predict nitrogen dioxide and sulphur dioxide concentrations and deposition in the Dampier region. Publicly available air dispersion and deposition modelling studies as defined in **Table 4-3** have been summarised below.

Table 4-3 Air Dispersion and Deposition Modelling Studies on the Burrup Peninsula

Study	Ownership	Date	Reference
Burrup Rock Art. Atmospheric Modelling – Concentrations and Depositions	WA Government	2003	Burrup Rock Art Atmospheric Modelling (SKM, 2003)
Pluto LNG Development Cumulative Air Quality Study	Woodside Burrup Pty Ltd	2006	Pluto Cumulative Air Quality Modelling (SKM, 2006)
Burrup Rock Art: Revised Modelling Taking into Account Recent Monitoring Results	WA Government	2009	Burrup Rock Art Revised Atmospheric Modelling (SKM, 2009)

4.3.1 Key Findings

+ Key findings of the SKM (2003) and SKM (2009) show a model for SO_2 and NO_2 ground level concentrations for the Dampier region
+ The SKM (2003) report concluded maximum concentrations of SO_2 are found close to shipping berths, while NO_2 emissions from industrial facilities are much hotter emissions with higher release points (stacks) which aids dispersion of NO_2 and causes maximum concentrations to be located further away from these sources
+ Monitoring data showed that influence of wind direction and speed caused the model to either overestimate or underestimate SO_2 and NO_2 ground level concentrations (SKM, 2009)

4.3.2 Discussion

As highlighted in SKM (2003; 2006; 2009) reports, there are significant uncertainties associated with the modelled deposition rates due to assumptions of surface resistance for water, soil and vegetation. Consequently, modelled deposition rates are indicative only and deposition monitoring is recommended for further clarity. As mentioned above, the Murujuga Rock Art Strategy will implement a coordinated ambient air-quality and deposition monitoring network on Murujuga and in the surrounding area. These data will allow ongoing refinement and ground-truthing of ambient air quality models (e.g. TAPM).

4.4 Deposition Flux of NO_x and SO_x

Deposition of NO_x and SO_x to an area of ground over a particular period of time can be calculated from measurements of ambient air quality, and analysis of particle matter and rainwater. Deposition monitoring was included as part of the Burrup Peninsula Air Monitoring Program commissioned under BRAMMC and measured over 2004 – 2005, 2007 – 2008 and 2008 – 2009 at the monitoring sites listed in **Section 4.2**. To understand acid deposition and acid deposition fluxes, Gillet (2010) calculated the wet and dry deposition of all nitrogen and sulphur species in the gas and aqueous phases. This included NO_2, SO_2, HNO_3 and NH_3 gases, and some other species in rainwater.

4.4.1 Key Findings

Gillet (2010) reported that for sites close to industrial activity, the total wet and dry deposition flux of nitrogen and sulphur ranged from 19.3 - 37.2 milliequivalents per square metre per year (meq/m²/year) over the three monitoring periods. For 'background' sites, the average deposition flux was 17.8 ± 4.6 meq/m²/year. Additionally, the average dry deposition flux for the monitoring stations close to industrial sites was composed mainly of NO_2 and NH_3 and accounts for approximately 55% of the total flux (Gillet, 2010).

4.4.2 Discussion

Based on research assessing the sensitivity of different ecosystems to acid deposition based on the buffering capacity of different soil types (Cinderby *et al* 1998), Gillet (2010) suggested that critical loads of deposition below 200 meq/m²/year would not affect the rock surfaces (and consequently the rock art) of Murujuga. Subsequently, the conclusions drawn by Gillet (2008; 2010) that Murujuga petroglyphs could withstand loads of up to 200 meq/m²/year was determined to be inappropriate, when used in the context of rock art on Murujuga (SECRC, 2018). Consequently, currently there is no empirical evidence for an acceptable critical acid load for rock surfaces on the Burrup Peninsula, beyond which rock art would be impacted.

The Murujuga Rock Art Strategy and associated Murujuga Rock Art Monitoring Program tender application includes scope for an atmospheric air quality and deposition monitoring network to provide a long-term dataset on the composition and concentration of atmospheric contaminants of concern (DWER, 2019a). A coordinated long-term monitoring network on Murujuga and the surrounding areas will provide data on the composition and concentrations of contaminants that are potentially transferred from the atmosphere to rock surfaces. The program will assist in understanding the exposure of the rock art to atmospheric contaminants and assessing changes in that exposure over time (DWER, 2019a). The network will be informed by the historical monitoring that has been conducted on Murujuga and will result in more informed decision making.

4.5 Accelerated Weathering Studies

4.5.1 Fumigation and Extreme Exposure Experiments

Laboratory fumigation experiments were conducted exposing Murujuga rock samples to a range of air pollutants including NO_2, SO_2, Benzene, Toluene, Xylene and NH_3 at different concentrations representing future industry levels and 10 x future industry levels (Lau *et al* 2007). Fumigation was conducted on rock samples with and without dust (iron ore) and accelerated aging was imitated through wetting and drying cycles in the fumigation chambers.

In addition, emersion studies were conducted to assess how iron ore hematite powder (a 'proxy' for iron oxide which is a main component of the rock patina) reacts to high concentrations of air pollutants (Lau *et al* 2007). Iron ore hematite powders were exposed to solutions of water, concentrated solvents (including benzene, toluene, xylene), and acids/bases (nitric acid, sulphuric acid and ammonia) for 22 days at both 25°C and 50°C. Mineralogy before and after exposure was characterised using X-Ray diffraction and photospectrometry (colour change) (Lau *et al* 2007).

4.5.1.1 Key Findings

Lau *et al* (2007) concludes that the fumigation studies indicated no significant observable difference was detected between the mineralogy of the rock surfaces exposed to pollutants at varying concentrations compared with unexposed (control) samples. In addition, the samples exposed to dust did not show a significant difference in colour. Lau *et al* (2007) results indicate that iron ore hematite powders do not produce a significant colour change when exposed to concentrated solvent or acid/base solutions, with the exception of concentrated sulphuric acid which produced a colour change after 22 days.

4.5.1.2 Discussion

The study acknowledged that there is a range of variables that contribute to the weathering of a rock surface and therefore it is extremely difficult to replicate these conditions in a laboratory environment. Black *et al* (2017a) highlighted that the statistical analysis of the study and subsequent conclusions drawn are limited by insufficient replication of each treatment. This study represents a preliminary investigation to understand how rock surfaces may alter when exposed to a range of air pollutants and dust.

Concerns were also raised over the inadequate selection of rock samples – petroglyphs occur on a range of rock types and were produced using a variety of methods. As highlighted by Mulvaney (SECRC, 2018) the fumigation experiments were "conducted on samples from a single gabbro rock with only a thin weathering rind rather than on a range of lithologies known to have rock art (granophyre, dolerite and gabbro), nor on differing surface weathering states" (SECRC, 2018). In addition, iron ore dust was used instead of actual samples of rocks from the Burrup Peninsula. A study by Ramanaidou *et al* (2017) was conducted in 2016 to build on Lau *et al* (2007) study and address these limitations.

4.5.2 Extreme Weathering Experiments

In 2016, the CSIRO commissioned a preliminary experimental weathering study (the Extreme Weathering Study) to explore the effects of solutions of different compositions and concentrations on rock weathering (Ramanaidou *et al* 2017). A total of 126 samples of weathered gabbro and granophyre were collected from the original seven sites used for the colour contrast monitoring program (Duffy *et al* 2017) and tested through exposure to industrial pollutants including nitric acid, sulphuric acid, ammonia, and ammonium nitrate (Ramanaidou *et al* 2017). Distilled water was also used as a control. The chemical composition and pH of the solutions were monitored and changes to the rock surface before and after exposure was quantified using a variety of methods including optical and scanning electronic microscopies, photospectrometry and reflectance spectroscopy.

4.5.2.1 Key Findings

The extreme weathering study by Ramanaidou *et al* (2017) was conducted on both of the major rock types that support petroglyphs: granophyre and gabbro. The study concluded that after three days of exposure at 50°C, dissolution of the granophyre started at pH 3.2 (and below) for aluminium, manganese, and iron, and at pH over 11 for aluminium. For the majority of gabbro samples, dissolution started at pH 3 (and below) for aluminium, manganese, and iron, and at pH over 11 for aluminium (Ramanaidou *et al* 2017). Dissolution of these components in laboratory conditions requires quite acidic or quite alkaline conditions. For some samples, the acidity of rainwater (pH 5.5) could cause the dissolution of some minerals, in particular manganese. Furthermore, measurements to detect changes to the rock surfaces before and after exposure had experimental challenges whereby variations in the monitoring methods (microscopy, spectrometry/spectroscopy), were observed to be often higher than the effect of the change to the rock surface (Ramanaidou *et al* 2017).

4.5.2.2 Discussion

Clearly at very high levels of acidity in the laboratory, minerals within the Murujuga rocks can dissolve. However, the relevance of these experiments to the field conditions remain unclear. As mentioned above, some samples showed dissolution of manganese in solutions at neutral pH (7). Ramanaidou *et al* (2017) suggested that these are unexpected results as it would indicate under rainwater (pH 5.5) conditions, manganese would be dissolved from the surface of the weathered rocks in the field, which is not the case given the longevity of the resident rocks on Murujuga.

The study highlights a novel sample preparation method to determine the potential effects of solutions on key elements of rock weathering. As the authors acknowledge, it is a valuable scoping study to target future work and was not intended to describe permissible pollution levels on the Murujuga (Ramanaidou *et al* 2017). As the authors suggest future studies need to use a larger number of samples (Ramanaidou *et al* 2017) and potentially with a broader range of pH treatments. In addition, Ramanaidou *et al* (2017) recommended that future monitoring programs should include measurements of surface pH on gabbro and granophyre rock types on Murujuga.

4.6 Rock Surface Acidity (pH Studies)

A number of studies (Bednarik, 2002; 2007; MacLeod, 2005; Black *et al* 2017) have investigated how the pH (acidity) of the rock surface can potentially alter the rock patina mineralogy (particularly with the mobilisation of iron and manganese compounds). Theoretically, acidic emissions (namely NO_x and SO_x) from industrial and shipping activities on the Burrup Peninsula can decrease pH of nearby rock surfaces on Murujuga through deposition and/or organic acids from nitrate stimulated microbial growth, in turn degrading the mineral composition, integrity and colour of the rock varnish (Black *et al* 2017).

4.6.1 Key Findings

Comparison of samples of "wash water" (using distilled water) from in situ rocks at the Burrup Peninsula compared to those housed within the WA Museum's collection indicated a decrease in pH on the Burrup rocks since industrialisation of the Burrup Peninsula (MacLeod, 2005; Black *et al* 2017b). It is assumed that rock samples at the museum have a surface pH that has not change with 40 years of storage over two museum storage sites.

Black *et al* (2017b) suggested:

+ pH is lower on rock surfaces currently on Murujuga compared to those stored at the WA Museum for the last 40 years
+ pH is variable across rock surfaces of Murujuga (however the spatial and temporal pattern of this variability is unknown)
+ there is a relationship between pH and the concentration of iron and manganese ions on rock surfaces
+ pH changes are theorised to make the rock surfaces lighter, redder and more white/yellow in colour over time. The changes are expected to be greater on engravings than on background rock because the rock varnish will be more recent and thinner on the engravings.

Black *et al* (2017b) theoretical evaluation suggested that pH and microbial activity are deteriorating Murujuga rock surfaces. However, no data was presented to link industrial air emission or subsequent deposition to changes in pH on Murujuga rock surfaces.

4.6.2 Discussion

The theoretical evaluation presented by Black *et al* (2017b) suggests that pH and microbial activity have the potential to accelerate the deterioration of Murujuga rock surfaces. However, no data is presented to link industrial air emissions and/or subsequent deposition to changes in pH on Murujuga rock surfaces. Future studies require a better statistical understanding of the spatial variability of pH on Murujuga rock surfaces and beyond, and the key physical and biological drivers of this variability (both natural and anthropogenic). Moving forward, the Murujuga Rock Art Strategy seeks to understand pH variability on Murujuga rock surfaces and its drivers.

4.7 Microbial Diversity on Rock Surfaces

It is thought that the natural rock weathering process over time may be influenced by the activity of microorganisms (such as bacteria, archaea and fungi) on the rock surface (MacLeod 2005; O'Hara 2008). Research indicates that microorganisms may be instrumental in setting off chemical processes that weather rocks into soil (EMSL, 2012).

The BRAMMC established a program to investigate whether rock surfaces closer to industrial emissions sources hosted different microbial communities as a potential impact pathway for industrial emissions to accelerate weathering of the rock surface, degrading the colour of the petroglyphs (O'Hara, 2008). The microbial diversity study assessed microbiological differences at seven petroglyph sites on Murujuga (five close to the industrial area, and two distant from it) over a four-year period from 2004 to 2008 (O'Hara, 2008).

4.7.1 Key Findings

The key findings of the microbial diversity study were that all monitored sites had very low populations of bacteria, with similar types of bacteria and low numbers of fungi across all seven sites. Based on these findings, the study concluded that there were "no evident differences in the gross number and broad diversity of microorganisms associated with samples collected from sites close to and distant from industrial emissions on the Burrup Peninsula" (O'Hara, 2008).

4.7.2 Discussion

There was no evidence of any relationship between the presence of microorganisms and site proximity to sources of industrial emissions. The Murujuga Rock Art Strategy seeks to undertake monitoring program to support the Environmental Quality Management framework and may include a microbiological component (DWER, 2019c).

4.8 Colour Change & Spectral Mineralogy Monitoring

The CSIRO conducted annual monitoring the surface colour and mineralogy of the Murujuga rock art from 2004 – 2016, with Yara Pilbara Nitrates Pty Ltd independently continuing a modified version of the program in proximity to their facilities from 2017 onwards with independent experts and MAC.

To understand potential changes to colour on petroglyphs on Murujuga, the CSIRO produced a series of reports analysing the colour of petroglyphs at seven sites including:

+ Five sites close to the industrial area on Murujuga, and
+ Two control sites located to the north of the industrial area on Murujuga (Duffy *et al* 2017).

Annual monitoring reports for each year can be found on DWER's website (DWER Murujuga Rock Art Monitoring Program). The analysis included colour measurement of the petroglyphs using spectrophotometric cameras, and spectral mineralogy analysis using an Analytical Spectral Device (ASD) (Duffy *et al* 2017). Colour was repeatedly assessed at multiple petroglyphs both across the years (since 2004) and within each sampling event in L*a*b* format; where 'L' measures lightness, 'a' measures degree of red/green, and 'b' measures the degree of blue/yellow.

4.8.1 Key Findings

The DAA (2016) conducted an independent review of the CSIRO 2015 monitoring report and identified several shortcomings in both the data collected and its subsequent statistical analysis. In response, CSIRO formally withdrew its 2015 monitoring report and reanalysed colour data; reissued in 2017 (Duffy *et al* 2017).

This reassessment was across the entirety of the 12 years available and released in the report 'Burrup Peninsula Aboriginal Petroglyphs: Colour Changes and Spectral Mineralogy 2004 – 2016' (Duffy *et al* 2017). Duffy *et al* (2017) report concluded "Petroglyph lightness monitoring data from the 'KM spectrophotometer' used, showed a decreasing modelled average rate of 0.31 units per year (a total decrease of about 2 units on this scale is just noticeable to the human eye)". However, no colour change in the degree of red/green nor the degree of blue/yellow was established across the years of the study (Duffy *et al* 2017). Duffy *et al* (2017) highlighted the change in lightness indicated by the data is inconclusive, on the basis that true colour change would be expected to affect all three of the colour measurement parameters. It was noted that none of the three spectrophotometers used showed any difference in the rate of change between the northern sites (remote from industry) and the southern sites (close to industry) (Duffy *et al* 2017). The report recommended that future observations could continue to mark out the possible trend more clearly, or, observations will likely continue to fluctuate over time, making the randomness of the recorded variation more apparent (Duffy *et al* 2017).

4.8.2 Discussion

Up until 2016, the CSIRO was comparing the colour measurements year-to-year, only comparing the current year's data with the data from the previous year (SECRC, 2018). Black and Diffey (2016) re-analysed the CSIRO data, and concluded that there were significant changes to the petroglyphs of Murujuga over the time of the CSIRO studies (Black and Diffey, 2016).

Following the production of the paper by Black and Diffey (2016), the WA Government requested that Data Analysis Australia (DAA) conduct an independent review of the CSIRO data. The report by DAA (2016) agreed with the statistical analysis methods used by Black and Diffey, concluding that the "statistical methods in the draft paper are highly appropriate (with some minor modifications) and they represent a substantial step forward in effective monitoring of the Burrup Peninsula rock art sites" (DAA 2016).

Over the years of the colour change study, different instruments were used (usually when instruments reached the end of their operational life span), and DAA identified "significant problems of cross-calibration between instruments, inconsistent error-prone data management, and clear errors in the data" (DAA 2016).

In response to the report by Black and Diffey (2016) and the findings by DAA (2016), Duffy *et al* (2017) concluded that if a true colour change was occurring, changes in the degree of red/green and/or the degree of blue/yellow would be expected to accompany the changes to lightness, and the results are currently inconclusive.

The CSIRO also concluded that while issues with cross-calibration and error-prone data management have not been able to be completely resolved, none of the three spectrophotometers used showed any difference in the rate of change between the northern sites (remote from industry) and the southern sites (close to industry) (Duffy *et al* 2017).

While criticism exist for these programs (Black and Diffey, 2016; SECRC, 2018), the longitudinal dataset is globally unique and provides useful baseline to inform future research. Recommendations that the addition of complimentary, non-invasive analytical techniques such as portable X-Ray Diffractometry and/or portable X-Ray Fluorescence Spectrometry, may prove useful in better understanding the natural geological weathering processes (SECRC, 2018).

5. FUTURE MONITORING

5.1 Murujuga Rock Art Strategy

As acknowledged by DWER (2019c), the integrity and condition of the Murujuga rock art is influenced by complex interactions of a range of extrinsic ('environmental') and intrinsic (characteristics of the rock and the petroglyph, including its weathering history) factors over different temporal and spatial scales. Due to the dynamic, non-linear nature of rock weathering processes, it is extremely challenging to identify definitive casual links between changes in environmental quality (including from industrial emissions) and the accelerated weathering/alteration/degradation of the rock art.

In February 2019 DWER released the final Murujuga Rock Art Strategy to guide future monitoring and management of the Murujuga Rock Art (DWER, 2019a). The Murujuga Rock Art strategy identified that:

+ "There are currently no existing or default guideline 'trigger values' for protecting the rock art from anthropogenic emissions that could be used as criteria."
+ There are also very few examples in the scientific literature where limits of 'acceptable' change have been identified that could be used to protect materials of cultural heritage." (DWER, 2019a)

As outlined by DWER (2019a) the strategy 'builds on the previous work on Murujuga to deliver a scientifically rigorous approach to monitoring, analysis and management that will provide an appropriate level of protection to the rock art".

The implementation of the strategy will be primarily managed through DWER and in partnership with MAC. The Murujuga Stakeholder Reference Group will enable effective consultation with stakeholders including industry, scientific organisations and the community.

The Murujuga Rock Art Strategy (DWER, 2019a) includes the following five scopes:

1. Establish an Environmental Quality Management Framework, including the derivation and implementation of environmental quality criteria (Murujuga Environmental Quality Management Framework (DWER, 2019b)).
2. Develop and implement a robust program for monitoring and analysis to determine whether change is occurring to the Murujuga Rock Art (Murujuga Rock Art Monitoring Program (DWER, 2019c)).
3. Identify and commission scientific studies to support the implementation of the monitoring and analysis program and management.
4. Establish governance arrangements to ensure that:
    + Monitoring, analysis and reporting are undertaken in such a way as to provide confidence to the Traditional Owners, the community, industry, scientists and other stakeholders about the integrity, robustness, repeatability and reliability of the monitoring data and results; and
    + Government is provided with accurate and appropriate recommendations regarding the protection of the rock art, consistent with legislative responsibilities.
5. Develop and implement a communication strategy in consultation with stakeholders (Murujuga Stakeholder Reference Group).

5.2 Murujuga Rock Art Environmental Quality Management Framework

In March 2019 the DWER released the Murujuga Rock Art: Environmental Quality Management Framework (EQMF) to establish "long-term management and monitoring to protect the rock art (petroglyphs) on Murujuga from the impacts of anthropogenic emissions" (DWER, 2019b). DWER intends that the EQMF will "provide a transparent, risk-based and adaptive framework for monitoring and managing environmental quality to protect the rock art on Murujuga from anthropogenic emissions" (DWER, 2019b).

The elements of the structural and conceptual framework behind the EQMF to protect the Murujuga Rock Art can be found in the DWER website (see DWER 2019 Murujuga Rock Art Draft EQMF).

5.3 Murujuga Rock Art Research and Monitoring Program

A fundamental part of the Murujuga Rock Art Strategy and the EMFQ, is the implementation of a program to monitor, evaluate and report on changes and trends in the integrity of the rock art and specifically to determine whether anthropogenic emissions are accelerating the natural weathering of the Murujuga rock art. The development and implementation of the monitoring program will be informed by the findings and lessons from the past 15 years of scientific studies and monitoring of the rock art on Murujuga, as well as information available in the scientific literature. A staged approach is proposed, including focused monitoring studies to inform the design of the program and the development of the EQMF.

The objectives of the monitoring program are to:

+ obtain data for comparison against the environmental quality criteria to ascertain whether the environmental quality objective is being achieved and the environmental value (Murujuga Rock Art) protected;
+ provide the WA government, MAC, industry and the community with robust, replicable and reliable information on the changes and trends in the integrity or condition of the Murujuga rock art;
+ ensure decisions regarding the protection of the Murujuga rock art are based on the best available science; and
+ inform the evaluation of the effectiveness of any measures taken to mitigate adverse effects on the rock art, including efforts to protect the rock art.

An independent review of the monitoring program will be conducted at least every five years. These reviews will address matters such as experimental design and effectiveness, whether best practice methodologies and techniques are being implemented, changes in environmental risks and any relevant emerging environmental issues

6. CONCLUSIONS

Over the past 15 years, numerous studies have been conducted to investigate the potential for industrial emissions from new and existing industrial development on the Burrup Peninsula to impact on the Murujuga rock art. It is recognised that whilst there is anecdotal evidence and stakeholder concerns that observable changes may have occurred, no published peer reviewed studies have identified measurable or observable changes to rock art as a result of industrial emissions to date.

Criticisms have been raised over the design, data collection and statistical analysis elements of some of the previous monitoring programs and studies, and therefore it is acknowledged that uncertainties exist regarding techniques for monitoring and detecting change (both natural weathering rate, and potential for accelerated weathering) and the determination of a critical load of acid deposition at which impacts to rock art may occur. Notwithstanding these criticisms the studies remain the most comprehensive large-scale investigation into the potential for industrial emissions to impact rock art.

To resolve these issues, it has been recommended by the State Government and DWER that an independent integrated monitoring program should be developed based upon well-established principles of experimental design to ensure robust reliable results are provided to inform management and decision making (DWER, 2019a). The Murujuga Rock Art Strategy will look to use existing data to form the basis of an independent world best practice rock art monitoring program to monitor, evaluate and report on changes and trends in the integrity or condition of the Murujuga rock art.

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8. TERMS

Terms	Definitions
AHC	Australian Heritage Council
ASD	Analytical Spectral Device
BMIEA	Burrup Maitland Industrial Estates Agreement
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
BRAMMC	Burrup Rock Art Monitoring Management Committee
BRATWG	Burrup Rock Art Technical Working Group
C	Celsius
CALM Act	*Conservation and Land Management Act 1984 (WA)*
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAA	Data Analysis Australia
DBCA	Western Australian Department of Biodiversity, Conservation and Attractions
DSD	Western Australian Department of State Development
DEC	Department of Environment and Conservation
DER	Western Australian Department of Environmental Regulation
DoEE	Commonwealth Department of Environment and Energy
DWER	Western Australian Department of Water and Environmental Regulation
EPA	Western Australian Environmental Protection Authority
EP Act	*Environmental Protection Act 1986* (WA)
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Commonwealth)
EQMP	Environmental Quality Management Framework
Gabbro	Igneous rock formed from the slow cooling of magnesium-rich and iron-rich magma into a holocrystalline mass deep beneath the Earth's surface
Granophyre	Subvolcanic rock that contains quartz and alkali feldspar in characteristic angular intergrowths
HNO_3	Nitric acid
LNG	Liquefied Natural Gas
m^{-2} yr^{-1}	Square metres per year
MAC	Murujuga Aboriginal Corporation
meq	Milliequivalent
Murujuga	Traditional name for the Burrup Peninsula and surrounding islands of the Dampier Archipelago.
National Heritage Place	National Heritage Place – Dampier Archipelago (including Burrup Peninsula)
Ngarda-Ngarli	Collective term for Aboriginal people of the Murujuga area
NEPM	National Environment Protection Measures
NH_3	Ammonia
NO_x	Oxides of nitrogen
NO_2	Nitrogen dioxide
NWS	North West Shelf

Terms	Definitions
NWS Project Extension Proposal	The Proposal as described in the NWS Project Extension **Section 38** Referral Supporting Information (November 2018) to continue to use the existing NWS Project facilities for the long-term processing of third-party gas and fluids and NWSJV field resources through the NWS Project facilities; and Ongoing operation of the NWS Project to enable long-term processing at the NWS Project facilities, currently expected to be until around 2070.
PAQS	Pilbara Air Quality Study
pH	Measure of acidity or basicity of a solution
PM	Particulate matter
ppb	Parts per billion
SECRC	Senate Environment and Communications References Committee
SO_2	Sulphur dioxide
SO_X	Oxides of sulphur
TAN Plant	Yara Pilbara Nitrates Pty Ltd Technical Ammonium Nitrate Plant
TSP	Total suspended particles
WA	Western Australia
Woodside	Woodside Energy Ltd