Appendix I

Air quality addendum

Santos

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AIR ENVIRONMENT CONSULTING

Report prepared for

GHD

Santos Narrabri Gas Project

Air Quality Impact Statement

Response to Submissions

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Glossary

Term	Definition
Units of measurement	
s	second
min	minute
h	hour
d	day
yr	year
ng	nanogram
µg	microgram
mg	milligram
g	gram
kg	kilogram
t	tonne
$\mu g/m^3$	microgram per cubic metre
mg/m^3	milligram per cubic metre
µm	micron or micrometre
mm	millimetre
m	metre
km	kilometre
m^2	square metres
m^3	cubic metres
m/s	metres per second
m^3/s	cubic metres per second
Am^3/s	actual cubic metres per second (at stack conditions)
Sm^3/s	standard cubic metres per second (25^{o}C, 1 Atm)
Nm^3/s	normalised cubic metres per second (0^{o}C, 1 Atm)
g/s	gram per second
km/h	kilometres per hour
Atm	atmosphere (unit of air pressure)
^{o}C	degrees Celsius
K	Kelvin (unit of temperature)
Air pollutants and chemical nomenclature	
NO_X	oxides of nitrogen
NO_2	nitrogen dioxide
SO_2	sulfur dioxide
CO	carbon monoxide
VOC	volatile organic compounds
PAH	polycyclic aromatic hydrocarbons
PM	particulate matter (dust)
TSP	total suspended particles (airborne dust)
PM_{10}	particulate matter with an aerodynamic diameter less than 10 microns
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than 2.5 microns

Other abbreviations

Air Toxics NEPM	National Environment Protection (Air Toxics) Measure
Approved Methods	Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (DEC, 2005)
BOM	Bureau of Meteorology
CALMET	Meteorological model used in conjunction with the CALPUFF dispersion model system
CALPUFF	California Puff Model - An advanced non-steady-state Lagrangian meteorological and dispersion modelling system
Clean Air Regulation	NSW Protection of the Environment Operations (Clean Air) Regulation 2010
Air NEPM	National Environment Protection (Ambient Air Quality) Measure
OEH	NSW Office of Environment and Heritage (formerly Department of Environment and Conservation [DEC])
TAPM	The Air Pollution Model developed the Commonwealth Scientific and Industrial Research Organisation (CSIRO)
TCEQ	Texas Commission on Environmental Quality
USEPA	United States Environmental Protection Agency

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1. Selection and Application of Dispersion models

The submission requested clarification of the rationale for the application of air quality modelling software CALPUFF and AUSPLUME to project activities.

CALPUFF was the preferred model for the AQIA in order to account for the spatial extent of the project activities and the variability of the terrain (i.e. elevation changes between approximately 170 and 470 metres above sea level) and land use (e.g. forest, scrub, rangeland, pastoral / agricultural land and urban features). CALPUFF however could only be used for air emission sources with a fixed geographic location. The CALPUFF model was used to model emissions associated with the operations of the fixed facilities at Leewood and Bibblewindi, as well as other emissions sources in the region considered in the study (i.e. Wilga Park Power Station). Due to the fixed geographic setup of CALPUFF, incorporating actual topographic and land use features, the use of CALPUFF was not feasible to assess the impact to air quality at sensitive receivers for sources that have not yet been determined and sited. At this stage of the project's development planning, the activities associated with the construction and operation of the well pads, pipeline trenches and roads are understood, but the final location of each activity is unknown. This means that while emissions from these activities can be estimated, these can not be modelled using CALPUFF.

To account for this, an alternative method was adopted. An activity source to sensitive receiver separation distance was determined through air dispersion modelling which determined the distance from the source at which all ground-level pollutant concentrations were below their air quality impact assessment criterion. As the location of infrastructure in relation to the surrounding terrain, land use and sensitive receivers is not yet fixed, a more generic AUSPLUME model configuration was used to determine the distance between the source and receptor at which the air quality assessment criterion is met. This separation distance, or buffer, could subsequently be applied in GIS modelling to determine a suitable location for each component of project infrastructure or identify distances at which mitigation and management controls may be required.

2. Estimation of Air Emissions

The submission noted the use of generic emission factors that were not equipment specific. It stated that the actual air emissions may differ from the air quality impact assessment depending on the selected equipment. As such, it requested further information on the selected equipment and their air emissions based on supplier guarantee or monitoring. Further submissions also noted the nitrogen oxide limit adopted from the Protection of the Environment Operations (Clean Air) Regulation 2010 assumed gas-fired reciprocating combustion engines and stated that a different limit would apply if gas turbines were instead selected. Another submission also stated that the emissions data for gas fired power generators incorrectly estimated oxygen correction at five per cent instead of three per cent as determined under the Environment Operations (Clean Air) Regulation 2010. Another submission also stated that the emissions data for diesel fired generators at well pads omitted sulfur dioxide emissions.

The air quality impact assessment was based on a dispersion modelling study that combined the site-specific details of the project with various assumptions and estimation techniques to simulate and assess the dispersion and impact of air pollutants in the local area. The approach defined air emission rates, source characteristics, local meteorology, land use, terrain and the location of sensitive receptors to assess the potential for future air quality to be affected in relation to the impact assessment criteria promulgated in the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (NSW EPA, 2017).

This air quality impact assessment has been undertaken primarily as a level two impact assessment (as defined in the Approved Methods, NSW EPA, 2017) with the inclusion of site-specific information and modelling processes. Notwithstanding this approach, some additionally conservative level 1 assessment measures have also been incorporated to account for uncertainties in the methodology and future changes in the project conditions or local environment beyond the proponent's control.

To account for uncertainty, a conservative approach is usually taken, such that:

- Emission factors from recognised references such as the NPI emissions estimation technique handbooks and the USEPA AP42 emission handbooks are considered to be standard approaches.
- Emission rates can also be estimated based on regulatory emission limits such as the emissions limit defined in the NSW Clean Air Regulation in-stack concentrations.

The use of the NSW Clean Air Regulation in-stack concentrations is highly conservative, as these limits represent the maximum allowable emissions concentration for any engine and equipment that are currently operating or will be given a license to operate within NSW.

Air Environment notes that EPA's statements on the equipment, emission sources and use of emission factors in the AQIA is correct. At this early stage of the project's development planning, no decisions have been made on the specific type and model of engines for power generation. Emission characteristics were adopted based on a specific gas fired reciprocating engine model similar to that, which could be selected to meet the proposed power requirements of 100 MW. Emissions of nitrogen oxides were compared for these engines based on engine specific data, NPI emission factors and the NSW Clean Air Regulation limit.

As previously stated, power generation at Leewood is based on gas fired reciprocating engines. Gas turbines were not proposed and have not been considered. Notwithstanding this, it would be expected that were gas turbines used, emissions of key pollutants such as nitrogen oxides would meet or be lower than the NSW Clean Air Regulation emission concentration standard of 70 mg/m^3.

In regard to EPA's notification of the oxygen correction used, the value of 5% in Table 5-7 of Appendix L of the Air Quality Impact Assessment report (AEC, 2016) was found to be correct based on actual engine specifications supplied by Santos. However, the value of 5% presented in Table 5-8 is a typographical error and should be 3% oxygen based on the NSW Clean Air Regulation standard.

Sulfur dioxide emissions for diesel-fired well pad generators were assessed in the AQIA modelling but not included in the report as the resultant mass emission rates and subsequent impacts were found to be extremely low. The mass emission rate of sulfur dioxide was calculated based on NPI emission factors and determined to be 0.0001 g/s against a 1-hour average ambient air quality criterion of 570 µg/m^3. This emission is based on the sulfur content of diesel reported in the NPI. Specific chemical compositions of diesel, and in particular sulfur, were not yet determined at the time of the AQIA and the diesel sulfur content was assumed to be standard. By comparison, the key pollutant of interest, nitrogen dioxide, had a mass emission rate of nitrogen oxides of 0.11 g/s against a 1-hour average criterion of 250 µg/m^3. Based on a 100% NO_2/NO_X conversion ratio, the predicted maximum ground-level concentration of nitrogen dioxide was well below the criterion, and therefore the impact of sulfur dioxide was determined to be negligible.

Furthermore, sulfur dioxide is a non-issue as the FEED gas should have low reduced sulfur compound concentrations. If the reduced sulfur (H_2S) was high, it is expected that an acid gas removal process would be applied. Therefore, emissions would not be released as SO_2.

Notwithstanding this, all known pollutants (including SO_2) associated with the Project have been assessed. Predicted ground-level concentrations of all pollutants for all scenarios are detailed in Appendix A.

It should be noted that actual equipment specifications and supplier details will not be known until the FEED is completed. It is not feasible to provide this information prior to FID and FEED. As stated above the modelling undertaken is conservative and accounted for this uncertainty in the assessment approach. As stated in the AQIA report, follow up stack emission testing should be conducted to verify that actual emissions comply with the regulatory emission limits set out in the NSW Clean Air Regulation and the project's Environmental Protection License. Dispersion modelling of the actual project emissions and source configurations should be conducted to verify that the air quality assessment criteria are met at sensitive places.

3. Determination of Buffer-limiting Pollutants and Separation Distances

The submission notes that ground level concentrations were estimated and displayed for buffer limiting pollutants. It requested justification of the assessment of buffer limiting pollutants and recommended further information of other emissions be provided, including polycyclic aromatic hydrocarbons and $PM_{2.5}$. Another submission argues that pollutants are omitted including CO, SO_2 etc. Further submissions request concentrations of air toxics at receptors.

The air quality assessment used a streamlined approach in order to prioritise the presentation of critical pollutants. The following assessment approach has been taken, in accordance with the requirements of the Approved Methods (NSW EPA, 2017):

- Criteria air pollutants have been assessed as the 100th percentile of predicted impact plus background at any location beyond the Leewood and Bibblewindi locations. This is considered highly conservative as the assessment criteria specifies assessments to be made at existing and future off-site sensitive receptors.
- Principal toxic, individual toxic and odorous air pollutants have been assessed as the 99.9th percentile of predicted incremental impact at any location beyond the boundaries of the Leewood and Bibblewindi locations. This is considered highly conservative as the assessment criteria specifies assessments to be made at existing and future off-site sensitive receptors.
- Polycyclic aromatic hydrocarbons have been assessed as equivalent benzo[a]pyrene, using the potency equivalency factors (PEFs) for PAHs provided in the Approved Methods (NSW EPA, 2017). These have been assessed as the 100th percentile of predicted incremental impact at any location beyond the boundaries of the Leewood and Bibblewindi locations. This is also considered highly conservative as the assessment criteria specifies use of the 99.9th percentile.
- Impacts associated with infrastructure with locations that are not yet fixed in location, such as well pads, roads and pipeline and transmission line trenches have been assessed to determine the buffer limiting pollutant. This infrastructure will, in the future, be located to account for the separation distance prescribed in this assessment or to inform where mitigation and management controls may be required.

Due to the broad suite of potential hazardous air pollutants and regulatory criteria associated with gas and diesel fired combusting engines (normal operations), the most critical air pollutants were assessed. These were ranked according to the ratio of their emission factor (in $g_{pollutant}$/ MJ_{energy} used) to impact assessment criteria (in µg/m³). The 1-hour average assessment criterion was used for most pollutants, except for PM_{10}, where the 24-hour average was used to be conservative. It should be noted that hazardous air pollutants are assessed in isolation, so a cumulative assessment is not required.

While not all potential pollutants were explicitly presented in the air quality assessment report, the adopted approach streamlined the assessment process as it could be assumed that if the top ranking pollutants meet the relevant air quality criteria, all lower ranking pollutants will meet their respective relevant criteria as well.

The air quality assessment report presented the ground-level concentrations of priority pollutants predicted beyond the Leewood and Bibblewindi boundaries. Ground-level concentrations of all other pollutants due to Project activities for all scenarios predicted at any location beyond these site boundaries and at the closest sensitive receptors are presented in Appendix A.

The full assessment of all pollutants for all scenarios shows that:

- The impact assessment criteria were met for all pollutants at all locations beyond the boundary of both the Leewood and Bibblewindi sites for all power options during routine and non-routine flaring operations.
- The impact assessment criteria were met for all pollutants at all locations at the closest sensitive receptors to the Leewood and Bibblewindi sites for all power options during routine and non-routine flaring operations.
- Predicted ground-level concentrations of modelled substances associated with both the gas and diesel-fired generator engines are all well below their respective ambient air quality impact assessment criteria at a distance of five metres from the engine stack.
- For diesel-fired engine emissions, nitrogen dioxide is the substance of most concern, reaching seven percent of its regulatory criterion, with carbon monoxide (0.9%), acrolein (0.3%) and formaldehyde (0.1 %) being the next most significant emissions.
- For gas-fired engine emissions the substance of most concern is acrolein at 48% of its regulatory criterion, followed by formaldehyde (10 %) and nitrogen dioxide (7%). All other substances are at levels lower than one percent of their respective criteria.

Further to the screening level assessment discussion above, the hierarchical screening assessment approach was used to identify the most important pollutant of concern. This pollutant was then used to assess the separation distance required to protect receivers from air quality impact or where additional mitigation or management controls may be required. This was the approach taken as locations of the well pad generators, roads and pipeline trenches are not yet fixed.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbons (PAH) did not feature in the top five ranked pollutants. For lean burn gas fired engines, the highest ranked PAH species was estimated to be Phenanthrene. There is no assessment criterion for Phenanthrene in the Approved Methods or the Victorian State Environmental Protection (Ambient Air Quality) Policy. To facilitate the assessment, the Texas Commission on Environmental Quality *Effects Screening Level* was used as a reference. Texas has a mature oil and gas industry and consequently, has a comprehensive air quality contaminants screening assessment criteria document. The TCEQ screening levels have regularly been used in air quality assessments in Australia without question, as they provide a reasonable reference point for a vast range of air pollutant criteria not promulgated in Australian state air policies.

Based on a hierarchical screening assessment method, the potential impact of Phenanthrene was estimated to be 588 times less than the most important pollutant, Acrolein, and 432 times less than nitrogen dioxide (based on a 100% NO_2/NO_X ratio).

To supplement this initial assessment, total polycyclic aromatic hydrocarbons were further assessed as benzo[a]pyrene equivalents, using the potency equivalency factors (PEFs) provided in the Approved

Methods (NSW EPA, 2017). These have been assessed as the 100th percentile of predicted incremental impact at any location beyond the boundaries of the Leewood and Bibblewindi locations. This is also considered highly conservative as the assessment criteria specifies the use of the 99.9th percentile.

For diesel fired engines at the well pad, Phenanthrene was also estimated to be the most important PAH with an impact 305 times less than the most import pollutant, nitrogen dioxide (based on a 100% NO_2/NO_X ratio). As the predicted maximum cumulative impact of nitrogen dioxide was well below the assessment criterion at the Leewood boundary and around the well pads, it was considered that all PAH concentrations were well below their respective assessment criteria.

Particulate matter - Construction

All particulate emissions were assessed as PM_{10}. This is a reasonable expectation for construction as the particle size distribution is expected to comprise a majority of coarser particles where the handling of earth is involved and the finer particles are expected primarily from diesel fired mobile and stationary plant and equipment. Consequently, PM10 was determined to be the buffer-limiting pollutant.

The approach to assessing air quality impacts due to the construction phase of the Project remains consistent with the methodologies described in the air quality report (AEC, 2016).

The air quality report has shown that the 24-hour average ground-level concentrations of PM_{10} at receiver 216 are predicted to exceed the 24-hour average 50 µg/m³ criterion on one day per year. However, it should be noted that emissions estimated for the construction phase were conservative.

The estimation of dust emissions during the construction phase is a complex task, given that construction consists of a series of activities, each with its own duration and potential for generation of particulate matter. In other words, emissions from any single construction site can be expected to have a definable beginning and end, and will vary substantially over different phases of the construction process.

It should be noted that the assessment of air quality impacts due to construction was conservative due to the assumed size of the construction area. The assessment assumed a constant emission rate for the entire construction area and did not account for individual emissions sources, source mitigation measures and wind speed dependency. A key source of construction site dust emissions is wind-blown dust from cleared and exposed surfaces. NPI and AP42 emission factors for wind eroded exposed surfaces use a wind speed threshold of 5.4 m/s for dust lift off. This was not applied in this assessment and consequently dust emissions associated with wind erosion are likely to be included when the wind is below the required lift off threshold.

Notwithstanding this, emissions during the construction phase will be minimised through a dust management plan. Mitigation measures are detailed in Section 9.1 of the air quality assessment report (AEC, 2016).

Particulate matter - Operation

For diesel and gas fired engines from the operational phase of the project, it is correct to assume a greater proportion of the exhaust emission particle size distribution will comprise $PM_{2.5}$ than the construction dust emissions. PM_{10} was initially assessed to account for all particles in the assessment, but since the change in the Air NEPM standards in 2016 and the promulgation of the revised Approved Methods criteria in January 2017, a supplementary assessment is considered to be appropriate to provide an assessment of the impact of particulate matter from gas and diesel fired engines during the operational phase against the 24-hour and annual average $PM_{2.5}$ criterion.

For the Leewood power generation plant engine emissions, the predicted maximum 24-hour average of PM_{10} (in isolation) at the plant boundary was 0.04 µg/m^3 (conservatively rounded up and presented in the report as 0.1 µg/m^3) against a criterion of 50 µg/m^3, which is 0.08 per cent of the criterion. The assessment was not shown with the inclusion of a background dust concentration to illustrate the negligible contribution of the gas engines to local dust loads. If it were conservatively assumed that the ratio of $PM_{2.5}/PM_{10}$ was 100 per cent and the engine particulate emissions were assessed against the 24-hour average $PM_{2.5}$ criterion of 25 µg/m^3, the predicted maximum impact of $PM_{2.5}$ (from the engines in isolation) at the boundary would be 0.16 per cent. As presented in the report, the 24-hour average background concentration of PM_{10} was determined to be 24.1 µg/m^3. Similarly, the predicted maximum annual average impact of PM_{10} at the boundary in isolation was 0.004 µg/m^3 or 0.016 per cent of the criterion of 25 µg/m^3. Assuming a $PM_{2.5}/PM_{10}$ ratio of 100%, the predicted maximum annual average ground-level concentration of $PM_{2.5}$ would be 0.05 per cent of a criterion of 8 µg/m^3.

For the diesel fired well pad generators, particulate emissions were assumed to be PM_{10} and determined in the hierarchy of pollutant importance to be the second most important substance. If a $PM_{2.5}/PM_{10}$ ratio of 100% is assumed, the ratio increases by a factor of two but $PM_{2.5}$ would remain the second most important pollutant behind nitrogen dioxide. This is based on the 24-hour average criterion being met in each hour, which is a conservative assumption. Consequently, a change in the assessment from PM_{10} to $PM_{2.5}$ is not likely to alter the conclusions of the AQIA.

4. Assessment of Gas Flaring Emissions during Operations

The submission suggests that the air quality impacts of flaring are not assessed. Operations (Clean Air) Regulation 2010. The submission also stated that the emissions data for diesel fired generators at well pads omitted sulfur dioxide emissions.

Flaring was addressed in the air quality assessment. In particular, the impact assessment considered the following scenarios:

- Power supply option 1 - routine
- Power supply option 1 – non-routine – Leewood and Bibblewindi Flares
- Power supply option 2 - routine
- Power supply option 2 – non-routine – Leewood and Bibblewindi Flares

Ground level concentrations of priority pollutants for these scenarios were presented in the air quality assessment report (AEC, 2016). Detailed results for all pollutants are presented in Appendix A.

5. Cumulative Air Quality Impacts of Leewood, Bibblewindi and Well Pad Generators

The submission stated that the air quality impact assessment should have considered the potential air quality cumulative impacts of well pads, Leewood and Bibblewindi accounting for the maximum number of well pads likely to be in operation concurrently.

As discussed above, the location of future well pads is not yet fixed. Notwithstanding this limitation to conducting a cumulative assessment, the combined effect of well pads and the Leewood plant was considered and the methodology conservative and adapted to address uncertainty. There are two key design and assessment features that illustrate that the cumulative impacts required to cause an exceedence of the nitrogen dioxide criterion would be extremely unlikely to occur.

- The first criterion is that the predicted maximum 1-hour average ground-level concentration of nitrogen dioxide at the Leewood plant boundary was 117 µg/m³ based on worst case emissions estimated from the NSW Clean Air Regulation emission concentration standard. This is equivalent to 47% of the ambient nitrogen dioxide criterion and based on a NO_2/NO_X ratio of 100%. This is an extremely conservative estimate.
- Secondly, and most importantly, predicted maximum cumulative 1-hour average ground-level concentrations of nitrogen dioxide from gas fired well pad generator emissions are predicted to

be below 50 µg/m3 within the boundary of the well pad, and approximately 25 µg/m³ in isolation. This means gas fired well pad generators could feasibly be placed around the Leewood plant boundary and not cause an exceedence of the nitrogen dioxide ambient criterion. It also means that a proposed well pad spacing of 750 m would provide a significant separation between emission sources.

Furthermore, if the well pad generators are diesel fired, the predicted maximum ground-level concentration of nitrogen dioxide of approximately 25 µg/m^3 (in isolation), based on the Clean Air Regulation emission concentration standard, was predicted to occur within 30 metres of the stack.

Based on this assessment, the project design featuring well pads separated by at least 750 metres means that the risk of cumulative air quality impacts that would exceed the air quality criterion is extremely unlikely to occur. In addition to this, well pads are part of the project's infrastructure and would not be situated in a sensitive place. Consequently, the cumulative impact within the well pad generator's area is considered to be 'on-site' and not subject to the ambient air quality criterion.

An indicative assessment of the cumulative effect of well pad emissions at both the Leewood and Bibblewindi sites was conducted as part of this study. The peak modelled pollutant concentration predicted at the boundary of a typical well site (nominally a distance of 25 to 30 m from the well pad) for each pollutant were added to the modelled scenarios as a constant background to provide a cumulative assessment. Pollutants with a criterion defined for averaging periods different from one-hour were extrapolated using the power law equation (Turner, 1970).

Ground-level concentrations of pollutants predicted for all scenarios are presented in isolation, and with the inclusion of the maximum incremental impacts from the well pads. These are presented in detail in Appendix A.

Appendix A shows that despite the conservative approach, ground-level concentrations of pollutants beyond the site boundaries and at any sensitive attributed to the cumulative effect of well pad emissions and Project emissions are well below the criterion defined for any pollutant.

6. Assessment of Ground-level Ozone Concentrations

The submission states that the assessment underestimates potential ozone formation from "escaping methane and volatile organic compounds, mixing with nitrogen oxides formed by flares and diesel engines to make ground level ozone".

Ozone is not directly released from the project as a primary pollutant but generated through the oxidation of nitrogen oxides in the presence of volatile organic compounds and sunlight in the atmosphere. The exhausts from the project engines and boilers contain approximately 90-95 percent of nitrogen oxides in the form of nitric oxide. Once the nitric oxide has been transformed into nitrogen dioxide, ozone may be produced via a multi-stage process. The rate at which ozone is generated is a function of:

- the in-plume concentration of nitrogen oxides,
- the concentration and reactivity of VOCs in the ambient air,
- the rate of plume dispersion, and
- the prevailing atmospheric conditions, including temperature and solar radiation fluxes.

Due to the low emissions of nitrogen oxides from the Project in comparison to a large urban airshed such as the Sydney Greater Metropolitan Region, which has ozone formation issues, modelling of ozone generation has not been conducted for this assessment.

Instead, a conservative assessment has been assumed wherein the predicted maximum 1-hour and 4-hour average incremental ground-level concentrations of nitrogen dioxide beyond the Leewood site boundary will be transformed in to ozone.

The cumulative assessment has been calculated by adding the 1-hour and 4-hour average incremental predictions to the maximum 1-hour and 4-hour average ozone concentrations recorded during the monitoring program and compared to the impact assessment criterion.

Furthermore, an analysis of the hydrocarbons measured by by the Commonwealth Science and Industrial Research Organisation (CSIRO) (Day *et al.*, 2016), discussed in Appendix B shows that levels of major organic precursors to the formation of ozone in the atmosphere are comparable to the natural environment.

7. Effect of Air Emissions on Regional Visibility

The submission suggests that emissions would concentrate and drift south under temperature inversion conditions and affect visibility at the Siding Springs Observatory. Other submissions also suggest that ozone or other emissions could "cloak nearby residential areas of Narrabri during still cloudy weather, temperature inversions and in still conditions at night". It also notes ozone may combine with PM10 to form smog.

The emission of pre-cursor pollutants from the project that are likely to form ozone and secondary aerosols is predicted to be relatively low. This means that the risk of generating adverse effects in the surrounding regions including at the Sidings Springs Observatory from the dispersion and formation of pollutants is very low.

It is very unlikely that long-distance visibility would be reduced due to emissions released from the Project. Despite the conservative approach taken to assessing impacts from ozone formation, levels of photochemical smog were predicted to be very low, even with the inclusion of background levels. Furthermore, as discussed in response to submission 3, regarding particulate emissions during the operational phase, incremental ground-level concentrations of $PM_{2.5}$ are predicted to be well below 1 per cent of the criterion at the boundary of all plant infrastructure. This modelling takes into consideration all worst-case plume dispersion conditions including stagnant calm and highly stable conditions, temperature inversions, and night-time katabatic drainage flows.

Therefore, the dispersion of fine particulates including secondary aerosol formation, and ozone any distance beyond a few kilometres of the Leewood facility is very unlikely to occur.

8. Assessment of Fugitive Emissions from CSG Operations

The submission notes that the air quality impact assessment omits fugitive methane and carbon dioxide emissions on grounds they do not pose a direct risk to human health. The submissions stated fugitives may contain "volatile organic compounds, air toxics and odour substances". It recommends that all potential components of fugitive emissions should be assessed and measures to mitigate and managed these emissions should be proposed.

CSIRO conducted a study that aimed to develop methods for characterising methane and other gaseous emissions from different area sources in NSW, particularly the CSG industry (Day *et al.*, 2016).

The findings of the study showed that:

- Methane levels attributed to CSG operations were low relative to other sources;

- Measurements of volatile organic compounds considered as major precursors to the formation of ozone in the atmosphere were shown to be lower at CSG sites than in the vicinity of the other source types;
- Measurements of volatile organic compounds prioritised under United States Environmental Protection Agency (USEPA) ambient air quality guidelines for human and environmental health were shown to be lower at CSG sites than in the vicinity of the other source types.

Further details of the study conducted by CSIRO are discussed in Appendix B.

9. Potential for Emissions from Produced Water Storages

Submission states the assessment does not consider the air emissions from volatilisation of produced water at wells, ponds and elsewhere. It argues the produced water is high hazard as it contains metals and other toxics that may volatalise and is high pH.

The risk of impacts to air quality associated with potential emissions from produced water storages are expected to be very low. Concentrations of gaseous pollutant emissions are expected to be low from the ponds. Notwithstanding this, odour, if any, is expected to be detectable at concentrations well below the health assessment criteria.

No emissions of metals dissolved or suspended in the produced water are expected. Consequently, there is not expected to be any impact beyond the boundary of the Leewood site from metals in the produced water.

Navi *et al*. (2015) conducted a review of the potential hazards to the human environment associated with produced water from the CSG industry in Queensland. Their research determined that there are five potential exposure pathways for humans to be exposed to contaminants in the produced water including:

1. Water used for municipal purposes,
2. Recreational water activities in rivers,
3. Occupational exposures,
4. Extracting water from contaminated aquifers, and
5. Indirect exposure through the food chain.

Navi *et al*. (2015) did not identify atmospheric diffusion and transport as a key exposure pathway for contaminants from produced water.

10. Potential for Impacts from Radioactive Gases

1. Submission states the assessment omits certain pollutants including radioactive gases.

All pollutants emitted from vents are addressed in the impact assessment (point 1), which includes all pollutants.

Humans are exposed to natural radiation from a number of sources. These may include cosmic radiation from outer space; the presence of uranium, thorium and potassium-40 (40K) in the Earth's crust; and radon gas released from the decay of uranium.

The total average dose to an individual from natural background radiation is about 2.4 millisieverts (mSv) per year, but this varies widely due to a number of factors. In some countries the average annual dose received from natural background radiation is in excess of 10 mSv. Australia is on the lower range of the spectrum, averaging approximately 0.9 mSv.

Radon and thoron gas are a significant source of exposure to natural radiation.

SGS Australian Radiation Services (SGS ARS) conducted a radiological survey of the Origin Coal Seam Gas operations in Queensland for the presence of Naturally Occurring Radioactive Material (NORM) in February 2010 (SGS, 2010) and August 2013 (SGS, 2013) in the Spring Gully and Talinga regions.

The study included the radiological survey of gas installations, including gas plants, field wells and water treatment facilities (WTF). Results of the survey show:

Levels of NORM at the time of assessment were negligible compared to natural background radiation levels,

The absence of elevated external gamma radiation levels that could be attributable to NORM within the process equipment,

The highest count rates observed during the survey were contributable to natural radioactive material present in the underlying soil, and

Negligible external radiation hazard to personnel working in any areas of those facilities assessed, when compared with an individual's exposure to natural background radiation levels.

The reasons for the presence of NORM in the extracted gas or produced water can be due to several factors including the geophysical nature of the reservoir and extraction techniques. In conventional gas production, newly operational plants may have insignificant levels of NORM during initial stages of commissioning, but can accumulate NORM over a period of time, sometimes within a few years. The rate of accumulation can depend on many factors. However, the potential for NORM to accumulate in a coal seam gas installation over an extended period of time is unknown.

11. Assessment of $PM_{2.5}$

Submission requests modelled contours of annual $PM_{2.5}$.

Concentration contours for the maximum 24-hour and annual average concentrations of $PM_{2.5}$ across the modelling domain, with ambient background concentrations, are presented in Appendix A.

12. Assessment of existing background air quality

The submission requested clarification for the air quality background concentrations used in the air quality impact assessment including nitrogen dioxide, ozone and particulate matter. It noted that the background concentration of nitrogen dioxide was based on monitoring about 14 kilometres southeast of Leewood and 13 kilometres northeast of Bibblewindi. It noted the statement in the EIS that background concentration of nitrogen dioxide and ozone would have low seasonal variability but stated that monitoring in NSW indicated nitrogen dioxide concentration peaks in winter while ozone concentration peaks in summer. It also stated that the adopted 70th percentile of PM10 as recorded at Tamworth was not considered in accordance with the Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA, 2017). Another submission also states that the growth in regional emissions as shown in the NPI are not reflected in the cumulative air quality impact assessment.

It is acknowledged that nitrogen dioxide levels in highly urbanised and industrialised locations in NSW may be seasonally variable and that ozone levels will be highly dependent on the availability of precursor pollutants and solar incidence. This is due to the variety of pollutant sources. Furthermore, higher solar incidence in the summer would likely lead to increased ozone generation. Notwithstanding this, the Project area is likely to have a very different mix of background air pollutants and sources when compared with other regions in NSW where ambient air monitoring is conducted. This is particularly the case for urban and industrial airsheds like Sydney and the lower Hunter Valley and Newcastle.

The use of background air quality data from most other NSW monitoring sites was not considered representative of the Project's setting. An analysis was conducted of the nearest ambient air quality monitoring sites in NSW, i.e. Tamworth, Muswellbrook, Singleton and Beresfield, and the pollutants measured and site's proximity to the project area summarised in Table 4-1 of the AQIA report. While data from these sites were presented in the existing environment chapter of the AQIA report to illustrate the air quality in other northern NSW regions, due to the unrepresentativeness of the publicly available monitoring data, a site-specific monitoring program for the key criteria pollutants, nitrogen dioxide and ozone, was conducted for use as background concentrations in the cumulative impact assessment. The results of this assessment were detailed in Appendix A of the AQIA report. Based on experience in assessing coal seam gas projects in Queensland, it was considered that particulate matter was not likely to be a critical air pollutant associated with the project, and consequently, was not monitored.

Air Environment understands that it is general practice to use a minimum of one full year of air quality monitoring data, where available, to represent the seasonal variability of emissions and meteorology in a region. However, after four months of the monitoring program, it was determined that nitrogen dioxide concentrations were extremely low and ozone concentrations were also quite low. Consequently, a decision was made to end the monitoring program. The data available from the four-month monitoring program was used to assess the cumulative impact of nitrogen dioxide and ozone.

At the time of the completion of the air quality assessment, there were no ambient air quality monitoring stations with publicly available data within the Narrabri region. As the publicly available data from the NSW Office of Environment and Heritage (OEH) monitoring network was determined to be unrepresentative of the project area, a contemporaneous background cumulative assessment was considered unfeasible for all pollutants. This was particularly true of 24-hour average concentrations of PM_{10} measured at Tamworth, which were determined to be consistently high, and synonymous with an urbanised environment in a warm temperate climate that has a mix of rural and commercial industry.

Consequently, an alternative method for the cumulative assessment was sought. The use of the Victorian PEM (2007) method, whereby a 70th percentile 24-hour average background concentration of PM_{10} is added to the predicted maximum 24-hour average for the project emissions is commonly used in AQIAs in Victoria and Queensland. The 70th percentile is commonly used in these jurisdictions for 1-hour and 24-hour average criteria. Considering the extremely low ground-level concentrations of particulates predicted from the project's operations, the use of a 70th percentile background concentration was considered to be appropriate and that project's contribution to the region's overall dust load to be negligible.

Since July 2015, the Namoi Region Air Quality Monitoring Project (NRAQMP) has been collecting data from four monitoring locations within the Namoi Region. Ambient concentrations of particulate matter, including PM_{10} and $PM_{2.5}$ are continuously measured within all sites. Two of the locations, Maules Creek and Wil-gai monitoring stations, are located within 70 km of the site of the Leewood site.

Details for the relevant stations are discussed in Appendix C.

As measurements for background $PM_{2.5}$ have become available, these have been included in the cumulative impact assessment. Background concentrations used in the study are summarised in Table 1. The data from the NRAQMP shows that background concentrations of $PM_{2.5}$ are very low and well below the ambient air criterion.

Table 1 Background concentrations used in the assessment

Air pollutant	Averaging period	Background Concentration (µg/m³)
Nitrogen dioxide	1-hour	18.5
	Annual	18.5
Ozone	1-hour	74.2
	4-hour	72.0
PM_{10}	24-hour[1]	13.7
	Annual	11.0
$PM_{2.5}$	24-hour[1]	4.9
	Annual	4.1

Table note: [1] 70th percentile concentration from Wil-gai monitoring station

The air quality assessment report included a list of all facilities within the Narrabri and Gunnedah region that reported to the NPI and discusses the major influence in regional air quality. Locations of these facilities, as well as emissions reported to the NPI for the most recent reporting period (2016-17) are discussed in Appendix D.

All of the industries are relatively well separated from the project by distance so that cumulative impacts are likely to be negligible.

13. Impacts Associated with the Existing Wilga Park Power Station

The submission questioned whether assessing the maximum predicted concentrations of NO_2 at the boundary of Leewood represented an overall assessment of maximum impact, stating that greater predicted concentrations were predicted about 10 kilometres to the north. The submission recommended that the maximum predicted concentration at existing or likely offsite sensitive receptors be presented to clarify the overall maximum impact.

It is noted that maximum cumulative 1-hour average ground-level concentrations of nitrogen dioxide are predicted to be higher to the north of the Leewood project area. This is due to emissions from Wilga Park Power Station that have been included in the model. Wilga Park was modelled to provide for the cumulative assessment of nitrogen dioxide and ozone but not featured in the concentration contour isopleths presented in the AQIA report as it is not a part of the Narrabri Gas Project.

The domain shown in the contour plots presented in the AQIA report has been extended to show the surrounding area around Wilga Park Power Station. These are presented in Appendix A.

Maximum one-hour and annual average ground level concentrations of NO2 for Power supply option 1 – routine operations are shown in Figure A-3 and Figure A-4, respectively.

Maximum one-hour and annual average ground level concentrations of NO2 for Power supply option 2 – routine operations are shown in Figure A-7 and Figure A-8, respectively.

14. Comparison of Predicted Nitrogen Dioxide Impacts near Leewood for Power Supply Options 1 and 2

The submission noted the similarity of predicted NO_2 for Leewood between power supply option 1 and power supply option 2. It argued that this was in contradiction to the statement that power supply at Leewood would be the largest emissions source.

The total combined emission of oxides of nitrogen from the 10 gas fired engines at Leewood is 27 g/s and 50 g/s for the nominal engine data and NSW Clean Air Regulation limit based emissions, respectively. In comparison, the total combined emission of oxides of nitrogen from the four hot oil boilers is 2.32 g/s and 4.4 g/s, for the NPI emission factor and NSW Clean Air Regulation limit based emissions, respectively. Consequently, the emissions of oxides of nitrogen associated with the engines are more than 11 times greater than the boilers. The statement in the AQIA report is correct.

However, the higher predicted maximum 1-hour average ground-level concentrations of boiler emissions are due to the significantly greater buoyancy flux (or plume rise) associated with the power generation engines. The exhausts from the six closely located 30-metre tall engine stacks at the end of each train were determined to have the potential to merge after release and consequently provide for an enhanced buoyancy effect. In contrast, the boiler emissions will be released from four 10-metre tall stacks with no enhanced buoyancy. Finally, the buoyancy flux of each of the two enhanced engine stack groups is 49 m^4/s^3 compared to 3.8 m^4/s^3 for each of the individual, non-buoyancy enhanced boiler stacks. All of these factors combine to result in the highest contribution to ground-level concentrations of nitrogen dioxide being from the boilers' emissions.

15. Assessment of PM_{10} and $PM_{2.5}$ based on Updated Impact Assessment Criterion

The submission stated that the assessment of $PM_{2.5}$ and PM_{10} in the air quality assessment should be updated in accordance with the revised Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA 2017). The revised guidelines include an annual PM_{10} criterion reduced from 30 µg/m³ to 25 µg/m³ and 24-hour and annual $PM_{2.5}$ criteria at 25 µg/m³ and 8 µg/m³ respectively.

An impact assessment criterion for $PM_{2.5}$ was not specified in the original version of the *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (DEC, 2005). As an alternative assessment criterion, the AQIA report (AEC, 2016) referred to the *National Environment Protection (Ambient Air Quality) Measure* (Air NEPM) (2016) standard for $PM_{2.5}$. The Air NEPM (2016) set the 24-hour and annual average ground-level concentration criteria at 25 µg/m³ and 8 µg/m³, respectively.

In January 2017, the *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW* (NSW EPA, 2017) were updated to include an impact assessment criterion for $PM_{2.5}$ that was consistent with the Air NEPM (2016). Consequently, the 24-hour and annual average ground-level concentration impact assessment criteria for $PM_{2.5}$, used in the air quality assessment and this addendum report, remain consistent at 25 µg/m³ and 8 µg/m³, respectively.

The current impact assessment criterion for the maximum 24-hour average ground-level concentration of PM_{10} (NSW EPA, 2017) is unchanged at 50 µg/m³ from the original version (DEC 2005). Notwithstanding this, the annual average impact assessment criterion for ground-level concentrations of PM_{10} was reduced in the revised Approved Methods (NSW EPA, 2017) from 30 µg/m³ to 25 µg/m³.

The changes in the impact assessment criteria of PM_{10} and $PM_{2.5}$ have not affected the conclusions of air quality assessment. Results of the assessment show that:

- Predicted maximum 24-hour and annual average ground-level concentrations of PM_{10} **complied** with the impact assessment criterion of 50 µg/m³ and 25 µg/m³, respectively. The assessment considered background concentrations determined from measurements within the region.
- Predicted maximum 24-hour ground-level and annual average ground-level concentrations of $PM_{2.5}$ **complied** with the impact assessment criterion of 25 µg/m³ and 8 µg/m³, respectively. The assessment considered background concentrations determined from measurements within the region.

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Appendix A. Impact Assessment

Power supply option 1 - routine operations

The air quality assessment report presented the ground-level concentrations of priority pollutants predicted beyond the boundary of Leewood due to impacts from Power supply option 1 – routine operations in isolation.

The ground-level concentrations of all other pollutants predicted beyond the boundary of Leewood due to impacts from Power supply option 1 – routine operations in isolation are presented in Table A 1.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted beyond the boundary of Leewood, due to cumulative impacts from Power supply option 1 – routine operations and well pad emissions at Leewood are presented in Table A 2.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted at the six closest sensitive receptors to the Leewood site, due to impacts from Power supply option 1 – routine operations in isolation are presented in Table A 3.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted at the six closest sensitive receptors to the Leewood site, due to cumulative impacts from Power supply option 1 – routine operations and well pad emissions at Leewood are presented in Table A 4.

Results show that:

- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood due to impacts from Power supply option 1 – routine operations in isolation, **comply** with the relevant air quality criteria.
- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood due to cumulative impacts from Power supply option 1 – routine operations and well pad emissions at Leewood, **comply** with the relevant air quality criteria.

The predicted maximum incremental maximum 24-hour average and annual average ground-level concentrations of $PM_{2.5}$ around the Leewood site, for Power supply option 1 – routine operations, with the inclusion of ambient background concentrations, are provided in Figure A-1 and Figure A-2.

The predicted maximum one-hour and annual average ground-level concentrations of NO_2 for Power supply option 1 – routine operations, with the inclusion of ambient background concentrations and including Wilga Park Power Station, are provided in Figure A-3 and Figure A-4.

Table A 1 Predicted maximum incremental ground-level pollutant concentrations beyond the boundary due to Power supply option 1 – routine operations (in isolation)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	Maximum beyond boundary (µg/m³)	% Criterion
1,1,2,2-Tetrachloroethane	Max	1-hour	70	3.32E-03	<0.01%
	Mean	Annual	7	3.33E-05	<0.01%
1,1,2-Trichloroethane	Max	1-hour	1000	2.64E-03	<0.01%
1,1-Dichloroethane	Max	1-hour	4000	1.96E-03	<0.01%
	Mean	Annual	400	1.97E-05	<0.01%
1,2,3-Trimethylbenzene	Max	1-hour	1250	1.91E-03	<0.01%
	Mean	Annual	125	1.92E-05	<0.01%
1,2,4-Trimethylbenzene	Max	1-hour	700	1.19E-03	<0.01%
	Mean	Annual	125	1.19E-05	<0.01%
1,2-Dichloroethane	Max	1-hour	70	1.96E-03	<0.01%
1,2-Dichloropropane	Max	1-hour	460	2.23E-03	<0.01%
	Mean	Annual	46	2.24E-05	<0.01%
1,3,5-Trimethylbenzene	Max	1-hour	1250	2.80E-03	<0.01%
	Mean	Annual	125	2.81E-05	<0.01%
1,3-Butadiene	Max	1-hour	40	2.22E-02	0.06%
1,3-Dichloropropene	Max	1-hour	45	2.19E-03	<0.01%
	Mean	Annual	4.5	2.19E-05	<0.01%
2,2,4-Trimethylpentane	Max	1-hour	3130	2.07E-02	<0.01%
	Mean	Annual	350	2.08E-04	<0.01%
2-Methylnaphthalene	Max	1-hour	30	2.75E-03	<0.01%
	Mean	Annual	3	2.78E-05	<0.01%
Acenaphthene	Max	1-hour	1	1.04E-04	0.01%
Acenaphthylene	Max	1-hour	200	4.60E-04	<0.01%
	Mean	Annual	50	4.63E-06	<0.01%
Anthracene	Max	1-hour	0.5	1.11E-06	<0.01%
	Mean	Annual	0.05	6.33E-08	<0.01%
Arsenic	Max	1-hour	0.09	1.07E-04	0.12%
Benzene	Max	1-hour	29	3.66E-02	0.13%
Benzo(b)fluoranthene	Max	1-hour	0.5	1.38E-05	<0.01%
	Mean	Annual	0.05	1.50E-07	<0.01%

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	Maximum beyond boundary (µg/m³)	% Criterion
Benzo(e)pyrene	Max	1-hour	0.5	3.45E-05	<0.01%
	Mean	Annual	0.05	3.46E-07	<0.01%
Benzo(k)fluoranthene	Max	1-hour	0.5	8.32E-07	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%
Beryllium	Max	1-hour	0.004	6.41E-07	0.02%
Biphenyl	Max	1-hour	24	1.76E-02	0.07%
Butane	Max	1-hour	66000	9.68E-01	<0.01%
	Mean	Annual	7200	5.56E-02	<0.01%
Butyr/Isobutyraldehyde	Max	1-hour	140	8.39E-03	<0.01%
	Mean	Annual	290	8.42E-05	<0.01%
Carbon Tetrachloride	Max	1-hour	12	3.04E-03	0.03%
Chlorobenzene	Max	1-hour	100	2.53E-03	<0.01%
Chloroethane	Max	1-hour	48000	1.55E-04	<0.01%
Chloroform	Max	1-hour	900	2.36E-03	<0.01%
Chromium III	Max	1-hour	9	7.48E-04	<0.01%
Chrysene	Max	1-hour	0.5	5.75E-05	0.01%
	Mean	Annual	0.05	5.89E-07	<0.01%
Copper	Max	1-hour	3.7	4.54E-04	0.01%
Cyclopentane	Max	1-hour	3400	1.88E-02	<0.01%
	Mean	Annual	340	1.88E-04	<0.01%
Dibenzo(a,h)anthracene	Max	1-hour	0.5	5.55E-07	<0.01%
	Mean	Annual	0.05	3.18E-08	<0.01%
Dichlorobenzene	Max	1-hour	5500	5.55E-04	<0.01%
Dioxins and furans	Max	1-hour	0.000002	2.64E-09	0.13%
Ethylbenzene	Max	1-hour	8000	3.30E-03	<0.01%
Ethylene Dibromide	Max	1-hour	4	3.68E-03	0.09%
	Mean	Annual	0.4	3.69E-05	<0.01%
Fluoranthene	Max	1-hour	0.5	9.21E-05	0.02%
Fluorene	Max	1-hour	10	4.71E-04	<0.01%
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	8.32E-07	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%
Lead	Mean	Annual	0.5	1.52E-05	<0.01%
Methanol	Max	1-hour	3000	2.07E-01	<0.01%

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	Maximum beyond boundary (µg/m³)	% Criterion
Methylcyclohexane	Max	1-hour	940	1.02E-01	0.01%
	Mean	Annual	94	1.03E-03	<0.01%
Methylene Chloride (Dichloromethane)	Max	1-hour	3190	1.67E-03	<0.01%
Naphthalene	Max	1-hour	200	6.17E-03	<0.01%
	Mean	Annual	50	6.59E-05	<0.01%
n-Hexane	Max	1-hour	3200	9.21E-02	<0.01%
n-Nonane	Max	1-hour	10500	9.13E-03	<0.01%
	Mean	Annual	1050	9.16E-05	<0.01%
n-Octane	Max	1-hour	3500	2.91E-02	<0.01%
	Mean	Annual	350	2.92E-04	<0.01%
n-Pentane	Max	1-hour	4100	1.20E+00	0.03%
	Mean	Annual	7100	6.98E-02	<0.01%
PAH as BaP	Max	1-hour	0.4	1.97E-06	<0.01%
Phenanthrene	Max	1-hour	0.5	8.63E-04	0.17%
	Mean	Annual	0.05	8.77E-06	0.02%
Phenol	Max	1-hour	20	1.99E-03	<0.01%
$PM_{2.5}$	Max	24-hour	25	1.15E+00	4.59%
	Mean	Annual	8	2.19E-01	2.74%
Pyrene	Max	1-hour	0.5	1.13E-04	0.02%
Styrene	Max	10-min	712	3.55E-03	<0.01%
	Max	1-hour	120	1.96E-03	<0.01%
Sulfur dioxide	Max	10-min	712	1.77E-01	0.02%
	Max	1-hour	570	9.79E-02	0.02%
	Max	24-hour	228	2.29E-02	0.01%
	Mean	Annual	60	4.77E-03	<0.01%
Tetrachloroethane	Max	1-hour	70	2.06E-04	<0.01%
	Mean	Annual	7	2.06E-06	<0.01%
Toluene	Max	1-hour	360	3.39E-02	<0.01%
Vinyl Chloride	Max	1-hour	24	1.24E-03	<0.01%
Xylene	Max	1-hour	190	1.53E-02	<0.01%

Table A 2 Predicted maximum incremental ground-level pollutant concentrations beyond the boundary due to Power supply option 1 – routine operations (with maximum incremental impacts from well pads at Leewood)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)	%	With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)	%
1,1,2,2-Tetrachloroethane	Max	1-hour	70	4.88E-03	<0.01%	3.32E-03	<0.01%
	Mean	Annual	7	2.87E-04	<0.01%	3.33E-05	<0.01%
1,1,2-Trichloroethane	Max	1-hour	1000	3.88E-03	<0.01%	2.64E-03	<0.01%
1,1-Dichloroethane	Max	1-hour	4000	2.88E-03	<0.01%	1.96E-03	<0.01%
	Mean	Annual	400	1.69E-04	<0.01%	1.97E-05	<0.01%
1,2,3-Trimethylbenzene	Max	1-hour	1250	2.80E-03	<0.01%	1.91E-03	<0.01%
	Mean	Annual	125	1.65E-04	<0.01%	1.92E-05	<0.01%
1,2,4-Trimethylbenzene	Max	1-hour	700	1.74E-03	<0.01%	1.19E-03	<0.01%
	Mean	Annual	125	1.03E-04	<0.01%	1.19E-05	<0.01%
1,2-Dichloroethane	Max	1-hour	70	2.88E-03	<0.01%	1.96E-03	<0.01%
1,2-Dichloropropane	Max	1-hour	460	3.28E-03	<0.01%	2.23E-03	<0.01%
	Mean	Annual	46	1.93E-04	<0.01%	2.24E-05	<0.01%
1,3,5-Trimethylbenzene	Max	1-hour	1250	4.12E-03	<0.01%	2.80E-03	<0.01%
	Mean	Annual	125	2.42E-04	<0.01%	2.81E-05	<0.01%
1,3-Butadiene	Max	1-hour	40	3.26E-02	0.08%	2.27E-02	0.06%
1,3-Dichloropropene	Max	1-hour	45	3.21E-03	<0.01%	2.19E-03	<0.01%
	Mean	Annual	4.5	1.89E-04	<0.01%	2.19E-05	<0.01%
2,2,4-Trimethylpentane	Max	1-hour	3130	3.05E-02	<0.01%	2.07E-02	<0.01%
	Mean	Annual	350	1.79E-03	<0.01%	2.08E-04	<0.01%
2-Methylnaphthalene	Max	1-hour	30	4.04E-03	0.01%	2.75E-03	<0.01%
	Mean	Annual	3	2.38E-04	<0.01%	2.78E-05	<0.01%
Acenaphthene	Max	1-hour	1	1.52E-04	0.02%	1.21E-04	0.01%
Acenaphthylene	Max	1-hour	200	6.75E-04	<0.01%	5.21E-04	<0.01%
	Mean	Annual	50	3.96E-05	<0.01%	1.46E-05	<0.01%
Acetaldehyde	9th	1-hour	42	5.70E-01	1.36%	2.57E-01	0.61%
Acrolein	9th	1-hour	0.42	3.49E-01	83.11%	1.51E-01	35.94%
Anthracene	Max	1-hour	0.5	1.11E-06	<0.01%	2.37E-05	<0.01%
	Mean	Annual	0.05	6.33E-08	<0.01%	3.74E-06	<0.01%

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)	%	With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)	%
Arsenic	Max	1-hour	0.09	1.07E-04	0.12%	1.07E-04	0.12%
Benzene	Max	1-hour	29	5.37E-02	0.19%	4.79E-02	0.17%
Benzo(b)fluoranthene	Max	1-hour	0.5	2.02E-05	<0.01%	1.50E-05	<0.01%
	Mean	Annual	0.05	1.20E-06	<0.01%	3.45E-07	<0.01%
Benzo(e)pyrene	Max	1-hour	0.5	5.06E-05	0.01%	3.45E-05	<0.01%
	Mean	Annual	0.05	2.97E-06	<0.01%	3.46E-07	<0.01%
Benzo(k)fluoranthene	Max	1-hour	0.5	8.32E-07	<0.01%	2.71E-06	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%	3.53E-07	<0.01%
Beryllium	Max	1-hour	0.004	6.41E-07	0.02%	6.41E-07	0.02%
Biphenyl	Max	1-hour	24	2.59E-02	0.11%	1.76E-02	0.07%
Butane	Max	1-hour	66000	9.89E-01	<0.01%	9.68E-01	<0.01%
	Mean	Annual	7200	5.91E-02	<0.01%	5.56E-02	<0.01%
Butyr/Isobutyraldehyde	Max	1-hour	140	1.23E-02	<0.01%	8.39E-03	<0.01%
	Mean	Annual	290	7.23E-04	<0.01%	8.42E-05	<0.01%
Cadmium	Max	1-hour	0.018	5.88E-04	3.27%	5.88E-04	3.27%
Carbon Monoxide	Max	1-hour	30000	4.18E+01	0.14%	2.62E+02	0.87%
	Max	8-hour	10000	2.35E+01	0.23%	1.68E+02	1.68%
Carbon Tetrachloride	Max	1-hour	12	4.47E-03	0.04%	3.04E-03	0.03%
Chlorobenzene	Max	1-hour	100	3.71E-03	<0.01%	2.53E-03	<0.01%
Chloroethane	Max	1-hour	48000	2.28E-04	<0.01%	1.55E-04	<0.01%
Chloroform	Max	1-hour	900	3.47E-03	<0.01%	2.36E-03	<0.01%
Chromium III	Max	1-hour	9	7.48E-04	<0.01%	7.48E-04	<0.01%
Chrysene	Max	1-hour	0.5	8.44E-05	0.02%	1.20E-04	0.02%
	Mean	Annual	0.05	4.98E-06	<0.01%	1.08E-05	0.02%
Copper	Max	1-hour	3.7	4.54E-04	0.01%	4.54E-04	0.01%
Cyclopentane	Max	1-hour	3400	2.76E-02	<0.01%	1.88E-02	<0.01%
	Mean	Annual	340	1.62E-03	<0.01%	1.88E-04	<0.01%
Dibenzo(a,h)anthracene	Max	1-hour	0.5	5.55E-07	<0.01%	6.47E-06	<0.01%
	Mean	Annual	0.05	3.18E-08	<0.01%	9.95E-07	<0.01%
Dichlorobenzene	Max	1-hour	5500	5.55E-04	<0.01%	5.55E-04	<0.01%
Dioxins and furans	Max	1-hour	0.000002	2.64E-09	0.13%	2.64E-09	0.13%

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired)		With maximum incremental impacts from well pads (diesel)	
				Concentration (µg/m³)	%	Concentration (µg/m³)	%
Ethylbenzene	Max	1-hour	8000	4.85E-03	<0.01%	3.30E-03	<0.01%
Ethylene Dibromide	Max	1-hour	4	5.40E-03	0.13%	3.68E-03	0.09%
	Mean	Annual	0.4	3.17E-04	0.08%	3.69E-05	<0.01%
Fluoranthene	Max	1-hour	0.5	1.35E-04	0.03%	1.84E-04	0.04%
Fluorene	Max	1-hour	10	6.92E-04	<0.01%	8.26E-04	<0.01%
Formaldehyde	9th	1-hour	20	3.61E+00	18.07%	1.58E+00	7.89%
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	8.32E-07	<0.01%	7.89E-06	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%	1.20E-06	<0.01%
Lead	Mean	Annual	0.5	1.52E-05	<0.01%	1.52E-05	<0.01%
Methanol	Max	1-hour	3000	3.05E-01	0.01%	2.07E-01	<0.01%
Methylcyclohexane	Max	1-hour	940	1.50E-01	0.02%	1.02E-01	0.01%
	Mean	Annual	94	8.80E-03	<0.01%	1.03E-03	<0.01%
Methylene Chloride (Dichloromethane)	Max	1-hour	3190	2.44E-03	<0.01%	1.67E-03	<0.01%
Naphthalene	Max	1-hour	200	9.06E-03	<0.01%	7.20E-03	<0.01%
	Mean	Annual	50	5.37E-04	<0.01%	2.33E-04	<0.01%
Nickel	Max	1-hour	0.18	1.12E-03	0.62%	1.12E-03	0.62%
Nitrogen dioxide	Max	1-hour	246	1.18E+02	47.98%	1.18E+02	47.98%
	Mean	Annual	62	8.84E+00	14.25%	8.84E+00	14.25%
Ozone	Max	1-hour	214	1.05E+02	48.97%	1.05E+02	48.97%
	Max	4-hour	171	1.57E+02	91.76%	1.57E+02	91.76%
n-Hexane	Max	1-hour	3200	1.35E-01	<0.01%	9.21E-02	<0.01%
n-Nonane	Max	1-hour	10500	1.34E-02	<0.01%	9.13E-03	<0.01%
	Mean	Annual	1050	7.88E-04	<0.01%	9.16E-05	<0.01%
n-Octane	Max	1-hour	3500	4.28E-02	<0.01%	2.91E-02	<0.01%
	Mean	Annual	350	2.51E-03	<0.01%	2.92E-04	<0.01%
n-Pentane	Max	1-hour	4100	1.30E+00	0.03%	1.20E+00	0.03%
	Mean	Annual	7100	8.62E-02	<0.01%	6.98E-02	<0.01%
PAH as BaP	Max	1-hour	0.4	1.97E-06	<0.01%	4.24E-06	<0.01%
Phenanthrene	Max	1-hour	0.5	1.27E-03	0.25%	1.22E-03	0.24%
	Mean	Annual	0.05	7.46E-05	0.15%	6.65E-05	0.13%
Phenol	Max	1-hour	20	2.92E-03	0.01%	1.99E-03	<0.01%

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired)		With maximum incremental impacts from well pads (diesel)	
				Concentration (µg/m³)	%	Concentration (µg/m³)	%
PM10	Max	24-hour	50	1.15E+00	2.29%	1.15E+00	2.29%
	Mean	Annual	25	2.19E-01	0.88%	2.19E-01	0.88%
PM2.5	Max	24-hour	25	1.35E+00	5.39%	5.80E+00	23.21%
	Mean	Annual	8	2.81E-01	3.51%	1.65E+00	20.62%
Pyrene	Max	1-hour	0.5	1.66E-04	0.03%	1.71E-04	0.03%
Styrene	Max	10-min	712	4.86E-03	<0.01%	3.55E-03	<0.01%
	Max	1-hour	120	2.88E-03	<0.01%	1.96E-03	<0.01%
Sulfur dioxide	Max	10-min	712	2.42E-01	0.03%	2.25E-01	0.03%
	Max	1-hour	570	1.43E-01	0.03%	1.32E-01	0.02%
	Max	24-hour	228	4.69E-02	0.02%	4.07E-02	0.02%
	Mean	Annual	60	1.21E-02	0.02%	1.02E-02	0.02%
Tetrachloroethane	Max	1-hour	70	3.02E-04	<0.01%	2.06E-04	<0.01%
	Mean	Annual	7	1.78E-05	<0.01%	2.06E-06	<0.01%
Toluene	Max	1-hour	360	4.97E-02	0.01%	3.88E-02	0.01%
Vinyl Chloride	Max	1-hour	24	1.82E-03	<0.01%	1.24E-03	<0.01%
Xylene	Max	1-hour	190	2.24E-02	0.01%	1.87E-02	<0.01%

Table A 3 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 1 – routine operations (in isolation)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
1,1,2,2-Tetrachloroethane	Max	1-hour	70	6.84E-04	1.01E-03	2.19E-03	1.69E-03	1.62E-03	1.50E-03
	Mean	Annual	7	8.20E-06	8.74E-06	7.43E-06	9.77E-06	8.65E-06	1.03E-05
1,1,2-Trichloroethane	Max	1-hour	1000	5.44E-04	8.05E-04	1.74E-03	1.34E-03	1.29E-03	1.20E-03
1,1-Dichloroethane	Max	1-hour	4000	4.04E-04	5.98E-04	1.29E-03	9.96E-04	9.57E-04	8.88E-04
	Mean	Annual	400	4.84E-06	5.16E-06	4.39E-06	5.76E-06	5.11E-06	6.05E-06
1,2,3-Trimethylbenzene	Max	1-hour	1250	3.94E-04	5.83E-04	1.26E-03	9.71E-04	9.34E-04	8.66E-04
	Mean	Annual	125	4.72E-06	5.03E-06	4.28E-06	5.62E-06	4.98E-06	5.90E-06
1,2,4-Trimethylbenzene	Max	1-hour	700	2.45E-04	3.62E-04	7.84E-04	6.03E-04	5.80E-04	5.38E-04
	Mean	Annual	125	2.93E-06	3.13E-06	2.66E-06	3.49E-06	3.09E-06	3.67E-06
1,2-Dichloroethane	Max	1-hour	70	4.04E-04	5.98E-04	1.29E-03	9.96E-04	9.57E-04	8.88E-04
1,2-Dichloropropane	Max	1-hour	460	4.61E-04	6.82E-04	1.48E-03	1.14E-03	1.09E-03	1.01E-03
	Mean	Annual	46	5.52E-06	5.89E-06	5.00E-06	6.57E-06	5.82E-06	6.90E-06
1,3,5-Trimethylbenzene	Max	1-hour	1250	5.77E-04	8.55E-04	1.85E-03	1.42E-03	1.37E-03	1.27E-03
	Mean	Annual	125	6.92E-06	7.38E-06	6.27E-06	8.24E-06	7.30E-06	8.65E-06
1,3-Butadiene	Max	1-hour	40	4.57E-03	6.77E-03	1.47E-02	1.13E-02	1.08E-02	1.01E-02
1,3-Dichloropropene	Max	1-hour	45	4.51E-04	6.67E-04	1.44E-03	1.11E-03	1.07E-03	9.91E-04
	Mean	Annual	4.5	5.40E-06	5.76E-06	4.90E-06	6.43E-06	5.70E-06	6.75E-06
2,2,4-Trimethylpentane	Max	1-hour	3130	4.27E-03	6.32E-03	1.37E-02	1.05E-02	1.01E-02	9.40E-03
	Mean	Annual	350	5.12E-05	5.46E-05	4.64E-05	6.10E-05	5.40E-05	6.40E-05
2-Methylnaphthalene	Max	1-hour	30	5.67E-04	8.40E-04	1.82E-03	1.40E-03	1.34E-03	1.25E-03
	Mean	Annual	3	6.84E-06	7.28E-06	6.19E-06	8.12E-06	7.19E-06	8.52E-06
Acenaphthene	Max	1-hour	1	2.14E-05	3.17E-05	6.86E-05	5.28E-05	5.07E-05	4.71E-05
Acenaphthylene	Max	1-hour	200	9.48E-05	1.40E-04	3.04E-04	2.34E-04	2.25E-04	2.08E-04
	Mean	Annual	50	1.14E-06	1.21E-06	1.03E-06	1.35E-06	1.20E-06	1.42E-06
Acetaldehyde	9th	1-hour	42	8.67E-02	1.04E-01	1.18E-01	1.27E-01	1.24E-01	1.17E-01
Acrolein	9th	1-hour	0.42	5.24E-02	6.27E-02	7.12E-02	7.67E-02	7.49E-02	7.06E-02
Anthracene	Max	1-hour	0.5	1.70E-07	2.08E-07	2.70E-07	2.87E-07	3.13E-07	2.64E-07
	Mean	Annual	0.05	3.75E-09	2.99E-09	2.13E-09	1.94E-09	1.44E-09	1.19E-09
Arsenic	Max	1-hour	0.09	1.65E-05	2.01E-05	2.61E-05	2.78E-05	3.02E-05	2.55E-05
Benzene	Max	1-hour	29	7.56E-03	1.12E-02	2.42E-02	1.86E-02	1.79E-02	1.66E-02

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
Benzo(b)fluoranthene	Max	1-hour	0.5	2.85E-06	4.21E-06	9.12E-06	7.02E-06	6.73E-06	6.26E-06
	Mean	Annual	0.05	3.69E-08	3.85E-08	3.25E-08	4.20E-08	3.70E-08	4.35E-08
Benzo(e)pyrene	Max	1-hour	0.5	7.11E-06	1.05E-05	2.28E-05	1.75E-05	1.69E-05	1.56E-05
	Mean	Annual	0.05	8.52E-08	9.08E-08	7.72E-08	1.01E-07	8.99E-08	1.07E-07
Benzo(k)fluoranthene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10
Beryllium	Max	1-hour	0.004	9.87E-08	1.21E-07	1.56E-07	1.67E-07	1.81E-07	1.53E-07
Biphenyl	Max	1-hour	24	3.64E-03	5.38E-03	1.17E-02	8.97E-03	8.62E-03	8.00E-03
Butane	Max	1-hour	66000	1.49E-01	1.82E-01	2.36E-01	2.52E-01	2.74E-01	2.31E-01
	Mean	Annual	7200	3.39E-03	2.74E-03	1.96E-03	1.83E-03	1.38E-03	1.18E-03
Butyr/Isobutyraldehyde	Max	1-hour	140	1.73E-03	2.56E-03	5.54E-03	4.26E-03	4.10E-03	3.80E-03
	Mean	Annual	290	2.07E-05	2.21E-05	1.88E-05	2.47E-05	2.19E-05	2.59E-05
Cadmium	Max	1-hour	0.018	9.05E-05	1.11E-04	1.43E-04	1.53E-04	1.66E-04	1.40E-04
Carbon Monoxide	Max	1-hour	30000	5.53E+00	6.76E+00	8.77E+00	9.34E+00	1.02E+01	8.58E+00
	Max	8-hour	10000	2.82E+00	3.80E+00	2.17E+00	2.17E+00	2.71E+00	2.56E+00
Carbon Tetrachloride	Max	1-hour	12	6.27E-04	9.29E-04	2.01E-03	1.55E-03	1.49E-03	1.38E-03
Chlorobenzene	Max	1-hour	100	5.21E-04	7.71E-04	1.67E-03	1.28E-03	1.23E-03	1.15E-03
Chloroethane	Max	1-hour	48000	3.20E-05	4.74E-05	1.03E-04	7.89E-05	7.59E-05	7.04E-05
Chloroform	Max	1-hour	900	4.87E-04	7.21E-04	1.56E-03	1.20E-03	1.16E-03	1.07E-03
Chromium III	Max	1-hour	9	1.15E-04	1.41E-04	1.83E-04	1.95E-04	2.12E-04	1.79E-04
Chrysene	Max	1-hour	0.5	1.19E-05	1.75E-05	3.80E-05	2.92E-05	2.81E-05	2.61E-05
	Mean	Annual	0.05	1.45E-07	1.54E-07	1.30E-07	1.71E-07	1.51E-07	1.79E-07
Copper	Max	1-hour	3.7	6.99E-05	8.54E-05	1.11E-04	1.18E-04	1.28E-04	1.09E-04
Cyclopentane	Max	1-hour	3400	3.87E-03	5.73E-03	1.24E-02	9.55E-03	9.18E-03	8.51E-03
	Mean	Annual	340	4.64E-05	4.95E-05	4.21E-05	5.53E-05	4.90E-05	5.80E-05
Dibenzo(a,h)anthracene	Max	1-hour	0.5	8.54E-08	1.04E-07	1.35E-07	1.44E-07	1.57E-07	1.32E-07
	Mean	Annual	0.05	1.88E-09	1.50E-09	1.07E-09	9.75E-10	7.23E-10	5.98E-10
Dichlorobenzene	Max	1-hour	5500	8.54E-05	1.04E-04	1.35E-04	1.44E-04	1.57E-04	1.32E-04
Dioxins and furans	Max	1-hour	0.000002	4.07E-10	4.97E-10	6.45E-10	6.87E-10	7.48E-10	6.32E-10
Ethylbenzene	Max	1-hour	8000	6.81E-04	1.01E-03	2.18E-03	1.68E-03	1.61E-03	1.50E-03
Ethylene Dibromide	Max	1-hour	4	7.58E-04	1.12E-03	2.43E-03	1.87E-03	1.80E-03	1.67E-03
	Mean	Annual	0.4	9.08E-06	9.68E-06	8.23E-06	1.08E-05	9.58E-06	1.14E-05
Fluoranthene	Max	1-hour	0.5	1.90E-05	2.81E-05	6.09E-05	4.69E-05	4.50E-05	4.18E-05

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
Fluorene	Max	1-hour	10	9.71E-05	1.44E-04	3.11E-04	2.40E-04	2.30E-04	2.14E-04
Formaldehyde	9th	1-hour	20	5.46E-01	6.54E-01	7.43E-01	8.01E-01	7.81E-01	7.36E-01
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10
Lead	Mean	Annual	0.5	9.03E-07	7.21E-07	5.12E-07	4.68E-07	3.47E-07	2.87E-07
Methanol	Max	1-hour	3000	4.27E-02	6.32E-02	1.37E-01	1.05E-01	1.01E-01	9.40E-02
Methylcyclohexane	Max	1-hour	940	2.11E-02	3.12E-02	6.75E-02	5.19E-02	4.99E-02	4.63E-02
	Mean	Annual	94	2.52E-04	2.69E-04	2.29E-04	3.01E-04	2.66E-04	3.16E-04
Methylene Chloride (Dichloromethane)	Max	1-hour	3190	3.44E-04	5.09E-04	1.10E-03	8.48E-04	8.15E-04	7.56E-04
Naphthalene	Max	1-hour	200	1.28E-03	1.88E-03	4.08E-03	3.14E-03	3.01E-03	2.80E-03
	Mean	Annual	50	1.62E-05	1.70E-05	1.44E-05	1.86E-05	1.64E-05	1.94E-05
Nickel	Max	1-hour	0.18	1.72E-04	2.10E-04	2.72E-04	2.90E-04	3.15E-04	2.66E-04
Nitrogen dioxide	Max	1-hour	246	1.55E+01	1.89E+01	2.91E+01	2.61E+01	2.84E+01	2.40E+01
	Mean	Annual	62	4.41E-01	3.78E-01	2.84E-01	2.96E-01	2.36E-01	2.33E-01
Ozone	Max	1-hour	214	1.61E+01	1.97E+01	3.03E+01	2.72E+01	2.96E+01	2.50E+01
	Max	4-hour	171	1.03E+01	1.48E+01	1.09E+01	9.66E+00	1.38E+01	1.22E+01
n-Hexane	Max	1-hour	3200	1.90E-02	2.81E-02	6.09E-02	4.68E-02	4.50E-02	4.18E-02
n-Nonane	Max	1-hour	10500	1.88E-03	2.79E-03	6.03E-03	4.64E-03	4.46E-03	4.14E-03
	Mean	Annual	1050	2.26E-05	2.41E-05	2.05E-05	2.69E-05	2.38E-05	2.82E-05
n-Octane	Max	1-hour	3500	6.01E-03	8.89E-03	1.92E-02	1.48E-02	1.42E-02	1.32E-02
	Mean	Annual	350	7.20E-05	7.68E-05	6.53E-05	8.58E-05	7.60E-05	9.01E-05
n-Pentane	Max	1-hour	4100	1.84E-01	2.25E-01	2.92E-01	3.11E-01	3.39E-01	2.86E-01
	Mean	Annual	7100	4.60E-03	3.81E-03	2.79E-03	2.74E-03	2.12E-03	1.96E-03
PAH as BaP	Max	1-hour	0.4	4.12E-07	6.02E-07	1.31E-06	1.01E-06	9.57E-07	8.95E-07
Phenanthrene	Max	1-hour	0.5	1.78E-04	2.63E-04	5.70E-04	4.39E-04	4.22E-04	3.91E-04
	Mean	Annual	0.05	2.16E-06	2.29E-06	1.95E-06	2.55E-06	2.26E-06	2.68E-06
Phenol	Max	1-hour	20	4.10E-04	6.08E-04	1.32E-03	1.01E-03	9.73E-04	9.03E-04
PM_{10}	Max	24-hour	50	1.12E-01	1.89E-01	9.14E-02	9.89E-02	9.25E-02	1.09E-01
	Mean	Annual	25	1.61E-02	1.38E-02	1.04E-02	1.08E-02	8.60E-03	8.48E-03
$PM_{2.5}$	Max	24-hour	25	1.12E-01	1.89E-01	9.14E-02	9.89E-02	9.25E-02	1.09E-01
	Mean	Annual	8	1.61E-02	1.38E-02	1.04E-02	1.08E-02	8.60E-03	8.48E-03
Pyrene	Max	1-hour	0.5	2.33E-05	3.44E-05	7.46E-05	5.74E-05	5.51E-05	5.12E-05

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
Styrene	Max	10-minute	712	7.31E-04	1.08E-03	2.34E-03	1.80E-03	1.73E-03	1.61E-03
	Max	1-hour	120	4.04E-04	5.98E-04	1.29E-03	9.96E-04	9.57E-04	8.88E-04
Sulfur dioxide	Max	10-minute	712	3.83E-02	5.46E-02	1.19E-01	9.20E-02	8.59E-02	8.13E-02
	Max	1-hour	570	2.11E-02	3.02E-02	6.59E-02	5.08E-02	4.75E-02	4.49E-02
	Max	24-hour	228	4.14E-03	4.52E-03	3.09E-03	3.76E-03	3.55E-03	2.94E-03
	Mean	Annual	60	4.90E-04	4.55E-04	3.59E-04	4.15E-04	3.49E-04	3.80E-04
Tetrachloroethane	Max	1-hour	70	4.24E-05	6.27E-05	1.36E-04	1.05E-04	1.00E-04	9.32E-05
	Mean	Annual	7	5.08E-07	5.42E-07	4.61E-07	6.05E-07	5.36E-07	6.35E-07
Toluene	Max	1-hour	360	7.00E-03	1.03E-02	2.24E-02	1.72E-02	1.65E-02	1.54E-02
Vinyl Chloride	Max	1-hour	24	2.55E-04	3.77E-04	8.17E-04	6.29E-04	6.04E-04	5.61E-04
Xylene	Max	1-hour	190	3.15E-03	4.66E-03	1.01E-02	7.76E-03	7.46E-03	6.92E-03

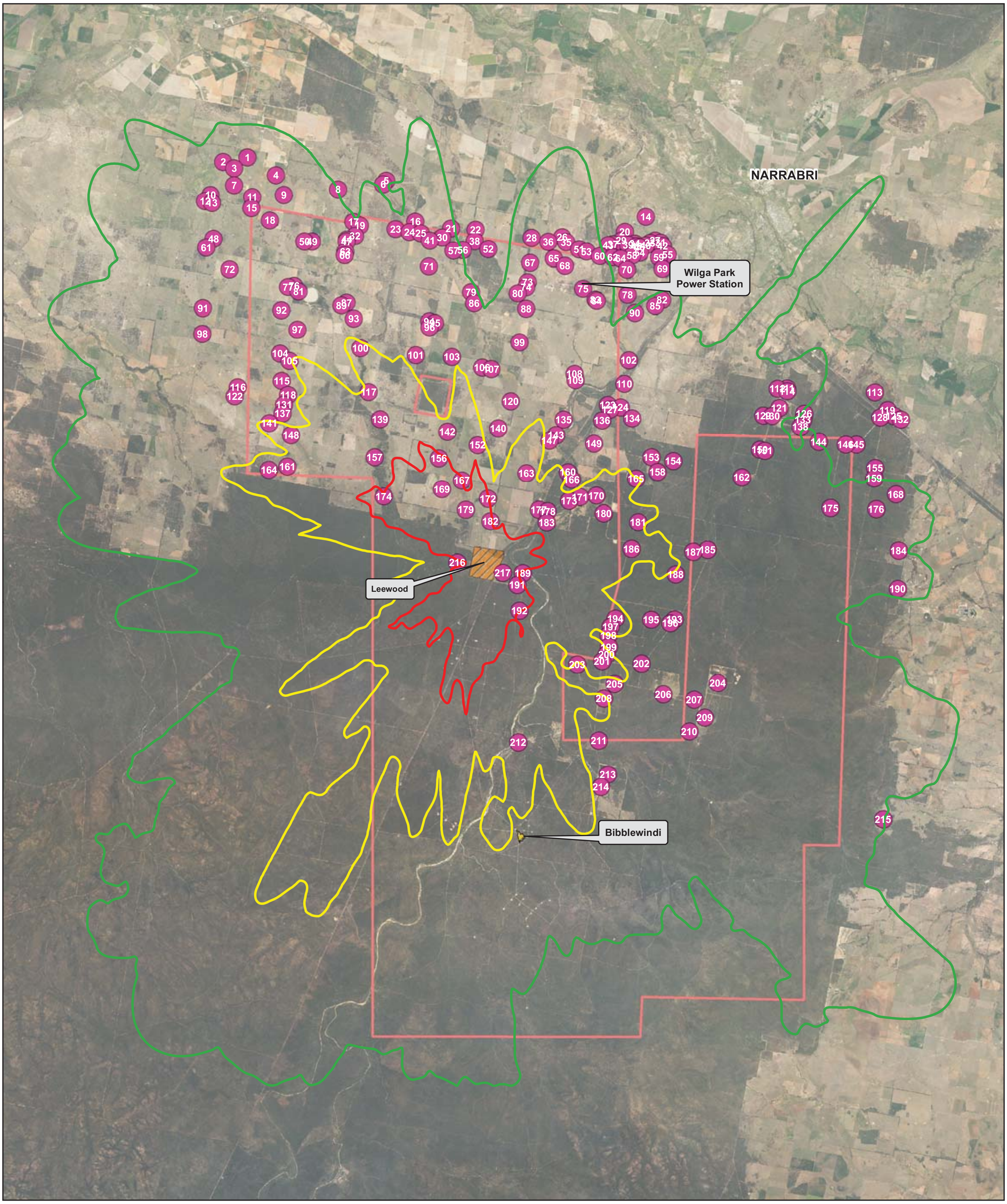
Table A 4 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 1 – routine operations (with maximum incremental impacts from well pads at Leewood)

Pollutant	Stat.	Ave. Period	Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)						With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
1,1,2,2-Tetrachloroethane	Max	1-hour	70	2.24E-03	2.57E-03	3.75E-03	3.24E-03	3.18E-03	3.06E-03	6.84E-04	1.01E-03	2.19E-03	1.69E-03	1.62E-03	1.50E-03
	Mean	Annual	7	2.61E-04	2.62E-04	2.61E-04	2.63E-04	2.62E-04	2.63E-04	8.20E-06	8.74E-06	7.43E-06	9.77E-06	8.65E-06	1.03E-05
1,1,2-Trichloroethane	Max	1-hour	1000	1.78E-03	2.04E-03	2.98E-03	2.58E-03	2.53E-03	2.43E-03	5.44E-04	8.05E-04	1.74E-03	1.34E-03	1.29E-03	1.20E-03
1,1-Dichloroethane	Max	1-hour	4000	1.32E-03	1.51E-03	2.21E-03	1.91E-03	1.87E-03	1.81E-03	4.04E-04	5.98E-04	1.29E-03	9.96E-04	9.57E-04	8.88E-04
	Mean	Annual	400	1.54E-04	1.54E-04	1.54E-04	1.55E-04	1.54E-04	1.55E-04	4.84E-06	5.16E-06	4.39E-06	5.76E-06	5.11E-06	6.05E-06
1,2,3-Trimethylbenzene	Max	1-hour	1250	1.29E-03	1.48E-03	2.16E-03	1.86E-03	1.83E-03	1.76E-03	3.94E-04	5.83E-04	1.26E-03	9.71E-04	9.34E-04	8.66E-04
	Mean	Annual	125	1.50E-04	1.50E-04	1.50E-04	1.51E-04	1.50E-04	1.51E-04	4.72E-06	5.03E-06	4.28E-06	5.62E-06	4.98E-06	5.90E-06
1,2,4-Trimethylbenzene	Max	1-hour	700	8.01E-04	9.19E-04	1.34E-03	1.16E-03	1.14E-03	1.09E-03	2.45E-04	3.62E-04	7.84E-04	6.03E-04	5.80E-04	5.38E-04
	Mean	Annual	125	9.35E-05	9.37E-05	9.33E-05	9.41E-05	9.37E-05	9.43E-05	2.93E-06	3.13E-06	2.66E-06	3.49E-06	3.09E-06	3.67E-06
1,2-Dichloroethane	Max	1-hour	70	1.32E-03	1.51E-03	2.21E-03	1.91E-03	1.87E-03	1.81E-03	4.04E-04	5.98E-04	1.29E-03	9.96E-04	9.57E-04	8.88E-04
1,2-Dichloropropane	Max	1-hour	460	1.51E-03	1.73E-03	2.52E-03	2.18E-03	2.14E-03	2.06E-03	4.61E-04	6.82E-04	1.48E-03	1.14E-03	1.09E-03	1.01E-03
	Mean	Annual	46	1.76E-04	1.76E-04	1.75E-04	1.77E-04	1.76E-04	1.77E-04	5.52E-06	5.89E-06	5.00E-06	6.57E-06	5.82E-06	6.90E-06
1,3,5-Trimethylbenzene	Max	1-hour	1250	1.89E-03	2.17E-03	3.17E-03	2.74E-03	2.68E-03	2.59E-03	5.77E-04	8.55E-04	1.85E-03	1.42E-03	1.37E-03	1.27E-03
	Mean	Annual	125	2.21E-04	2.21E-04	2.20E-04	2.22E-04	2.21E-04	2.23E-04	6.92E-06	7.38E-06	6.27E-06	8.24E-06	7.30E-06	8.65E-06
1,3-Butadiene	Max	1-hour	40	1.49E-02	1.71E-02	2.50E-02	2.16E-02	2.12E-02	2.04E-02	5.04E-03	7.24E-03	1.51E-02	1.17E-02	1.13E-02	1.05E-02
1,3-Dichloropropene	Max	1-hour	45	1.48E-03	1.69E-03	2.47E-03	2.14E-03	2.09E-03	2.02E-03	4.51E-04	6.67E-04	1.44E-03	1.11E-03	1.07E-03	9.91E-04
	Mean	Annual	4.5	1.72E-04	1.73E-04	1.72E-04	1.73E-04	1.73E-04	1.74E-04	5.40E-06	5.76E-06	4.90E-06	6.43E-06	5.70E-06	6.75E-06
2,2,4-Trimethylpentane	Max	1-hour	3130	1.40E-02	1.61E-02	2.34E-02	2.03E-02	1.99E-02	1.91E-02	4.27E-03	6.32E-03	1.37E-02	1.05E-02	1.01E-02	9.40E-03
	Mean	Annual	350	1.63E-03	1.64E-03	1.63E-03	1.64E-03	1.64E-03	1.65E-03	5.12E-05	5.46E-05	4.64E-05	6.10E-05	5.40E-05	6.40E-05
2-Methylnaphthalene	Max	1-hour	30	1.86E-03	2.13E-03	3.11E-03	2.69E-03	2.64E-03	2.54E-03	5.67E-04	8.40E-04	1.82E-03	1.40E-03	1.34E-03	1.25E-03
	Mean	Annual	3	2.17E-04	2.18E-04	2.16E-04	2.18E-04	2.17E-04	2.19E-04	6.84E-06	7.28E-06	6.19E-06	8.12E-06	7.19E-06	8.52E-06
Acenaphthene	Max	1-hour	1	7.00E-05	8.03E-05	1.17E-04	1.01E-04	9.94E-05	9.57E-05	3.86E-05	4.88E-05	8.57E-05	6.99E-05	6.79E-05	6.42E-05
Acenaphthylene	Max	1-hour	200	3.10E-04	3.55E-04	5.19E-04	4.49E-04	4.40E-04	4.24E-04	1.56E-04	2.02E-04	3.65E-04	2.95E-04	2.86E-04	2.70E-04
	Mean	Annual	50	3.61E-05	3.62E-05	3.60E-05	3.64E-05	3.62E-05	3.64E-05	1.11E-05	1.12E-05	1.10E-05	1.13E-05	1.12E-05	1.14E-05
Acetaldehyde	9th	1-hour	42	4.09E-01	4.26E-01	4.40E-01	4.49E-01	4.46E-01	4.39E-01	9.60E-02	1.13E-01	1.27E-01	1.36E-01	1.33E-01	1.26E-01
Acrolein	9th	1-hour	0.42	2.52E-01	2.62E-01	2.70E-01	2.76E-01	2.74E-01	2.70E-01	5.35E-02	6.38E-02	7.23E-02	7.79E-02	7.60E-02	7.18E-02
Anthracene	Max	1-hour	0.5	1.70E-07	2.08E-07	2.70E-07	2.87E-07	3.13E-07	2.64E-07	2.28E-05	2.28E-05	2.29E-05	2.29E-05	2.29E-05	2.29E-05
	Mean	Annual	0.05	3.75E-09	2.99E-09	2.13E-09	1.94E-09	1.44E-09	1.19E-09	3.69E-06	3.68E-06	3.68E-06	3.68E-06	3.68E-06	3.68E-06
Arsenic	Max	1-hour	0.09	1.65E-05	2.01E-05	2.61E-05	2.78E-05	3.02E-05	2.55E-05	1.65E-05	2.01E-05	2.61E-05	2.78E-05	3.02E-05	2.55E-05
Benzene	Max	1-hour	29	2.47E-02	2.83E-02	4.13E-02	3.57E-02	3.50E-02	3.37E-02	1.88E-02	2.25E-02	3.55E-02	2.99E-02	2.92E-02	2.79E-02

Pollutant	Stat.	Ave. Period	Criterion ($\mu g/m^3$)	With maximum incremental impacts from well pads (gas-fired) Concentration ($\mu g/m^3$)						With maximum incremental impacts from well pads (diesel) Concentration ($\mu g/m^3$)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
Benzo(b)fluoranthene	Max	1-hour	0.5	9.30E-06	1.07E-05	1.56E-05	1.35E-05	1.32E-05	1.27E-05	4.05E-06	5.41E-06	1.03E-05	8.22E-06	7.93E-06	7.45E-06
	Mean	Annual	0.05	1.09E-06	1.09E-06	1.08E-06	1.09E-06	1.09E-06	1.09E-06	2.32E-07	2.34E-07	2.27E-07	2.37E-07	2.32E-07	2.39E-07
Benzo(e)pyrene	Max	1-hour	0.5	2.33E-05	2.67E-05	3.89E-05	3.37E-05	3.30E-05	3.18E-05	7.11E-06	1.05E-05	2.28E-05	1.75E-05	1.69E-05	1.56E-05
	Mean	Annual	0.05	2.71E-06	2.72E-06	2.70E-06	2.73E-06	2.72E-06	2.73E-06	8.52E-08	9.08E-08	7.72E-08	1.01E-07	8.99E-08	1.07E-07
Benzo(k)fluoranthene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07	2.00E-06	2.03E-06	2.08E-06	2.09E-06	2.11E-06	2.07E-06
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10	3.08E-07	3.07E-07	3.07E-07	3.07E-07	3.06E-07	3.06E-07
Beryllium	Max	1-hour	0.004	9.87E-08	1.21E-07	1.56E-07	1.67E-07	1.81E-07	1.53E-07	9.87E-08	1.21E-07	1.56E-07	1.67E-07	1.81E-07	1.53E-07
Biphenyl	Max	1-hour	24	1.19E-02	1.36E-02	1.99E-02	1.72E-02	1.69E-02	1.62E-02	3.64E-03	5.38E-03	1.17E-02	8.97E-03	8.62E-03	8.00E-03
Butane	Max	1-hour	66000	1.70E-01	2.03E-01	2.57E-01	2.73E-01	2.95E-01	2.52E-01	1.49E-01	1.82E-01	2.36E-01	2.52E-01	2.74E-01	2.31E-01
	Mean	Annual	7200	6.82E-03	6.16E-03	5.38E-03	5.26E-03	4.80E-03	4.61E-03	3.39E-03	2.74E-03	1.96E-03	1.83E-03	1.38E-03	1.18E-03
Butyr/Isobutyraldehyde	Max	1-hour	140	5.66E-03	6.49E-03	9.47E-03	8.19E-03	8.02E-03	7.73E-03	1.73E-03	2.56E-03	5.54E-03	4.26E-03	4.10E-03	3.80E-03
	Mean	Annual	290	6.60E-04	6.61E-04	6.58E-04	6.64E-04	6.61E-04	6.65E-04	2.07E-05	2.21E-05	1.88E-05	2.47E-05	2.19E-05	2.59E-05
Cadmium	Max	1-hour	0.018	9.05E-05	1.11E-04	1.43E-04	1.53E-04	1.66E-04	1.40E-04	9.05E-05	1.11E-04	1.43E-04	1.53E-04	1.66E-04	1.40E-04
Carbon Monoxide	Max	1-hour	30000	1.14E+01	1.26E+01	1.46E+01	1.52E+01	1.60E+01	1.44E+01	2.31E+02	2.32E+02	2.34E+02	2.35E+02	2.36E+02	2.34E+02
	Max	8-hour	10000	6.69E+00	7.66E+00	6.04E+00	6.04E+00	6.57E+00	6.42E+00	1.52E+02	1.53E+02	1.51E+02	1.51E+02	1.52E+02	1.51E+02
Carbon Tetrachloride	Max	1-hour	12	2.05E-03	2.36E-03	3.44E-03	2.97E-03	2.91E-03	2.81E-03	6.27E-04	9.29E-04	2.01E-03	1.55E-03	1.49E-03	1.38E-03
Chlorobenzene	Max	1-hour	100	1.70E-03	1.95E-03	2.85E-03	2.46E-03	2.41E-03	2.33E-03	5.21E-04	7.71E-04	1.67E-03	1.28E-03	1.23E-03	1.15E-03
Chloroethane	Max	1-hour	48000	1.05E-04	1.20E-04	1.75E-04	1.52E-04	1.49E-04	1.43E-04	3.20E-05	4.74E-05	1.03E-04	7.89E-05	7.59E-05	7.04E-05
Chloroform	Max	1-hour	900	1.59E-03	1.83E-03	2.67E-03	2.31E-03	2.26E-03	2.18E-03	4.87E-04	7.21E-04	1.56E-03	1.20E-03	1.16E-03	1.07E-03
Chromium III	Max	1-hour	9	1.15E-04	1.41E-04	1.83E-04	1.95E-04	2.12E-04	1.79E-04	1.15E-04	1.41E-04	1.83E-04	1.95E-04	2.12E-04	1.79E-04
Chrysene	Max	1-hour	0.5	3.88E-05	4.45E-05	6.49E-05	5.62E-05	5.50E-05	5.30E-05	7.47E-05	8.04E-05	1.01E-04	9.21E-05	9.10E-05	8.89E-05
	Mean	Annual	0.05	4.53E-06	4.54E-06	4.52E-06	4.56E-06	4.54E-06	4.57E-06	1.04E-05	1.04E-05	1.04E-05	1.04E-05	1.04E-05	1.04E-05
Copper	Max	1-hour	3.7	6.99E-05	8.54E-05	1.11E-04	1.18E-04	1.28E-04	1.09E-04	6.99E-05	8.54E-05	1.11E-04	1.18E-04	1.28E-04	1.09E-04
Cyclopentane	Max	1-hour	3400	1.27E-02	1.46E-02	2.12E-02	1.84E-02	1.80E-02	1.73E-02	3.87E-03	5.73E-03	1.24E-02	9.55E-03	9.18E-03	8.51E-03
	Mean	Annual	340	1.48E-03	1.48E-03	1.48E-03	1.49E-03	1.48E-03	1.49E-03	4.64E-05	4.95E-05	4.21E-05	5.53E-05	4.90E-05	5.80E-05
Dibenzo(a,h)anthracen e	Max	1-hour	0.5	8.54E-08	1.04E-07	1.35E-07	1.44E-07	1.57E-07	1.32E-07	6.00E-06	6.02E-06	6.05E-06	6.06E-06	6.08E-06	6.05E-06
	Mean	Annual	0.05	1.88E-09	1.50E-09	1.07E-09	9.75E-10	7.23E-10	5.98E-10	9.65E-07	9.65E-07	9.64E-07	9.64E-07	9.64E-07	9.64E-07
Dichlorobenzene	Max	1-hour	5500	8.54E-05	1.04E-04	1.35E-04	1.44E-04	1.57E-04	1.32E-04	8.54E-05	1.04E-04	1.35E-04	1.44E-04	1.57E-04	1.32E-04
Dioxins and furans	Max	1-hour	0.000002	4.07E-10	4.97E-10	6.45E-10	6.87E-10	7.48E-10	6.32E-10	4.07E-10	4.97E-10	6.45E-10	6.87E-10	7.48E-10	6.32E-10
Ethylbenzene	Max	1-hour	8000	2.22E-03	2.55E-03	3.73E-03	3.22E-03	3.16E-03	3.04E-03	6.81E-04	1.01E-03	2.18E-03	1.68E-03	1.61E-03	1.50E-03
Ethylene Dibromide	Max	1-hour	4	2.48E-03	2.84E-03	4.15E-03	3.59E-03	3.52E-03	3.39E-03	7.58E-04	1.12E-03	2.43E-03	1.87E-03	1.80E-03	1.67E-03
	Mean	Annual	0.4	2.89E-04	2.90E-04	2.89E-04	2.91E-04	2.90E-04	2.92E-04	9.08E-06	9.68E-06	8.23E-06	1.08E-05	9.58E-06	1.14E-05
Fluoranthene	Max	1-hour	0.5	6.21E-05	7.12E-05	1.04E-04	8.99E-05	8.81E-05	8.49E-05	1.11E-04	1.20E-04	1.53E-04	1.39E-04	1.37E-04	1.34E-04
Fluorene	Max	1-hour	10	3.17E-04	3.64E-04	5.32E-04	4.60E-04	4.51E-04	4.34E-04	4.52E-04	4.98E-04	6.66E-04	5.94E-04	5.85E-04	5.68E-04

Pollutant	Stat.	Ave. Period	Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)						With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
Formaldehyde	9th	1-hour	20	2.60E+00	2.70E+00	2.79E+00	2.85E+00	2.83E+00	2.79E+00	5.61E-01	6.68E-01	7.58E-01	8.15E-01	7.95E-01	7.51E-01
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07	7.19E-06	7.22E-06	7.26E-06	7.28E-06	7.30E-06	7.26E-06
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10	1.15E-06	1.15E-06	1.15E-06	1.15E-06	1.15E-06	1.15E-06
Lead	Mean	Annual	0.5	9.03E-07	7.21E-07	5.12E-07	4.68E-07	3.47E-07	2.87E-07	9.03E-07	7.21E-07	5.12E-07	4.68E-07	3.47E-07	2.87E-07
Methanol	Max	1-hour	3000	1.40E-01	1.61E-01	2.34E-01	2.03E-01	1.99E-01	1.91E-01	4.27E-02	6.32E-02	1.37E-01	1.05E-01	1.01E-01	9.40E-02
Methylcyclohexane	Max	1-hour	940	6.88E-02	7.89E-02	1.15E-01	9.97E-02	9.77E-02	9.41E-02	2.11E-02	3.12E-02	6.75E-02	5.19E-02	4.99E-02	4.63E-02
	Mean	Annual	94	8.03E-03	8.04E-03	8.00E-03	8.07E-03	8.04E-03	8.09E-03	2.52E-04	2.69E-04	2.29E-04	3.01E-04	2.66E-04	3.16E-04
Methylene Chloride (Dichloromethane)	Max	1-hour	3190	1.12E-03	1.29E-03	1.88E-03	1.62E-03	1.59E-03	1.53E-03	3.44E-04	5.09E-04	1.10E-03	8.48E-04	8.15E-04	7.56E-04
Naphthalene	Max	1-hour	200	4.17E-03	4.78E-03	6.97E-03	6.03E-03	5.91E-03	5.69E-03	2.30E-03	2.91E-03	5.11E-03	4.17E-03	4.04E-03	3.83E-03
	Mean	Annual	50	4.87E-04	4.88E-04	4.85E-04	4.89E-04	4.87E-04	4.90E-04	1.83E-04	1.84E-04	1.81E-04	1.86E-04	1.83E-04	1.86E-04
Nickel	Max	1-hour	0.18	1.72E-04	2.10E-04	2.72E-04	2.90E-04	3.15E-04	2.66E-04	1.72E-04	2.10E-04	2.72E-04	2.90E-04	3.15E-04	2.66E-04
Nitrogen dioxide	Max	1-hour	246	3.30E+01	3.65E+01	4.67E+01	4.37E+01	4.60E+01	4.16E+01	3.30E+01	3.65E+01	4.67E+01	4.37E+01	4.60E+01	4.16E+01
	Mean	Annual	62	3.30E+00	3.24E+00	3.14E+00	3.16E+00	3.10E+00	3.09E+00	3.30E+00	3.24E+00	3.14E+00	3.16E+00	3.10E+00	3.09E+00
Ozone	Max	1-hour	214	1.61E+01	1.97E+01	3.03E+01	2.72E+01	2.96E+01	2.50E+01	1.61E+01	1.97E+01	3.03E+01	2.72E+01	2.96E+01	2.50E+01
	Max	4-hour	171	1.03E+01	1.48E+01	1.09E+01	9.66E+00	1.38E+01	1.22E+01	1.03E+01	1.48E+01	1.09E+01	9.66E+00	1.38E+01	1.22E+01
n-Hexane	Max	1-hour	3200	6.21E-02	7.12E-02	1.04E-01	8.99E-02	8.81E-02	8.48E-02	1.90E-02	2.81E-02	6.09E-02	4.68E-02	4.50E-02	4.18E-02
n-Nonane	Max	1-hour	10500	6.16E-03	7.06E-03	1.03E-02	8.92E-03	8.74E-03	8.42E-03	1.88E-03	2.79E-03	6.03E-03	4.64E-03	4.46E-03	4.14E-03
	Mean	Annual	1050	7.19E-04	7.20E-04	7.17E-04	7.23E-04	7.20E-04	7.24E-04	2.26E-05	2.41E-05	2.05E-05	2.69E-05	2.38E-05	2.82E-05
n-Octane	Max	1-hour	3500	1.97E-02	2.25E-02	3.29E-02	2.85E-02	2.79E-02	2.69E-02	6.01E-03	8.89E-03	1.92E-02	1.48E-02	1.42E-02	1.32E-02
	Mean	Annual	350	2.29E-03	2.30E-03	2.29E-03	2.31E-03	2.30E-03	2.31E-03	7.20E-05	7.68E-05	6.53E-05	8.58E-05	7.60E-05	9.01E-05
n-Pentane	Max	1-hour	4100	2.86E-01	3.26E-01	3.93E-01	4.12E-01	4.40E-01	3.87E-01	1.84E-01	2.25E-01	2.92E-01	3.11E-01	3.39E-01	2.86E-01
	Mean	Annual	7100	2.10E-02	2.03E-02	1.92E-02	1.92E-02	1.86E-02	1.84E-02	4.60E-03	3.81E-03	2.79E-03	2.74E-03	2.12E-03	1.96E-03
PAH as BaP	Max	1-hour	0.4	4.12E-07	6.02E-07	1.31E-06	1.01E-06	9.57E-07	8.95E-07	2.69E-06	2.88E-06	3.58E-06	3.28E-06	3.23E-06	3.17E-06
Phenanthrene	Max	1-hour	0.5	5.82E-04	6.68E-04	9.75E-04	8.43E-04	8.26E-04	7.96E-04	5.33E-04	6.18E-04	9.25E-04	7.93E-04	7.76E-04	7.46E-04
	Mean	Annual	0.05	6.80E-05	6.81E-05	6.78E-05	6.84E-05	6.81E-05	6.85E-05	5.99E-05	6.00E-05	5.96E-05	6.03E-05	6.00E-05	6.04E-05
Phenol	Max	1-hour	20	1.34E-03	1.54E-03	2.25E-03	1.94E-03	1.90E-03	1.83E-03	4.10E-04	6.08E-04	1.32E-03	1.01E-03	9.73E-04	9.03E-04
PM_{10}	Max	24-hour	50	1.12E-01	1.89E-01	9.14E-02	9.89E-02	9.25E-02	1.09E-01	1.12E-01	1.89E-01	9.14E-02	9.89E-02	9.25E-02	1.09E-01
	Mean	Annual	25	1.61E-02	1.38E-02	1.04E-02	1.08E-02	8.60E-03	8.48E-03	1.61E-02	1.38E-02	1.04E-02	1.08E-02	8.60E-03	8.48E-03
$PM_{2.5}$	Max	24-hour	25	3.13E-01	3.91E-01	2.93E-01	3.01E-01	2.94E-01	3.11E-01	4.77E+00	4.84E+00	4.75E+00	4.75E+00	4.75E+00	4.76E+00
	Mean	Annual	8	7.81E-02	7.58E-02	7.23E-02	7.28E-02	7.06E-02	7.05E-02	1.45E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00
Pyrene	Max	1-hour	0.5	7.60E-05	8.72E-05	1.27E-04	1.10E-04	1.08E-04	1.04E-04	8.10E-05	9.22E-05	1.32E-04	1.15E-04	1.13E-04	1.09E-04
Styrene	Max	10-minute	712	2.04E-03	2.39E-03	3.65E-03	3.11E-03	3.05E-03	2.92E-03	7.31E-04	1.08E-03	2.34E-03	1.80E-03	1.73E-03	1.61E-03
	Max	1-hour	120	1.32E-03	1.51E-03	2.21E-03	1.91E-03	1.87E-03	1.81E-03	4.04E-04	5.98E-04	1.29E-03	9.96E-04	9.57E-04	8.88E-04
Sulfur dioxide	Max	10-minute	712	1.03E-01	1.19E-01	1.84E-01	1.57E-01	1.51E-01	1.46E-01	8.64E-02	1.03E-01	1.67E-01	1.40E-01	1.34E-01	1.29E-01

Pollutant	Stat.	Ave. Period	Criterion (µg/m^3)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m^3)						With maximum incremental impacts from well pads (diesel) Concentration (µg/m^3)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
	Max	1-hour	570	6.63E-02	7.54E-02	1.11E-01	9.60E-02	9.26E-02	9.01E-02	5.47E-02	6.38E-02	9.95E-02	8.44E-02	8.11E-02	7.85E-02
	Max	24-hour	228	2.81E-02	2.84E-02	2.70E-02	2.77E-02	2.75E-02	2.69E-02	2.19E-02	2.23E-02	2.09E-02	2.16E-02	2.13E-02	2.07E-02
	Mean	Annual	60	7.84E-03	7.81E-03	7.71E-03	7.77E-03	7.70E-03	7.73E-03	5.96E-03	5.92E-03	5.83E-03	5.88E-03	5.82E-03	5.85E-03
Tetrachloroethane	Max	1-hour	70	1.39E-04	1.59E-04	2.32E-04	2.01E-04	1.97E-04	1.90E-04	4.24E-05	6.27E-05	1.36E-04	1.05E-04	1.00E-04	9.32E-05
	Mean	Annual	7	1.62E-05	1.62E-05	1.61E-05	1.63E-05	1.62E-05	1.63E-05	5.08E-07	5.42E-07	4.61E-07	6.05E-07	5.36E-07	6.35E-07
Toluene	Max	1-hour	360	2.29E-02	2.62E-02	3.82E-02	3.31E-02	3.24E-02	3.12E-02	1.20E-02	1.53E-02	2.73E-02	2.22E-02	2.15E-02	2.03E-02
Vinyl Chloride	Max	1-hour	24	8.35E-04	9.58E-04	1.40E-03	1.21E-03	1.18E-03	1.14E-03	2.55E-04	3.77E-04	8.17E-04	6.29E-04	6.04E-04	5.61E-04
Xylene	Max	1-hour	190	1.03E-02	1.18E-02	1.72E-02	1.49E-02	1.46E-02	1.41E-02	6.60E-03	8.12E-03	1.35E-02	1.12E-02	1.09E-02	1.04E-02



LEGEND

Leewood

Bibblewindi

Sensitive receivers

PM2.5 Concentration (µg/m3)

0.02

0.05

0.1

0 2.25 4.5 9
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Narrabri Gas Project Line
Response to Submissions

Job Number 21-22463
Revision A
Date FEB 2015

Predicted max. incremental 24-hr ave $PM_{2.5}$ concentrations (Power option 1)

Figure A-1

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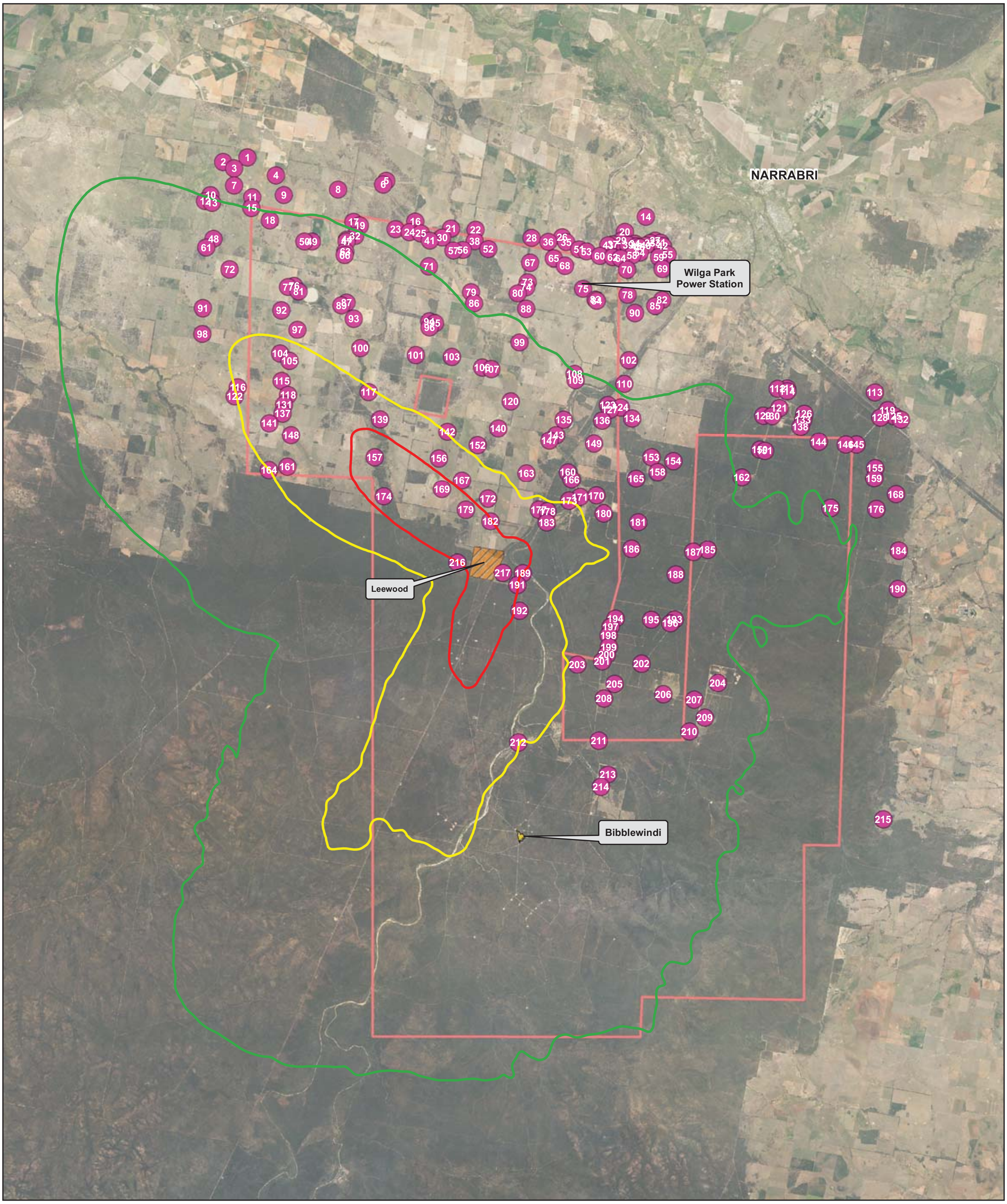
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy



LEGEND

Leewood

Bibblewindi

Sensitive receivers

PM2.5 Concentration (µg/m3)

0.002

0.005

0.01

0 2.25 4.5 9

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project Line
Response to Submissions

Job Number 21-22463
Revision A
Date FEB 2015

Predicted max. incremental annual ave.
$PM_{2.5}$ concentrations (Power option 1)

Figure A-2

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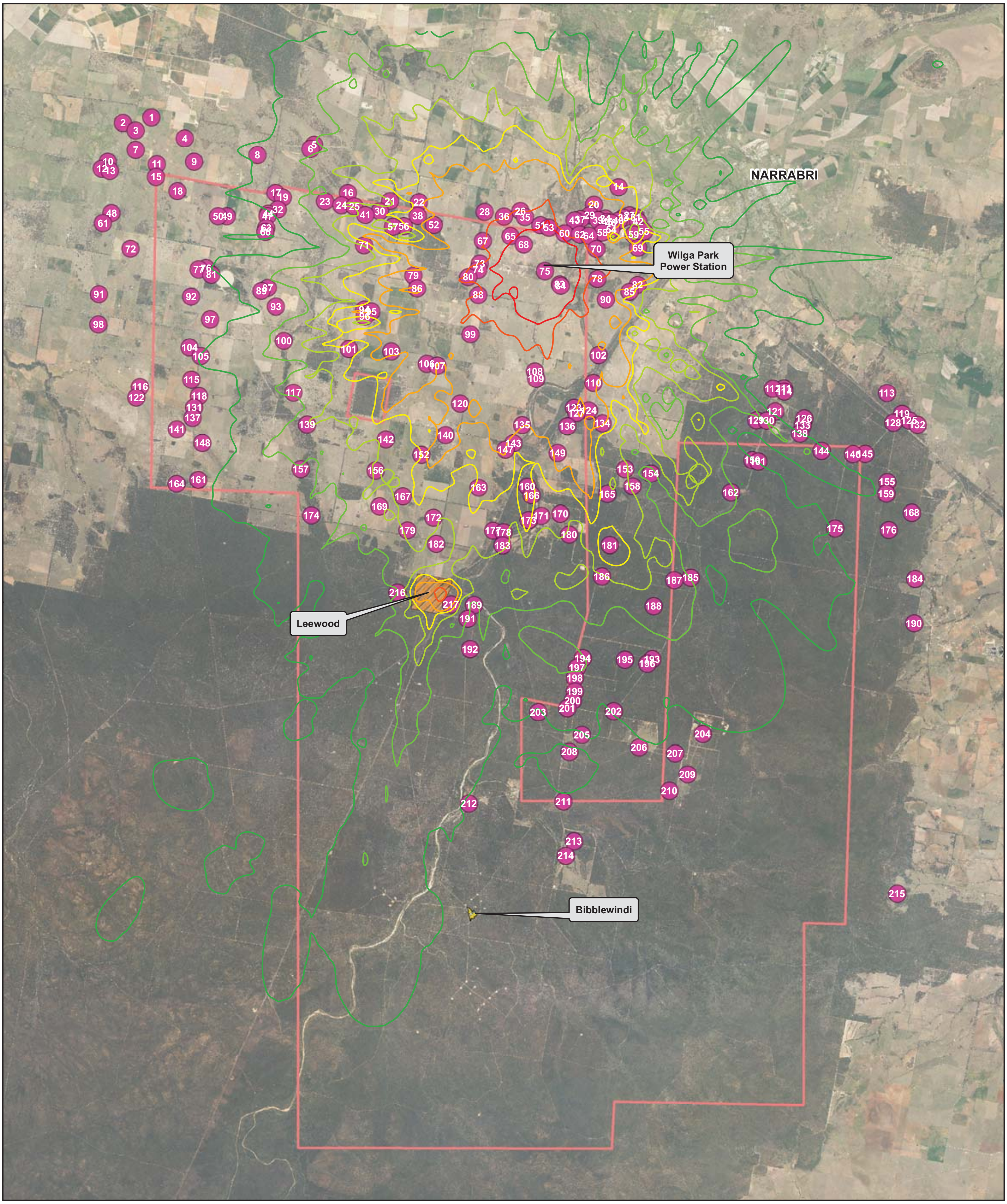
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy



LEGEND

Leewood

Bibblewindi

Sensitive receivers

NO_2 Concentration (µg/m3)

- 30
- 35
- 40
- 45
- 50
- 75
- 100

0 2 4 8
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

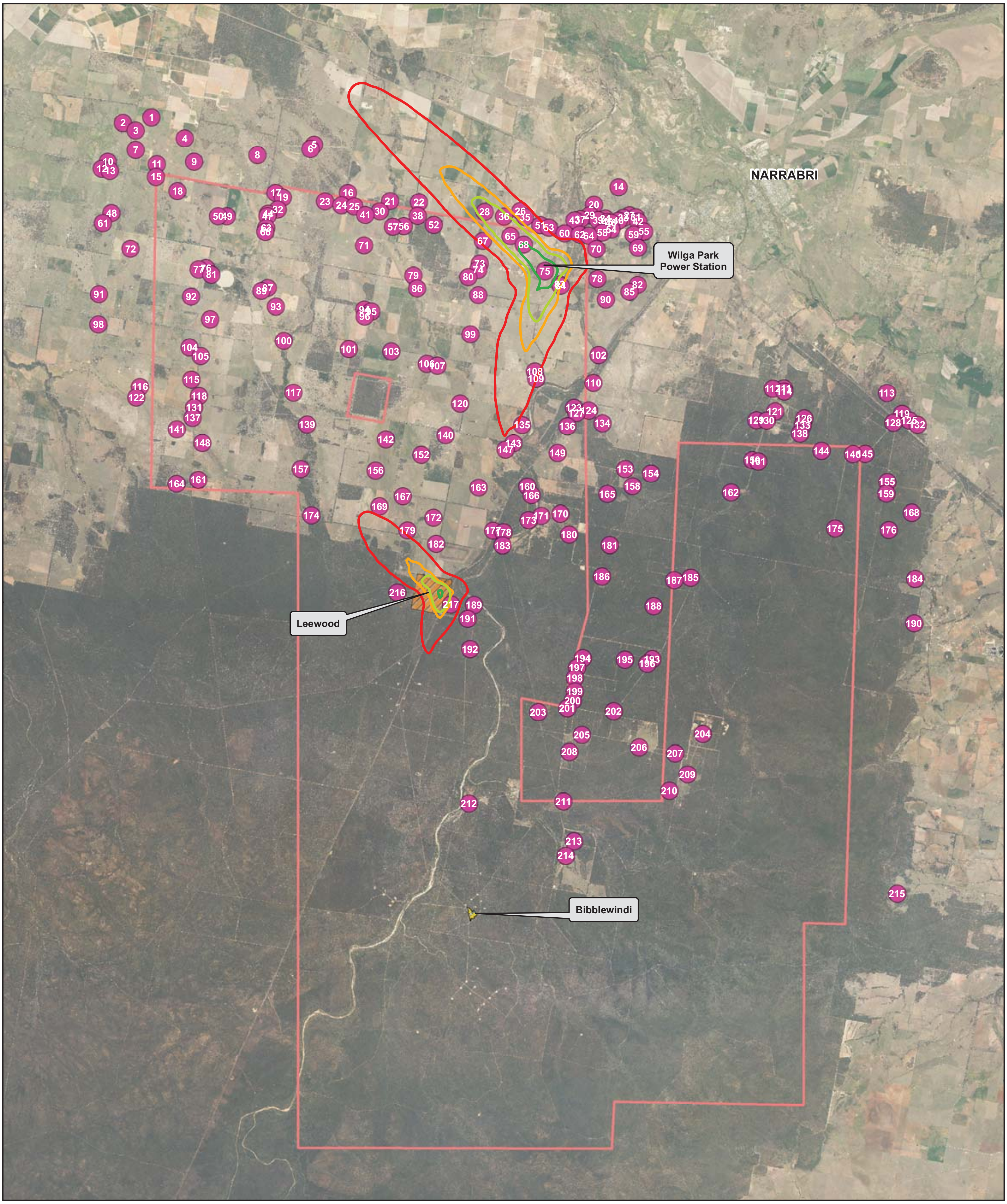
Narrabri Gas Project Line
Response to Submissions

Predicted maximum cumulative 1-hour average ground-level concentrations of NO_2 for power supply option 1 routine operations, with background

Job Number	21-22463
Revision	A
Date	FEB 2015

Figure A-3

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy



LEGEND

- Leewood
- Bibblewindi
- Sensitive receivers

NO_2 Concentration (µg/m3)

- 19
- 19.5
- 20
- 22.5

0 2 4 8
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project Line
Response to Submissions

Predicted maximum cumulative annual average ground-level concentrations of NO_2 for power supply option 1 routine operations, with background

Job Number 21-22463
Revision A
Date FEB 2015

Figure A-4

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Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy

Power supply option 1 - non-routine operations

The air quality assessment report presented the ground-level concentrations of relevant pollutants predicted beyond the boundary of Leewood due to impacts from Power supply option 1 – non-routine operations.

The ground-level concentrations of all relevant pollutants, predicted beyond the boundary of Leewood, due to cumulative impacts from Power supply option 1 – non-routine operations and well pad emissions at Leewood are presented in Table A 5.

The ground-level concentrations of all relevant pollutants predicted at the six closest sensitive receptors to the Leewood site, due to impacts from Power supply option 1 – non-routine operations are presented in Table A 6.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted at the six closest sensitive receptors to the Leewood site, due to cumulative impacts from Power supply option 1 – routine operations and well pad emissions at Leewood are presented in Table A 7.

The ground-level concentrations of all relevant pollutants, predicted beyond the boundary of Bibblewindi, due to cumulative impacts from Power supply option 1 – non-routine operations and well pad emissions at Leewood are presented in Table A 8.

The ground-level concentrations of all relevant pollutants predicted at the four closest sensitive receptors to the Bibblewindi site, due to impacts from Power supply option 1 – non-routine operations are presented in Table A 9.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted at the four closest sensitive receptors to the Bibblewindi site, due to cumulative impacts from Power supply option 1 – routine operations and well pad emissions at Bibblewindi are presented in Table A 10.

Results show that:

- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood and Bibblewindi due to impacts from Power supply option 1 – non-routine operations, **comply** with the relevant air quality criteria.
- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood and Bibblewindi due to cumulative impacts from Power supply option 1 – non-routine operations and well pad emissions at Leewood, **comply** with the relevant air quality criteria.

Table A 5 Predicted maximum incremental ground-level pollutant concentrations beyond the boundary due to Power supply option 1 – non-routine operations (with maximum incremental impacts from well pads at Leewood)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)	%	With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)	%
Acetylene	Max	1-hour	26600	3.30	0.01%	3.30	0.01%
Carbon monoxide	Max	1-hour	30000	180.30	0.60%	400.06	1.33%
	Max	8-hour	10000	53.22	0.53%	198.21	1.98%
Ethane	Max	1-hour	12000	5.28	0.04%	5.28	0.04%
Nitrogen dioxide	Max	1-hour	246	118.03	47.98%	118.03	47.98%
	Mean	Annual	62	8.63	13.92%	8.63	13.92%
Propane	Max	1-hour	18000	4.62	0.03%	4.62	0.03%
Propylene	Max	1-hour	8750	16.50	0.19%	16.53	0.19%

Table A 6 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 1 – non-routine operations (in isolation)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
Acetylene	Max	1-hour	26600	0.40	0.39	1.91	0.95	0.65	0.77
Carbon monoxide	Max	1-hour	30000	22.99	20.87	109.06	51.52	35.86	40.84
	Max	8-hour	10000	7.28	8.04	14.14	10.93	10.44	8.05
Ethane	Max	1-hour	12000	0.64	0.62	3.05	1.52	1.04	1.23
Nitrogen dioxide	Max	1-hour	246	15.49	18.89	47.60	26.11	28.40	23.99
	Mean	Annual	62	0.56	0.52	0.43	0.43	0.37	0.36
Propane	Max	1-hour	18000	0.56	0.55	2.67	1.33	0.91	1.07
Propylene	Max	1-hour	8750	2.01	1.95	9.53	4.75	3.26	3.84

Table A 7 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 1 – non-routine operations (with maximum incremental impacts from well pads at Leewood)

Pollutant	Stat.	Ave. Period	Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)						With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
Acetylene	Max	1-hour	26600	0.40	0.39	1.91	0.95	0.65	0.77	0.40	0.39	1.91	0.95	0.65	0.77
Carbon monoxide	Max	1-hour	30000	28.85	26.73	114.92	57.38	41.72	46.70	248.62	246.49	334.68	277.14	261.48	266.46
	Max	8-hour	10000	11.15	11.91	18.01	14.80	14.31	11.91	156.14	156.90	163.00	159.79	159.30	156.90
Ethane	Max	1-hour	12000	0.64	0.62	3.05	1.52	1.04	1.23	0.64	0.62	3.05	1.52	1.04	1.23
Nitrogen dioxide	Max	1-hour	246	33.07	36.47	65.18	43.69	45.98	41.57	33.07	36.47	65.18	43.69	45.98	41.57
	Mean	Annual	62	3.42	3.39	3.29	3.30	3.23	3.22	3.42	3.39	3.29	3.30	3.23	3.22
Propane	Max	1-hour	18000	0.56	0.55	2.67	1.33	0.91	1.07	0.56	0.55	2.67	1.33	0.91	1.07
Propylene	Max	1-hour	8750	2.01	1.95	9.53	4.75	3.26	3.84	2.04	1.98	9.57	4.78	3.29	3.87

Table A 8 Predicted maximum incremental ground-level pollutant concentrations beyond the boundary due to Power supply option 1 – non-routine operations (with maximum incremental impacts from well pads at Bibblewindi)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired)		With maximum incremental impacts from well pads (diesel)	
				Concentration (µg/m³)	%	Concentration (µg/m³)	%
Acetylene	Max	1-hour	26600	2.67	0.01%	2.67	0.01%
Carbon monoxide	Max	1-hour	30000	146.99	0.49%	366.75	1.22%
	Max	8-hour	10000	23.84	0.24%	168.83	1.69%
Ethane	Max	1-hour	12000	4.27	0.04%	4.27	0.04%
Nitrogen dioxide	Max	1-hour	246	43.52	17.69%	43.52	17.69%
	Mean	Annual	62	2.88	4.64%	2.88	4.64%
Propane	Max	1-hour	18000	3.74	0.02%	3.74	0.02%
Propylene	Max	1-hour	8750	13.35	0.15%	13.38	0.15%

Table A 9 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Bibblewindi due to Power supply option 1 – non-routine operations (in isolation)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	B211	B212	B213	B214
Acetylene	Max	1-hour	26600	0.36	1.27	0.45	0.46
Carbon monoxide	Max	1-hour	30000	18.94	67.10	24.00	24.39
	Max	8-hour	10000	4.54	10.16	5.09	5.49
Ethane	Max	1-hour	12000	0.57	2.03	0.73	0.74
Nitrogen dioxide	Max	1-hour	246	3.48	12.33	4.41	4.48
	Mean	Annual	62	0.01	0.01	0.01	0.01
Propane	Max	1-hour	18000	0.50	1.78	0.64	0.65
Propylene	Max	1-hour	8750	1.79	6.35	2.27	2.31

Table A 10 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Bibblewindi due to Power supply option 1 – non-routine operations (with maximum incremental impacts from well pads at Leewood)

Pollutant	Stat.	Ave. Period	Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)				With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)			
				B211	B212	B213	B214	B211	B212	B213	B214
Acetylene	Max	1-hour	26600	0.36	1.27	0.45	0.46	0.36	1.27	0.45	0.46
Carbon monoxide	Max	1-hour	30000	24.80	72.96	29.86	30.25	244.56	292.72	249.62	250.01
	Max	8-hour	10000	8.41	14.03	8.95	9.35	153.40	159.02	153.94	154.34
Ethane	Max	1-hour	12000	0.57	2.03	0.73	0.74	0.57	2.03	0.73	0.74
Nitrogen dioxide	Max	1-hour	246	21.06	29.91	21.99	22.06	21.06	29.91	21.99	22.06
	Mean	Annual	62	2.87	2.87	2.87	2.87	2.87	2.87	2.87	2.87
Propane	Max	1-hour	18000	0.50	1.78	0.64	0.65	0.50	1.78	0.64	0.65
Propylene	Max	1-hour	8750	1.79	6.35	2.27	2.31	1.82	6.38	2.30	2.34

Power supply option 2 - routine operations

The air quality assessment report presented the ground-level concentrations of priority pollutants predicted beyond the boundary of Leewood due to impacts from Power supply option 2 – routine operations in isolation.

The ground-level concentrations of all other pollutants predicted beyond the boundary of Leewood due to impacts from Power supply option 2 – routine operations in isolation are presented in Table A 11.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted beyond the boundary of Leewood, due to cumulative impacts from Power supply option 2 – routine operations and well pad emissions at Leewood are presented in Table A 12.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted at the six closest sensitive receptors to the Leewood site, due to impacts from Power supply option 2 – routine operations in isolation are presented in Table A 13.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted at the six closest sensitive receptors to the Leewood site, due to cumulative impacts from Power supply option 2 – routine operations and well pad emissions at Leewood are presented in Table A 14.

Results show that:

- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood due to impacts from Power supply option 2 – routine operations in isolation, **comply** with the relevant air quality criteria.
- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood due to cumulative impacts from Power supply option 2 – routine operations and well pad emissions at Leewood, **comply** with the relevant air quality criteria.

The predicted maximum incremental maximum 24-hour average and annual average ground-level concentrations of $PM_{2.5}$ around the Leewood site, for Power supply option 2 – routine operations, with the inclusion of ambient background concentrations, are provided in Figure A-5 and Figure A-6.

The predicted maximum one-hour and annual average ground-level concentrations of NO_2 for Power supply option 2 – routine operations, with the inclusion of ambient background concentrations and including Wilga Park Power Station, are provided in Figure A-7 and Figure A-8.

Table A 11 Predicted maximum incremental ground-level pollutant concentrations beyond the boundary due to Power supply option 2 – routine operations (in isolation)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	Maximum beyond boundary (µg/m³)	% Criterion
2-Methylnaphthalene	Max	1-hour	30	1.11E-05	<0.01%
	Mean	Annual	3	6.33E-07	<0.01%
Acenaphthene	Max	1-hour	1	8.32E-07	<0.01%
Acenaphthylene	Max	1-hour	200	8.32E-07	<0.01%
	Mean	Annual	50	4.76E-08	<0.01%
Anthracene	Max	1-hour	0.5	1.11E-06	<0.01%
	Mean	Annual	0.05	6.33E-08	<0.01%
Arsenic	Max	1-hour	0.09	1.07E-04	0.12%
Benzene	Max	1-hour	29	9.68E-04	<0.01%
Benzo(b)fluoranthene	Max	1-hour	0.5	8.32E-07	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%
Benzo(k)fluoranthene	Max	1-hour	0.5	8.32E-07	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%
Beryllium	Max	1-hour	0.004	6.41E-07	0.02%
Butane	Max	1-hour	66000	9.68E-01	<0.01%
	Mean	Annual	7200	5.54E-02	<0.01%
Cadmium	Max	1-hour	0.018	5.88E-04	3.27%
Carbon Monoxide	Max	1-hour	30000	3.59E+01	0.12%
	Max	8-hour	10000	1.96E+01	0.20%
Chromium III	Max	1-hour	9	7.48E-04	<0.01%
Chrysene	Max	1-hour	0.5	8.32E-07	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%
Copper	Max	1-hour	3.7	4.54E-04	0.01%
Dibenzo(a,h)anthracene	Max	1-hour	0.5	5.55E-07	<0.01%
	Mean	Annual	0.05	3.18E-08	<0.01%
Dichlorobenzene	Max	1-hour	5500	5.55E-04	<0.01%
Dioxins and furans	Max	1-hour	0.000002	2.64E-09	0.13%
Fluoranthene	Max	1-hour	0.5	1.38E-06	<0.01%
Fluorene	Max	1-hour	10	1.29E-06	<0.01%
Formaldehyde	9th	1-hour	20	2.33E-02	0.12%

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	Maximum beyond boundary (µg/m³)	% Criterion
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	8.32E-07	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%
Lead	Mean	Annual	0.5	1.52E-05	<0.01%
Naphthalene	Max	1-hour	200	2.82E-04	<0.01%
	Mean	Annual	50	1.61E-05	<0.01%
Nickel	Max	1-hour	0.18	1.12E-03	0.62%
n-Pentane	Max	1-hour	4100	1.20E+00	0.03%
	Mean	Annual	7100	6.86E-02	<0.01%
PAH as BaP	Max	1-hour	0.4	5.55E-07	<0.01%
Phenanthrene	Max	1-hour	0.5	7.86E-06	<0.01%
	Mean	Annual	0.05	4.50E-07	<0.01%
PM_{10}	Max	24-hour	50	1.15E+00	2.29%
	Mean	Annual	25	2.11E-01	0.84%
$PM_{2.5}$	Max	24-hour	25	1.15E+00	4.59%
	Mean	Annual	8	2.11E-01	2.64%
Pyrene	Max	1-hour	0.5	2.31E-06	<0.01%
Sulfur dioxide	Max	10-min	712	1.33E-01	0.02%
	Max	1-hour	570	7.37E-02	0.01%
	Max	24-hour	228	2.29E-02	0.01%
	Mean	Annual	60	4.22E-03	<0.01%
Toluene	Max	1-hour	360	1.58E-03	<0.01%

Table A 12 Predicted maximum incremental ground-level pollutant concentrations beyond the boundary due to Power supply option 2 – routine operations (with maximum incremental impacts from well pads at Leewood)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m^3)	With maximum incremental impacts from well pads (gas-fired)		With maximum incremental impacts from well pads (diesel)	
				Concentration (µg/m^3)	%	Concentration (µg/m^3)	%
2-Methylnaphthalene	Max	1-hour	30	1.30E-03	<0.01%	1.11E-05	<0.01%
	Mean	Annual	3	2.11E-04	<0.01%	6.33E-07	<0.01%
Acenaphthene	Max	1-hour	1	4.95E-05	<0.01%	1.80E-05	<0.01%
Acenaphthylene	Max	1-hour	200	2.16E-04	<0.01%	6.21E-05	<0.01%
	Mean	Annual	50	3.50E-05	<0.01%	1.00E-05	<0.01%
Anthracene	Max	1-hour	0.5	1.11E-06	<0.01%	2.37E-05	<0.01%
	Mean	Annual	0.05	6.33E-08	<0.01%	3.74E-06	<0.01%
Arsenic	Max	1-hour	0.09	1.07E-04	0.12%	1.07E-04	0.12%
Benzene	Max	1-hour	29	1.81E-02	0.06%	1.22E-02	0.04%
Benzo(b)fluoranthene	Max	1-hour	0.5	7.28E-06	<0.01%	2.03E-06	<0.01%
	Mean	Annual	0.05	1.10E-06	<0.01%	2.43E-07	<0.01%
Benzo(k)fluoranthene	Max	1-hour	0.5	8.32E-07	<0.01%	2.71E-06	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%	3.53E-07	<0.01%
Beryllium	Max	1-hour	0.004	6.41E-07	0.02%	6.41E-07	0.02%
Butane	Max	1-hour	66000	9.89E-01	<0.01%	9.68E-01	<0.01%
	Mean	Annual	7200	5.88E-02	<0.01%	5.54E-02	<0.01%
Cadmium	Max	1-hour	0.018	5.88E-04	3.27%	5.88E-04	3.27%
Carbon Monoxide	Max	1-hour	30000	4.18E+01	0.14%	2.62E+02	0.87%
	Max	8-hour	10000	2.35E+01	0.23%	1.68E+02	1.68%
Chromium III	Max	1-hour	9	7.48E-04	<0.01%	7.48E-04	<0.01%
Chrysene	Max	1-hour	0.5	2.78E-05	<0.01%	6.37E-05	0.01%
	Mean	Annual	0.05	4.43E-06	<0.01%	1.03E-05	0.02%
Copper	Max	1-hour	3.7	4.54E-04	0.01%	4.54E-04	0.01%
Dibenzo(a,h)anthracene	Max	1-hour	0.5	5.55E-07	<0.01%	6.47E-06	<0.01%
	Mean	Annual	0.05	3.18E-08	<0.01%	9.95E-07	<0.01%
Dichlorobenzene	Max	1-hour	5500	5.55E-04	<0.01%	5.55E-04	<0.01%
Dioxins and furans	Max	1-hour	0.000002	2.64E-09	0.13%	2.64E-09	0.13%
Fluoranthene	Max	1-hour	0.5	4.45E-05	<0.01%	9.34E-05	0.02%

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)	%	With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)	%
Fluorene	Max	1-hour	10	2.22E-04	<0.01%	3.56E-04	<0.01%
Formaldehyde	9th	1-hour	20	2.07E+00	10.37%	3.76E-02	0.19%
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	8.32E-07	<0.01%	7.89E-06	<0.01%
	Mean	Annual	0.05	4.76E-08	<0.01%	1.20E-06	<0.01%
Lead	Mean	Annual	0.5	1.52E-05	<0.01%	1.52E-05	<0.01%
Naphthalene	Max	1-hour	200	3.17E-03	<0.01%	1.31E-03	<0.01%
	Mean	Annual	50	4.87E-04	<0.01%	1.83E-04	<0.01%
Nickel	Max	1-hour	0.18	1.12E-03	0.62%	1.12E-03	0.62%
Nitrogen dioxide	Max	1-hour	246	1.18E+02	47.98%	1.18E+02	47.98%
	Mean	Annual	62	8.61E+00	13.89%	8.61E+00	13.89%
Ozone	Max	1-hour	214	1.05E+02	48.97%	1.05E+02	48.97%
	Max	4-hour	171	6.21E+01	36.33%	6.21E+01	36.33%
n-Pentane	Max	1-hour	4100	1.30E+00	0.03%	1.20E+00	0.03%
	Mean	Annual	7100	8.50E-02	<0.01%	6.86E-02	<0.01%
PAH as BaP	Max	1-hour	0.4	5.55E-07	<0.01%	2.83E-06	<0.01%
Phenanthrene	Max	1-hour	0.5	4.12E-04	0.08%	3.62E-04	0.07%
	Mean	Annual	0.05	6.63E-05	0.13%	5.82E-05	0.12%
PM_{10}	Max	24-hour	50	1.15E+00	2.29%	1.15E+00	2.29%
	Mean	Annual	25	2.11E-01	0.84%	2.11E-01	0.84%
$PM_{2.5}$	Max	24-hour	25	1.35E+00	5.39%	5.80E+00	23.21%
	Mean	Annual	8	2.73E-01	3.41%	1.64E+00	20.52%
Pyrene	Max	1-hour	0.5	5.51E-05	0.01%	6.00E-05	0.01%
Sulfur dioxide	Max	10-min	712	1.98E-01	0.03%	1.82E-01	0.03%
	Max	1-hour	570	1.19E-01	0.02%	1.07E-01	0.02%
	Max	24-hour	228	4.69E-02	0.02%	4.07E-02	0.02%
	Mean	Annual	60	1.16E-02	0.02%	9.69E-03	0.02%
Toluene	Max	1-hour	360	1.74E-02	<0.01%	6.53E-03	<0.01%

Table A 13 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 2 – routine operations (in isolation)

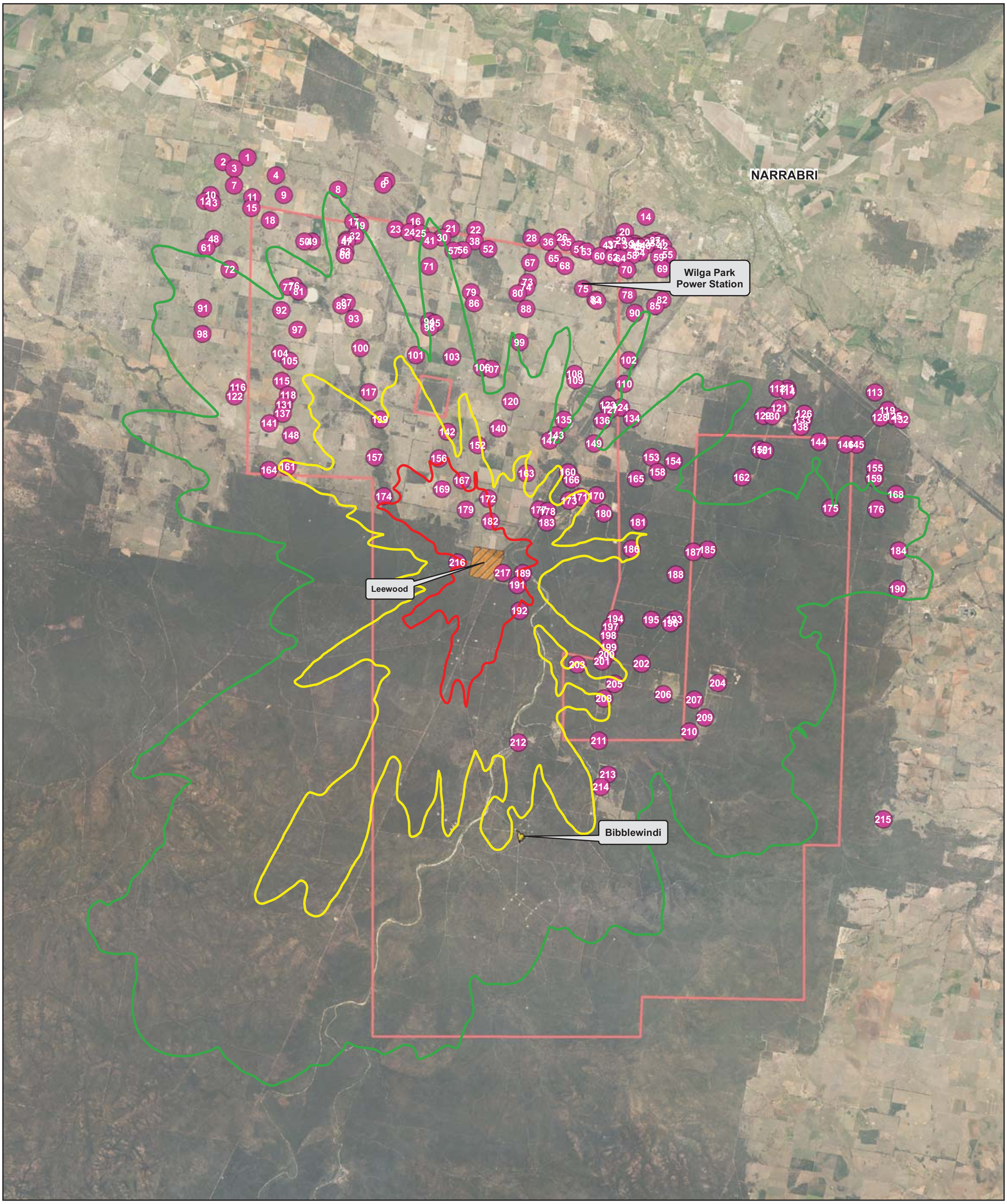
Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
2-Methylnaphthalene	Max	1-hour	30	1.70E-06	2.08E-06	2.70E-06	2.87E-06	3.13E-06	2.64E-06
	Mean	Annual	3	3.75E-08	2.99E-08	2.13E-08	1.94E-08	1.44E-08	1.19E-08
Acenaphthene	Max	1-hour	1	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
Acenaphthylene	Max	1-hour	200	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
	Mean	Annual	50	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10
Anthracene	Max	1-hour	0.5	1.70E-07	2.08E-07	2.70E-07	2.87E-07	3.13E-07	2.64E-07
	Mean	Annual	0.05	3.75E-09	2.99E-09	2.13E-09	1.94E-09	1.44E-09	1.19E-09
Arsenic	Max	1-hour	0.09	1.65E-05	2.01E-05	2.61E-05	2.78E-05	3.02E-05	2.55E-05
Benzene	Max	1-hour	29	1.49E-04	1.82E-04	2.36E-04	2.52E-04	2.73E-04	2.31E-04
Benzo(b)fluoranthene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10
Benzo(k)fluoranthene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10
Beryllium	Max	1-hour	0.004	9.87E-08	1.21E-07	1.56E-07	1.67E-07	1.81E-07	1.53E-07
Butane	Max	1-hour	66000	1.49E-01	1.82E-01	2.36E-01	2.52E-01	2.73E-01	2.31E-01
	Mean	Annual	7200	3.28E-03	2.62E-03	1.86E-03	1.70E-03	1.26E-03	1.04E-03
Cadmium	Max	1-hour	0.018	9.05E-05	1.11E-04	1.43E-04	1.53E-04	1.66E-04	1.40E-04
Carbon Monoxide	Max	1-hour	30000	5.53E+00	6.76E+00	8.77E+00	9.34E+00	1.02E+01	8.58E+00
	Max	8-hour	10000	2.82E+00	3.80E+00	2.17E+00	2.16E+00	2.70E+00	2.55E+00
Chromium III	Max	1-hour	9	1.15E-04	1.41E-04	1.83E-04	1.95E-04	2.12E-04	1.79E-04
Chrysene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10
Copper	Max	1-hour	3.7	6.99E-05	8.54E-05	1.11E-04	1.18E-04	1.28E-04	1.09E-04
Dibenzo(a,h)anthracene	Max	1-hour	0.5	8.54E-08	1.04E-07	1.35E-07	1.44E-07	1.57E-07	1.32E-07
	Mean	Annual	0.05	1.88E-09	1.50E-09	1.07E-09	9.75E-10	7.23E-10	5.98E-10
Dichlorobenzene	Max	1-hour	5500	8.54E-05	1.04E-04	1.35E-04	1.44E-04	1.57E-04	1.32E-04
Dioxins and furans	Max	1-hour	0.000002	4.07E-10	4.97E-10	6.45E-10	6.87E-10	7.48E-10	6.32E-10
Fluoranthene	Max	1-hour	0.5	2.13E-07	2.60E-07	3.37E-07	3.59E-07	3.91E-07	3.30E-07
Fluorene	Max	1-hour	10	1.99E-07	2.43E-07	3.15E-07	3.35E-07	3.65E-07	3.08E-07
Formaldehyde	9th	1-hour	20	4.09E-03	5.33E-03	5.45E-03	4.38E-03	3.15E-03	3.44E-03

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10
Lead	Mean	Annual	0.5	9.03E-07	7.21E-07	5.12E-07	4.68E-07	3.47E-07	2.87E-07
Naphthalene	Max	1-hour	200	4.34E-05	5.30E-05	6.88E-05	7.33E-05	7.97E-05	6.73E-05
	Mean	Annual	50	9.56E-07	7.63E-07	5.42E-07	4.96E-07	3.68E-07	3.04E-07
Nickel	Max	1-hour	0.18	1.72E-04	2.10E-04	2.72E-04	2.90E-04	3.15E-04	2.66E-04
Nitrogen dioxide	Max	1-hour	246	1.55E+01	1.89E+01	2.45E+01	2.61E+01	2.84E+01	2.40E+01
	Mean	Annual	62	3.41E-01	2.72E-01	1.93E-01	1.77E-01	1.31E-01	1.08E-01
Ozone	Max	1-hour	214	1.61E+01	1.97E+01	2.56E+01	2.72E+01	2.96E+01	2.50E+01
	Max	4-hour	171	1.03E+01	1.48E+01	1.06E+01	9.61E+00	1.37E+01	1.22E+01
n-Pentane	Max	1-hour	4100	1.84E-01	2.25E-01	2.92E-01	3.11E-01	3.39E-01	2.86E-01
	Mean	Annual	7100	4.06E-03	3.24E-03	2.30E-03	2.11E-03	1.56E-03	1.29E-03
PAH as BaP	Max	1-hour	0.4	8.54E-08	1.04E-07	1.35E-07	1.44E-07	1.57E-07	1.32E-07
Phenanthrene	Max	1-hour	0.5	1.21E-06	1.48E-06	1.92E-06	2.04E-06	2.22E-06	1.88E-06
	Mean	Annual	0.05	2.67E-08	2.13E-08	1.51E-08	1.38E-08	1.02E-08	8.48E-09
PM_{10}	Max	24-hour	50	9.86E-02	1.89E-01	8.73E-02	8.41E-02	9.24E-02	9.44E-02
	Mean	Annual	25	1.25E-02	9.98E-03	7.09E-03	6.48E-03	4.80E-03	3.97E-03
$PM_{2.5}$	Max	24-hour	25	9.86E-02	1.89E-01	8.73E-02	8.41E-02	9.24E-02	9.44E-02
	Mean	Annual	8	1.25E-02	9.98E-03	7.09E-03	6.48E-03	4.80E-03	3.97E-03
Pyrene	Max	1-hour	0.5	3.56E-07	4.35E-07	5.64E-07	6.01E-07	6.54E-07	5.52E-07
Sulfur dioxide	Max	10-min	712	2.05E-02	2.51E-02	3.25E-02	3.47E-02	3.77E-02	3.19E-02
	Max	1-hour	570	1.14E-02	1.39E-02	1.80E-02	1.92E-02	2.08E-02	1.76E-02
	Max	24-hour	228	1.97E-03	3.78E-03	1.75E-03	1.68E-03	1.85E-03	1.89E-03
	Mean	Annual	60	2.50E-04	2.00E-04	1.42E-04	1.30E-04	9.61E-05	7.95E-05
Toluene	Max	1-hour	360	2.43E-04	2.96E-04	3.84E-04	4.10E-04	4.45E-04	3.76E-04

Table A 14 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 1 – routine operations (with maximum incremental impacts from well pads at Leewood)

Pollutant	Stat.	Ave. Period	Criterion (µg/m^3)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m^3)						With maximum incremental impacts from well pads (diesel) Concentration (µg/m^3)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
2-Methylnaphthalene	Max	1-hour	30	1.29E-03	1.29E-03	1.29E-03	1.30E-03	1.30E-03	1.29E-03	1.70E-06	2.08E-06	2.70E-06	2.87E-06	3.13E-06	2.64E-06
	Mean	Annual	3	2.10E-04	2.10E-04	2.10E-04	2.10E-04	2.10E-04	2.10E-04	3.75E-08	2.99E-08	2.13E-08	1.94E-08	1.44E-08	1.19E-08
Acenaphthene	Max	1-hour	1	4.88E-05	4.88E-05	4.88E-05	4.89E-05	4.89E-05	4.88E-05	1.73E-05	1.73E-05	1.74E-05	1.74E-05	1.74E-05	1.74E-05
Acenaphthylene	Max	1-hour	200	2.15E-04	2.15E-04	2.15E-04	2.15E-04	2.15E-04	2.15E-04	6.14E-05	6.14E-05	6.14E-05	6.15E-05	6.15E-05	6.14E-05
	Mean	Annual	50	3.50E-05	3.50E-05	3.50E-05	3.50E-05	3.50E-05	3.50E-05	9.97E-06	9.97E-06	9.97E-06	9.97E-06	9.97E-06	9.97E-06
Anthracene	Max	1-hour	0.5	1.70E-07	2.08E-07	2.70E-07	2.87E-07	3.13E-07	2.64E-07	2.28E-05	2.28E-05	2.29E-05	2.29E-05	2.29E-05	2.29E-05
	Mean	Annual	0.05	3.75E-09	2.99E-09	2.13E-09	1.94E-09	1.44E-09	1.19E-09	3.69E-06	3.68E-06	3.68E-06	3.68E-06	3.68E-06	3.68E-06
Arsenic	Max	1-hour	0.09	1.65E-05	2.01E-05	2.61E-05	2.78E-05	3.02E-05	2.55E-05	1.65E-05	2.01E-05	2.61E-05	2.78E-05	3.02E-05	2.55E-05
Benzene	Max	1-hour	29	1.73E-02	1.73E-02	1.73E-02	1.74E-02	1.74E-02	1.73E-02	1.14E-02	1.15E-02	1.15E-02	1.15E-02	1.16E-02	1.15E-02
Benzo(b)fluoranthene	Max	1-hour	0.5	6.57E-06	6.60E-06	6.65E-06	6.66E-06	6.68E-06	6.65E-06	1.33E-06	1.35E-06	1.40E-06	1.41E-06	1.43E-06	1.40E-06
	Mean	Annual	0.05	1.05E-06	1.05E-06	1.05E-06	1.05E-06	1.05E-06	1.05E-06	1.98E-07	1.97E-07	1.97E-07	1.96E-07	1.96E-07	1.96E-07
Benzo(k)fluoranthene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07	2.00E-06	2.03E-06	2.08E-06	2.09E-06	2.11E-06	2.07E-06
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10	3.08E-07	3.07E-07	3.07E-07	3.07E-07	3.06E-07	3.06E-07
Beryllium	Max	1-hour	0.004	9.87E-08	1.21E-07	1.56E-07	1.67E-07	1.81E-07	1.53E-07	9.87E-08	1.21E-07	1.56E-07	1.67E-07	1.81E-07	1.53E-07
Butane	Max	1-hour	66000	1.70E-01	2.03E-01	2.57E-01	2.73E-01	2.95E-01	2.52E-01	1.49E-01	1.82E-01	2.36E-01	2.52E-01	2.73E-01	2.31E-01
	Mean	Annual	7200	6.71E-03	6.04E-03	5.28E-03	5.12E-03	4.69E-03	4.47E-03	3.28E-03	2.62E-03	1.86E-03	1.70E-03	1.26E-03	1.04E-03
Cadmium	Max	1-hour	0.018	9.05E-05	1.11E-04	1.43E-04	1.53E-04	1.66E-04	1.40E-04	9.05E-05	1.11E-04	1.43E-04	1.53E-04	1.66E-04	1.40E-04
Carbon Monoxide	Max	1-hour	30000	1.14E+01	1.26E+01	1.46E+01	1.52E+01	1.60E+01	1.44E+01	2.31E+02	2.32E+02	2.34E+02	2.35E+02	2.36E+02	2.34E+02
	Max	8-hour	10000	6.69E+00	7.66E+00	6.04E+00	6.03E+00	6.57E+00	6.42E+00	1.52E+02	1.53E+02	1.51E+02	1.51E+02	1.52E+02	1.51E+02
Chromium III	Max	1-hour	9	1.15E-04	1.41E-04	1.83E-04	1.95E-04	2.12E-04	1.79E-04	1.15E-04	1.41E-04	1.83E-04	1.95E-04	2.12E-04	1.79E-04
Chrysene	Max	1-hour	0.5	2.71E-05	2.71E-05	2.72E-05	2.72E-05	2.72E-05	2.72E-05	6.30E-05	6.30E-05	6.31E-05	6.31E-05	6.31E-05	6.31E-05
	Mean	Annual	0.05	4.39E-06	4.39E-06	4.39E-06	4.39E-06	4.39E-06	4.39E-06	1.02E-05	1.02E-05	1.02E-05	1.02E-05	1.02E-05	1.02E-05
Copper	Max	1-hour	3.7	6.99E-05	8.54E-05	1.11E-04	1.18E-04	1.28E-04	1.09E-04	6.99E-05	8.54E-05	1.11E-04	1.18E-04	1.28E-04	1.09E-04
Dibenzo(a,h)anthracene	Max	1-hour	0.5	8.54E-08	1.04E-07	1.35E-07	1.44E-07	1.57E-07	1.32E-07	6.00E-06	6.02E-06	6.05E-06	6.06E-06	6.08E-06	6.05E-06
	Mean	Annual	0.05	1.88E-09	1.50E-09	1.07E-09	9.75E-10	7.23E-10	5.98E-10	9.65E-07	9.65E-07	9.64E-07	9.64E-07	9.64E-07	9.64E-07
Dichlorobenzene	Max	1-hour	5500	8.54E-05	1.04E-04	1.35E-04	1.44E-04	1.57E-04	1.32E-04	8.54E-05	1.04E-04	1.35E-04	1.44E-04	1.57E-04	1.32E-04
Dioxins and furans	Max	1-hour	0.000002	4.07E-10	4.97E-10	6.45E-10	6.87E-10	7.48E-10	6.32E-10	4.07E-10	4.97E-10	6.45E-10	6.87E-10	7.48E-10	6.32E-10
Fluoranthene	Max	1-hour	0.5	4.33E-05	4.33E-05	4.34E-05	4.34E-05	4.35E-05	4.34E-05	9.22E-05	9.23E-05	9.23E-05	9.24E-05	9.24E-05	9.23E-05
Fluorene	Max	1-hour	10	2.21E-04	2.21E-04	2.21E-04	2.21E-04	2.21E-04	2.21E-04	3.55E-04	3.55E-04	3.55E-04	3.55E-04	3.55E-04	3.55E-04
Formaldehyde	9th	1-hour	20	2.06E+00	2.06E+00	2.06E+00	2.06E+00	2.05E+00	2.05E+00	1.84E-02	1.96E-02	1.97E-02	1.87E-02	1.74E-02	1.77E-02

Pollutant	Stat.	Ave. Period	Criterion (µg/m^3)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m^3)						With maximum incremental impacts from well pads (diesel) Concentration (µg/m^3)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
Indeno(1,2,3-cd)pyrene	Max	1-hour	0.5	1.28E-07	1.56E-07	2.03E-07	2.16E-07	2.35E-07	1.99E-07	7.19E-06	7.22E-06	7.26E-06	7.28E-06	7.30E-06	7.26E-06
	Mean	Annual	0.05	2.82E-09	2.25E-09	1.60E-09	1.46E-09	1.08E-09	8.97E-10	1.15E-06	1.15E-06	1.15E-06	1.15E-06	1.15E-06	1.15E-06
Lead	Mean	Annual	0.5	9.03E-07	7.21E-07	5.12E-07	4.68E-07	3.47E-07	2.87E-07	9.03E-07	7.21E-07	5.12E-07	4.68E-07	3.47E-07	2.87E-07
Naphthalene	Max	1-hour	200	2.94E-03	2.95E-03	2.96E-03	2.97E-03	2.97E-03	2.96E-03	1.07E-03	1.08E-03	1.09E-03	1.10E-03	1.11E-03	1.09E-03
	Mean	Annual	50	4.72E-04	4.71E-04	4.71E-04	4.71E-04	4.71E-04	4.71E-04	1.68E-04	1.68E-04	1.67E-04	1.67E-04	1.67E-04	1.67E-04
Nickel	Max	1-hour	0.18	1.72E-04	2.10E-04	2.72E-04	2.90E-04	3.15E-04	2.66E-04	1.72E-04	2.10E-04	2.72E-04	2.90E-04	3.15E-04	2.66E-04
Nitrogen dioxide	Max	1-hour	246	3.30E+01	3.65E+01	4.21E+01	4.37E+01	4.60E+01	4.16E+01	3.30E+01	3.65E+01	4.21E+01	4.37E+01	4.60E+01	4.16E+01
	Mean	Annual	62	3.20E+00	3.13E+00	3.05E+00	3.04E+00	2.99E+00	2.97E+00	3.20E+00	3.13E+00	3.05E+00	3.04E+00	2.99E+00	2.97E+00
Ozone	Max	1-hour	214	1.61E+01	1.97E+01	2.56E+01	2.72E+01	2.96E+01	2.50E+01	1.61E+01	1.97E+01	2.56E+01	2.72E+01	2.96E+01	2.50E+01
	Max	4-hour	171	1.03E+01	1.48E+01	1.06E+01	9.61E+00	1.37E+01	1.22E+01	1.03E+01	1.48E+01	1.06E+01	9.61E+00	1.37E+01	1.22E+01
n-Pentane	Max	1-hour	4100	2.86E-01	3.26E-01	3.93E-01	4.12E-01	4.40E-01	3.87E-01	1.84E-01	2.25E-01	2.92E-01	3.11E-01	3.39E-01	2.86E-01
	Mean	Annual	7100	2.05E-02	1.97E-02	1.88E-02	1.86E-02	1.80E-02	1.77E-02	4.06E-03	3.24E-03	2.30E-03	2.11E-03	1.56E-03	1.29E-03
PAH as BaP	Max	1-hour	0.4	8.54E-08	1.04E-07	1.35E-07	1.44E-07	1.57E-07	1.32E-07	2.36E-06	2.38E-06	2.41E-06	2.42E-06	2.43E-06	2.41E-06
Phenanthrene	Max	1-hour	0.5	4.06E-04	4.06E-04	4.06E-04	4.06E-04	4.07E-04	4.06E-04	3.56E-04	3.56E-04	3.56E-04	3.57E-04	3.57E-04	3.56E-04
	Mean	Annual	0.05	6.58E-05	6.58E-05	6.58E-05	6.58E-05	6.58E-05	6.58E-05	5.77E-05	5.77E-05	5.77E-05	5.77E-05	5.77E-05	5.77E-05
PM_{10}	Max	24-hour	50	9.86E-02	1.89E-01	8.73E-02	8.41E-02	9.24E-02	9.44E-02	9.86E-02	1.89E-01	8.73E-02	8.41E-02	9.24E-02	9.44E-02
	Mean	Annual	25	1.25E-02	9.98E-03	7.09E-03	6.48E-03	4.80E-03	3.97E-03	1.25E-02	9.98E-03	7.09E-03	6.48E-03	4.80E-03	3.97E-03
$PM_{2.5}$	Max	24-hour	25	3.00E-01	3.91E-01	2.89E-01	2.86E-01	2.94E-01	2.96E-01	4.75E+00	4.84E+00	4.74E+00	4.74E+00	4.75E+00	4.75E+00
	Mean	Annual	8	7.45E-02	7.20E-02	6.91E-02	6.85E-02	6.68E-02	6.60E-02	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.44E+00	1.43E+00
Pyrene	Max	1-hour	0.5	5.31E-05	5.32E-05	5.33E-05	5.33E-05	5.34E-05	5.33E-05	5.81E-05	5.82E-05	5.83E-05	5.83E-05	5.84E-05	5.83E-05
Sulfur dioxide	Max	10-min	712	8.52E-02	8.97E-02	9.72E-02	9.93E-02	1.02E-01	9.65E-02	6.86E-02	7.32E-02	8.06E-02	8.28E-02	8.58E-02	7.99E-02
	Max	1-hour	570	5.65E-02	5.90E-02	6.31E-02	6.43E-02	6.60E-02	6.28E-02	4.49E-02	4.75E-02	5.16E-02	5.28E-02	5.44E-02	5.12E-02
	Max	24-hour	228	2.59E-02	2.77E-02	2.57E-02	2.56E-02	2.58E-02	2.58E-02	1.98E-02	2.16E-02	1.95E-02	1.95E-02	1.96E-02	1.97E-02
	Mean	Annual	60	7.60E-03	7.55E-03	7.49E-03	7.48E-03	7.45E-03	7.43E-03	5.72E-03	5.67E-03	5.61E-03	5.60E-03	5.56E-03	5.55E-03
Toluene	Max	1-hour	360	1.61E-02	1.61E-02	1.62E-02	1.63E-02	1.63E-02	1.62E-02	5.19E-03	5.25E-03	5.34E-03	5.36E-03	5.40E-03	5.33E-03



LEGEND

- Leewood
- Bibblewindi
- Sensitive receivers

PM2.5 Concentration (µg/m3)

- 0.02
- 0.05
- 0.1

0 2.25 4.5 9
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project Line
Response to Submissions

Predicted max. incremental 24hr ave. $PM_{2.5}$ concentrations (Power option 2)

Job Number	21-22463
Revision	A
Date	FEB 2015

Figure A-5

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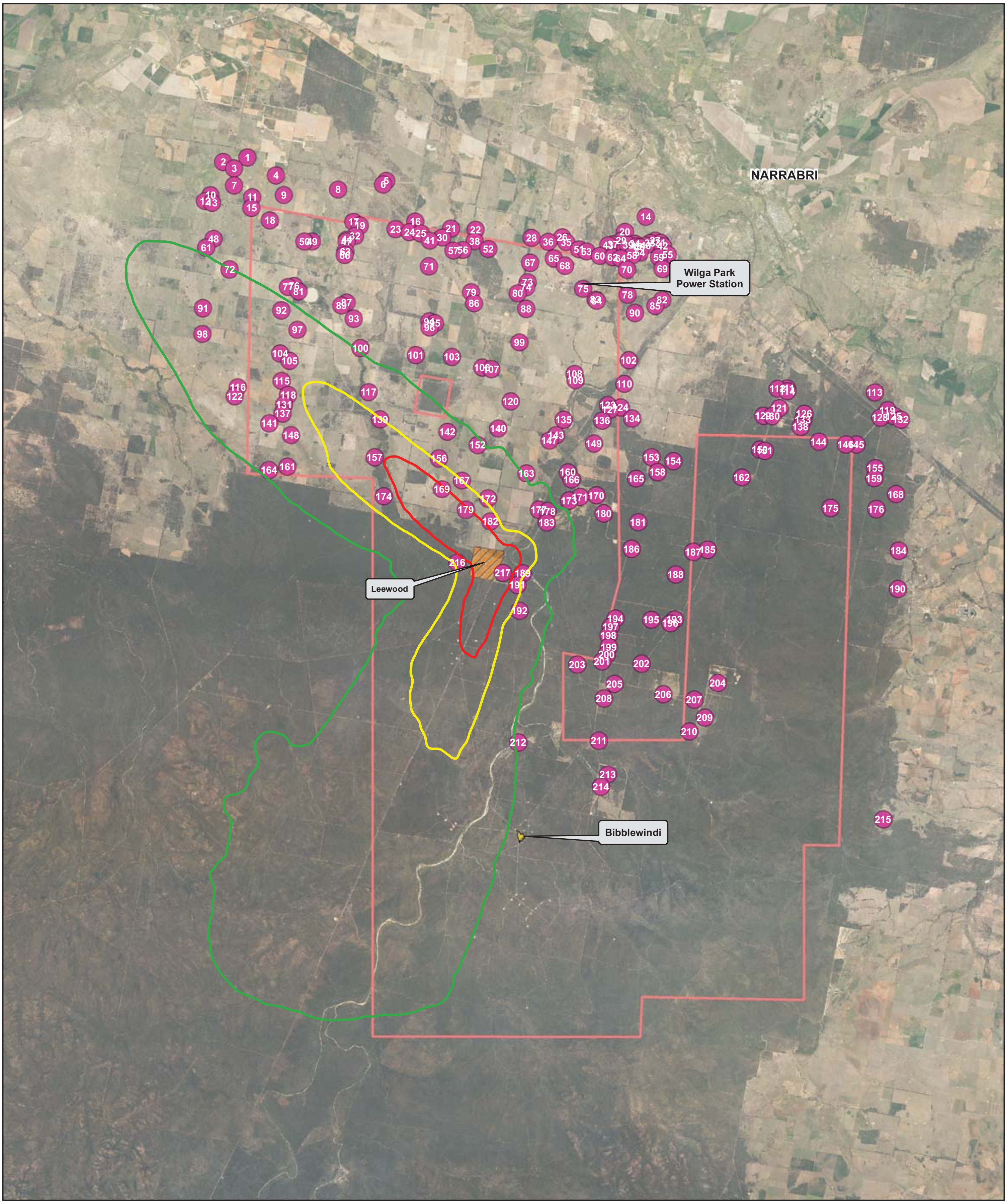
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy



LEGEND

- Leewood
- Bibblewindi
- Sensitive receivers

PM2.5 Concentration (µg/m3)

- 0.002
- 0.005
- 0.01

0 2.25 4.5 9
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project Line
Response to Submissions

Job Number 21-22463
Revision A
Date FEB 2015

Predicted max. incremental annual ave.
$PM_{2.5}$ concentrations (Power option 2)

Figure A-6

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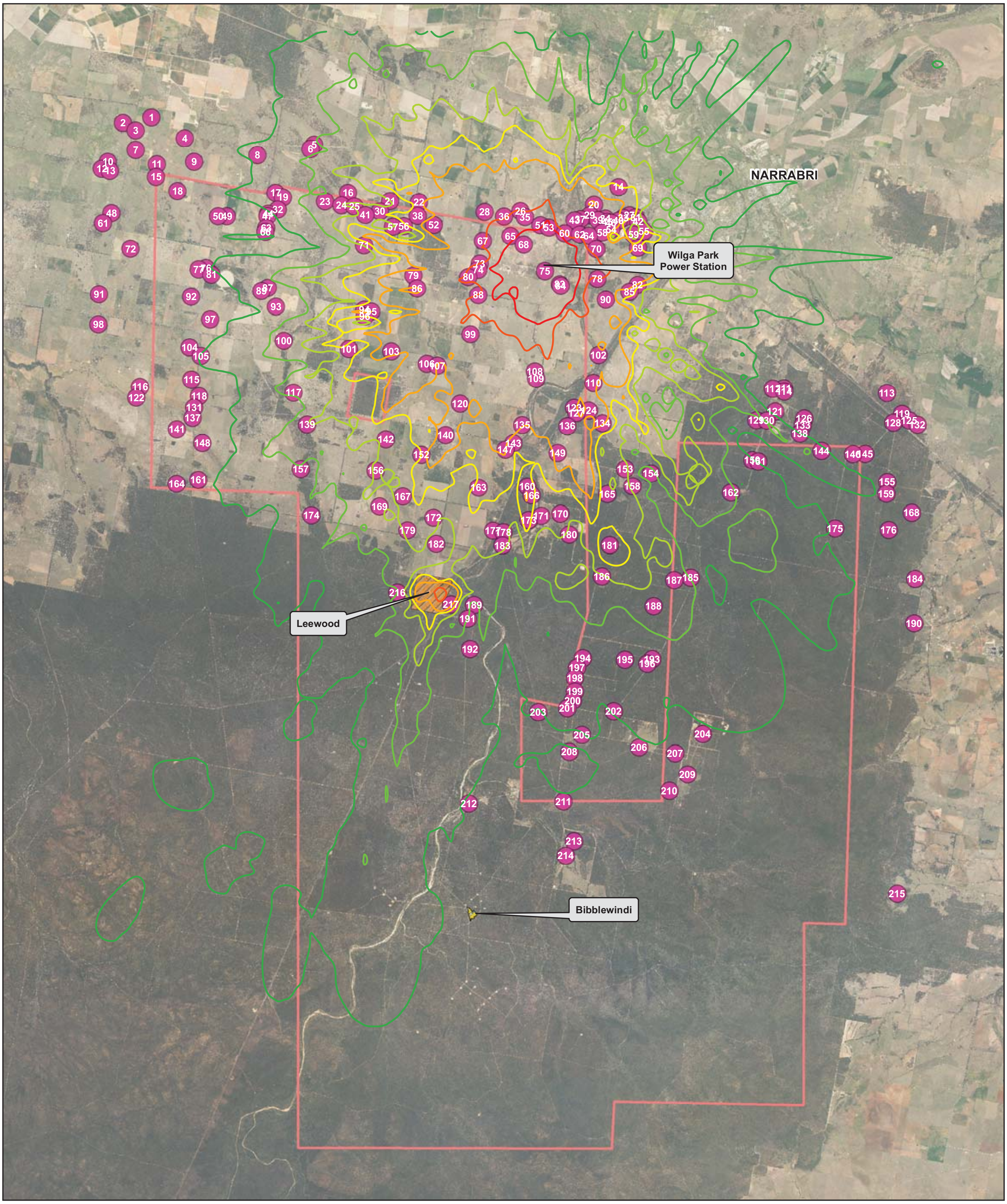
Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy



LEGEND

- Leewood
- Bibblewindi
- Sensitive receivers

NO2 Concentration (µg/m3)

- 30
- 35
- 40
- 45
- 50
- 75
- 100

0 2 4 8

Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project Line

Response to Submissions

Predicted maximum cumulative 1-hour average ground-level concentrations of NO_2 for power supply option 2 routine operations, with background

Job Number 21-22463
Revision A
Date FEB 2015

Figure A-7

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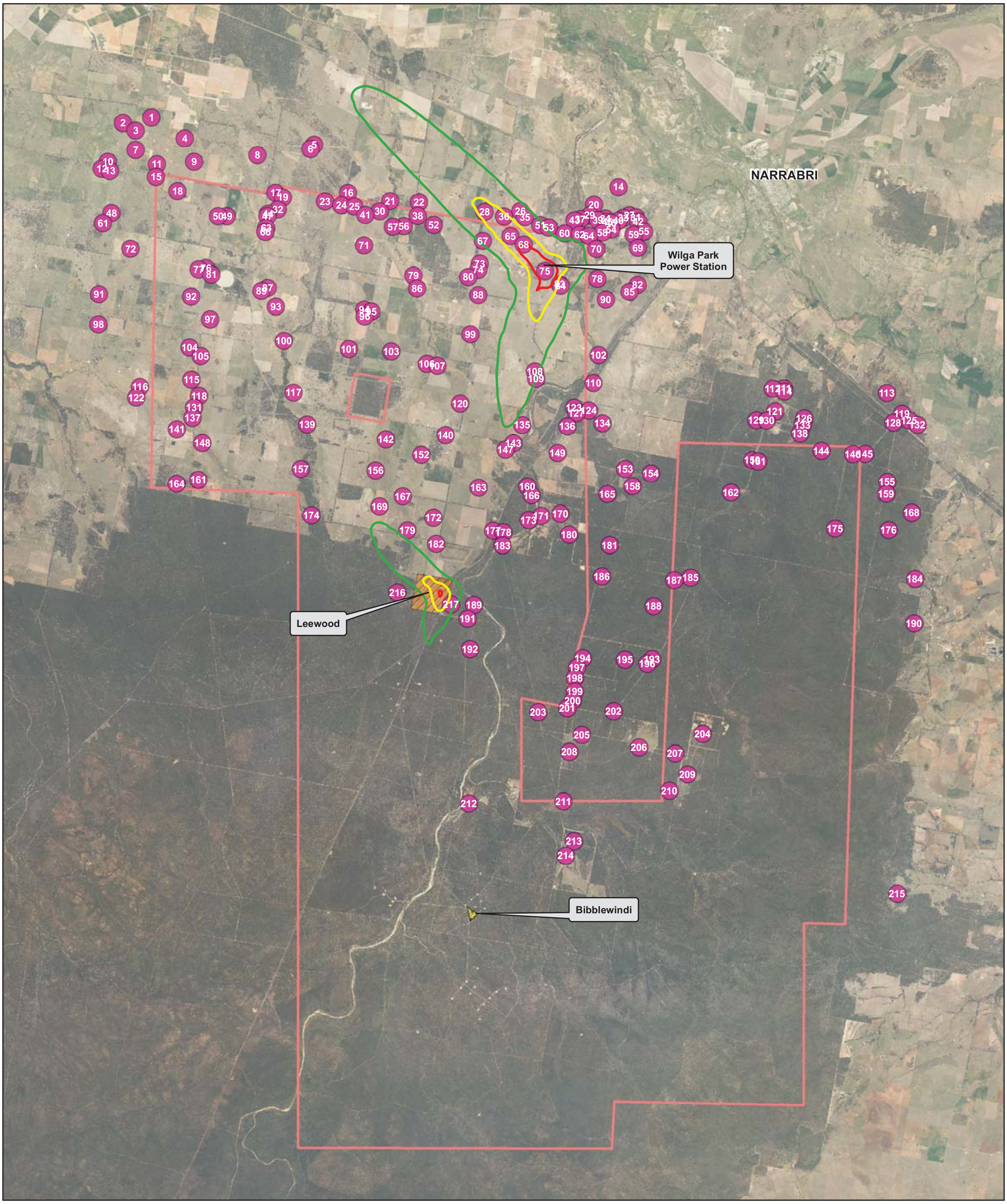
Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy



LEGEND

- Leewood
- Bibblewindi
- Sensitive receivers

NO_2 Concentration (µg/m3)

- 19
- 20
- 22.5

0 2 4 8
Kilometres

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabri Gas Project Line
Response to Submissions

Predicted maximum cumulative annual average ground-level concentrations of NO_2 for power supply option 2 routine operations, with background

Job Number	21-22463
Revision	A
Date	FEB 2015

Figure A-8

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Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: Data Custodian, Data Set Name/Title, Version/Date. Created by:afoddy

Power supply option 2 – non-routine operations

The air quality assessment report presented the ground-level concentrations of relevant pollutants predicted beyond the boundary of Leewood due to impacts from Power supply option 2 – non-routine operations.

The ground-level concentrations of all relevant pollutants, predicted beyond the boundary of Leewood, due to cumulative impacts from Power supply option 2 – non-routine operations and well pad emissions at Leewood are presented in Table A 15.

The ground-level concentrations of all relevant pollutants predicted at the six closest sensitive receptors to the Leewood site, due to impacts from Power supply option 2 – non-routine operations are presented in Table A 16.

The ground-level concentrations of all pollutants, including the priority pollutants, predicted at the six closest sensitive receptors to the Leewood site, due to cumulative impacts from Power supply option 2 – routine operations and well pad emissions at Leewood are presented in Table A 17.

Results show that:

- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood due to impacts from Power supply option 2 – non-routine operations, **comply** with the relevant air quality criteria.
- Predicted ground-level concentrations of all pollutants predicted at all sensitive receptors and at any location beyond the boundary of Leewood and Bibblewindi due to cumulative impacts from Power supply option 2 – non-routine operations and well pad emissions at Leewood, **comply** with the relevant air quality criteria.

.

Table A 15 Predicted maximum incremental ground-level pollutant concentrations beyond the boundary due to Power supply option 2 – non-routine operations (with maximum incremental impacts from well pads at Leewood)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)	%	With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)	%
Acetylene	Max	1-hour	26600	3.30	0.01%	3.30	0.01%
Carbon monoxide	Max	1-hour	30000	180.28	0.60%	400.04	1.33%
	Max	8-hour	10000	32.99	0.33%	177.98	1.78%
Ethane	Max	1-hour	12000	5.28	0.04%	5.28	0.04%
Nitrogen dioxide	Max	1-hour	246	118.03	47.98%	118.03	47.98%
	Mean	Annual	62	8.63	13.92%	8.63	13.92%
Propane	Max	1-hour	18000	4.62	0.03%	4.62	0.03%
Propylene	Max	1-hour	8750	16.50	0.19%	16.53	0.19%

Table A 16 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 2 – non-routine operations (in isolation)

Air Pollutant	Statistic	Averaging Period	Impact Assessment Criterion (µg/m³)	L169	L179	L182	L189	L191	L192
Acetylene	Max	1-hour	26600	0.40	0.39	1.91	0.95	0.65	0.77
Carbon monoxide	Max	1-hour	30000	21.59	20.85	101.64	50.47	34.51	40.56
	Max	8-hour	10000	6.52	7.81	13.87	9.89	9.62	7.82
Ethane	Max	1-hour	12000	0.64	0.62	3.05	1.52	1.04	1.23
Nitrogen dioxide	Max	1-hour	246	15.49	18.89	24.50	26.11	28.39	23.99
	Mean	Annual	62	0.35	0.28	0.21	0.19	0.15	0.12
Propane	Max	1-hour	18000	0.56	0.55	2.67	1.33	0.91	1.07
Propylene	Max	1-hour	8750	2.01	1.95	9.53	4.75	3.26	3.84

Table A 17 Predicted maximum incremental ground-level pollutant concentrations at the closest sensitive receptors to Leewood due to Power supply option 2 – non-routine operations (with maximum incremental impacts from well pads at Leewood)

Pollutant	Stat.	Ave. Period	Criterion (µg/m³)	With maximum incremental impacts from well pads (gas-fired) Concentration (µg/m³)						With maximum incremental impacts from well pads (diesel) Concentration (µg/m³)					
				L169	L179	L182	L189	L191	L192	L169	L179	L182	L189	L191	L192
Acetylene	Max	1-hour	26600	0.40	0.39	1.91	0.95	0.65	0.77	0.40	0.39	1.91	0.95	0.65	0.77
Carbon monoxide	Max	1-hour	30000	27.45	26.71	107.50	56.33	40.37	46.42	247.22	246.48	327.26	276.09	260.13	266.18
	Max	8-hour	10000	10.38	11.68	17.73	13.76	13.48	11.68	155.37	156.67	162.72	158.75	158.47	156.67
Ethane	Max	1-hour	12000	0.64	0.62	3.05	1.52	1.04	1.23	0.64	0.62	3.05	1.52	1.04	1.23
Nitrogen dioxide	Max	1-hour	246	33.07	36.47	42.08	43.69	45.97	41.57	33.07	36.47	42.08	43.69	45.97	41.57
	Mean	Annual	62	3.21	3.15	3.07	3.05	3.01	2.98	3.21	3.15	3.07	3.05	3.01	2.98
Propane	Max	1-hour	18000	0.56	0.55	2.67	1.33	0.91	1.07	0.56	0.55	2.67	1.33	0.91	1.07
Propylene	Max	1-hour	8750	2.01	1.95	9.53	4.75	3.26	3.84	2.04	1.98	9.57	4.78	3.29	3.87

Well pad power generation

The assessment of well pad generator engine emissions is presented in Table A 18 and Table A 19, which show the decline in one hour average pollutant concentration with distance from the diesel-fired and gas-fired generator engines respectively. Each table also provides the percentage of the predicted downwind concentration, at a five metre distance downwind of the engines, to its relevant regulatory criterion.

The assessment is based on emission factors for gas and diesel-fired engines. Where possible emission factors were derived from the NSW emission concentration standard limits, and otherwise were selected from engine technical specifications or the AP42 collection of emission factors in this order of preference.

Table A 18 Decline in 1-hour average pollutant concentration with distance from diesel-fired well pad generators

	Approximate distance, m							
Substance	**5**	**30**	**100**	**200**	**300**	**400**	**500**	**% Criterion at 5 m**
Nitrogen dioxide	1.78E+01	1.76E+01	1.32E+01	6.87E+00	4.36E+00	4.21E+00	4.22E+00	7.24%
$PM_{2.5}$	1.03E+01	8.79E+00	7.97E+00	5.33E+00	3.36E+00	2.82E+00	2.92E+00	N/A[1]
Carbon monoxide	2.65E+02	2.26E+02	2.05E+02	1.37E+02	8.62E+01	7.24E+01	7.49E+01	0.88%
Sulfur dioxide	3.95E-02	3.36E-02	3.05E-02	2.04E-02	1.28E-02	1.08E-02	1.11E-02	0.01%
1,3-Butadiene	5.55E-04	4.72E-04	4.28E-04	2.86E-04	1.80E-04	1.51E-04	1.57E-04	<0.01%
Acenaphthene	2.02E-05	1.72E-05	1.56E-05	1.04E-05	6.56E-06	5.51E-06	5.70E-06	<0.01%
Acenaphthylene	7.20E-05	6.12E-05	5.55E-05	3.71E-05	2.34E-05	1.97E-05	2.03E-05	<0.01%
Acetaldehyde	1.09E-02	9.29E-03	8.42E-03	5.63E-03	3.55E-03	2.98E-03	3.08E-03	0.03%
Acrolein	1.32E-03	1.12E-03	1.01E-03	6.78E-04	4.27E-04	3.59E-04	3.71E-04	0.31%
Anthracene	2.66E-05	2.26E-05	2.05E-05	1.37E-05	8.64E-06	7.26E-06	7.51E-06	0.01%
Benzene	1.33E-02	1.13E-02	1.02E-02	6.84E-03	4.31E-03	3.62E-03	3.74E-03	0.05%
Benzo(b)fluoranthene	1.41E-06	1.20E-06	1.09E-06	7.26E-07	4.58E-07	3.85E-07	3.98E-07	<0.01%
Benzo(k)fluoranthene	2.21E-06	1.88E-06	1.70E-06	1.14E-06	7.16E-07	6.02E-07	6.22E-07	<0.01%
Chrysene	7.39E-05	6.29E-05	5.70E-05	3.81E-05	2.40E-05	2.02E-05	2.09E-05	0.01%
Dibenzo(a,h)anthracene	6.96E-06	5.92E-06	5.37E-06	3.59E-06	2.26E-06	1.90E-06	1.96E-06	<0.01%
Fluoranthene	1.08E-04	9.20E-05	8.34E-05	5.58E-05	3.51E-05	2.95E-05	3.05E-05	0.02%
Fluorene	4.17E-04	3.55E-04	3.21E-04	2.15E-04	1.35E-04	1.14E-04	1.18E-04	<0.01%
Formaldehyde	1.68E-02	1.43E-02	1.29E-02	8.65E-03	5.45E-03	4.58E-03	4.73E-03	0.08%
Indeno(1,2,3-cd)pyrene	8.30E-06	7.06E-06	6.40E-06	4.28E-06	2.70E-06	2.27E-06	2.34E-06	<0.01%
Naphthalene	1.21E-03	1.03E-03	9.30E-04	6.21E-04	3.92E-04	3.29E-04	3.40E-04	<0.01%
PAH as BaP	2.67E-06	2.27E-06	2.06E-06	1.38E-06	8.68E-07	7.30E-07	7.54E-07	<0.01%
Phenanthrene	4.17E-04	3.55E-04	3.21E-04	2.15E-04	1.35E-04	1.14E-04	1.18E-04	0.08%
Propylene	3.69E-02	3.14E-02	2.84E-02	1.90E-02	1.20E-02	1.01E-02	1.04E-02	<0.01%
Pyrene	6.79E-05	5.77E-05	5.23E-05	3.50E-05	2.20E-05	1.85E-05	1.92E-05	0.01%
Toluene	5.82E-03	4.95E-03	4.49E-03	3.00E-03	1.89E-03	1.59E-03	1.64E-03	<0.01%
Xylene	4.07E-03	3.46E-03	3.14E-03	2.10E-03	1.32E-03	1.11E-03	1.15E-03	<0.01%

Table Note: [1]There is no 1-hour impact criterion for PM2.5.

Table A 19 Decline in 1-hour average pollutant concentration with distance from gas-fired well pad generators

Substance	Approximate distance, m 5	30	100	200	300	400	500	% Criterion at 5 m
Nitrogen dioxide	1.78E+01	1.76E+01	1.32E+01	6.87E+00	4.36E+00	4.21E+00	4.22E+00	7.24%
$PM_{2.5}$	3.86E-01	3.81E-01	2.86E-01	1.49E-01	9.44E-02	9.12E-02	9.15E-02	N/A[1]
Carbon monoxide	5.94E+00	5.86E+00	4.40E+00	2.29E+00	1.45E+00	1.40E+00	1.41E+00	0.02%
Sulfur dioxide	4.58E-02	4.52E-02	3.39E-02	1.76E-02	1.12E-02	1.08E-02	1.08E-02	0.01%
1,1,2,2-Tetrachloroethane	1.58E-03	1.56E-03	1.17E-03	6.08E-04	3.85E-04	3.72E-04	3.74E-04	<0.01%
1,1,2-Trichloroethane	1.25E-03	1.24E-03	9.28E-04	4.83E-04	3.06E-04	2.96E-04	2.97E-04	<0.01%
1,1-Dichloroethane	9.30E-04	9.17E-04	6.88E-04	3.58E-04	2.27E-04	2.20E-04	2.20E-04	<0.01%
1,2,3-Trimethylbenzene	9.06E-04	8.94E-04	6.71E-04	3.49E-04	2.21E-04	2.14E-04	2.15E-04	<0.01%
1,2,4-Trimethylbenzene	5.64E-04	5.57E-04	4.18E-04	2.18E-04	1.38E-04	1.33E-04	1.34E-04	<0.01%
1,2-Dichloroethane	9.30E-04	9.17E-04	6.88E-04	3.58E-04	2.27E-04	2.20E-04	2.20E-04	<0.01%
1,2-Dichloropropane	1.06E-03	1.05E-03	7.85E-04	4.09E-04	2.59E-04	2.50E-04	2.51E-04	<0.01%
1,3,5-Trimethylbenzene	1.33E-03	1.32E-03	9.88E-04	5.14E-04	3.26E-04	3.15E-04	3.16E-04	<0.01%
1,3-Butadiene	1.05E-02	1.04E-02	7.79E-03	4.05E-03	2.57E-03	2.48E-03	2.49E-03	0.03%
1,3-Dichloropropene	1.04E-03	1.03E-03	7.70E-04	4.01E-04	2.54E-04	2.46E-04	2.46E-04	<0.01%
2,2,4-Trimethylpentane	9.86E-03	9.73E-03	7.30E-03	3.80E-03	2.41E-03	2.33E-03	2.34E-03	<0.01%
2-Methylnaphthalene	1.31E-03	1.29E-03	9.70E-04	5.05E-04	3.20E-04	3.09E-04	3.10E-04	<0.01%
Acenaphthene	4.93E-05	4.86E-05	3.65E-05	1.90E-05	1.20E-05	1.16E-05	1.17E-05	<0.01%
Acenaphthylene	2.18E-04	2.15E-04	1.61E-04	8.40E-05	5.33E-05	5.15E-05	5.17E-05	<0.01%
Acetaldehyde	3.27E-01	3.22E-01	2.42E-01	1.26E-01	7.98E-02	7.72E-02	7.74E-02	0.78%
Acrolein	2.02E-01	1.99E-01	1.50E-01	7.79E-02	4.94E-02	4.77E-02	4.79E-02	48.09%
Benzene	1.73E-02	1.71E-02	1.28E-02	6.69E-03	4.24E-03	4.10E-03	4.11E-03	0.06%
Benzo(b)fluoranthene	6.53E-06	6.45E-06	4.84E-06	2.52E-06	1.60E-06	1.54E-06	1.55E-06	<0.01%
Benzo(e)pyrene	1.64E-05	1.61E-05	1.21E-05	6.31E-06	4.00E-06	3.87E-06	3.88E-06	<0.01%
Biphenyl	8.35E-03	8.23E-03	6.18E-03	3.22E-03	2.04E-03	1.97E-03	1.98E-03	0.03%
Butane	2.13E-02	2.10E-02	1.58E-02	8.22E-03	5.21E-03	5.04E-03	5.05E-03	<0.01%
Butyr/Isobutyraldehyde	3.98E-03	3.93E-03	2.95E-03	1.53E-03	9.73E-04	9.40E-04	9.43E-04	<0.01%
Carbon Tetrachloride	1.45E-03	1.43E-03	1.07E-03	5.58E-04	3.54E-04	3.42E-04	3.43E-04	0.01%
Chlorobenzene	1.20E-03	1.18E-03	8.86E-04	4.61E-04	2.93E-04	2.83E-04	2.84E-04	<0.01%
Chloroethane	7.37E-05	7.27E-05	5.46E-05	2.84E-05	1.80E-05	1.74E-05	1.75E-05	<0.01%
Chloroform	1.12E-03	1.11E-03	8.31E-04	4.33E-04	2.74E-04	2.65E-04	2.66E-04	<0.01%
Chrysene	2.73E-05	2.70E-05	2.02E-05	1.05E-05	6.68E-06	6.45E-06	6.48E-06	0.01%
Cyclopentane	8.94E-03	8.82E-03	6.62E-03	3.45E-03	2.18E-03	2.11E-03	2.12E-03	<0.01%
Ethylbenzene	1.57E-03	1.54E-03	1.16E-03	6.03E-04	3.83E-04	3.70E-04	3.71E-04	<0.01%
Ethylene Dibromide	1.75E-03	1.72E-03	1.29E-03	6.73E-04	4.27E-04	4.12E-04	4.14E-04	0.04%
Fluoranthene	4.37E-05	4.31E-05	3.23E-05	1.68E-05	1.07E-05	1.03E-05	1.03E-05	0.01%
Fluorene	2.23E-04	2.20E-04	1.65E-04	8.61E-05	5.46E-05	5.27E-05	5.29E-05	<0.01%
Formaldehyde	2.08E+00	2.05E+00	1.54E+00	8.02E-01	5.08E-01	4.91E-01	4.93E-01	10.40%
Methanol	9.86E-02	9.73E-02	7.30E-02	3.80E-02	2.41E-02	2.33E-02	2.34E-02	<0.01%
Methylcyclohexane	4.84E-02	4.78E-02	3.59E-02	1.87E-02	1.18E-02	1.14E-02	1.15E-02	0.01%
Methylene Chloride (Dichloromethane)	7.87E-04	7.76E-04	5.83E-04	3.03E-04	1.92E-04	1.86E-04	1.87E-04	<0.01%
Naphthalene	2.93E-03	2.89E-03	2.17E-03	1.13E-03	7.16E-04	6.92E-04	6.95E-04	<0.01%
n-Hexane	4.37E-02	4.31E-02	3.23E-02	1.68E-02	1.07E-02	1.03E-02	1.03E-02	<0.01%
n-Nonane	4.34E-03	4.28E-03	3.21E-03	1.67E-03	1.06E-03	1.02E-03	1.03E-03	<0.01%
n-Octane	1.38E-02	1.37E-02	1.03E-02	5.34E-03	3.38E-03	3.27E-03	3.28E-03	<0.01%
n-Pentane	1.02E-01	1.01E-01	7.59E-02	3.95E-02	2.50E-02	2.42E-02	2.43E-02	<0.01%

Substance	5	30	100	Approximate distance, m 200	300	400	500	% Criterion at 5 m
Phenanthrene	4.10E-04	4.04E-04	3.04E-04	1.58E-04	1.00E-04	9.68E-05	9.71E-05	0.08%
Phenol	9.45E-04	9.32E-04	6.99E-04	3.64E-04	2.31E-04	2.23E-04	2.24E-04	<0.01%
Pyrene	5.35E-05	5.27E-05	3.96E-05	2.06E-05	1.31E-05	1.26E-05	1.27E-05	0.01%
Styrene	9.30E-04	9.17E-04	6.88E-04	3.58E-04	2.27E-04	2.20E-04	2.20E-04	<0.01%
Tetrachloroethane	9.77E-05	9.64E-05	7.24E-05	3.77E-05	2.39E-05	2.31E-05	2.32E-05	<0.01%
Toluene	1.61E-02	1.59E-02	1.19E-02	6.19E-03	3.93E-03	3.79E-03	3.81E-03	<0.01%
Vinyl Chloride	5.88E-04	5.80E-04	4.36E-04	2.27E-04	1.44E-04	1.39E-04	1.39E-04	<0.01%
Xylene	7.25E-03	7.15E-03	5.37E-03	2.79E-03	1.77E-03	1.71E-03	1.72E-03	<0.01%

Table Note: [1]There is no 1-hour impact criterion for $PM_{2.5}$.

Appendix B. Fugitive emissions

While there are several studies that have been made in the United States regarding the air quality effects of unconventional gas extraction, it cannot be assumed that these studies are applicable to the Australian CSG industry. Differences are due to the history of gas development, the size of the industry, differences in environmental regulatory controls, and the dominance of shale gas in the United States. Abandoned wells are a source of methane in the US, but measurements from 19 abandoned shale gas wells in Australia show that these are relatively low by comparison (with a median of 0.0013 kg/day and mean 0.27 kg/day).

In Australia, the CSIRO conducted a study that aimed to develop methods for characterising methane and other gaseous emissions from different area sources in NSW, particularly the CSG industry (Day *et al.*, 2016). Measurements were made between June 2014 and May 2016 at 16 sites across NSW that included the following source types:

- Coal seam gas operations – from wells; active (producing for sale/use or flared) or inactive (plugged, suspended or abandoned), gas processing plant, gas and water treatment facilities
- Landfills – a single country landfill (Parkes Shire) and a metropolitan landfill (Newcastle City)
- Wastewater treatment plants - four wastewater treatment plants, three country plants (located in Dubbo, Singleton, Wagga Wagga) and a metropolitan plant (in Picton)
- Agriculture - Rice Farm, experimental rice crop run by NSWDPI at Murrumbidgee Rural Studies Centre North West of Wagga Wagga and a cattle feedlot North of Wagga Wagga that can hold up to 17,000 head of cattle.
- Coal mining - Two mines in the Hunter Valley one open cut and the other mixed, i.e. open cut and underground
- Natural sources - Yaegl Nature Reserve, owned by NSW National Parks and Wildlife Service, the reserve comprises a floodplain of mainly paperbark forest and some coastal saltmarsh. The total area of the reserve is 312 ha.

Methane

Methane is typically not considered a substance of concern in air quality assessments, but is considered within the context of the greenhouse gas assessment or workplace exposure and risk assessments. For this study, measurements of methane undertaken by CSIRO were covered as a pre-cursor in secondary photochemical smog formation. However, based on the low levels gathered, methane is a minor consideration in the air quality assessment, and as such, has not been assessed further.

Measurements conducted by CSIRO show that methane levels attributed to CSG operations are low relative to other sources, as shown in Table B 1.

Data for underground and open cut coal mining operations, livestock, and landfills have been based on the fact sheet released by CSIRO (2017). Methane emissions detailed for Narrabri wells and wastewater treatment plant based on the study by Day et al. (2016).

Table B 1 Sources of methane

Source	Methane emissions (kg/day)	Details
Narrabri wells	4.6 (median) 0 – 64 per well	In general, CSG wells in Qld and NSW are generally very low, with less than 1% of wells, releasing 63 kg/day. There was little seasonal variation in emissions.
Narrabri waste water treatment plant	32	The facility comprises four ponds, covering a total area of roughly 12 ha. Therefore, the maximum CH_4 emissions from water storage ponds were low (32 kg/day), given the size of the facility. However, it should be noted that the water had been held in the ponds for some time (possibly weeks) during which much of the dissolved CH4 originally present in the produced water would have outgassed to the atmosphere. It is therefore probable that the actual emissions from the facility are higher than indicated by these single measurements. The actual amount of CH4 released will be determined by the concentration of CH4 dissolved in the water under seam conditions, which is dependent upon the temperature, pressure and salinity of the water.
Underground coal mine	12960	About the same amount of methane produced by 150,000 Narrabri cows (2.7% of the total herd in NSW). This emission rate is taken from company's publically available documents.
Open cut mining operations	229 - 516	This emission rate is taken from company's publically available documents.
Livestock	7320	Emissions estimated from Narrabri cattle and sheep numbers in 2010 using published per‑head emission levels.
Landfill	405	From a single medium sized landfill in the Narrabri region.

Most of the peak methane concentrations observed during the mobile surveys were attributed to gas wells within about 50 m of the survey vehicle but there were also numerous other wells within similar distances of the survey routes that showed no sign of elevated methane. However, it should be noted that source detection using the mobile survey method is influenced by factors such as local wind conditions, size of the source and whether or not it is intermittent or continuous.

The mobile surveys through the Narrabri Gas Project area included driving along a 17 km section of the gas pipeline easement. During these surveys, the gas pipeline was within a few metres of the methane analyser inlet. Due to the high sensitivity of the Picarro instrument, even a small leak in the pipe would have been detectable under the conditions of the surveys. For example, measurements at the AGL

Camden well pads, the only commercial CSG project operating in NSW, were readily detected approximately 10 m from the source.

Although source detection is dependent upon suitable wind conditions, during the pipeline surveys the wind was very light and in any case, the survey route was sheltered from wind to a large extent by the forest on either side of the easement. Elevated methane levels was not detected near the pipeline during any of the surveys, thus confirming the integrity of this section of the pipeline.

Overall, the emission rates measured on the Narrabri wells are comparable to measurements made previously at CSG wells throughout NSW and Queensland, where the average emission rate was 3.2 g CH_4/min, but with a range of zero to about 44 g CH_4/min (Day et al., 2014).

Since most of the gas wells within the Narrabri Gas Project require dewatering, water treatment facilities have been established to accommodate water produced from the wells throughout the field. At present, treatment is limited to storage in purpose built ponds. Notwithstanding this, approval has been granted to construct a reverse osmosis plant at Leewood that would treat all produced water onsite.

Produced water is a potential emission route for CH_4. Emissions from the ponds at the Leewood facility, which currently accepts all of the produced water from the field, were measured during two site visits. The facility comprises four ponds, covering a total area of roughly 12 ha.

The maximum methane emissions from water storage ponds were low (32 kg/day), given the size of the facility. However, it should be noted that the water had been held in the ponds for some time (possibly weeks) during which much of the dissolved methane originally present in the produced water would have outgassed to the atmosphere. It is therefore probable that the actual emissions from the facility are higher than indicated by these single measurements. The actual amount of methane released will be determined by the concentration of methane dissolved in the water under seam conditions, which is dependent upon the temperature, pressure and salinity of the water.

Volatile organic compounds

The VOCs targeted in the study conducted by the CSIRO (Day et al., 2016) are prioritised under Australian and International guidelines for air quality assessment. These compounds are incorporated into two VOC suites:

- PAMS (Photochemical Assessment Monitoring Stations) hydrocarbon suite is prioritised under United States Environmental Protection Agency (USEPA) and California Air Resources Board (CARB) protocols as major organic precursors to the formation of ozone in the atmosphere. There are 57 hydrocarbons included in the PAMS suite.
- The TO-15 (Toxic Organics - Method 15) air toxics suite is prioritised under USEPA ambient air quality guidelines for human and environmental health. There are 65 organic compounds included in the TO-15 air toxics suite.

CSG production facilities in Camden and Gloucester, and the Santos operations at Narrabri were monitored for ambient VOC's. Details of the CSG sampling sites include:

- Camden Gas Project (AGL Energy) - 144 wells, with 96 producing. One gas processing plant. The Camden gas project is currently the only CSG producer in NSW selling gas commercially.
- Gloucester Gas Project (AGL Energy) - Four pilot wells producing gas. Produced gas is flared. The project was cancelled in February 2016, and since then all wells have been suspended with no gas production.
- Narrabri Gas Project (Santos Ltd) - About 50 pilot wells with gas and water treatment facilities. Some of the gas produced is used in the Wilga Park Power Station, while the remainder is flared.

The 21 hydrocarbons detected within the CSG sites from the PAMS suite are listed in Table B 2. Other hydrocarbons within the PAMS suite were not detected within any of the CSG sites. Table B 2 also shows the measured hydrocarbons for other source types. In general, measurements at the CSG sites were shown to be lower than the different source types.

The 15 hydrocarbons detected within the CSG sites from the TO-15 air toxics suite are listed in Table B 3. Other hydrocarbons within the TO-15 air toxics suite were not detected within any of the CSG sites. Table B 3 also shows the measured hydrocarbons for other source types. In general, measurements at the CSG sites were shown to be lower than the different source types.

Table B 2 PAMS hydrocarbon suite – Maximum measured ambient VOCs measured (ppbv) at source types/regions

Hydrocarbon VOC	CSG	Natural Sources	Camden Region	Cattle Feedlot	Coal Mine	Landfill	Wastewater treatment
Ethane	1	2.3	11	0.43	7.9	2	10.2
Propane	0.96	0.72	6.1	0.72	2.6	2.2	0.90
Isobutane	0.87	0.88	4	3	0.74	2.6	0.39
n-Butane	0.29	0.14	3.5	0.48	0.71	2.6	0.49
Benzene	0.56	0.77	0.26	0.15	0.11	- [3]	0.61
Toluene	0.71	0.26	3.9	0.36	3.3	1.1	0.48
Ethylbenzene	0.09	0.04	0.43	0.09	0.22	0.21	0.13
m- + p-Xylene	0.66	0.17	1.8	0.5	0.99	0.57	0.66
o-Xylene	0.32	0.08	0.58	0.23	0.3	0.24	0.30
n-Nonane	0.03	0.03	0.06	0.02	0.2	0.21	0.02
Isopropylbenzene	0.006	- [3]	0.05	0.13	0.01	0.13	0.33
n-Propylbenzene	0.03	0.02	0.1	0.05	0.03	0.07	0.05
m-Ethyltoluene	0.13	0.08	0.34	0.14	0.08	0.22	0.18
p-Ethyltoluene	0.04	0.04	0.13	0.07	0.03	0.1	0.08
1,3,5-Trimethylbenzene	0.07	0.02	0.14	0.04	0.08	0.15	004
o-Ethyltoluene	0.08	0.05	0.13	0.09	0.03	0.1	0.11
1,2,4-Trimethylbenzene	0.22	0.22	0.46	0.24	0.22	0.45	0.28
n-Decane	0.02	0.08	0.12	0.04	0.31	0.38	0.04
1,2,3-Trimethylbenzene	0.08	0.06	0.11	0.09	0.08	0.12	0.10
1,3-Diethylbenzene	0.01	0.01	0.03	0.01	0.006	0.01	0.02
1,4-Diethylbenzene	0.03	0.06	0.08	- [3]	0.14	0.17	- [3]

Table Note: [1]Table only lists hydrocarbon VOCs measured at CSG sites
[2]Not detected

Table B 3 TO-15 air toxics suite – Maximum measured ambient VOCs measured (ppbv) at source types/regions

Hydrocarbon VOC	CSG	Natural Sources	Camden Region	Cattle Feedlot	Coal Mine	Landfill	Wastewater treatment
Dichlorodifluoromethane	0.54	0.62	0.74	0.57	0.64	0.47	0.62
1,2-Dichloro-1,1,2,2-tetrafluoroethane	0.01	-[3]	-[3]	-[3]	-[3]	-[3]	-[3]
Ethanol	4.2	7.2	24.2	253	10.8	24.9	40.9
Acetone	4.8	18.7	11	26.4	21.4	202	93.2
Trichlorofluoromethane	0.25	0.31	0.32	0.28	0.32	0.25	0.30
Isopropanol	0.94	3.6	3.4	1.2	0.81	4.5	20.0
1,1,2-Trichloro-1,2,2-trifluoroethane	0.1	0.09	0.31	0.04	0.07	0.06	0.24
2-Butanone	0.27	0.93	0	4.1	2.2	18.1	2.9
Chloroform	0.05	0.06	0.43	0.02	0.27	0.06	0.30
1,3-Dichlorobenzene	0.01	0.01	0.1	-[3]	0.02	-[3]	-[3]
1,4-Dichlorobenzene	0.02	0.02	0.14	0.007	0.02	0.01	0.02
1,2-Dichlorobenzene	0.01	0.009	0.1	-[3]	0.02	-[3]	-[3]
1,2,4-Trichlorobenzene	0.02	0.03	0.4	-[3]	0.04	0.006	0.02
Naphthalene	0.02	0.04	0.44	0.02	0.06	0.31	0.06
Hexachloro-1,3-butadiene	0.01	-[3]	0.06	0.05	0.02	-[3]	0.009

Table Note: [1]Table only lists hydrocarbon VOCs measured at CSG sites
[2]Not detected

Appendix C. Namoi Region Air Quality Monitoring Project

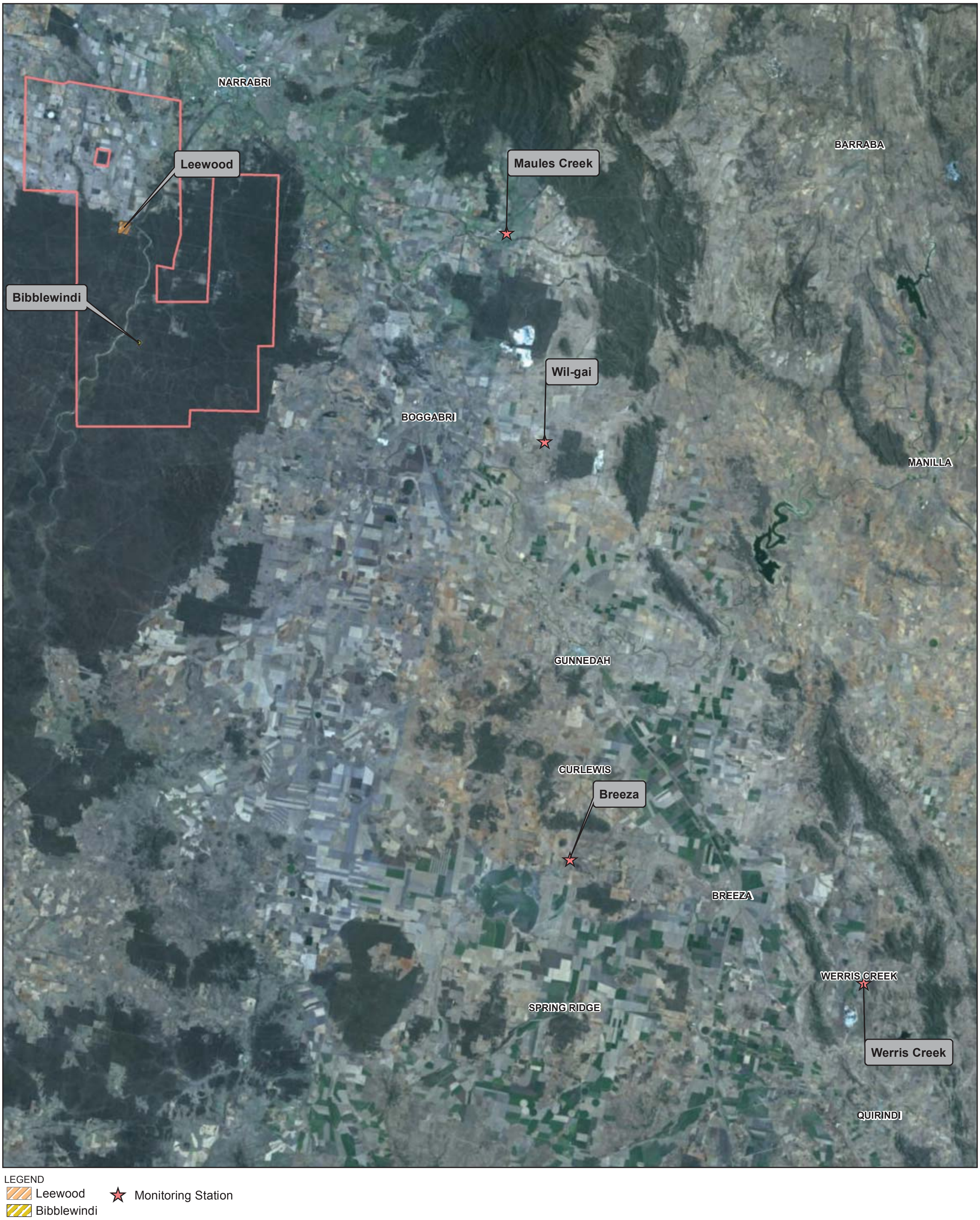
At the time of the completion of the air quality assessment, there no ambient air quality monitoring stations with publicly available data within the Narrabri region.

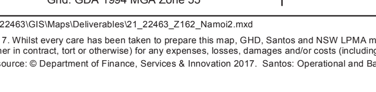
Since July 2015, the Namoi Region Air Quality Monitoring Project (NRAQMP) has been collecting data from four monitoring locations within the Namoi Region. Two of the sites are within 70 km of the site of the proposed development.

The NRAQMP, run by the NSW EPA, aims to provide community members with access to baseline ambient air quality data from privately-owned monitoring stations, while continuing to evaluate the requirement for a public regional air quality monitoring network.

Ambient concentrations of particulate matter, including PM_{10} and $PM_{2.5}$ are continuously measured within all sites. Two of the locations, Maules Creek and Wil-gail monitoring stations, are located within the region. Locations are shown in Figure C-1.

The data collected for the sites for 2015 (July to December), 2016, and 2017 (January to October) are summarised in Table C 1 and Table C 2.





Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

Narrabi Gas Project Line
Response to Submissions

Job Number	21-22463
Revision	A
Date	07 Nov 2017

Location of Monitoring Stations

Figure C-1

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Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: © Department of Finance, Services & Innovation 2017. Santos: Operational and Base Data - 2013. . Created by:jrbacani

Table C 1 Summary of PM_{10} concentration (µg/m³) statistics

Site	Year	Start	End	Highest 24-hr average	70th %ile	Annual mean	Events above criteria
Maules Creek	2015	July	Dec	28.6	11.7	9.7	-
	2016	Jan	Dec	62.8	12.3	9.7	1
	2017	Jan	Oct	53.5	10.2	9.1	1
Wil-gai	2015	July	Dec	39.2	9.4	8.2	-
	2016	Jan	Dec	48.4	13.7	11.0	-
	2017	Jan	Oct	51.2	15.3	12.9	1
NSW impact assessment criteria				50		25	5 allowable exceedances

Table C 2 Summary of $PM_{2.5}$ concentration (µg/m³) statistics

Site	Year	Start	End	Highest 24-hr average	70th %ile	Annual mean	Events above criteria
Maules Creek	2015	July	Dec	13.7	5.4	4.4	-
	2016	Jan	Dec	15.7	4.5	3.7	-
	2017	Jan	Oct	34.8	4.1	3.6	1
Wil-gai	2015	July	Dec	16.5	4.4	3.4	-
	2016	Jan	Dec	21.3	4.9	4.1	-
	2017	Jan	Oct	11.5	4.8	4.1	-
NSW impact assessment criteria				25	-	8	-

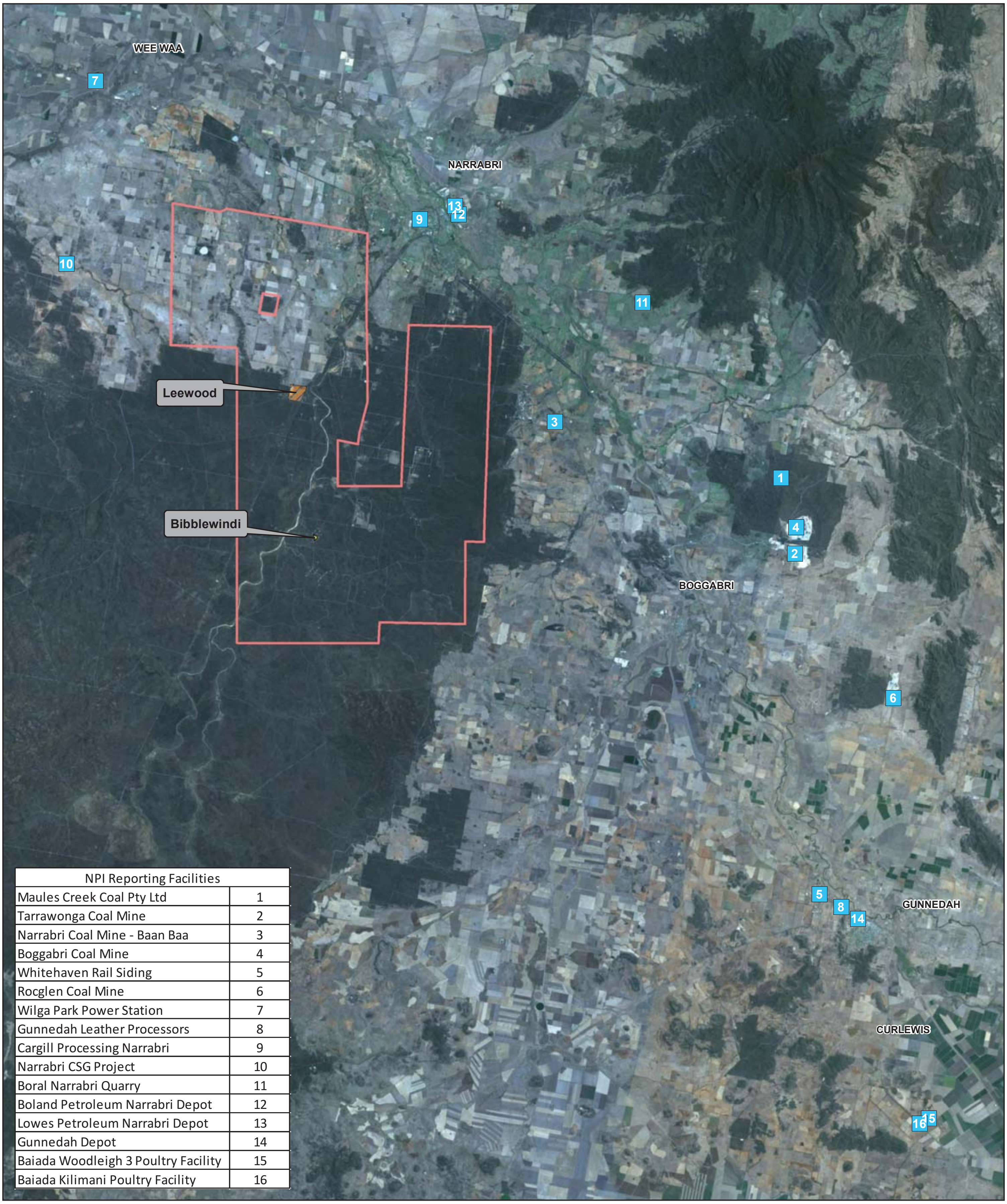
Appendix D. Emissions from Existing Local Industries based on the NPI

Regional air quality within the project area is mainly influenced by mining, coal seam gas (CSG) exploration activities, and agriculture. The National Pollutant Inventory (NPI) lists 16 sources of emissions within the Narrabri and Gunnedah Local Government Areas (LGA). The locations of these industries are shown in Figure D-1.

Emissions of substances reported to the NPI for the year 2016-17 are detailed in Table D 1.

Of the 16 emission sources, seven are associated with extractive industries for which the primary emissions are likely to be dust, with minor emissions of nitrogen oxides and volatile organic compounds.

Three industries are associated with fuel storage and distribution, where volatile organic compounds will likely be released. Odour is likely to be the primary emission for four industries associated with intensive animal husbandry or processing. Finally, the former Narrabri CSG Project (appraisal wells that provide gas to the Wilga Park Power Station) and the Wilga Park Power Station itself are only partially operating.



NPI Reporting Facilities	
Maules Creek Coal Pty Ltd	1
Tarrawonga Coal Mine	2
Narrabri Coal Mine - Baan Baa	3
Boggabri Coal Mine	4
Whitehaven Rail Siding	5
Rocglen Coal Mine	6
Wilga Park Power Station	7
Gunnedah Leather Processors	8
Cargill Processing Narrabri	9
Narrabri CSG Project	10
Boral Narrabri Quarry	11
Boland Petroleum Narrabri Depot	12
Lowes Petroleum Narrabri Depot	13
Gunnedah Depot	14
Baiada Woodleigh 3 Poultry Facility	15
Baiada Kilimani Poultry Facility	16

LEGEND
Leewood
Bibblewindi
Facilities

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

Narrabi Gas Project Line
Response to Submissions

Job Number 21-22463
Revision A
Date 16 Nov 2017

Regional NPI Reporting Facilities

Figure D-1

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Level 15, 133 Castlereagh Street Sydney NSW 2000 **T** 61 2 9239 7100 **F** 61 2 9239 7199 **E** sydmail@ghd.com.au **W** www.ghd.com.au

Data source: © Department of Finance, Services & Innovation 2017. Santos: Operational and Base Data - 2013. . Created by:jrbacani

Table D 1 Emissions (tonnes/yr) of industrial sources within the Narrabri and Gunnedah LGA reported to the NPI for 2016-17

Industry	Coal Mining						Fossil Fuel Elec. Gen.	Leather Mfg.	Oil and Fat Mfg.	Oil and Gas Extract	Other Const. Mat. Mining	Petroleum Product Wholesaling			Poultry Farming (Meat)	
Substance	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Ammonia (total)	-	-	-	-	-	-	-	1.61	-	-	-	-	-	-	18.57	-
Antimony & compounds	0.01	-	< 0.01	< 0.01	< 0.01	-	-	-	-	-	-	-	-	-	-	-
Arsenic & compounds	0.03	0.01	0.01	0.02	< 0.01	0.01	-	-	< 0.01	-	-	-	-	-	-	-
Benzene	0.03	-	-	0.02	-	-	-	-	-	-	-	-	0.01	-	-	-
Beryllium & compounds	0.01	< 0.01	< 0.01	< 0.01	-	< 0.01	-	-	< 0.01	-	-	-	-	-	-	-
Boron & compounds	0.41	0.13	0.09	0.34	0.02	0.05	-	-	-	-	-	-	-	-	-	-
Cadmium & compounds	< 0.01	< 0.01	< 0.01	< 0.01	-	< 0.01	-	-	< 0.01	-	-	-	-	-	-	-
Carbon monoxide	694.88	231.65	62.77	595.05	8.16	77.59	47.05	-	18.20	10.38	2.86	-	-	-	-	-
Chromium (III) compounds	0.42	0.09	0.07	0.34	0.01	0.07	-	-	< 0.01	-	-	-	-	-	-	-
Chromium (VI) compounds	-	-	-	-	-	-	-	-	< 0.01	-	-	-	-	-	-	-
Cobalt & compounds	0.02	0.01	0.01	0.01	< 0.01	-	-	-	-	-	-	-	-	-	-	-
Copper & compounds	0.30	0.06	0.04	0.28	< 0.01	0.04	-	-	< 0.01	-	-	-	-	-	-	-
Cumene (1-methylethylbenzene)	0.01	0.01	0.00	0.02	-	< 0.01	-	-	-	-	-	0.01	< 0.01	-	-	-
Cyclohexane	-	-	-	-	-	-	-	-	-	-	-	-	< 0.01	0.02	-	-
Ethylbenzene	< 0.01	< 0.01	-	0.01	-	-	-	-	-	-	-	< 0.01	< 0.01	< 0.01	-	-
Fluoride compounds	1.86	0.22	0.16	1.60	< 0.01	0.20	-	-	0.46	-	0.01	-	-	-	-	-
Hydrochloric acid	-	-	-	-	-	-	-	-	3.58	-	-	-	-	-	-	-
Lead & compounds	0.17	0.07	0.05	0.12	0.01	0.04	-	-	< 0.01	-	-	-	< 0.01	-	-	-
Manganese & compounds	4.40	0.86	0.68	4.22	0.02	0.89	-	-	-	-	-	-	-	-	-	-
Mercury & compounds	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	< 0.01	< 0.01	-	-	-	-	-	-
n-Hexane	-	-	-	-	-	-	-	-	0.37	-	-	-	0.01	0.04	-	-
Nickel & compounds	0.15	0.06	0.04	0.10	0.01	0.05	-	-	< 0.01	-	-	-	-	-	-	-

Industry	Coal Mining						Fossil Fuel Elec. Gen.	Leather Mfg.	Oil and Fat Mfg.	Oil and Gas Extract	Other Const. Mat. Mining	Petroleum Product Wholesaling			Poultry Farming (Meat)	
Substance	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
Oxides of Nitrogen	1553.93	525.43	208.45	1173.73	22.81	112.92	183.89	-	23.67	22.90	9.50	-	-	-	-	-
Phosphoric acid	-	-	-	-	-	-	-	-	0.04	-	-	-	-	-	-	-
Polychlorinated dioxins and furans (TEQ)	-	-	-	-	-	-	-	-	0.00	-	-	-	-	-	-	-
Polycyclic aromatic hydrocarbons (B[a]Peq)	0.04	0.01	0.00	0.03	0.00	0.00	-	-	0.00	0.00	0.00	-	-	-	-	-
Selenium & compounds	0.01	-	0.01	0.00	-	-	-	-	-	-	-	-	-	-	-	-
Sulfur dioxide	1.01	0.39	0.06	0.77	0.01	0.07	0.29	-	45.37	0.04	0.00	-	-	-	-	-
Toluene (methylbenzene)	0.04	0.01	-	0.04	-	-	-	-	-	-	-	0.01	0.01	0.05	-	-
Total Volatile Organic Compounds	119.83	39.91	10.58	83.31	2.07	8.18	1.21	-	0.68	6.25	0.83	1.13	0.97	3.88	-	-
Particulate Matter 10.0 um	4184.42	1703.65	706.08	4373.92	92.66	797.97	1.09	-	4.45	0.97	9.10	-	-	-	-	-
Particulate Matter 2.5 um	95.49	29.99	9.78	70.63	1.49	6.60	1.09	-	1.57	0.94	0.65	-	-	-	-	-
Xylenes (individual or mixed isomers)	0.02	0.01	0.01	0.02	-	0.00	-	-	-	-	-	0.01	0.00	0.02	-	-
Zinc and compounds	2.09	0.18	0.15	1.95	0.00	0.13	-	-	-	-	-	-	-	-	-	-

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Appendix J

Cultural Heritage Management Plan

Santos
We have the energy.

Cultural Heritage Management Plan

Narrabri Gas Project

December 2017

Appendix J

CONTENTS

CLAUSE **PAGE**

Schedule

CULTURAL HERITAGE MANAGEMENT PLAN
NARRABRI GAS PROJECT

1. INTRODUCTION

1.1 The Proponent

Santos NSW (Eastern) Pty Ltd (Santos) is proposing to develop natural gas from coal seams in the Gunnedah Basin in New South Wales (NSW), southwest of Narrabri.

1.2 EIS requirements for the Project

Santos is in the process of making an application for State significant development consent under the *Environmental Planning and Assessment Act 1979 (NSW)* to carry out the Project. The development application is to be accompanied by an Environmental Impact Statement (EIS).

Amongst other requirements, the EIS is required to include:

(a) assessment of the impacts of the Project on Aboriginal Cultural Heritage;

(b) Cultural Heritage Management Plan (CHMP) providing the framework for the management of Aboriginal Cultural Heritage during the implementation of the Project. The CHMP is also to incorporate:

   (i) Aboriginal Cultural Heritage sensitivity mapping for the Project Area;

   (ii) an update of the mapping every five years as part of a CHMP review; and

   (iii) avoidance strategies and mitigation measures in the placement of infrastructure.

1.3 Development of this CHMP

Santos has developed this CHMP in consultation with the Aboriginal stakeholders e.g. the Gomeroi Native Title Applicant, Registered Aboriginal Parties, and Local Aboriginal Land Councils, to provide the framework for avoiding or minimising impacts from the Project on Aboriginal Cultural Heritage and to promote the responsible management of Aboriginal Cultural Heritage Values in connection with the undertaking of the Project.

This CHMP describes how the impact of activities required for the Project on Aboriginal Cultural Heritage will be managed. Project Activities will be designed such that, to the greatest extent possible, there is no impact on Aboriginal Cultural Heritage. Where the impact cannot be avoided, then the Project Activity will minimise impact on any Aboriginal Cultural Heritage, and other management measures, as appropriate, are to be implemented to minimise or mitigate harm.

Santos is committed to fully implementing the CHMP.

The CHMP provides parties undertaking activities for the Project in the future with a clear understanding of the commitment of Santos to manage any impact on Aboriginal Cultural Heritage. The CHMP sets out:

(a) the background to the Project and development of the CHMP;

(b) the details of the approval process, the objectives of the CHMP and the consultation undertaken in the preparation of the CHMP;

(c) Section 3 – Aboriginal Cultural Heritage in the Project Area describes the results of the Aboriginal cultural heritage assessment undertaken for the Project Area;

(d) the management strategies to be implemented for the known Aboriginal cultural heritage sites and any future sites which may be identified during the life of the Project;

(e) ongoing consultation, management and reporting requirements;

(f) proposed review processes; and

(g) dispute resolution procedures.

2. BACKGROUND TO THE PROJECT AND THIS CHMP

2.1 Project

(a) Description of the Project

The Project seeks to develop gas wells, gas and water gathering systems and supporting infrastructure in the Project Area. The natural gas produced would be treated through additional compression, carbon dioxide removal and dehydration at a central gas processing facility on a rural property located south-west of Narrabri (the Leewood property) within the Project Area. The gas would then be piped via a high-pressure gas transmission pipeline to market. The gas transmission pipeline would be part of a separate approvals process and is therefore not part of this Project.

The specific elements of the Project for which planning approval is being sought, and those that are therefore assessed in this EIS, are the gas field, major facilities including a central water management facility and a gas processing facility, and supporting infrastructure.

The primary objective of the Project is to commercialise natural gas from coal seams for the East Australian gas market to support the energy security needs of NSW.

(b) Requirements for the Project

The development of the Project would include the construction and operation of a range of exploration and production activities and infrastructure including:

(i) Gas exploration and appraisal activities including seismic surveys, chip holes, core holes and pilot wells (sets of pilot wells), associated temporary supporting infrastructure (flares or water balance tanks) and the installation of monitoring equipment. These may be converted to production wells.

(ii) Installation and operation of up to 850 new individual production wells on a maximum of 425 new well pads. A single well may be vertical, vertical deviated, or lateral; the latter may include several horizontal connections sometimes referred to as a multi-lateral. The target production peak rate is approximately 200 terajoules per day. Each well pad would be approximately one hectare in size during drilling and construction, reducing to approximately 0.25 hectares during operation.

(iii) Gas and water gathering systems (comprising underground pipelines) link each well head to the gas processing facility, and the water management treatment and beneficial reuse facilities. A right of way up to 12 metres wide would be required during installation of the gas and water gathering systems, reducing to about five metres during operation.

(iv) A central gas processing facility for the compression, dehydration and treatment of the gas.

(v) Augmentation of the approved water management, treatment and beneficial reuse facilities at Leewood to treat the produced water.

Supporting infrastructure such as power generation and distribution, communications, roads and operational management facilities as well as temporary workers' accommodation and concrete batching plant at Leewood.

The Project involves installing the wells and associated infrastructure within the Project Area in accordance with site locational criteria, including as set out in the CHMP.

The Project is expected to generate 1,300 jobs during the construction phase and sustain around 200 jobs during operations.

Subject to obtaining all the required regulatory approvals, construction of the Project is expected to commence in 2019, with first gas scheduled for 2020/2021.

(c) **Project Location**

The Project would be located to the south and west of Narrabri (see the map provided in Schedule 1).

The total Project Area is approximately 95,000 ha in size. The surface infrastructure required for the Project will directly impact approximately one percent of the total Project Area. The majority of the Project is located within an area known as the 'Pilliga', with the remainder of the Project, approximately 30 per cent, located on agricultural land supporting dry-land cropping and pastoral (livestock) activities. None of the agricultural land has been mapped as prime 'biophysical strategic agricultural land' under NSW Government approvals legislation pertaining to coal seam gas.

The collective term 'Pilliga' represents an agglomeration of forested area that totals in excess of 500,000 ha within north-western NSW around Coonabarabran, Baradine and Narrabri. Nearly half of the Pilliga is currently allocated to conservation, and is managed under the NSW *National Parks and Wildlife Act 1974*. Within the Pilliga, the Project would be developed primarily within State Forest (within the area identified for coal seam gas development in the public land assessment process that concluded in 2005), and also on some privately managed land, though would avoid conservation areas such as the Pilliga Nature Reserve, the Pilliga State Conservation Area and Brigalow State Conservation Area.

2.2 Project approval process and EIS requirements

(a) **Statutory requirements**

The Project is permissible with development consent under the *State Environmental Planning Policy (Mining, Petroleum and Extractive Industries) 2007*, and is identified as a 'State significant development' under section 89C(2) of the EP&A Act and the *State Environmental Planning Policy (State and Regional Development) 2011*.

The Project is subject to the State significant development assessment and approval provisions of Division 4.1 of Part 4 of the EP&A Act. The Minister for Planning is the consent authority, who is able to delegate the consent authority function to the Planning Assessment Commission, the Secretary of the Department of Planning and Environment or to any other public authority.

If the Project is granted approval as a State significant development under the *Environmental Planning and Assessment Act 1979 (NSW),* then an Aboriginal heritage impact permit is not required to be obtained under Part 6 of the *National Parks and Wildlife Act 1974 (NSW).* However, a Care and Control Permit under section 85A of the *National Parks and Wildlife Act 1974 (NSW)* will be required should there be a need for any salvage works that require the transfer of Aboriginal objects to Aboriginal groups. Further, section 89A of the *National Parks and Wildlife Act 1974 (NSW)* requires the OEH to be notified about the location of any newly discovered Aboriginal objects as soon as practicable after their discovery.

(b) **EIS requirements**

The EIS for the Project is required to address the Secretary's Requirements. The Secretary's Requirements require:

"Heritage – including an assessment of the likely Aboriginal and historic heritage (cultural and archaeological) impacts of the development, having regard to OEH's recommendations to the Secretary."

The OEH's recommendations appended to the Secretary's Requirements are:

(a) an Aboriginal cultural heritage assessment (including both cultural and archaeological significance) which:

(i) demonstrates effective consultation with Aboriginal communities in determining and assessing impacts, and developing and selecting mitigation options and measures. The proponent must comply with the OEH 2010 Consultation Requirements for Proponents and consult with all Registered Aboriginal Parties (RAPs) not just Gomeroi Native Title Applicant and relevant LALC in relation to the development and implementation of the CHMP;

(A) an assessment of the impacts of the Project on Aboriginal cultural heritage; and

(B) outlines any proposed impact mitigation and management measures (including an evaluation of the effectiveness and reliability of the measures).

(b) Aboriginal cultural heritage sensitivity mapping for the Project Area

(c) Descriptions of the Cultural Heritage Values inclusive of relevant archive and oral history transcriptions documented in the ACH Brigalow Belt South Bioregion assessment (RACD 2002: LALC report).

(d) Significance statements about Aboriginal objects inclusive of the results of previous studies including the studies titled the Aboriginal cultural heritage Stage 1 Preliminary Assessment report (RACD 2000) including Appendix C titled, Aboriginal cultural heritage field survey of the Goonoo and Pilliga Forests.

(e) Description of the sensitivity of landforms affected by the Project inclusive of the geomorphic landforms described in the ACH Brigalow Belt South Bioregion assessment (RACD 2000: Appendix C (as titled above) and Appendix Ca titled, Geomorphology of the Goonoo and Pilliga Forests, Brigalow Belt South Bioregion as part of the Indigenous cultural heritage assessment and community consultation of the BBSB).

(f) A review of Aboriginal Cultural Data held by OEH and the Narrabri LALC, and strategic validation of this data.

(g) A Cultural Heritage Management Plan (CHMP) providing the framework for the management of Aboriginal cultural heritage during the implementation of the Project.

(h) The CHMP is proposed to:

(i) incorporate the ACH sensitivity mapping; provide for an update of the mapping every five years as part of the CHMP review; and

(ii) incorporate avoidance strategies and mitigation measures in the placement of infrastructure;

(i) the participation of the Aboriginal community (being representatives of the Gomeroi Native Title Applicant and relevant LALC) in pre-clearance surveys for the placement of infrastructure in accordance with the avoidance strategies in the CHMP. The proponent must comply with the OEH 2010 Consultation Requirements for Proponents and consult with all Registered Aboriginal Parties (RAPs) not just Gomeroi Native Title Applicant and relevant LALC in relation to the development and implementation of the CHMP;

(j) the significance of any impacts and appropriate management response determined by the Aboriginal community (being representatives of Gomeroi Native Title Applicant and the relevant LALC) in discussion with the proponent;

(k) provide a report on implementation of the CHMP to OEH every year; and

(l) an independent dispute resolution process where the Aboriginal community and proponent cannot agree on matters under the CHMP.

2.3 Objectives of CHMP

The objectives of this CHMP are:

(a) to address the OEH recommendations appended to the Secretary's requirements;

(b) to provide the framework for the management of Aboriginal Cultural Heritage during the implementation of the Project;

(c) to set out the processes and procedures to ensure that the Project will be designed such that to the greatest extent possible, there is no impact on Aboriginal Cultural Heritage. Where impact cannot be avoided then the Project Activity will be designed to minimise impact on any Aboriginal Cultural Heritage, and other management measures as appropriate are to be implemented to minimise or mitigate harm; and

(d) to include participation of the local Aboriginal community in management of potential impacts from the Project on Aboriginal Cultural Heritage.

2.4 Development of this CHMP – compliance with statutory processes

This CHMP has been developed with the cooperation of members of the local Aboriginal community, and Aboriginal people who have a traditional or cultural connection to, the Project Area.

As part of the process to develop this CHMP, Santos issued notices to relevant Aboriginal stakeholders and published notices in local newspapers circulating in the general location of the Project Area, in accordance with the *Aboriginal Cultural Heritage Consultation Requirements for Proponents 2010*. These notices invited Aboriginal people who hold cultural knowledge relevant to determining the significance of Aboriginal cultural heritage in the Project Area to register their interest in contributing to the development of this CHMP.

All those persons who responded to those notices and sought to register an interest in contributing to the development of this CHMP were recorded and given the status of Registered Aboriginal Parties (RAP).

Santos met with and consulted with those RAPs in relation to the development of the Project and the development of this CHMP. Each RAP was sent a copy of the proposed methodology for review and comment. Similarly, each RAP was asked to provide information about whether there are any Aboriginal objects, information regarding Aboriginal cultural values or places of cultural value to Aboriginal People in the Project Area.

Santos provided each RAP with an opportunity to comment on the provisions of this CHMP, either in writing or verbally, or to express their views regarding the nature or significance of Aboriginal Cultural Heritage within the Project Area.

The comments and views of the RAPs have been considered and reflected in the development of this CHMP.

2.5 Application, Term and Amendment of this CHMP

This CHMP sets out the principles and processes by which Aboriginal Cultural Heritage will be managed within the Project Area, and will apply to all activities carried out for the Project within the Project Area. It is intended that this CHMP will apply, subject to any amendments or revisions, throughout the life of the Project.

Santos acknowledges that, given the 25-year life of the Project, the CHMP may require review and amendment. Any modification to the application of this CHMP or its amendment will involve appropriate consultation with Aboriginal stakeholders in accordance with this CHMP and compliance with any relevant statutory approval process for amendment.

3. ABORIGINAL CULTURAL HERITAGE IN THE PROJECT AREA

3.1 Cultural Heritage Audit Review

In compliance with the OEH requirements and for the purposes of preparing the EIS, Santos reviewed a broad range of baseline data and undertook comprehensive field surveys as part of a cultural heritage audit review. The data obtained through the cultural heritage audit review were integrated into a comprehensive data set which has allowed the generation of a sensitivity map and the creation of an Aboriginal Cultural Heritage Zoning Scheme (CHZS) for the Project Area (see Schedule 2).

As it currently stands it contains three general sets of zones in the CHZS. The definitions of these and how each has been developed is discussed below.

3.2 Zone 1 – Identified Aboriginal Cultural Heritage Places

Zone 1 represents areas where there is known Aboriginal Cultural Heritage.

The cultural heritage audit review collated information on 268 individual places containing Aboriginal cultural heritage material and values within the field survey area. Of these places, 90 are located in the Project Area. These have been grouped into two sub-zones (Zone 1a and 1b) based around the source of this information.

Buffers for each of these two sub-zones have been generated as follow:

- Zone 1a includes a 100m buffer (radius) of all places currently included on AHIMS – this buffer will be revised down as additional data becomes available from the site verification program (see Section 4.6):

- Zone 1b includes a graduated buffer based on the place-type and values adhering to it for the remaining identified Aboriginal cultural heritage places. The buffer has been applied to both the point-based data and, where available, the extent of the place where such has been provided or able to have been generated. Five buffer categories have been applied to the items in this particular Zone as follows:

    - 20m around isolated stone artefact/s;

- 40m around stone artefact scatters;
- 50m around places including scarred trees, resource places, rock shelters/ caves, hearths and general historic places (such as camps);
- 75m around grinding grooves; and
- 100m around places including those associated with Aboriginal ceremony (such as stone arrangements and rings) and burials, as well as the considerably undefined places identified as being an ochre source and that containing shell.

Santos will avoid the identified Aboriginal Cultural Heritage Sites within this Zone.

3.3 Zone 2 – Previously surveyed / developed areas

Zone 2 represents areas where an Aboriginal cultural heritage survey and assessment has been undertaken but within which no Aboriginal Cultural Heritage has been identified.

This zone has been created from an amalgam of various sources relating to portions of the field survey area which have been the subject of Aboriginal cultural heritage survey and assessment and within which areas have subsequently been developed as part of CSG (both ESG and/or Santos) development programs. There were two types of data that were provided either as digital data sets or which could be created from information provided within reports, and which represented areas that had been inspected during fieldwork: actual survey areas (polygons) or survey transects (lines). The transect records were buffered using the widths nominated within the associated reporting and added to the existing polygons. These records were then merged together to remove overlap.

3.4 Zone 3 – Aboriginal Cultural Heritage Sensitivity

Zone 3 represents areas where an Aboriginal cultural heritage survey and assessment has identified the potential for Aboriginal Cultural Heritage to exist, in a sufficient manner to prepare sensitivity mapping.

This has been broken down into six sub-zones (Zones 3a - 3f). The first five identify portions of the field survey area which have been identified as having an Aboriginal cultural heritage sensitivity graduated from very high (Zone 3a) to very low (Zone 3e). The sixth sub zone (3f) relates to four small portions of the study area (approximately 362 ha or <0.2% of the field survey area) for which information was not sufficient to make an adequate assessment of its likely sensitivity with respect to Aboriginal Cultural Heritage.

It is possible that there may be cultural heritage sites that have not been identified in previous studies within Zone 3. This CHMP provides for the methodology to deal with any Aboriginal Cultural Heritage that has not yet been identified.

4. MANAGEMENT FRAMEWORK FOR ABORIGINAL CULTURAL HERITAGE

4.1 Principles

The Project will be managed in accordance with the following principles:

(a) the Avoidance Principle, which is defined in the following terms:

(i) Project Activities will be designed such that, to the greatest extent possible, there is no impact on Aboriginal Cultural heritage. Where impact cannot be avoided then the Project Activity will be designed to minimise impact on any Aboriginal Cultural Heritage, and other management measures as appropriate are to be implemented to minimise or mitigate harm; and

(b) the Precautionary Principle, which is defined as:

(i) the implementation of actions that are reasonable and practicable to minimise causing harm to known Aboriginal objects; and/or

(ii) identifying Aboriginal Cultural Heritage so they can be managed in accordance with the provisions of relevant legislation and regulations, and implementing reasonable and practicable management measures for these Aboriginal Cultural Heritage.

4.2 Site protection of known Aboriginal cultural heritage Sites

The cultural heritage audit review identified 90 known Aboriginal cultural heritage sites within the Project Area. Santos will ensure that the infrastructure required for the Project will not be located in areas where the 90 known Aboriginal cultural heritage sites are located or within specified buffer distances around these areas. The 90 currently known sites and proposed buffer areas for each site are identified in Schedule 7.

The cultural heritage audit review recognised that there was some uncertainty about the specific location of each of the 90 known Aboriginal cultural heritage sites. Santos undertook a pilot site verification audit for a portion of the known Aboriginal sites to verify the precise location of each site and update the details in the sites register.

The audit identified some discrepancies between the Aboriginal Heritage Information Management System (AHIMS) recorded locations of the sites and the actual on-ground locations. Santos has updated the Aboriginal Cultural Heritage Site Register to reflect the verified locations and is committed to undertake a further audit as part of this CHMP to verify the ground locations and to update the Aboriginal Cultural Heritage Site Register for the remaining known sites (see section 5). This will ensure that Santos, as a practical matter, is able to locate its infrastructure for the Project so as not to be in areas where the 90 sites are located. Further, as a precautionary approach, Santos has proposed an additional buffer around the sites in which it will not disturb the ground for installation of infrastructure.

The cultural heritage audit review also recognised that given the size of, and vegetation cover within the Project Area, there may be other Aboriginal cultural heritage sites which have not been identified in the surveys undertaken to date. In order to manage the risk of the installation of infrastructure for the Project impacting on these potential sites, Santos is committed to a process of undertaking pre-clearance surveys prior to disturbing the land for the particular infrastructure to verify whether the proposed site contains any Aboriginal cultural heritage sites. The process for the pre-clearance surveys is set out in section 4.8.

Should the pre-clearance survey identify an Aboriginal cultural heritage site of the type in the table in Schedule 3, then Santos will not locate the infrastructure in that area and will re-site the infrastructure after following the same process again.

Should the pre-clearance survey identify an Aboriginal cultural heritage site of the type in the table in Schedule 4, then Santos will, where practicable, not locate the infrastructure in that area and will re-site the infrastructure after following the same process again. If it is not practicable to re-site the infrastructure, then Santos will adopt the management measures identified in the third column of the table.

A description of each site type is located in Schedule 5.

The cultural heritage audit review specifications identified that Yarrie Lake was a place of Aboriginal cultural heritage significance. Yarrie Lake reserve is a designated surface development exclusion zone (including a buffer of at least 50 m) for the project.

4.3 Aboriginal Cultural Heritage Working Group

Santos will establish an Aboriginal Cultural Heritage Working Group (ACHWG) to assist in the implementation of this CHMP.

The process to establish the ACHWG and its purpose, functions and procedures are described in Schedule 6.

On agreement by Santos, Santos will provide all resources reasonably required to enable the ACHWG to perform all required duties and functions. Resourcing will be in accordance with Santos' schedule of rates.

4.4 Cultural Heritage Coordinator

The ACHWG will be requested to appoint a Cultural Heritage Coordinator by majority decision and to notify Santos of the name and contact details of the person appointed as Cultural Heritage Coordinator within 10 business days of each nomination from time to time.

The Cultural Heritage Coordinator will be the first point of contact for Santos in matters relating to the implementation of this CHMP on which the views of the ACHWG are required. The Cultural Heritage Coordinator's role and essential skills are described in Schedule 8, including that they must have knowledge of Gomeroi cultural heritage.

The Cultural Heritage Coordinator will not be a member of the ACHWG and will not have voting or any other procedural rights under this CHMP.

The Cultural Heritage Coordinator's performance will be reviewed annually by their employer or head contractor in consultation with the ACHWG and Santos with a view to confirm whether the appointment of the Cultural Heritage Coordinator will continue or if the Cultural Heritage Coordinator will be replaced.

The functions of the Cultural Heritage Coordinator under this CHMP are:

(a) nominating Cultural Heritage Officers that are able to observe and comply with Santos policies and procedures, to be members of a Survey Team to undertake Pre-Clearance Surveys in relation to Work Programs issued by Santos;

(b) ensuring that all members of the Survey Team will unconditionally observe and comply with any health, safety, environmental and other reasonable procedures and policies implemented by Santos;

(c) receipt and issue of notices under provisions of this CHMP; and

(d) responsibility for the timely implementation of any Pre-Clearance Surveys relating to Work Programs prepared or issued under provisions of this CHMP.

The Cultural Heritage Coordinator may also perform any other duties as requested by the ACHWG where such duties and functions are consistent with the provisions and intent of this CHMP.

On agreement by Santos, Santos will provide all resources reasonably required to enable the Cultural Heritage Coordinator to perform all required duties and functions.

4.5 Santos Aboriginal Cultural Heritage Site Register

Santos will maintain a comprehensive Aboriginal Cultural Heritage Site Register for the Project Area.

Santos will maintain the Aboriginal Cultural Heritage Site Register for the life of the Project and will ensure that all confidentiality requirements of information obtained during the life of the Project are complied with and maintained.

The Site Register will be amended from time to time as information becomes available through the site verification program, Additional Research Program and Pre-Clearance Survey Program as described in sections 4.6 to 4.8.

The Site Register, in collaboration with GIS and other mapping tools, will be used by Santos to implement management measures provided for in this CHMP.

The Aboriginal Cultural Heritage Site Register for the Project Area will be made available to the ACHWG, subject to any confidentiality requirements.

4.6 **Site verification, reporting and reconciliation**

Santos has undertaken a pilot study to confirm the ground location of each of the recorded known Aboriginal cultural heritage sites mentioned in section 4.2.

Santos will implement a Site Verification Program for all other sites identified from the cultural heritage audit review within the Project Area.

The program will be completed within 12 months of project sanction.

The site verification program will use the same methodology as used in the pilot site verification program described in the Project EIS.

Where Santos identifies inconsistencies between any information included on the Santos Aboriginal Cultural Heritage Site Register and the AHIMS, Santos may liaise with OEH to have the AHIMS revised so that it is consistent with the Aboriginal Cultural Heritage Site Register.

Where OEH agrees to revise any information on the AHIMS database, the ACHWG Coordinator will advise the members of the ACHWG and note such amendments in the Aboriginal Cultural Heritage Site Register.

Santos may amend the Sensitivity Mapping as necessary to reflect any amendments to the Aboriginal Cultural Heritage Site Register that results from the site verification program.

4.7 **Additional Research Program**

To further Santos' commitment to adopt the Precautionary Principle as it relates to the management of impacts on Aboriginal Cultural Heritage, supplementary research will be undertaken in consultation with the Aboriginal community to confirm existing data sets for places of Aboriginal Cultural Heritage and, where it proves necessary, augment data.

This will be done by the conduct of an Additional Research Program. The aim will be to collate a body of data on places and values that can be integrated into general project planning such that the locations where these places and values are identified can be managed by the Avoidance Principle.

A research program targeting places and values of particular traditional, anthropological, historical and contemporary significance to Aboriginal people will be developed and completed within 12 months of project sanction.

4.8 **Disturbance Activities and Pre-Clearance Surveys**

(a) **Disturbance Activities**

Santos will not carry out Disturbance Activities in the Project Area except in accordance with the process set out below.

(b) **Work Programs**

Subject to section 4.8, if Santos proposes to conduct Disturbance Activities on any part of the Project Area, Santos will provide to the Cultural Heritage Coordinator a copy of Santos' intended Work Program for the relevant area and request a planning meeting with the Cultural Heritage Coordinator.

The Cultural Heritage Coordinator, the Santos Senior Cultural Heritage Field Supervisor and, where applicable, a Technical Expert will meet (in person or by telephone) within 2 Business Days following provision of a copy of Santos' intended Work Program to agree on:

(i) the number of (and identity of, as nominated by the Cultural Heritage Coordinator) persons required to conduct a Pre-Clearance Survey of the Work Area which will be:

(A) for Work Areas in a Zone 3d and 3e of the CHZS (**Low to very low Sensitivity Zone)**, a maximum of 2 persons unless otherwise agreed by Santos;

(B) for Work Areas in Zone 3c of the CHZS (**Medium Sensitivity Zone)** or above, a minimum of 2 persons and a maximum of 4 persons unless otherwise agreed by Santos, plus one Technical Expert if requested by the Cultural Heritage Coordinator.

(Pre-Clearance Planning Meeting)

(ii) the methodology and logistics for the Pre-Clearance Survey of the Work Area; and

(iii) a timetable for the Pre-Clearance Survey of the Work Area (which shall commence within a further 10 Business Days following the planning meeting or any later date as agreed between the Cultural Heritage Coordinator and the Santos Senior Cultural Heritage Field Supervisor).

If, at the Pre-Clearance Planning Meeting, the Santos Senior Cultural Heritage Field Supervisor and the Cultural Heritage Coordinator are unable to reach agreement on either 4.8(b)(i), 4.8(b)(ii) or 4.8(b)(iii) above Santos may independently determine these items.

(c) **Contents of Work Programs**

Each Work Program issued by Santos to the Cultural Heritage Coordinator will contain the Program Timeframe and sufficient detail to identify the proposed Disturbance Activities and the Work Area and may include:

(i) a topographic map at a scale of 1:100 000 or other appropriate scale of the Work Area, and/or aerial/satellite images showing with reasonable accuracy the Work Area; and

(ii) with respect to the Work Area, details of:

(A) the nature and extent of the proposed Disturbance Activities;

(B) the estimated duration of the proposed Disturbance Activities;

(C) the means of access to undertake the proposed Disturbance Activities;

(D) the resourcing offered for the conduct of a Pre-Clearance Survey; and

(E) any other information considered relevant by Santos.

(d) **No Pre-Clearance Surveys or Work Programs required for some Project Activities**

Santos may undertake Project Activities without undertaking a Pre-Clearance Survey or Work Program:

(i) when there will be No Additional Surface Disturbance; or

(ii) on areas that have been subject to Significant Ground Disturbance; or

(iii) on areas where a Cultural Heritage Compliance Plan (or equivalent due diligence or other survey conducted under the Due Diligence Code of Practice for the Protection of Aboriginal Objects in New South Wales) has previously been issued, or

(iv) on areas marked Zone 2 on the CHZS.

(e) **Pre-Clearance Survey**

Following Santos' provision of a Work Program to the Cultural Heritage Coordinator, it is proposed that the Survey Team, in the relevant Program Timeframe, would undertake the survey of the Work Area with objectives to:

(i) provide an opportunity for the members of the Survey Team to walk over and inspect the Work Area and to consider the Aboriginal Cultural Heritage in the Work Area including test excavations in areas associated with water features as directed by the Technical Expert;

(ii) identify, document and determine the geographical coordinates of, and report upon, any Aboriginal Cultural Heritage within the Work Area;

(iii) peg or flag Aboriginal Cultural Heritage within the Work Area, if deemed necessary by the Survey Team; and

(iv) recommend any required management measures consistent with the provisions of the CHMP.

(f) **Santos Representative**

Santos Senior Cultural Heritage Field Supervisor will accompany each Survey Team while it performs the Pre-Clearance Survey.

The Santos Senior Cultural Heritage Field Supervisor will have authority to undertake their role in accordance with this CHMP.

(g) **Alternative Work Area Clearance**

If a Work Area is suspected by the Survey Team to contain Aboriginal Cultural Heritage, the Survey Team will advise the Santos Senior Cultural Heritage Field

Supervisor to that effect and the Santos Senior Cultural Heritage Field Supervisor may propose alternative Work Areas during the course of the Pre-Clearance Survey without the need for Santos to issue a new Work Program.

(h) **Cultural Heritage Compliance Report**

At the completion of the Pre-Clearance Survey, a Cultural Heritage Compliance Report will be prepared by Santos and presented to the Survey Team for endorsement. The Cultural Heritage Compliance Report will identify:

(i) the geographic area for which the Pre-Clearance Survey was undertaken;

(ii) any Aboriginal Cultural Heritage identified by the Survey Team or confirmation that no Aboriginal Cultural Heritage was identified; and

(iii) arrangements for the management of Aboriginal Cultural Heritage including the measures required to be implemented in Schedule 3 and Schedule 4 for specific site types (e.g. avoidance for sites where the CHMP specifies avoidance and management measures for other sites where it is not practicable to re-site the infrastructure).

(i) **Cultural Heritage Compliance Plan**

The Cultural Heritage Compliance Report will become a Cultural Heritage Compliance Plan through the following process:

(i) the Survey Team is to consider the Cultural Heritage Compliance Report when presented to it by Santos and endorse it as approved;

(ii) if the Survey Team fails to, or is not able to for any reason, endorse the Cultural Heritage Compliance Report, Santos may present it to the Cultural Heritage Coordinator and request the Cultural Heritage Coordinator endorse it as approved;

(iii) if the Cultural Heritage Compliance Report is not endorsed as approved by the two proceeding methods, Santos may refer the plan to an Expert for consideration and determination.

Any one of these parties may endorse a Cultural Heritage Compliance Report by marking it with their signature.

Santos will be entitled to undertake the Disturbance Activities set out in the relevant Work Program once the Cultural Heritage Compliance Report becomes the Cultural Heritage Compliance Plan.

Once a Cultural Heritage Compliance Report becomes a Cultural Heritage Compliance Plan, no party may raise a dispute under this condition in relation to the arrangements for the management of Aboriginal cultural heritage within the Work Area to which it relates.

4.9 **Management of New Finds**

(a) **Discovery of New Cultural Heritage Sites During Construction**

Subject to section 4.10, if, in the course of undertaking Project Activities, Santos locates a New Find, Santos will continue Project Activities in the relevant New Find Area only if such activities are in accordance with relevant New Find Measures.

(b) **New Find Measures**

The Project Activities in the New Find Area will stop and the New Find Area will be secured to prevent impact or harm.

Santos will use reasonable endeavours to deal with a New Find through agreement between the Cultural Heritage Coordinator and the Santos Senior Cultural Heritage Field Supervisor.

If agreement is not reached within 2 Business Days after the location of a New Cultural Heritage Site, or there are no Survey Teams working in the Project Area at the time of discovery of the New Cultural Heritage Site, Santos may arrange for the Santos Senior Cultural Heritage Field Supervisor to provide notice to the Cultural Heritage Coordinator (**New Find Notice**).

If a New Find Notice is issued, Santos will endeavour to arrange a meeting between the Santos Senior Cultural Heritage Field Supervisor and the Cultural Heritage Coordinator within 2 Business Days after Santos' delivery of a New Find Notice to discuss, and document measures to deal with the relevant New Find.

If measures to deal with a New Find are not agreed and documented by the Santos Senior Cultural Heritage Field Supervisor and the Cultural Heritage Coordinator within 2 Business Days of Santos' delivery of the relevant New Find Notice, Santos may independently determine the New Find Measures.

Santos will complete the required OEH card and forward to the regulator for inclusion in the AHIMS database. Santos will also include the New Find in the Aboriginal Cultural Heritage Site Register.

The New Find Measures employed by Santos must be consistent with any directions received from OEH.

4.10 **Human Remains**

If human remains are discovered during the course of Project Activities, Santos:

(a) will comply with the requirements of the *Coroners Act 2009* (NSW) and *National Parks and Wildlife Act 1974* (NSW) and all other Applicable Laws;

(b) report the discovery to the NSW Police or Coroner as soon as possible;

(c) will not allow Project Activities in the vicinity of the find until such time as Santos has advice from relevant Government Agencies that it may proceed;

(d) if the remains are proved to be the remains of an Aboriginal person, this site will be avoided;

4.11 **Workforce Education**

Santos will provide site induction training to employees and contractors working in the Project Area, and will ensure that induction training includes information about Aboriginal Cultural Heritage and the provisions of this CHMP.

5. CONSULTATION, MANAGEMENT, REPORTING AND REVIEWS

5.1 Annual Report

Within 6 weeks of the anniversary of the approval of this CHMP Santos will report to OEH on the implementation of this CHMP. A copy of the Annual Report will also be provided to the ACHWG.

This report will set out:

(a) the number of surveys conducted that previous year;

(b) whether additional Aboriginal Cultural Heritage sites were found, and their locations;

(c) how many sites were avoided as a result of this CHMP; and

(d) how many, and the nature of sites mitigated, and the mitigation measures implemented in accordance with this CHMP.

An Aboriginal Site Impact Recording Form will be completed and submitted to the AHIMS Registrar, in respect of any Aboriginal Cultural Heritage that is harmed through archaeological investigations required, permitted under this CHMP, or authorised in any Cultural Heritage Compliance Report.

5.2 AHIMS Reporting

An AHIMS Site Recording Form will be submitted to the AHIMS Registrar for each Aboriginal site found as a result of implementation of this CHMP.

5.3 5 Year Review Process

Santos will appoint a third party (**CHMP Auditor)** to undertake a review of this CHMP within 5 years after the CHMP is approved, and then every 5 years during the life of the CHMP.

Santos will provide a notice (**Review Notice)** to the ACHWG, OEH and take out an advertisement in a local paper stating:

(a) the identity of the CHMP Auditor;

(b) the date, time and location of the proposed Review Consultation Meeting; and

(c) the scope of the review process (eg sensitivity mapping, dispute resolution clauses, the entire CHMP etc).

Santos will hold a Review Consultation Meeting within 6 weeks of providing the Review Notice.

Any person who attended the Review Consultation meeting will be able to provide written submissions to the CHMP Auditor within 6 weeks of the Review Notice being advertised (**Review Submission Date**).

Within four weeks after the Review Submission Date the CHMP Auditor will provide a report outlining any issues identified in the CHMP Review Process and propose any recommendations for consideration (**CHMP Auditor's Report**) to each of the Review Participants.

Within 8 weeks of receiving the CHMP Auditor's Report, Santos will provide OEH with a proposed revised CHMP along with a copy of the CHMP Auditor's Report and any comments or responses Santos may have to the report.

OEH may review Santos' proposal and responses and either:

(a) approve the proposed revised CHMP;

(b) reject the proposed revised CHMP; or

(c) otherwise provide comments on the revised CHMP.

Santos will take into consideration OEH's comments and provide OEH with a proposed revised CHMP along with any comments or responses to the recommendations.

The Review Process will not impact on the ongoing operation of the CHMP.

5.4 Review Consultation Meeting

The purpose of this meeting is to give each attendee an opportunity to discuss issues with the CHMP in its current form and to propose amendments.

The meeting is to be held within 6 weeks of Santos issuing the Review Notice at a time, date and location determined by Santos.

The attendees at this meeting will be the CHMP Auditor, a representative from OEH, representatives from Santos and any Aboriginal person who has an interest in the Project Area and the implementation of this CHMP.

The agenda for this meeting will be determined by the CHMP Auditor 1 week prior to the meeting and will be circulated at the meeting.

If any person does not attend the Review Consultation Meeting the meeting will proceed without that person.

5.5 Sensitivity mapping must be reviewed

The Sensitivity Mapping must be reviewed and amended where necessary within the scope of the 5 Year Review.

5.6 Legislative Change Review Process

If there is a legislative change which affects the operation of this CHMP or management of Aboriginal cultural heritage, Santos may appoint a CHMP Auditor to undertake a review of the CHMP in the same manner as set out in condition 5.3.

5.7 Dispute Resolution

(a) Dispute Notice

If there is a dispute between Santos and either the Cultural Heritage Coordinator and the ACHWG (by majority resolution) relating to this CHMP (including agreeing New Find Measures) (**Dispute**), that party must give written notice to the other party, providing details of the Dispute (**Dispute Notice**).

(b) **Dispute Procedures**

On delivery of a Dispute Notice by either party, the following procedures will apply:

(i) Santos may use reasonable endeavours to convene, within 2 Business Days from the delivery of the Dispute Notice, a meeting between the parties relevant to the dispute, Santos Senior Cultural Heritage Field Supervisor and the Cultural Heritage Coordinator (**Dispute Parties**) to discuss the Dispute in a manner which ensures minimum disruption to the Project Activities;

(ii) if the Dispute is not resolved at the meeting held pursuant to paragraph (i), Santos must use reasonable endeavours to convene a meeting as soon as possible between the Dispute Parties, an Expert and must request the Expert's decision about the Dispute;

(iii) the Dispute Parties must advise each other if they propose to bring other representatives to the meeting held pursuant to paragraph (ii);

(iv) at the meeting held pursuant to paragraph (ii), each of the Dispute Parties present may, within a reasonable period of time, present their issues in the Dispute to the Expert;

(v) the Dispute Parties will be bound by the decision of the Expert in relation to the Dispute;

(vi) the costs of the Expert pursuant to this section will be borne by Santos.

5.8 **Engagement of Expert**

Santos may from time to time, but is not obliged to, engage an Expert to undertake any one or more of the following:

(a) be the Cultural Heritage Coordinator if:

(i) the ACHWGhas not nominated a Cultural Heritage Coordinator;

(ii) the Cultural Heritage Coordinator does not respond to a Work Program within 2 Business Days of it being provided by Santos;

(iii) the Cultural Heritage Coordinator does not attend a Pre-Clearance Planning Meeting; or

(iv) the Cultural Heritage Coordinator has not otherwise complied with the requirements of a Cultural Heritage Coordinator under this CHMP.

(b) perform the role of a Survey Team if:

(i) the ACHWGhas not nominated sufficient Cultural Heritage Officers to conduct a Work Program within the Program Timetable;

(ii) the Cultural Heritage Coordinator:

(A) does not respond to a request from the Senior Santos Field Supervisor for a Pre-Clearance Planning Meeting; or

(B) does not attend a Pre-Clearance Planning Meeting; or

(C) at the Pre-Clearance Planning Meeting does not nominate the number of persons required or nominates unsuitable persons; or

(iii) another Cultural Heritage Officer is unable to perform his or her role;

(iv) the Survey Team fails to conduct a Pre-Clearance Survey of a Work Area within the Program Timetable;

(v) subject to, and in accordance with condition 4.10 of, this CHMP, assess human remains located during the course of Project Activities; and

(vi) resolve disputes arising from condition 5.7 of this CHMP,

provided in relation to conditions 5.8(b)(i), 5.8(b)(ii), 5.8(b)(iii) and 5.8(b)(iv), notice has first been provided by Santos to the ACHWG and the ACHWGhave failed to procure the relevant person to undertake the relevant task listed in this section within 2 Business Days.

(c) consider and determine the contents of a Cultural Heritage Compliance Report in circumstances described in clause 4.8(i).

6. CONFIDENTIALITY

(a) Santos

Santos will keep confidential and not disclose any information it receives as a result of this CHMP relating to cultural heritage or cultural values without the consent of the ACHWGunless:

(i) required by law;

(ii) required under official listing requirements of an Australian or overseas stock exchange;

(iii) contemplated by the provisions of this CHMP;

(iv) it is or becomes public knowledge;

(v) it is disclosed to Santos' accountants, financiers, financial institutions, legal advisors, auditors, consultants or employees;

(vi) it is disclosed to a related body corporate, joint venture party or a bona fide potential assignee; or

(vii) to perform an obligation, or preserve or enforce a right or interest under this CHMP.

(b) Other Parties

The members of the ACHWG, its Independent Chair, the Cultural Heritage Coordinator, Cultural Heritage Officers and the CHMP Auditor will all be bound to keep confidential and not disclose any information it receives as a result of this CHMP or about any activity undertaken pursuant to this CHMP without Santos' consent unless:

(i) required by law;

(ii) contemplated by the provisions of this CHMP;

(iii) it is or becomes public knowledge;

(iv) it is disclosed to that party's accountants, financiers, financial institutions, legal advisors, auditors, consultants or employees.

SCHEDULE 1

Project Map

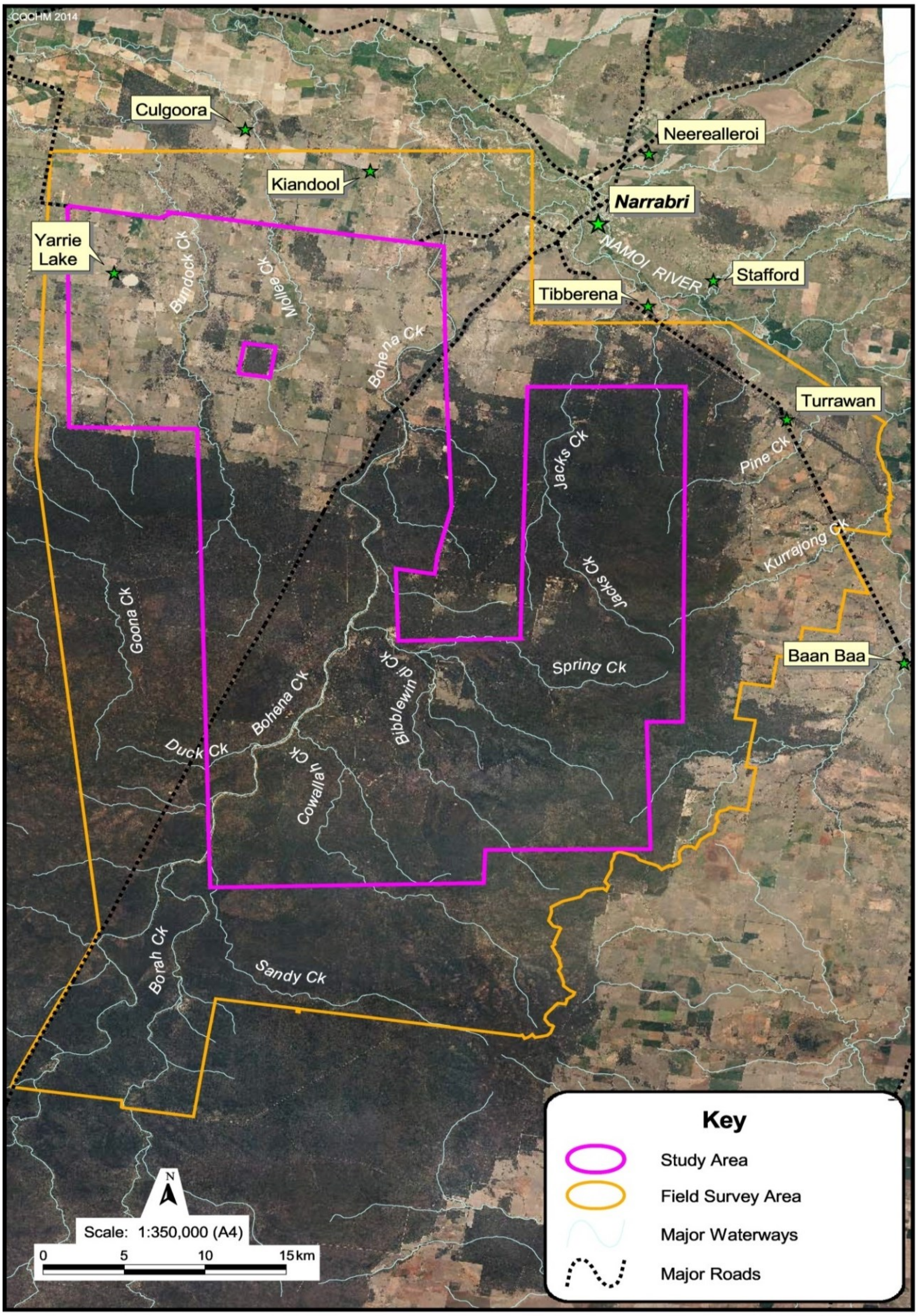

Figure 2-1: Relationship of the Study Area and the Field Survey Area

SCHEDULE 2

Sensitivity Mapping

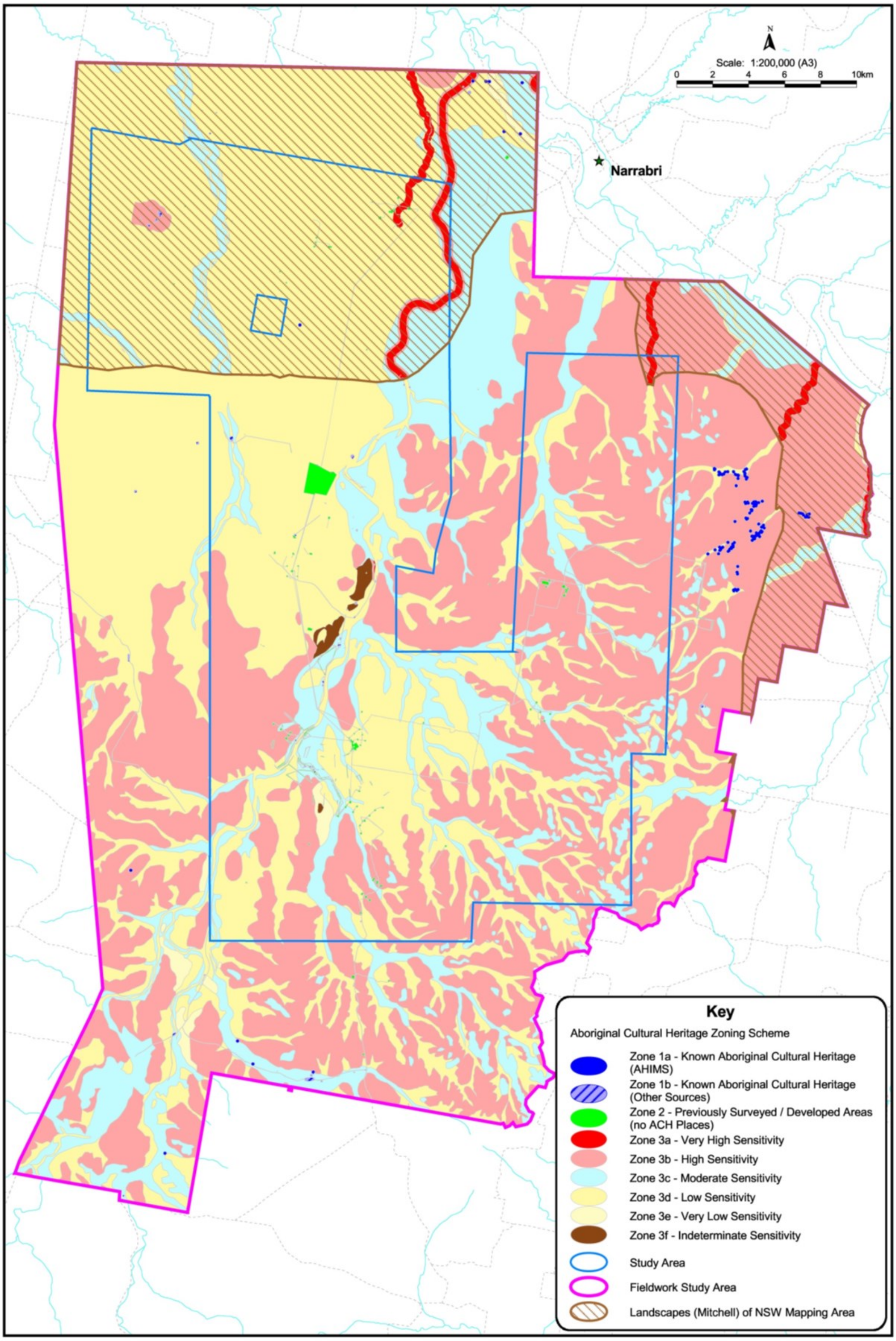

Figure 4-3: Aboriginal Cultural Heritage Zoning Scheme as it applies to the Study Area and Fieldwork Survey Area

SCHEDULE 3

Complete avoidance of site types

Should the pre-clearance survey identify an Aboriginal cultural heritage site of the type in the table below, then Santos will not locate the infrastructure in that area and will re-site the infrastructure after following the same process again. A full description of each type of site is contained in Schedule 5.

Site Type	**Commitment**	**Detail**
Burials	Complete Avoidance	
Stone Arrangements and Earthen Circles	Complete Avoidance	
Carved Trees	Complete Avoidance	
Rock Shelters	Complete Avoidance	
Rock Art	Complete Avoidance	
Grinding Grooves	Complete Avoidance	
Quarries	Complete Avoidance	
Mounds	Complete Avoidance	Subject to confirmation as a cultural feature.
Scarred Trees	Complete Avoidance	Subject to confirmation as a cultural feature there will be complete avoidance of this site type.
Hearths and Ovens	Complete Avoidance unless identification during construction	Subject to confirmation as a cultural feature. If identified during construction, mitigation will be in line with the New Find Measures under condition 4.9 of this CHMP.
Places of Traditional and Anthropological Significance identified in the cultural heritage audit review or in a Cultural Heritage Compliance Plan	Complete Avoidance	Sites previously identified by Santos as a Place of Traditional and Anthropological Significance or otherwise identified in the Additional Research Program.
Recent Historic and Contact Sites	Complete Avoidance	Sites previously identified by Santos as a Recent Historic and Contact Site or otherwise identified in the Additional Research Program.

SCHEDULE 4

Mitigation measures to be applied to site types

Should the pre-clearance survey identify an Aboriginal cultural heritage site of the type in the table below, then Santos will, where practicable, not locate the infrastructure in that area and will re-site the infrastructure after following the same process again. If it is not practicable to re-site the infrastructure, then Santos will adopt the management measures identified in the third column of the table. A full description of each type of site is contained in Schedule 5.

Site Type	**Commitment**	**Detail**
Stone Artefact Concentrations	Maximise avoidance Avoidance efforts will be focussed on complex sites.	Stone Artefact Concentrations, where any two or more artefacts are within 1m of each other. May be subject to relocation except where complex sites are encountered, at these sites avoidance efforts must be increased further. Complex sites are defined as places where a specific knapping event can be identified, grinding equipment (or fragments thereof) and/or ground edge tools (or fragments thereof) are present or form an element of the stone artefact concentration, there is any sub-surface material that may be *in situ*, or the stone artefact concentration is directly associated with any other site type.
Shell Middens	Maximise avoidance Avoidance efforts will be focussed on complex sites.	Shell Middens may be subject to mitigation except where complex sites are encountered. Where complex sites are encountered they will be avoided. Complex sites are defined as where the shell midden material has not been subject to any process that has caused any disaggregation of the material, where a defined concentration of more than 10 shells or shell fragments over an area of more than $2m^2$, there is a definable lens of shell, there is any sub-surface material that may be *in situ* or the shell midden is directly associated with any other site type.
Sub-surface Cultural Material	Maximise avoidance	Potential Archaeological Deposits will be subject of testing in line with OEH specifications for same. Where it is confirmed to exist, all Sub-surface Cultural Material, other than stone artefacts, will be avoided. This will apply irrespective of whether the material is *in situ* or not.
Isolated Stone Artefacts	Maximise avoidance	Where they cannot be avoided, Isolated Stone Artefacts may be relocated.

SCHEDULE 5

Description of site types

A description of each site type identified in Schedules 3 and 4 is described below for reference:

1. Burials

Burials are the most sensitive site type that can be encountered: with the remains of ancestors being of immense importance to Aboriginal people. They can also be of considerable scientific significance by virtue of their antiquity, evidence of genetic development of the Aboriginal population, evidence of cultural practices (care for wounded or aged individuals, tooth evulsion, mortuary practices such as cremation or painting of bone) and the goods that may be buried with the individual. In some areas what can only be described as cemeteries have also been identified. Interment can take place as burials in locations such as watercourse-bordering dunes or lunettes, areas where soft sand is available, in rock shelters and within the limbs and trunks of hollow trees. Evidence of complex burial practices including maceration of flesh prior to final interment is also known. The geochemistry and base geology of an area has a major impact on the likelihood of finding burials and the locations in which they will be discovered. Tree burials are susceptible to destruction by bushfires and clearing. The study of burials in the region has provided information on where burials might be expected, how these are related to residential patterning and some interpretations of social patterns (McBryde 1974; Pardoe 1986, 1988; Witter *et al.* 1993).

RCAD (2002 appendix C: 15) notes oral testimony from Monty Ruttley that burials were found on 'a sandy creek in the Pilliga in the 1920s'. However, it is also noted that portions of the Pilliga have acidic soils. With this biochemistry it is unlikely that bone will survive for long. Therefore, any burials encountered in such areas are not likely to have any great antiquity.

2. Stone arrangements and earthen circles

Stone arrangements have been located in the region, typically at higher elevations, both where stone is available and perhaps so that they are less accessible. These are commonly presumed to be associated with ceremonial activities, including initiations.

3. Carved trees

Examples of this type of site have been reported for Bohena Creek. Carved trees result from the removal of bark and the carving of both figures and geometric patterns on the wood with axes or sharp stone tools. They were associated both with ceremonial sites such as bora grounds and to mark the boundaries of burial sites. In recognising these dual functions, Etheridge (1918) referred to them as teleteglyphs and taphoglyphs. Numbers of carved trees, including apparently the Bohena Creek example, were cut and removed to national and local museums, and to other keeping places, or have otherwise been destroyed by bushfires.

4. Rock shelters

Examples of this site type have been identified in the study area, but none are with the Project Area for the proposed Project. Where sediment has been trapped in the rock shelter and the shelter occupied, and the site geochemistry favours it, there can be deep, stratified deposits containing a wide range of cultural materials including: stone artefacts; organic equipment (e.g. dilly bags, boomerangs) and decorative items (e.g. grass necklaces and beads); remains of food stuffs both faunal and vegetable; charcoal from camp fires; and interred human remains. Rock art can sometimes be found rendered on the walls of shelters.

5. Rock art

Rock art can be found as drawings (dry pigment) and paintings (wet pigment) in rock shelters and overhangs. Engravings, both in rock shelters and on large expanses of rock of suitable composition, are known in the region but are unlikely in the Project Area due to the nature of the landscape. McBryde (1974) recorded engravings at Bullawa Creek, near Narrabri. RCAD (2002, appendix C: 15) notes that rock art is also found in shelters in the Pilliga Nature Reserve and Wilderness Area.

6. Grinding grooves

Wherever there are suitable large slabs of stone (typically sandstone) axes and other tools such as wooden spear points can be ground. This grinding results in creation of grooves on the large slabs. Grooving may also result from seed grinding. Grooves associated with axe production are typically associated with a source of water to allow creation of suitable grinding paste.

7. Quarries

Quarries [stone sources] are locations where stone used in the manufacture of stone artefacts has been found and there is evidence of manufacture in the form of stone artefacts such as debitage or blanks of the tools themselves. Quarries of various raw material are found and these relate to the tools or equipment that is to be manufactured. Sources where highly siliceous, krypto-crystalline and isotropic material are available are used for flaked tools. Hard volcanic and metamorphic material provides axes. Well-stratified outcrops of sandstone can provide material for grindstones, but materials can also be found as floaters or collected from gravel beds in watercourses and palaeochannels.

Ochre quarries can also be found. These can take two forms: locations where strata of clays with high content of iron compounds are found, and locations where there are large concentrations of stone nodules within which talc-like iron oxide is found – the nodules are cracked open and the iron oxide then ground to a powder. Kaolin (white clay) was used for purposes of painting, as was charcoal.

8. Mounds

Mounds might be encountered but the probability is low and will be limited to the largest watercourses in the study area in the extreme northwest, as they are found in floodplain country. Mounds may contain by-products of occupation including food debris, stone artefacts tools, charcoal and baked clay heat retainers. Burials are occasionally found in mounds. Mounds are raised areas typically measuring 10m to 20m in diameter, although larger examples have been recorded. Earthen mounds have been recorded to the west of the study area at the Macquarie Marshes (Balme and Beck 1996) and to the south and west along major rivers and watercourses. Excavation of mounds demonstrate they are of fairly recent origin, generally the late Holocene.

9. Scarred trees

These are sometimes referred to as culturally modified trees. They result from various types of activities:

- trees that have been scarred as a result of removing bark for the manufacture of various implements (coolamons), for construction of gunyahs and canoes or to mark particular trees associated with important events or places;
- trees where wood has been removed for the manufacture of particular tools such as bowls, spears, shields and clubs;

- trees where the bark has been removed as an ancillary to cutting into a tree to retrieve a resource such as honey or possums from hollow limbs.

Scarred trees should not be confused with carved trees where there has been removal or bark followed by figurative and geometric patterns on the trunk or major branches of a tree.

The size and shape of a scar may provide some indication of the use made of the bark or reason for scarring. It is sometimes possible to identify whether axes made of stone and steel have been used, usually in the form of the presence of cut marks and the definition of those marks. But there can be significant amounts of regrowth as the tree responds to the wound and this can obscure the size and shape of the scar as well as cut marks.

Many scarred trees have been registered. We note that both Roberts (1991) and oral testimony (RCAD 2002) urge caution in attributing all scarred trees to traditional practices of Aboriginal people. Trees will be found in areas where there has not been complete clearing of vegetation. The banks of creeks and watercourses and corridors of remnant vegetation in stock routes and along roads offer opportunity for their discovery.

10. Hearths and ovens

Hearths are surface features while ovens have been excavated. Heat retainers in the form most usually of pieces of baked clay, but less commonly small cobbles of stone along with charcoal, can be found in them. Other organic material may also be found. The charcoal and organic material offers the opportunity to date these features.

11. Places of traditional and anthropological significance

Again, RCAD (2002) contains statements that such places exist. These may be associated with a range of beings and events: important creator beings and culture heroes, places associated with important dreaming stories, dangerous places where the creator beings or dreaming characters may be encountered, places where important ceremonies were performed, birthing locations etc. There may be no material markers of such locations and they will be known only to suitably enculturated individuals who may choose to disclose the location and significance of these places.

12. Recent historic and contact sites

Archaeological evidence of Aboriginal life from the contact period of the 1800s has been documented in the region: RCAD (2002) demonstrates there is plenty of scope for this type of site in the study area.

13. Stone artefact concentrations

Stone artefact concentrations represent areas where there has been discard of artefactual material and are the most common form of open site that will be encountered. This is commonly believed associated with occupation of an area, but this is not necessarily the case. The density of discard and types of stone tools are commonly interpreted as demonstrating different activities in an area and intensity of occupation. However, the level of discard can also be closely related to the amount of raw material available and to the technology used to reduce the raw material and manufacture of specific tool types.

Quartz is a common raw material in this area. Various techniques are used in its reduction: bipolar flaking, lamellate reduction, shatter along natural flaws as well as conchoidal percussion. Identification of quartz artefacts can prove difficult dependent on technique used and the degree of natural flawing present in a block. Other stone materials likely present will include: silcrete, chert, quartzite, basalt and various other volcanic and metamorphosed materials.

14. Shell middens

Shell middens will be found close to rivers, lakes and other watercourses. Composed of mussel shells, they may be in stratified deposits or found as exposures in eroded areas. They vary in size from small dinner time camps to extensive and stratified lens of shell. Stone artefacts, hearths, animal bones, other organic material, and burials can be found in larger examples or associated with them. The high carbonate content of the midden creates an excellent micro-environment for the preservation of organic material.

15. Isolated stone artefacts

Isolated stone artefacts usually are simple stone flakes but can include edge ground axes, grinding equipment, retouched flakes and cores. While individual artefacts can look unprepossessing, they may well be indicators of subsurface materials. RCAD (2002) notes this possibility and it is a point made by Roberts (1991) and Hughes (2002). Grinding equipment including such as slabs or dishes (the bottom stone), top stones, mortars and pestles, pieces of stone used for axe sharpening and preparation of ochre are possible. So, too, are edge ground axes and fragments of such axes. These are important for various reasons. They can provide direct evidence of the activities undertaken in the general area where they have been left. This can come from the type of tool itself and the residues that may adhere to them: the residue and phytoliths of various seeds ground or pounded; particles of ochre. Axes themselves provide a broad date for sites on which they are found, dating from about 4,000 years b.p. Grinding equipment, notably grinding slabs, have been found in deposits at Cuddie Springs dating to the Pleistocene. However, there are ongoing doubts about these dates – not least that such equipment has typically been found in deposits at most sites dating to the mid-Holocene. Sandstone is the most common material used for grinding equipment, but various other materials can be used. Edge-ground axes are manufactured using hard volcanic and metamorphosed material to preserve the edge achieved after great effort grinding the blank with a suitable paste of sandstone and water.

SCHEDULE 6

Aboriginal Cultural Heritage Working Group

1. Purpose of the ACHWG

The ACHWG will assist Santos to ensure the participation of the Aboriginal community in Pre-Clearance Surveys for the development of the Project in accordance with the Avoidance Principle in this CHMP.

2. Functions of the ACHWG

The functions of the ACHWG are to:

(a) represent the views and interests of the Aboriginal community in relation to the management of the impact of the Project on Aboriginal Cultural Heritage;

(b) nominate persons to be Cultural Heritage Officers to participate in the Pre-Clearance Surveys as part of the Survey Teams;

(c) appoint and empower the Cultural Heritage Coordinator to implement the CHMP and provide support and direction to the Cultural Heritage Coordinator where requested; and

(d) participate in the implementation of the CHMP during the life of the Project, including any review of the operation of the CHMP.

3. Membership of the ACHWG

Membership of the ACHWG will be a maximum of 9 people and will be constituted as set out below:

(a) eight people chosen as follows:

   (i) If there is a Registered Native Title Claim within the Project Area and one or more Local Aboriginal Land Councils, four persons nominated by the Registered Native Title Claimants and four persons nominated by the Local Aboriginal Land Councils;

   (ii) If there is a Registered Native Title Claim, but no Local Aboriginal Land Council, eight persons nominated by the Registered Native Title Claimants;

   (iii) If there is no Registered Native Title Claim within the Project Area but there is one or more Local Aboriginal Land Councils, eight persons nominated by the Local Aboriginal Land Councils; or

   (iv) If there is no Registered Native Title Claims and no Local Aboriginal Land Council, eight persons from the local Aboriginal community nominated by Santos; and

(b) an Independent Chair appointed by Santos.

At the date of approval of this CHMP, if there is a Registered Native Title Claim, then the four representatives from the Local Aboriginal Land Councils will consist of three people nominated by the Narrabri Local Aboriginal Land Council and one being nominated by the Wee Waa Local Aboriginal Land Council.

4. Quorum

A meeting of the ACHWG will have achieved quorum when the Independent Chair and five other ACHWG Members attend.

ACHWG Members may attend by phone subject to the prior approval of the Independent Chair.

ACHWG Members will use all reasonable endeavours to ensure that ACHWG Members are present at all meetings.

5. Decisions

All decisions, approvals, advice and recommendations of the ACHWG made pursuant to provisions of this CHMP will be made by majority vote of all members of the ACHWG attending the meeting at which the vote is taken, provided a quorum is present (with the exception of the appointment of the Cultural Heritage Coordinator). All decisions, approvals, advice and recommendations made by the ACHWG must relate to the functions and duties of the ACHWG as described in clause 2 of this Schedule.

All decisions, approvals, advice and recommendations of the ACHWG made pursuant to provisions of this CHMP will be made as follows:

(a) a resolution is to be tabled specifying the decisions, approvals, advice and recommendations;

(b) the ACHWG may discuss the resolution and discussion points will be noted;

(c) the resolution is to be the subject of a formal vote and the results will be recorded; and

(d) the resolution and the results of the vote are to be included in minutes of the meeting.

Where there is no quorum, decisions may not be made by the ACHWG at that meeting, and must be deferred to the next meeting;

Only ACHWG Members may vote at any meeting of the ACHWG.

The Independent Chair will be responsible for ensuring there are records of the items discussed in the meeting of the ACHWG.

6. Timing of Meetings

Unless otherwise convened by the Independent Chair (with the agreement of Santos) under other provisions of this CHMP, meetings of the ACHWG will be held at least every six months during the life of this CHMP.

The time and venue for the meetings will be as agreed by the Independent Chair.

7. Person who may attend ACHWG Meetings

All ACHWG Members may attend all meetings of the ACHWG.

The Cultural Heritage Coordinator may attend meetings.

A person appointed by the Independent Chair to record the proceedings of a meeting of the ACHWG may attend.

8. Additional People Attending

ACHWG members may advise the Independent Chair they wish to invite other persons to attend meetings. Such notice must be provided in writing at least 48 hours before any meeting and must specify the name of the person and the specific agenda item for which attendance is requested.

The Independent Chair must advise all other ACHWG Members of the receipt of the request.

The Independent Chair may agree to the request.

Where the Independent Chair agrees to the request, it is on the basis that the person who is requested to attend agrees to comply with the following conditions:

(a) they may attend the meeting only while the specific agenda item is being discussed; and

(b) they may only address the ACHWG with the majority agreement of the ACHWG; and

(c) they are not a member of the ACHWG and so have no voting rights or any other procedural rights that fall to an ACHWG member under provisions of this CHMP.

The Independent Chair will, in considering requests for any person to attend, ensure that no more than 14 persons (including ACHWG Members) attend any one meeting of the ACHWG.

It is the responsibility of the ACHWG Member who makes the request to contact the Independent Chair to secure the decision of the Independent Chair in this matter, and to advise the person they requested to attend of the Independent Chair's decision. In meeting their responsibility under this section the ACHWG Member may telephone the Independent Chair for the decision.

9. Register of Decisions

All decisions, approvals, advice and recommendations of the ACHWG made pursuant to provisions of this CHMP on any matter arising from the implementation of this CHMP will be entered in a Register of Decisions which will be maintained by the Independent Chair.

The Register of Decisions may be used by the Cultural Heritage Coordinator as part of day to day management planning and implementation of Management Measures.

10. Correspondence

Where correspondence by mail, email, fax or verbally with Santos on any element of the CHMP or any Management Measure is received, Santos will forward copies of such correspondence to the Independent Chair who will distribute to all ACHWG Members and the ACHWG shall consider such correspondence.

SCHEDULE 7

Previously Recorded Sites

REMOVED FOLLOWING REQUEST MADE DURING CONSULTATION PROCESS WITH REGISTERED ABORIGINAL PARTIES

SCHEDULE 8

Cultural Heritage Coordinator Role Summary

Employer
A third party, to be identified.

Purpose and role
The coordinator's role is to support the implementation of the CHMP through responding to work programs and to work with Santos to give effect to the terms and intent of the CHMP; and

Ensuring that all members of the Survey Team will unconditionally commit to implementation of this CHMP, observe and comply with any health, safety, environmental and other reasonable procedures and policies required by Santos; and

Responsibility for the timely implementation of any Pre-Clearance Surveys relating to Work Programs prepared or issued under provisions of this CHMP.

On agreement by Santos, Santos will provide all resources reasonably required to enable the Cultural Heritage Coordinator to perform all required duties and functions. Resourcing will be in accordance with Santos' schedule of rates.

Responsibilities

- comply with all requirements of this CHMP
- the first point of contact for Santos in matters relating to the implementation of this CHMP
- fulfil all requirements of the Cultural Heritage Coordinator role in accordance with the CHMP
- prepare reports as required including Cultural Heritage Compliance Reports.

Essential qualifications and skills

- Knowledge of Gomeroi cultural heritage
- Ability to identify cultural heritage sites and implement appropriate protective measures
- Ability to use GIS and GPS
- Competent use and understanding of basic computer programs e.g. Word, Excel etc.
- Ability to forward plan and prioritise work and project demands
- Proficient report writing skills
- Experience and ability to work across diversity of backgrounds and experience.

Performance review
The coordinator's employer or head contractor will be required to review the coordinators performance annually, in consultation with the ACHWG and Santos.

GLOSSARY

Aboriginal Cultural Heritage includes all places of archaeological and anthropological significance (including places of traditional, historical and contemporary significance to Aboriginal people) that are in the Project Area. It includes, but is not limited to, archaeological sites (such as artefact scatters, stone arrangements, scarred trees and the like), Aboriginal Objects associated with sites, any places that have traditional stories associated with them, places which are historically important (such as old camps) and places which are important today (such as good food-gathering places or places used for recreational purposes). It also includes, but is not limited to, Aboriginal cultural values as identified and described in the Project EIS.

Applicable Laws means every law and regulation of any Government Agency from time to time in operation and applicable to the Project Area.

Cultural Heritage Management Plan (or CHMP) means this document and its associated schedules. This CHMP constitutes the Heritage Management Plan established in fulfilment of the Secretary's Requirements, OEH recommendations and any Consent Conditions specified by the Secretary, Department of Planning and Infrastructure.

Aboriginal Objects are defined under the *National Parks and Wildlife Act 1974* as "any deposit, object or material evidence (not being a handicraft made for sale) relating to the Aboriginal habitation of the area that comprises New South Wales, being habitation before or concurrent with (or both) the occupation of that area by persons of non-Aboriginal extraction, and includes Aboriginal remains".

Aboriginal Cultural Heritage Site Register means a register including the location of Aboriginal Cultural Heritage sites in and near the Project Area, but does not necessarily include information about the objects or values at a site.

Aboriginal Cultural Heritage Working Group (ACHWG) means the Aboriginal Cultural Heritage Working Group established under this CHMP. The ACHWG is the primary entity with whom Santos proposes to engage with during the life of the Project regarding the management of Aboriginal Cultural Heritage associated with the Project.

ACHWG Members means the persons who are members of the ACHWG appointed in accordance with clause 3 of Schedule 6.

Additional Research Program means the research program described in condition 4.6 commissioned by Santos.

Avoidance Commitments are the commitments to avoid or mitigate impact to Aboriginal cultural heritage as detailed in this CHMP.

Avoidance Principle means Project Activities will be designed such that, to the greatest extent possible, there is no impact on Aboriginal Cultural Heritage. Where impact cannot be avoided then the Project Activity will be designed to minimise impact on any Aboriginal Cultural Heritage, and other management measures as appropriate are to be implemented to minimise or mitigate harm.

Complete Avoidance means to ensure Project Activities do not:

- have a physical impact on; or
- cause harm to Aboriginal Cultural Heritage.

Consent Conditions means any conditions specified by the Secretary for the Department of Planning and Infrastructure (NSW) on which basis the Project has been given approval to proceed.

Cultural Heritage Field Supervisor (CHFS) means those persons appointed by Santos to implement elements of the CHMP relating to the management of Aboriginal Cultural Heritage associated with the Project Area.

Cultural Heritage Officer means an Aboriginal person nominated by the ACHWG in accordance with the processes in this CHMP in response to a request for cultural heritage assessment and who meets all Santos OHS requirements. The Cultural Heritage Officer is not an employee of Santos.

Cultural Heritage Compliance Report means a report prepared after the Pre-Clearance Survey for an area is complete.

Cultural Heritage Compliance Plan means a Cultural Heritage Compliance Report which has been endorsed by either:

- a Survey Team;
- the Cultural Heritage Coordinator; or
- an Expert.

Cultural Heritage Coordinator means the person appointed by the ACHWG to carry out the duties specified in this CHMP. The Cultural Heritage Coordinator is not an employee of Santos.

Cultural Heritage Zoning Scheme – zones based on the cultural heritage sensitivity of an area.

Dispute Notice means a notice issued in writing by any member of the ACHWG under this CHMP.

Disturbance Activity means Project Activities that involve surface disturbance other than those which involve No Additional Surface Disturbance.

Expert means a suitably qualified archaeologist or anthropologist appointed by Santos pursuant to section 5.8 of the CHMP.

Gomeroi Native Title Claim Application means the native title application registered by the Native Title Tribunal and currently allocated Federal Court file number Federal Court NSD2208/1911.

Government Agency means:

(a) a government or government department or other body;

(b) a governmental, semi–governmental or judicial person including a statutory corporation; or

(c) a person (whether autonomous or not) who is charged with the administration of a law.

Independent Chair means the independent chair appointed by Santos to the Aboriginal Cultural Heritage Working Group.

Native Title Applicant means those persons specified in the registered Gomeroi Native Title Claim Application as the named applicants for this native title claim.

New Find means Aboriginal Cultural Heritage that has not been identified by the Project EIS, the Pre-Clearance Survey and is discovered during Project Activities.

New Find Area means any part of the Project Area which is within 20 metres laterally of a New Find.

New Find Measures means a way for dealing with a New Find:

(a) as agreed and documented; or

(b) as independently determined by Santos.

New Find Notice means a notice referred to in this CHMP.

No Additional Surface Disturbance means planned disturbance of an area must be consistent with any previous disturbance including any disturbance within areas previously the subject of:

(a) permanent and mobile camps;

(b) plant sites including ancillary infrastructure such as lay down areas:

(i) compressor stations;

(ii) drilling leases; and

(iii) pipeline and flowline rights of way

(c) works associated with the repair and maintenance of existing roads (including drains); and

(d) excavation of existing borrow pits

OEH Recommendations means the Recommendations prepared by OEH and specified in the Secretary's Requirements.

OEH means the Office of Environment and Heritage (NSW).

Pre-Clearance Planning Meeting means a meeting between the Santos Senior Field Supervisor and the Cultural Heritage Coordinator prior to a Pre-Clearance Survey.

Pre-Clearance Survey means a survey to identify if there is any Aboriginal Cultural Heritage present within an identified area.

Program Timeframe means the timeframe in which Santos requires a Pre-Clearance Survey of a Work Area to be undertaken.

Project means Santos Narrabri Gas Project described in the Project EIS.

Project Activities means the physical carrying out of the Project within the Project Area.

Project Area means the area of PPLA 13, 14, 15 and 16 as shown in the map in Schedule 1.

Project EIS means the Environmental Impact Statement prepared for the Project.

Registered Aboriginal Parties (RAPs) means those Aboriginal people being individuals. Local Aboriginal Land Councils and other groups that are registered in accordance with the OEH Consultation Requirements for consultation in relation to the assessment of this Project.

Registered Native Title Claimants means the registered claimants in the Gomeroi Native Title Claim Application.

Reported Site means Aboriginal Cultural Heritage recorded in a Cultural Heritage Compliance Plan.

Santos means Santos NSW (Eastern) Pty Ltd.

Santos Cultural Heritage GIS means the Santos GIS established in compliance with Santos management systems.

Santos Senior Cultural Heritage Field Supervisor means the Santos employee from time to time responsible for the field coordination of Santos' work priorities and the provision of support for Pre-Clearance Surveys, or the nominee from time to time of such employee.

Secretary means Secretary of the Department of Planning and Infrastructure (NSW).

Secretary's Requirements means the requirements specified by the Secretary of the Department of Planning and Infrastructure (NSW) for the preparation of an Environmental Impact Statement for the Project.

Sensitivity Mapping means that mapping undertaken in compliance with the OEH Recommendations for the Project EIS, a copy of which is included in Schedule 2 of this CHMP, which is stored in the Project Aboriginal cultural heritage GIS and which must be amended every five years from the date of commencement of this CHMP.

Significant Ground Disturbance means:

(a) disturbance by machinery of the topsoil or surface rock layer (excluding consolidated rock or solid sheet rock) of the ground, such as by grading, bulldozing, trenching, drilling or dredging; and

(b) the removal of vegetation by disturbance of root systems and exposing underlying soil.

Surface Disturbance means any disturbance of any area which causes lasting impact to the land or waters during the activity or after the activity has ceased.

Study Area is the area shown as the Study Area in the Project EIS and depicted as the Study Area on the map in schedule 2 of this CHMP.

Survey Team means the team of Cultural Heritage Officers employed or contracted to conduct a Pre-Clearance Survey.

Technical Expert means a suitably qualified archaeologist or person appointed by the Aboriginal Cultural Heritage Working Group with the consent of Santos.

Work Area means the area which is the subject of a Work Program.

Work Program means a program of Project Activities.

Appendix K

Gas flare light assessment

Santos
We have the energy.

Narrabri Gas Project

Gas Flare Light Assessment

October 2017

Prepared for:
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Prepared by
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FIGURES

1.0 INTRODUCTION

1.1 Narrabri Coal Seam Gas Project

Santos NSW (Eastern) Pty Ltd propose to construct and operate gas processing facilities, including a network of wells and pipelines, as part of the Narrabri Gas Project, which is approximately 20 km southwest of Narrabri in NSW (Figure 1). There are currently three pilot appraisal flares operating at the Bibblewindi, Dewhurst and Tintsfield sites to support gas exploration and appraisal activities in the Narrabri area. For the Narrabri Gas Project (the Project) it is proposed to operate up to six pilot flares and two larger safety flares to support operations.

In response to submissions received on the Narrabri Gas Project (NGP) EIS relating to the potential impacts of light emissions to the Siding Spring Observatory (the Observatory), an assessment was undertaken to determine the cumulative emissions from current light sources and the predicted contribution of proposed flaring from the NGP across the north-eastern horizon from the Observatory. The investigations outlined in this report have been conducted to assess the potential for light emissions from the use of flares for the project to contribute towards artificial skyglow levels at the Observatory.

1.2 Dark Sky Planning Guidelines

The Dark Sky Planning Guidelines (the guideline) are a matter for consideration for state significant development that is within 200 kilometres of the Observatory and likely to impact the night sky. The guideline states that “at the Observatory a threshold figure of 10% of the natural skyglow at 30^{o} above the horizon has been adopted as the maximum tolerable level of artificial light” (Department of Planning & Environment 2016), as this is critical to the assessment of impacts on the observing conditions at the Observatory. The guideline also refers to the cumulative effect of artificial skyglow within the region caused by rural industries and intensive livestock agriculture operations, urban development including sports fields, industrial and commercial buildings, housing development and street lights and other development including mining and extractive industries and gas flares. In addition, the potential impacts of dust associated with rural and some extractive industries is raised as it has the capacity to disperse light at night.

This lighting assessment will determine whether the current night sky conditions including appraisal flares and cumulative light sources are within the guidelines and determine the extent to which the proposed flaring operations for the Project will contribute towards artificial skyglow levels at the Observatory.

1.3 Proposed Flaring Operations

1.3.1 Routine flaring operations

Up to six routine pilot appraisal flares are proposed to operate continuously for up to a three year period each to safely manage gas produced in appraisal areas that are not connected to the pipeline network within the project area. The pilot flares will consist of a 6-m stack and an orange coloured flame up to 4 m from the top of the stack in calm conditions (average flow rate = 3 to 5 million standard cubic feet per day).

One safety flare is proposed to be located at each of the Bibblewindi and Leewood operational sites with a stack height of 50 m. These flares are required to operate continuously for the safe management of gas and would have an orange pilot flame average height of 1.5m (average flow rate = 0.03 million standard cubic feet per day). They may be required to operate at a higher flow rate during commissioning and maintenance activities or in non-routine situations (expected to occur infrequently).

During commissioning of the facilities and infrastructure gas may be required to be flared to ensure its safe management. The required timing and duration of these activities is still to be determined (during detailed design and installation), although the volume of gas to be flared is likely to be minimised for commercial reasons.

Routine facility maintenance requiring the use of the flare beyond its standard operation is expected to occur relatively infrequently. For example, in similar operations, scheduled maintenance for critical function tests and vessel inspection activities that require a total planned outage requiring the use of the flares, are scheduled to occur once every two years. The duration of these activities is generally up to seven days, however depending on well operating scenarios, well production may be able to be reduced significantly during the shutdown, minimising the volume of gas that is required to be flared.

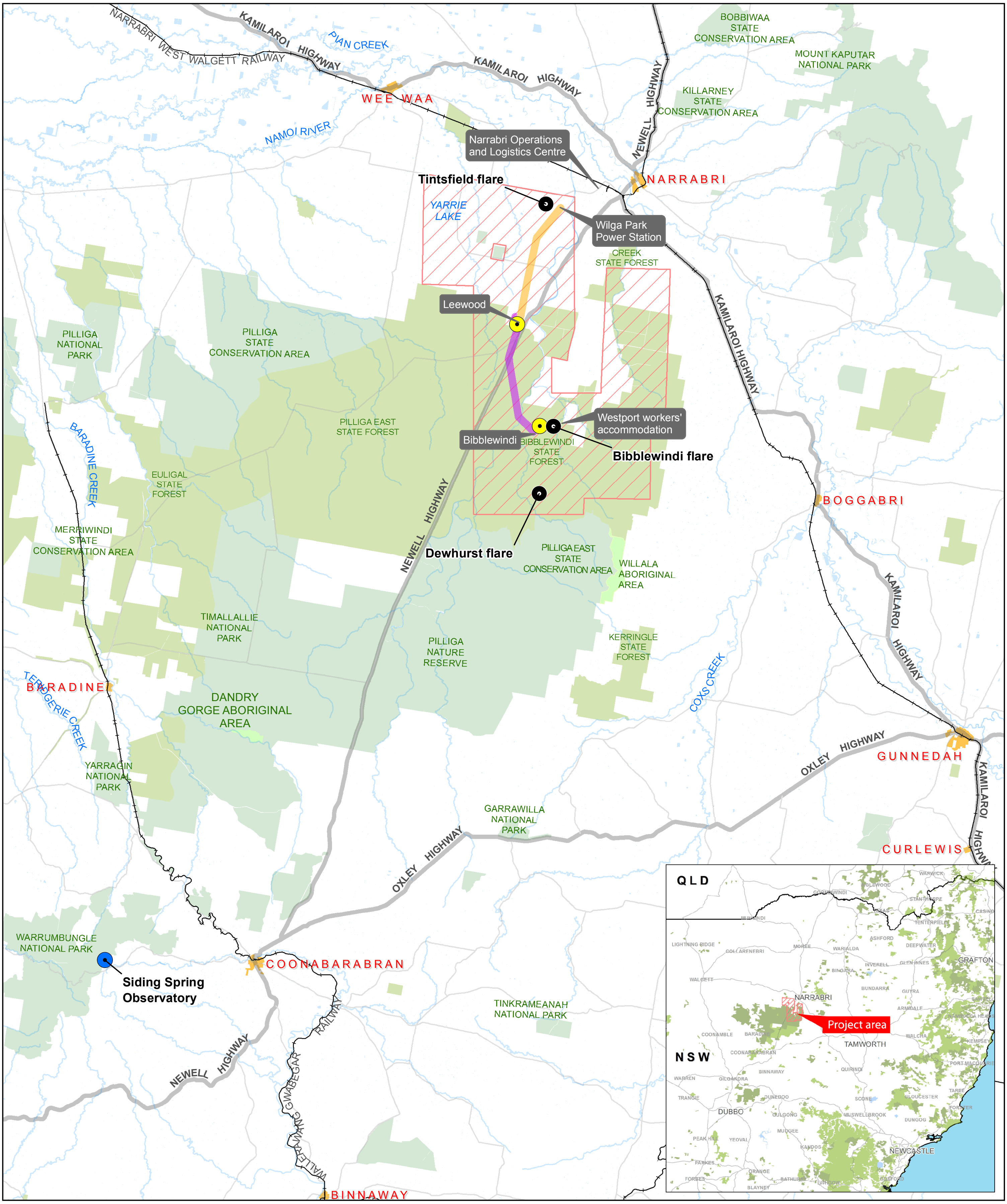
1.3.2 Non-routine flaring operations

Non-routine flaring operations are required to safely manage gas in the event of an occurrence where gas is required to be flared rather than processed. In such an instance the safety flares at Bibblewindi and/or Leewood would be required to be used. The flaring of the maximum gas throughput (200TJ) would produce a flame height of up to 30 m flame in calm conditions (average flow rate = 244 million standard cubic feet per day). By its nature, it is difficult to predict the timing of these required uses of the flare. Similar to planned maintenance activities that require the use of the flares, well production may be able to be reduced to minimise the volume of gas to be flared.

1.4 **Key Objectives**

The key objectives of the assessment are to:

1. Identify and measure the current light sources that are visible across the northeast horizon from the observatory
2. Determine whether the current light sources and predicted light emissions from the proposed routine flaring for the Narrabri Gas Project would exceed the guidelines
3. Determine whether the current light sources and predicted light emissions from the proposed non-routine flaring for the Narrabri Gas Project would would exceed the guidelines.



LEGEND

- Project area
- Urban Areas
- State forest
- Parks and reserves
- Aboriginal areas
- Lakes and dams
- Watercourses
- Highways
- Major Roads
- Train line
- Leewood to Wilga Park infrastructure corridor
- Bibblewindi to Leewood infrastructure corridor
- Siding Spring Observatory
- Existing pilot flare locations
- Proposed safety flare locations

0 5 10 20
Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 55

N

GHD

Narrabri Gas Project
Response to Submissions

Job Number	21-22463
Revision	A
Date	27 Feb 2018

Proposed and existing flare locations

Figure 1

N:\AU\Sydney\Projects\21\22463\GIS\Maps\21_22463_Z161_FlareLocations.mxd

Level 15, 133 Castlereagh Street Sydney NSW 2000 T 61 2 9239 7100 F 61 2 9239 7199 E sydmail@ghd.com.au W www.ghd.com.au

Data source: NSW Department of Lands: DTDB and DCDB - 2012-13. Santos: Operational and Base Data - 2013. Created by:jrprice

2.0 LIGHT EMISSIONS OVERVIEW

2.1 Light Theory

Light is part of the electromagnetic spectrum, which is a collection of waves, including visible light, microwaves, radio wave, X-rays and gamma rays. Anthropogenic light source emits visible range of the electromagnetic spectrum. Visible light falls between short wavelength ultra-violet light (< 4000 nm) and long wavelength intra-red light (>700 nm) radiation (Figure 2). The human eye has different sensitivities to light of different wavelengths within the spectrum. A light source emits different amounts of energy at each wavelength across the visual spectrum (380 – 780 nm). The maximum reception of light energy occurs at 555 nm (green light).

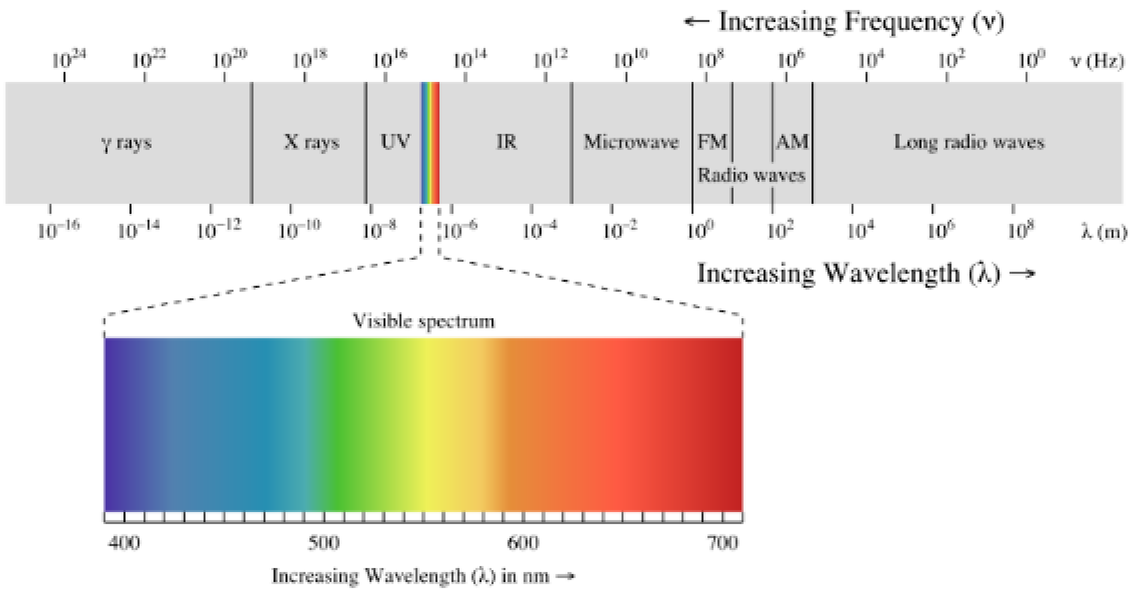


Figure 2 Electromagnetic spectrum with visible light highlighted.

2.1.1 Nature of skyglow

While usually referring to sky luminance arising from artificial lighting, skyglow may also involve any night time sources of diffuse light, including natural light like the zodiacal light, starlight, and airglow (Roach and Gordon 1973). Light propagating into the atmosphere directly from upward-directed, incompletely shielded sources, or after reflection from the ground or other surfaces, produce a diffuse glow that can be seen from large distances. Skyglow from artificial lights is most often noticed as a glowing dome of light over cities and towns.

Skyglow occurs when artificial light reflects off clouds and atmospheric particles such as dust and water vapour, causing a scattering effect. Sky glow is highly variable depending on localised weather conditions, quantity of dust and gas in the atmosphere, amount of light directed skyward, and the direction from which it is viewed. In cloudy weather conditions (< 4 oktas), more particles are present in the atmosphere to scatter the upward-bound light, so sky glow becomes a very visible effect of wasted light and wasted energy. Different light sources produce different amounts of skyglow from the same amount of light being emitted into the atmosphere, depending on the nature of the source, including its light fitting, direction of light emitted, colour/wavelength and reflective surfaces surrounding the source.

Air molecules are far smaller than the wavelength of light. They scatter light forwards and backwards equally, and scatter light sideways at half the forward intensity. They are very much more effective at scattering shorter (bluer) wavelengths. This is known as Rayleigh scattering, and is the reason why the sky appears blue.

Aerosols are suspended water droplets and dust particles with sizes that are not always smaller than a wavelength of light. These scatter light sharply forwards, very little sideways, and only very slightly backwards, and are not affected by wavelength. This is known as Mie scattering, and is why clouds appear white. Airborne particles, cloud density and height will all have an effect at which skyglow is perceived by an observer

2.1.2 Skyglow and distance

Sky glow brightness arising from artificial light sources decreases exponentially with distance from the light source, due to the geometric effects characterized by an inverse square law in combination with atmospheric absorption. An approximate relation is given by Walker's Law, which is that intensity $\propto 1/r^{2.5}$ (Walker 1977; Duriscoe et al. 2007). Walker's Law has been verified by observation to describe both the measurements of sky brightness at any given point or direction in the sky caused by a light source, as well as to integrated measures such as the brightness of the "light dome" over a city, or the integrated brightness of the entire night sky. At large distances (over about 50 km) the brightness of a light source falls more rapidly, largely due to extinction and geometric effects caused by the curvature of the Earth.

Different light sources produce differing amounts of visual sky glow. The dominant effect arises from the Purkinje shift, and not as commonly claimed from Rayleigh scattering of short wavelengths (Aubé et al. 2013; Luginbuhl et al. 2014). When observing the night sky, even from moderately light polluted areas, the eye becomes nearly or completely dark adapted or scotopic. The scotopic eye is much more sensitive to blue and green light, and much less sensitive to yellow and red light, than the photopic eye. Predominantly because of this effect, white light sources such as metal halide, fluorescent, or white LED can produce as much as 3.3 times the visual sky glow brightness of the most common high-pressure sodium lamp or a flame.

2.1.3 Influence of clouds

The cloud-cover and cloud height influence the dispersal of skyglow by reflecting at the cloud-ceiling causing increased luminance at lower light intensities due to light scattering. Cloud cover refers to the fraction of the sky (oktas 1-8) obscured by clouds when observed from a particular location. Cloud coverage of oktas 8 is overcast, which is not conducive to viewing celestial objects. As cloud cover decreases, the extent of upward light reflection decreases, subsequently increasing the ability to view celestial objects at night. Cloud height is defined by the height of the cloud-ceiling from the ground. Clouds that enhance skyglow are often lower clouds between 1 – 2 km AHD (e.g. nimbostratus and stratocumulus) and mid-level clouds up to 4km (e.g. altocumulus), as artificial upward light intensity decreases with altitude. A recent study by Jechow et al. (2017) tracked the reach of skyglow from a peri-urban into a remote area on a clear and a partly cloudy night. They showed that zenith luminance reached near-natural levels at 5 km distance from a town on the clear night, but similar levels were only reached at 27 km on the partly cloudy night.

These cloud formations can also act as a barrier at the cloud-ceiling, restricting further vertical light dispersal above the clouds. The reflection on the cloud-ceiling will be perceived at different altitudes from the horizon depending on the observers' distance to the cloud mass. For example, the closer the reflected cloud mass to the observer, the higher the light is perceived from the horizon.

Numerical simulations have proved that clouds can affect skyglow in many ways, although it is difficult to demonstrate them all experimentally owing to the variability of meteorological conditions, which in turn prohibits well-controlled measurements (Kocifaj 2007). For instance, different clouds can amplify the skyglow in different ways, and thus there is a large variability in the amplification factor (Kyba et al. 2012) . The position of an observer is not the only variable that influences this amplification factor. It is also affected by the geometrical relations regarding the distance to the individual clouds (or cloud layer), by the reflectance and altitude of clouds, and by the deployment, emissivity and spectral features of ground-based light sources.

To analyse the amplification of downward-directed radiative fluxes under overcast conditions, the optical characteristics of both the clouds and the undercloud atmosphere need to be considered simultaneously. It is evident that the spectral features of night-sky radiances are determined by the wavelength-dependent Rayleigh and Mie scattering functions weighted by volume scattering coefficients. However, the backscatter as well as the side-scatter features play a key role in forming the skyglow component of the undercloud atmosphere.

Air molecules and aerosol particles are the greatest modulators of skyglow under clear sky conditions. Clouds, however, can change the radiance pattern of a night sky even more markedly. This is not only because they remove a large portion of upwardly emitted radiation, but also because they change significantly the luminance/ radiance pattern at the level of the cloud-ceiling. Clouds behave like random disperse media with enhanced multiple-scattering efficiency and reflect light according to the water content, especially as a function of the size, spatial density and asymmetry parameter of the water droplets (Kokhanovsky and Rozanov 2012).

The clouds amplify the flux density of downwelling radiation through the diffuse reflection of up-light, in which the direct emissions and forward scatter dominate. There is no doubt that the spectral and angular behaviour of upwardly propagated radiation differs from that scattered in a cloudless atmosphere. Therefore, no simple approach to calculating the amplification factor exists, and, rather than being a simple function of input parameters, the amplification factor will have a complex dependence on the optical properties of clouds, the position of an observer with respect to the position of the dominant light source, and its size and spectral properties. Due to this complexity, the amplitude of reflectance from the cloud-ceiling will not be considered in the analysis.

3.0 EXISTING LIGHT EMISSIONS

3.1 Study area

The Observatory is located at the peak of Mt Woorut at the edge of the Warrumbungle National Park at 1146 m AHD. The topography of the mountain is characterised by rocky steep ridges. There is a ridge that runs through the southwest section of Warrumbungle National Park between Mt Woorut and the Bibblewindi site, which acts as a barrier of direct light to the base of the mountain (see Figure 12). The area northeast of the ridge is typically flat and comprises a dense eucalypt forest elevated approximately 20 m above the landform.

The monthly weather conditions indicate a high percentage of days with clear skies (38.5%) compared to cloudy days (27.2%) and rainy days (17.6%) (BOM 2017). Clear skies are more frequent during the winter (July – September), while clouds form more frequently prior to the winter in between May and July. The relative humidity remains fairly consistent throughout the year, with an increase during the autumn months (May – July). The average cloud cover on cloudy days was 4.1 oktas (BOM 2017), meaning that partly cloudy conditions are more common than cloudy and overcast.

The moon rises in the E – NE direction ranging between 67 and 113^{o} over the horizon. The intensity of moonlight varies greatly depending its zenith angle, lunar cycle and cloud cover. Thee full moon typically provides about 0.05-0.1 lux, while a quarter moon typically provides 0.001 lux. Moonlight generally impacts astronomical viewing, so observation opportunities are more limited around the period of the full moon.

The cumulative impacts of light emissions need to be considered to understand how the proposed flares will contribute to the light regime in the region. The light pollution map presented in Figure 3 provides context to the overall light emissions within the region (Falchi, FabioISTIL - Istituto di Scienza e Tecnologia dell'Inquinamento Luminoso, Light Pollution Science and Technology Institute, Thiene, Italy et al. 2016). This mapping application displays Visible Infrared Imaging Radiometer Suite (VIIRS) radiance intensity data across the world on March 2017.

The map shows several artificial light sources in the northeast direction from the Observatory, including Baradine (36 km), Narrabri (123 km), existing flares at Tintsfield (115 km), Bibblewindi (90 km) and Dewhurst (87 km) sites, Narrabri mine (115 km), Maules Creek mine (128 km), Boggabri mine (125 km), Boggabri township (113 km), Gunnedah township (118 km) and Coonabarabran (20 km) (Figure 3). The map also highlights that from the Observatory viewpoint, there are multiple light sources with similar bearings. This can make it difficult to delineate the individual light sources when viewed from a large distance. For example, the existing appraisal flares at Bibblewindi, Leewood and Tintsfield are within the same general direction as the town of Narrabri and the Narrabri mine. In this report, these light sources referred to as the Narrabri Light Sources. Similarly, Boggabri town has the same bearing as the Boggabri mine from the Observatory, and will be referred to collectively as the Boggabri Light Sources.

Figure 3 Light pollution map of the region. Source: Falchi, FabioISTIL - Istituto di Scienza e Tecnologia dell'Inquinamento Luminoso, Light Pollution Science and Technology Institute, Thiene, Italy et al. (2016) taken in March 2017.

3.2 In situ Light Surveys

3.2.1 Light emissions viewed at the Observatory

3.2.1.1 Survey design

Light measurements were undertaken from the most eastern point of the Observatory to ensure no obstructions to the northeast horizon, which is the direction of the NGP project area. From the measurement point, there were Observatory buildings and vegetation to the south (see Figure 7) that were visible in the images and measurements. The survey was conducted 12/13 October 2017 between 2000 – 0400 hours, during the third quarter moon, providing an opportunity to gather data before and after the moon rises. All visible light sources from the Observatory were measured across the northeast horizon between bearings N60^{o}W - N100^{o}E. Light measurements taken from the Observatory provided data relating to the extent and intensity of natural and existing light sources. These measurements were taken every 1.5 hours during the night, including before and after moon rise.

The environmental conditions at the Observatory were relatively consistent, including relatively humidity (40.5 - 59.7 %RH), temperature (9.8 – 12.5^{o}C) and maximum wind speed during the night ranged between 10.9 and 34.6 km/hr in a SSW direction. A low haze was present across the northeast horizon with no cloud formations visible over the night sky. The moon rise was at 01:51 at a bearing of N47.4^{o}E with a maximum illumination of 46.4% (third quarter moon phase).

The methods involved taking vertical photographs into the night sky using a Canon Digital SLR with a Sigma fisheye lens (FOV = 185^{o}). These photographs were converted to Hemispherical Radiance Images (HRIs) by correcting for dark offsets and applying radiometric calibration coefficients to each pixel of the raw images. The HRI presented a scale spectral radiance (555 nm) emitted across the entire sky. During processing, a dashed line was overlayed onto the image to show the 30^{o} above the horizon reference point as prescribed in the guidelines.

The illuminance (lux) and luminance (cd/m^2) were also measured using a ILT1700 Research Radiometer/Photometer (International Light Technologies, http://www.intl-lighttech.com). The brightness of light sources and ambient light were measured using a handheld Sky Quality Meter-L (Unihedron, http://www.unihedron.com) at the flare sites at increasing distance. These results are provided in Section 3.2.2.

3.2.1.2 Survey results

Direct light sources were observed at Baradine (bearing = N1^{o}E) and Coonabarabran (bearing = N90^{o}E), which comprised several faint orange street lights. Skyglow visible on the horizon in the northeast direction from the Observatory included skyglow from Narrabri Light Sources (bearing = N30^{o}E - N40^{o}E), Maules Creek mine (bearing = N52^{o}E), and Boggabri Light sources (bearing = N54^{o}E - N57^{o}E) (Figure 4). The skyglow from Gunnedah and Tamworth townships were not visible from the Observatory on a clear night. From the Observatory, the horizon is reached at 120 km and Tamworth is approximately 178 km, which means the skyglow on a clear night may be hidden behind the earth’s surface. The skyglow from these locations has not be assessed in cloudy conditions.

In the absense of the moon, the greatest radiance was emitted from the milky way ($L_{e,\Omega,v}$ = 2.0E-04 µWcm-2nm-1sr-1) followed by the Boggabri Light Sources ($L_{e,\Omega,v}$ = 1.5E-04 µWcm-2nm-1sr-1) and Maules Creek mine ($L_{e,\Omega,v}$ = 1.5E-04 µWcm^{-2}nm^{-1}sr^{-1}) (Table 1 and Figure 5). Images SSO1 and SSO2 in Figure 6 show how the skyglow was distributed across the horizon. The images show that the milky way to the west, while the artificial light sources were barely visible given their low altitude. The maximum vertical extent of the skyglow from these light sources was recorded at an angle < 3^{o} above horizon, which corresponded with the height of the haze over the horizon.

As the moon rises to about 25⁰ over the northeast horizon, the distribution of moonlight covers most of the night sky. Figure 5 shows a 6-fold increase (maximum of 7.2E-04 $\mu Wcm^{-2}nm^{-1}sr^{-1}$) across the horizon. The moonlight dominated the night sky and superseded the radiance generated by the artificial light sources (Figure 7). The narrow peak at BGB shown in Figure 7, is likely to be associated with the moonlight, rather than a dramatic increase in radiance from the Boggabri Light Sources. It is unclear what this peak represents. The reflection of the moon on the Observatory buildings (located in a southerly direction from the measurement point) also resulted in a significant increased radiance as evident in SS05 (Figure 7).

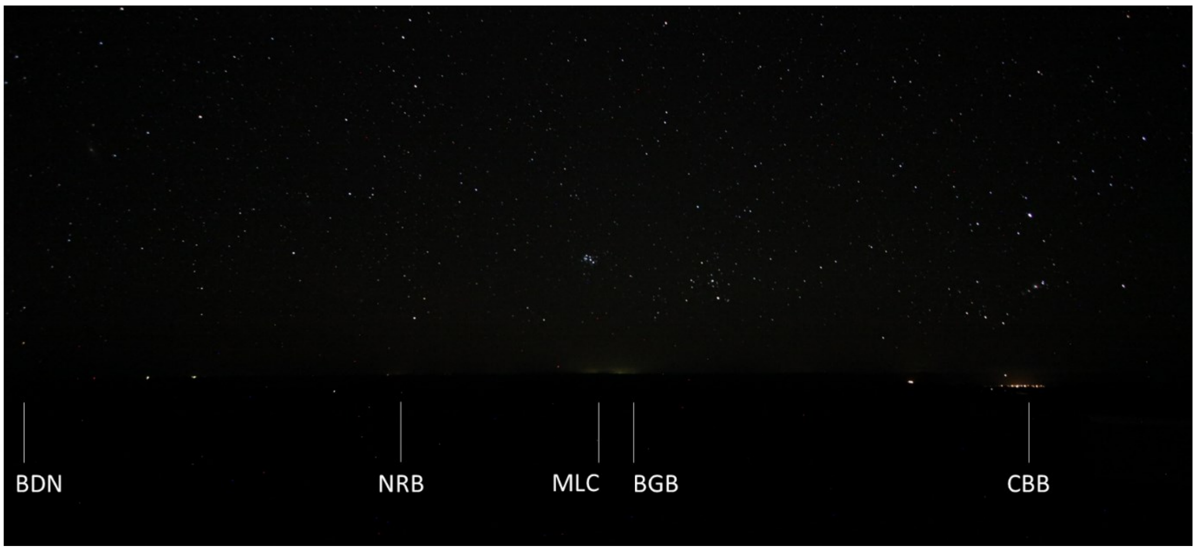


Figure 4 Identification of light sources over the northeast horizon from the observatory before moonrise. Time taken at 01:33 EST. Source locations: BDN: Baradine township; NRB: Narrabri Light Sources; MLC: Maules Creek mine; BGB: Boggabri Light Sources; CBB: Coonabarabran township.

Table 1 Mean radiance, luminance and illuminance readings of visible light sources from the Observatory.

	Moon absent (SSO2)			Moon present (SSO5)		
	Mean radiance	**Luminance**	**Illuminance**	**Mean radiance**	**Luminance**	**Illuminance**
Milky way (MW)	2.0E-04	5.0E-04	2.0E-03	2.7E-04	3.0E-03	3.0E-03
Baradine (BDN)	9.6E-05	5.0E-04	3.0E-03	3.7E-04	4.6E-03	3.1E-03
Narrabri Light Sources (NRB)	1.1E-04	5.0E-04	3.0E-03	6.7E-04	4.6E-03	3.1E-03
Maules Creek mine (MLC)	1.5E-04	2.1E-03	9.0E-03	7.2E-04	4.6E-03	3.2E-03
Boggabri Light Sources (BGB)	1.5E-04	2.1E-03	9.0E-03	5.7E-04	4.6E-03	3.2E-03
Coonabarabran (CBB)	1.2E-04	7.0E-04	3.0E-03	4.3E-04	3.3E-03	3.7E-03

Mean radiance in $\mu Wcm^{-2}nm^{-1}sr^{-1}$
Luminance in cd/m^2
Illuminance in lux

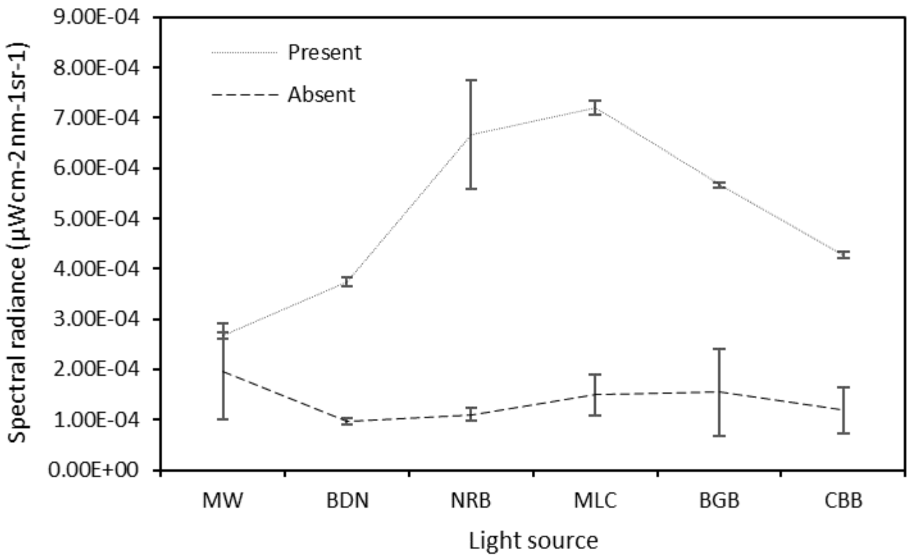


Figure 5 Radiance (555 nm) of light sources visible from the observatory. Source locations: MW: Milky Way; BDN: Baradine township; NRB: Narrabri Group; MLC: Maules Creek mine; BGB: Boggabri Group; CBB: Coonabarabran.

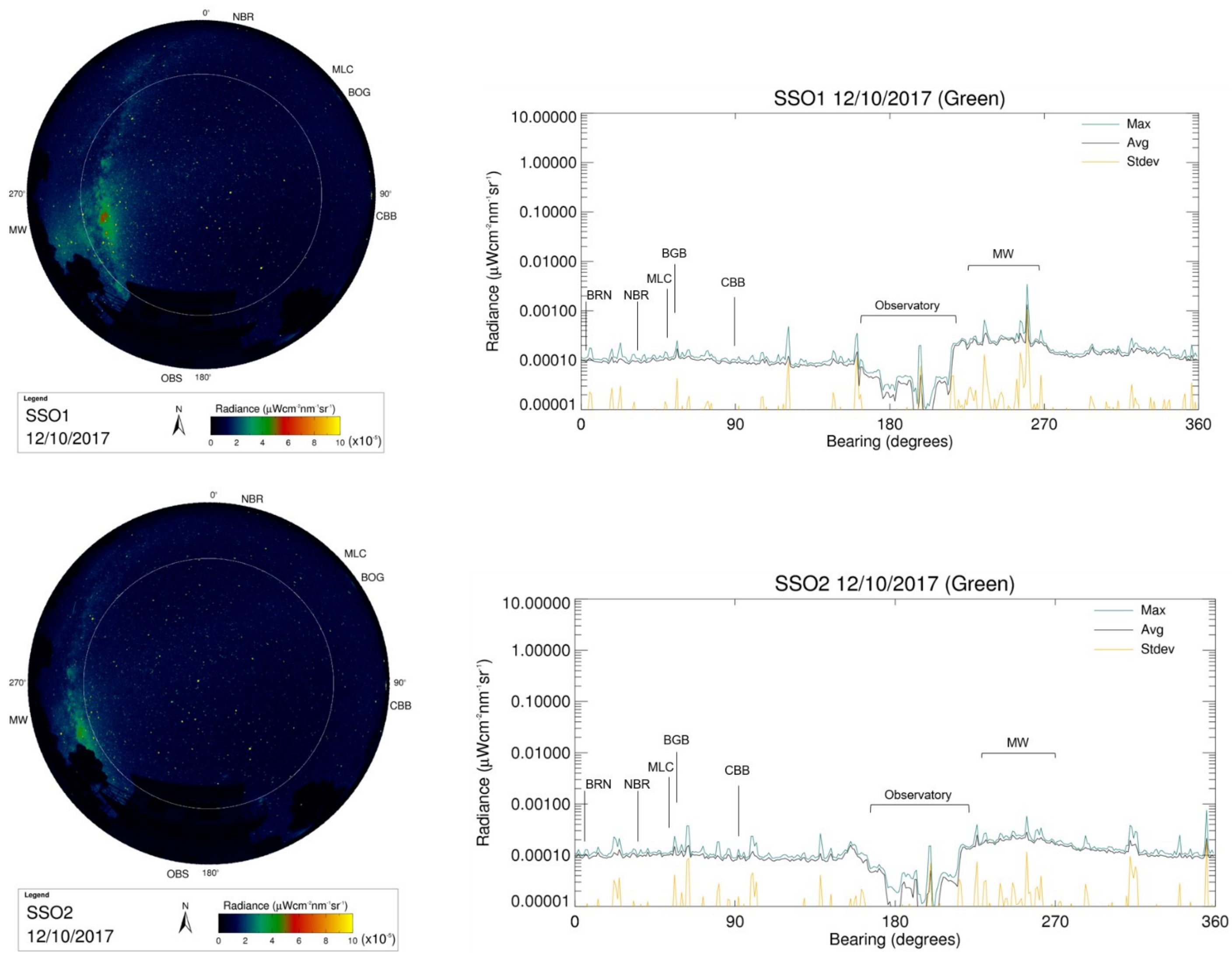


Figure 6 HRI outputs of radiance across a clear night sky with no moon from SSO. The dashed white line represents the 30° above the horizon as referenced in the guidelines. Time taken: top image 21:24, bottom image 22:58 EST

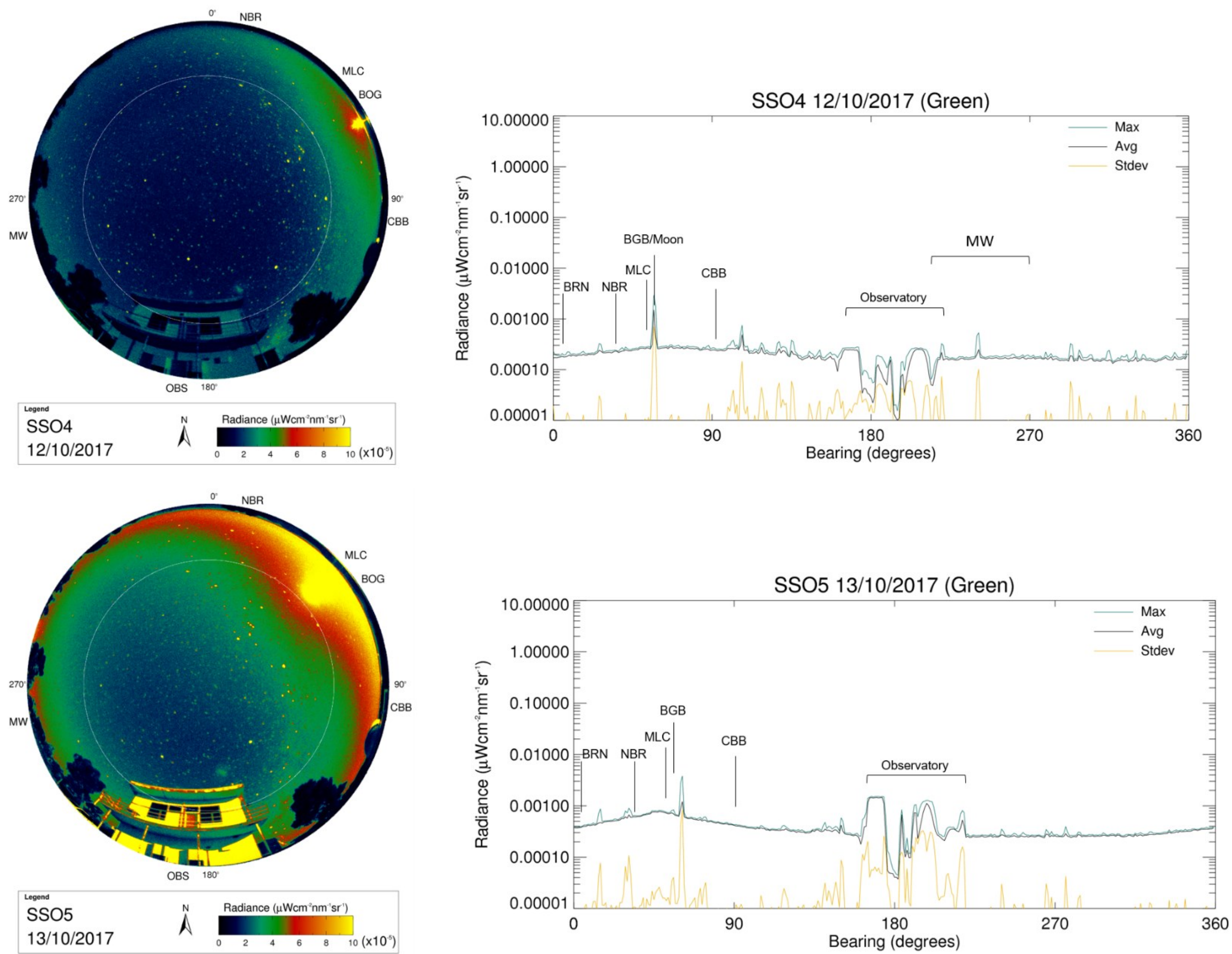


Figure 7 HRI outputs of radiance across a clear night sky at SSO as the moon rises in the northeast. The dashed white line represents the 30° threshold above the horizon. Time taken: top image 02:41, bottom image 04:09 EST.

3.2.2 Light emissions from existing gas appraisal flares

3.2.2.1 Survey design

Light measurements were taken at distances from the existing flares to provide data relating to the decay rate of light from the source to ambient light conditions. Measurements were taken near each of the flares (30 m from flare base), then 250 m intervals up to 1 km and every kilometre thereafter. Given the sampling locations from the flares were surrounded by 20 m tall eucalyptus forest, measures of brightness (mag/arcsec^2) and luminance (lux) were taken. The data was collected in the absence of the moon with a clear sky with no other light source in the area contaminating the readings. Four measurements of brightness and illuminance were taken in different directions including:

- Direction of the flare
- Direction of zenith (vertically into the sky)
- Direction of the milky way
- Direction opposite to the flare.

3.2.2.2 Survey results

The intensity of light at all flares sites was consistent with the inverse square law (intensity $\propto 1/r^2$) and decreased rapidly within 250 m from the source and reached ambient light conditions within 1 km from the source (Figure 8 - 9). Note that these figures are measured in mag/arcsec^2, which means luminance of the light source increases as with decreased mag/arcsec^2. The flow rates of each flare also corresponded to the magnitude of brightness in proximity to the flares (30 m).

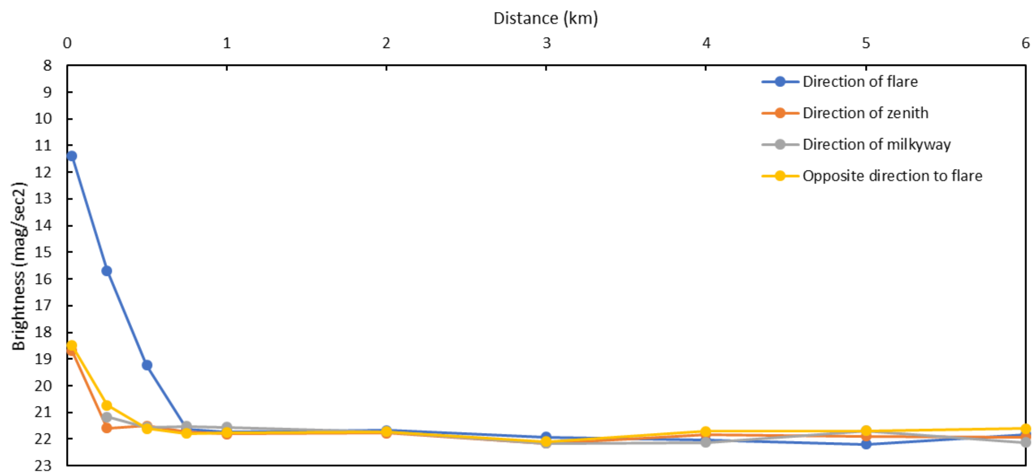


Figure 8 Decay of light from the Bibblewindi appraisal flare. Average Flow rate: 0.36 million standard cubic feet per day (MMCSFD).

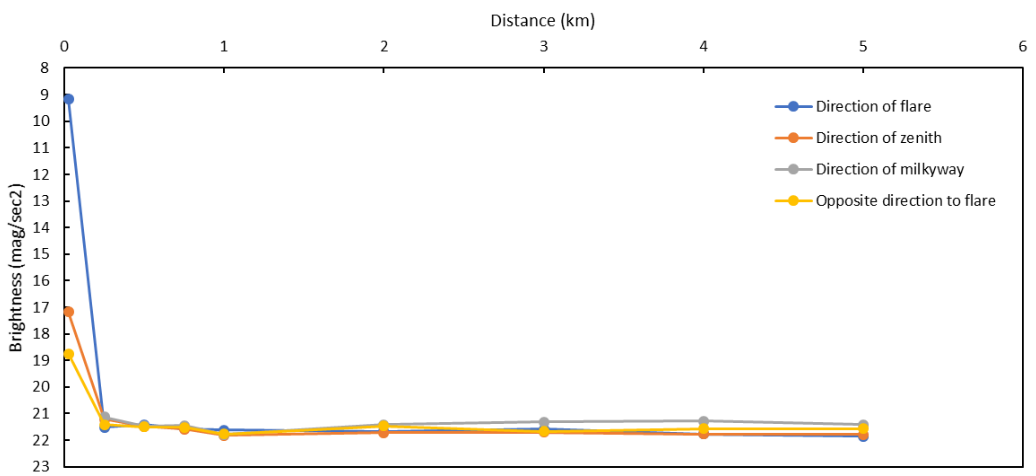


Figure 9 Decay of light from the Dewhurst appraisal flare. Average Flow rate: 0.82 MMCSFD.

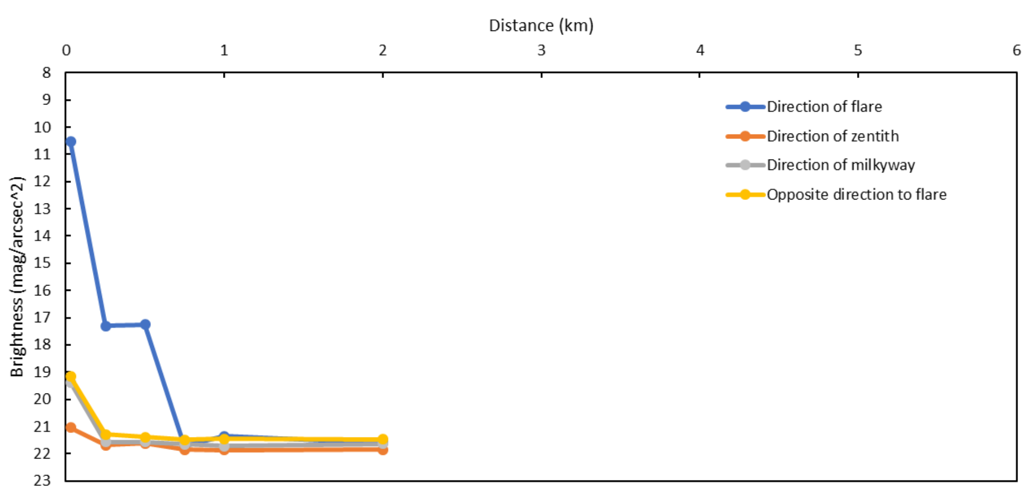


Figure 10 Decay of light from the Tintsfield appraisal flare. Average Flow rate: 0.48 MMCSFD.

4.0 PREDICTED LIGHT EMISSIONS

The direct line of sight and the estimated propagation of skyglow were modelled for scenarios during routine and non-routine flaring operations on a clear and cloudy night. The modelling was also used to predict the extent of the vertical propagation of light of flares against the Guidelines. The following assessment examined routine and non-routine flaring scenarios separately due to the different probabilities of each occurring. The assessment of routine flaring was based on the decay rates of the existing flares and light intensity measured at the Observatory during in-situ light surveys (Section 3.2.). Non-routine events would occur at either Bibblewindi or Leewood at any one time. Given that the Bibblewindi site is closer to the Observatory, representing the worst-case scenario, i.e. brightest, it was used in the modelling at a maximum throughput.

The direct line of sight between the proposed flares and the Observatory were determined using Viewshed in Global Map v15 (Blue Marble Geographics Hallowell, ME, USA. http://www.bluemarblegeo.com/about-us/press.php). The Digital Evaluation Model (1 second DEM) was sourced via the Geoscience database (Geoscience Australia 2017).

The transmitter elevation (maximum elevation of the flare flame) at the Bibblewindi site was set at 80 m to represent the maximum height of the stack at 50 m stack and a 30-m flame, representative of it operating with the maximum flow rate of gas. The expected light directly visible at the Observatory was projected across the landscape allowing for the earths curvature.

The modelling involved predicting the direct light and skyglow for the following scenarios:

- Routine flaring (all six appraisal pilot flares operating and 2 x safety flare operating with an average 1.5 m pilot flame) on clear night
- Routine flaring (all six appraisal pilot flares operating and 2 x safety flares operating with average 1.5m pilot flame) on cloudy night
- Non-routine maximum throughput flaring at the Bibblewindi safety flare on clear night
- Non-routine maximum throughput flaring at the Bibblewindi safety flare on a cloudy night

The outputs from the in-situ surveys were used to inform the predictive light modelling. The skyglow estimations were based on Rayleigh's inverse square law to determine horizontal light spill (assuming consistent scattering at low altitude) and Walter's law of scatter (assuming scattering decreases with altitude) to determine vertical light dispersal).

The distance at which natural skyglow light conditions are reached were determined from the modelling and compared against the 30^{o} above horizon reference height provided by the Guidelines. To estimate the altitude of this threshold based in the earths curvature, it was calculated that the horizon is 120 km from the Observatory. Therefore, the altitude at a 30^{o} angle from the observatory is 72 km above the horizon and the altitude above the Bibblewindi flare, which is 90 km from the observatory, would be approximately 54 km above the safety flare.

4.1 Routine flaring

4.1.1 Direct light

There are no topographic obstructions between the Observatory and the Narrabri Gas Project area, however none of the existing pilot flares were directly visible from the Observatory. Approximately two-thirds of the Project area is in State Forest that generally comprised of around 20 m high trees that act as a barrier of horizontal light spill. This is the case for the existing appraisal flares at Bibblewindi and Dewhurst sites. The Tintsfield appraisal flare is located further north in an area that comprises sparsely distributed trees. The cumulative effect of tree densities at distance also appears to provide some filtering of horizontal spill.

The proposed safety flares will be beyond the height of the tree canopy and will be in the direct line of sight to the Observatory (Figure 12). However, during routine operations of the safety flare, the flame will be an average of 1.5 m high, which will emit negligible luminance extending up to 1^{o} altitude above the horizon at the Observatory.

4.1.2 Skyglow

Given that there are multiple factors that influence light emissions from the flares, the modelling was based on the following assumptions:

- Pilot flares are at least 5 km apart
- The magnitude of light intensity is related to the flow rate of the flare
- Light intensity will be the same to that recorded during the light survey
- Ambient light conditions based on in-situ light survey are 21.48 mag/arcsec^2, 0.3 mcd/m^2 and 0.007 Iux (lumens/m^2)
- The horizontal decay rate of light will be the same as the existing flares and consistent with Raleigh's Inverse Square Law
- The vertical decay rate of light relates to Walker's Scattering Law, which considers changes in scattering properties with altitude.
- The flame height is the same for all pilot flares
- Flow rates will be consistent
- Safety flare will be average flame of 1.5 m from the top of the 50m stack.

4.1.2.1 Routine flaring (clear sky)

The horizontal dispersal of sky glow will be < 1 km under clear sky conditions, while the vertical skyglow will reach an altitude of 500 m. Horizontal accumulation of all pilot flares operating continuously at the same time will depend on the final location of the appraisal flares within the project area, with the extent of this area being between bearings of N22^{o}E – N55^{o}E from the Observatory. While the horizontal distribution of light will increase, the vertical propagation of light will remain <1^{o} above the horizon.

Therefore, artificial skyglow associated with the operation of the proposed six pilot flares and routine operation of both safety flares is predicted to extend to a height of less than 1 km, which is equivalent to less than 1^{o} as viewed at the Observatory. Above a height of 1^{o} the routine flaring operations do not contribute to artificial skyglow and thus do not contribute to artificial skyglow at the 30^{o} reference point.

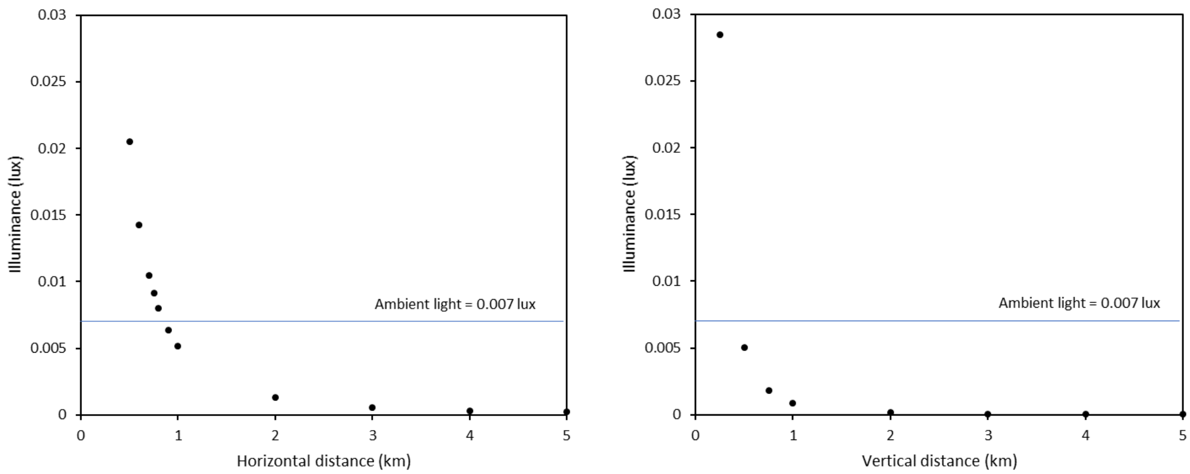


Figure 11 Estimation of horizontal and vertical illuminance from single pilot flares within the Project area based on the existing flare light data.

4.1.2.2 Routine flaring (with cloud)

The amount of light reflected off the cloud-ceiling will depend on the height, coverage and density of the clouds, and their proximity to the observatory. While this factor will vary considerably throughout the year (average oktas of 4.1 in the region), the worst-case scenario would be oktas of 7 (87% cloud cover, which would provide limited viewing opportunities at the Observatory), with a cloud-ceiling height above the altitude of Mt Woorut (i.e. 1146 m) (e.g. stratocumulus, cumulonimbus, stratus and cumulus clouds). Given that the modelling showed the vertical extent of the skyglow only reaching an altitude of 500 m, it is likely that low levels of light would reach the cloud-ceiling at a greater attitude than the Observatory.

4.2 Non-routine flaring

4.2.1 Direct Light

The non-routine flaring scenario consists of the use of the safety flare to its full capacity together with the ongoing use of the pilot flares. During a non-routine flaring event, the maximum flame height is up to 30 m from the top the stack, which would be directly visible up to 60 m above the tree line. Line of sight predictions show that parts of the north-western face of Mt Woorut would experience direct light from the Bibblewindi safety flare during a non-routine event at the night (Figure 12). The illuminance reaching the Observatory would be 0.0001 lux, which is less than Venus on a clear night (E_v = 0.00014 lux).

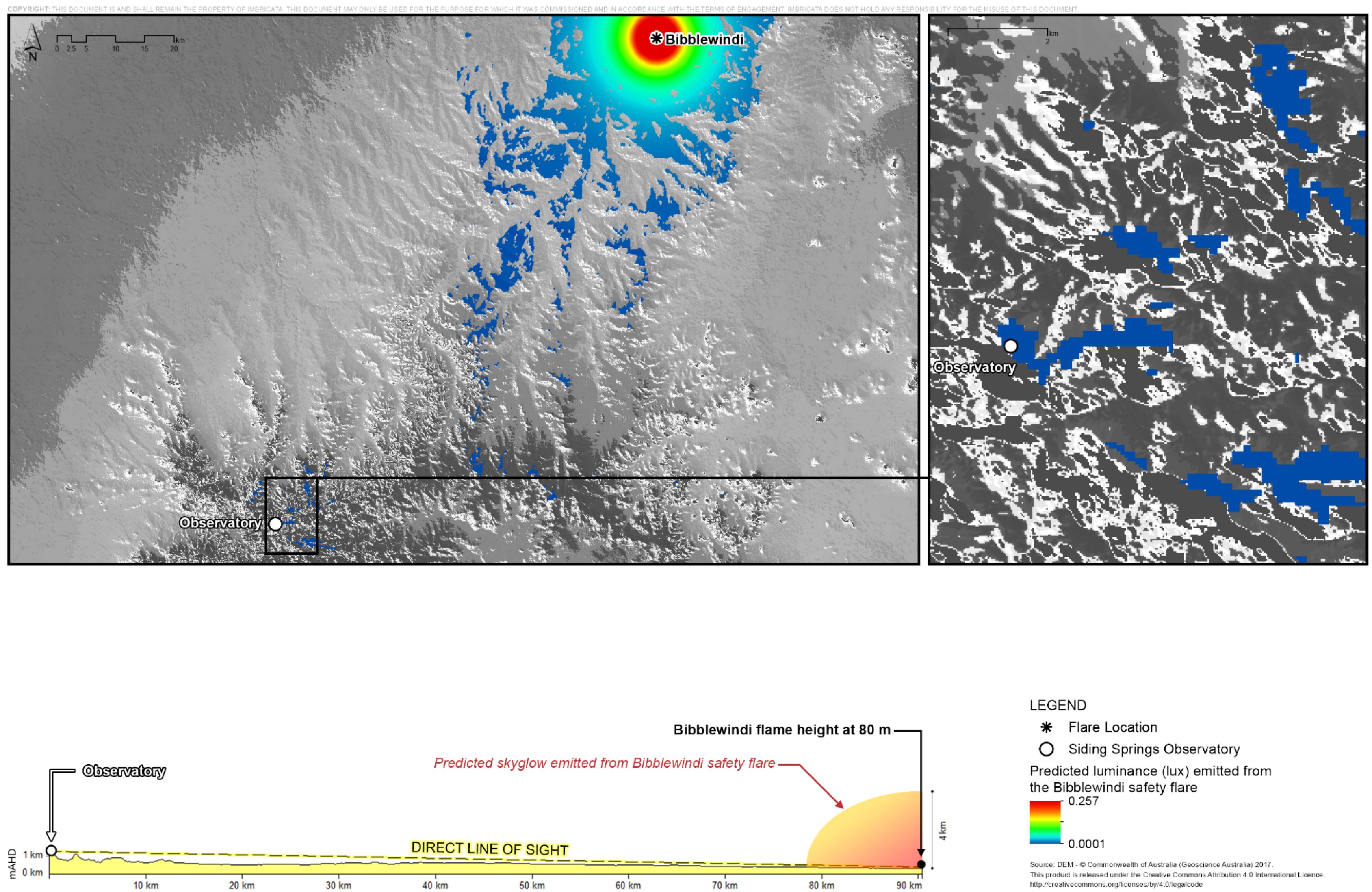


Figure 12 Horizontal (top) and vertical (bottom) light modelling outputs based on clear sky assumptions. The horizontal image accounts for the earth's curvature, but the vertical diagram does not show the earth's curvature. Note: Approximate vertical exaggeration of 2 on the line of sight cross section diagram.

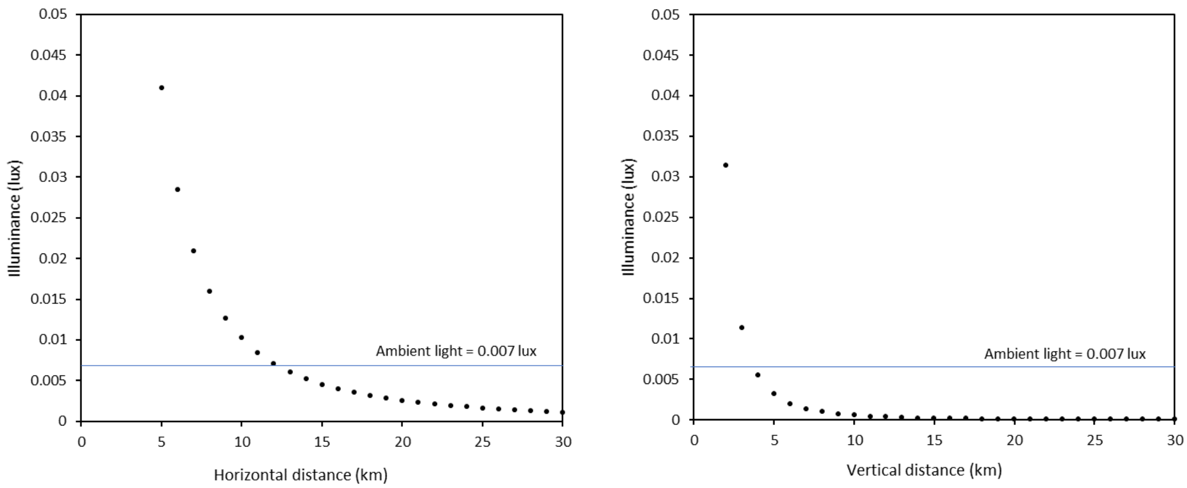


Figure 13 Estimation of horizontal and vertical illuminance from the Bibblewindi safety flare.

4.2.2 Skyglow

The modelling assumptions for deriving skyglow estimates from the safety flare at Bibblewindi are summarised below:

- Maximum flare height during a non-routine safety flare is 80 m from the ground
- The intensity and extent of skyglow would be the same at the Leewood site
- Only one safety flare will be operational in an event
- The distribution of light will form a dome shape around the source
- The magnitude of light intensity is related to the flow rate of gas
- Ambient light conditions are consistent with the in-situ light survey (i.e. 21.48 mag/arcsec^2, 0.3 mcd/m^2 and 0.007 lux.(lumens/m^2))
- The horizontal decay rate of light will be the same as the existing flares and consistent with Raleigh's Inverse Square Law
- The vertical decay rate of light relates to Walker's Scattering Law, which considers changes in scattering properties with altitude.
- Flow rates will be consistent

4.2.2.1 Non-routine flaring (clear sky)

Horizontal and vertical extent to ambient light conditions was estimated to be up 12 km and 4 km respectively from the Bibblewindi safety flare. This equates to an altitude of the skyglow reaching natural skyglow conditions at 2.5^o at a bearing range between N34^{o}E – N42^{o}E in the northeast direction from the Observatory.

Above a height of 2.5^o the non-routine flaring operations do not contribute to artificial skyglow and thus do not contribute to artificial skyglow at the 30^o reference point.

4.2.2.2 Non-routine flaring (with cloud)

Clouds influence how skyglow is distributed at altitude in two ways: reflecting vertical light at the cloud-ceiling, which increases the perceived light across the sky at a specific altitude; and limiting further vertical light propagating beyond the base of the cloud. Based on the modelling of horizontal light spill of the Bibblewindi safety flare, horizontal light spill from the flare would decrease to reach ambient levels at 12 km from the proposed flare. The clouds at an altitude up to 4 km (e.g. altostratus, altocumulus) will reflect light from the safety flare up to 78 km from the Observatory (3^o above the horizon). However, if the clouds disperse closer towards the Observatory, the reflection off the cloud-ceiling will be perceived at a greater angle above the horizon. Likewise, if the altitude of the clouds increases, the reflected light from the cloud-ceiling will be perceived higher above the horizon. If we apply a 5-fold amplification factor based on work by Jechow et al. (2017), the natural skyglow on a partly cloudy night would be 30 km from the Observatory at an angle of 7.4^o above the horizon. To produce skyglow at an angle of 30^o (the Guidelines reference point) with a cloud-ceiling of 4 km altitude, the reflectance and scattered aerosols from the flare light would need to reach within 6.7 km of the Observatory. At this point the light would be 0.0001 lux, which is less than natural skyglow intensity on a moonless night.

Above a height of 7.4^o the non-routine flaring operations would not contribute to artificial skyglow and thus do not contribute to skyglow conditions at the 30^o reference point.

5.0 DISCUSSION AND CONCLUSIONS

The current light regime across the northeast horizon from the Observatory (including the existing appraisal flares) is well within the guidelines, with low levels of skyglow extending to less than 3^o above the horizon on a clear night. Once the moon rises in the northeast direction, the major artificial light sources are masked by the extensive light scatter of the moonlight, which covers a significant portion of the sky.

The in-situ light surveys indicated that the existing flares at Bibblewindi, Dewhurst and Tintsfield emit light horizontally <1 km. While the skyglow from these sites are not discernible from other light sources (Narrabri township and Narrabri mine) from the Observatory, the combined light from these sources presents almost minor skyglow (< 1^o altitude) above the horizon from the Observatory on a clear night.

For routine flaring operations for the NGP, the extent of the horizontal skyglow will widen with up to six pilot flares, but will be limited to bearings N22^{o}E – N55^{o}E. The vertical extent of skyglow will remain at the same altitude currently perceived from the Observatory, which is less than 1^o above the horizon. Low lying cloud cover and aerosols (<500 m altitude) will influence the extent of skyglow emitted throughout the atmosphere, however this affect will be negligible compared to natural skyglow produced by starlight.

The safety flare would be directly visible from the Observatory, if it produced the maximum gas flow rate during a non-routine safety flaring event. From the flare, the extent of skyglow would progressively decrease in intensity to approximately 12 km horizontally and 4 km vertically on a clear night, equating to 2.5^o above the horizon. The frequency and extent of a non-routine flaring event occurring is significantly less than the frequency of a quarter moon rising over the northeast horizon on a clear night, which would produce significantly greater skyglow having the potential to affect observing conditions.

Overall, the assessment has found that the proposed flaring operations during both routine and non-routine scenarios would result in limited vertical light impacts, well below the 30^o guidelines reference point. The flaring would contribute to horizontal skyglow within a narrow band across the horizon as viewed at the Observatory. Based on the survey results, modelling and skyglow literature, a non-routine event requiring maximum throughput of gas to the safety flare would result in the maximum contribution to skyglow. In this event the light would reach natural skyglow levels at a maximum of 7.4^o above the horizon during cloudy conditions. Thus, the project would not make any contribution to sky glow conditions at the 30^o reference location used in the guidelines and would have negligible impact on the Observatory’s operations.

6.0 REFERENCES

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Appendix L

Errata

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Table L-1 Errata

EIS cross-reference	Correction
Chapter 6, Table 6-3	Design flow rate should read: 244 *million* standard cubic feet per day (equates to 200 TJ / day) Typical flow rate should read: 0.03 *million* standard cubic feet per day (equates to 0.02 TJ / day)
Chapter 6, Table 6-5	Average flow rate should read: 3 to 5 *million* standard cubic feet per day
Chapter 11, Table 11-6 and Appendix F, Table 5-13	The text incorrectly placed the Purlawaugh Formation in the Gunnedah-Oxley Basin with the Digby and Napperby Formations. The Purlawaugh Formation should be included in the Great Artesian Basin sequence.
Chapter 23, Section 23.3.4	The text incorrectly states that the pilot and safety flares would have a yellow flame. This should read that both the pilot and safety flares would have an orange flame.
Chapter 34	The terms and abbreviations table incorrect defines State forest as "land reserved by the Department of Natural Parks, Recreation, Sport and Racing for state forest purposes". It should state that State forest may be declared under Section 14 of the *Forestry Act 2012*.
Appendix F, Figure 6-18	There is a flux accounting error that has been corrected in the DPI Water response in Section 5.4 of this RTS.
Appendix F, Section 2.1.3	The stated reductions in sustainable diversion limits (SDLs) for the Lower Namoi Alluvium in Table 2-2 are outdated, and instead represent the proposed reductions to guide SDLs that were under consideration at the time of the proposed Basin Plan. There are currently no SDL changes proposed for the LNA and UNA.

EIS cross-reference	Correction
Appendix F, Section 2.2.4	The reference to the Available Water Determinations for the supplementary water access licences and extraction limit is incorrect and the statement following 'This is in response to the observed decline in groundwater levels in the Upper and Lower Alluvium' is incorrect. An assumption was made in the Groundwater Impact Assessment that the purpose of reducing groundwater extraction from this groundwater source was to mitigate decline in storage.
Appendix F, Section 5.2.1	The Cubbaroo Formation is incorrectly described as a "less significant transmissive unit". This should be "The Cubbaroo Formation is considered to be a significantly transmissive unit".
Appendix F, Appendix B	The proponent acknowledges that there is an omission of listing of Type 1 groundwater dependent ecosystems. The Namoi aquifer is, however, acknowledged as a groundwater dependent ecosystems in the Bohena Creek study, though it was not mentioned in the Groundwater Dependent Ecosystem Report (EIS Appendix B to Appendix F) as the focus for that assessment was on 'spring' ecosystems, not all groundwater dependent ecosystems.

EIS cross-reference	Correction
Appendix F, Appendix D	The proponent acknowledges that items 14 to 16 in Table 2 of the *Aquifer Interference Policy* were omitted from *Appendix D - Aquifer Interference Framework* within the Groundwater Impact Assessment (EIS Appendix F). The subject matter of these items, however, was addressed within the EIS and items 14 to 16 are specifically addressed below. *Table 2 of the aquifer interference assessment is a sixteen-point checklist that asks the question: Has the proponent*: • *Item 14: Considered the potential for causing or enhancing hydraulic connections, and quantify the risk?* The Risk Assessment in Section 7 of the Groundwater Impact Assessment (EIS Appendix F) considers potential risks of aquifer connectivity via wells (Section 7.4.2), including coal seam gas wells (7.4.2.1), conventional gas wells (7.4.2.2), coal mine core holes (7.4.2.3) and groundwater bores (7.4.2.4). Potential for enhanced aquifer connectivity via geological faulting is also addressed in Section 7.4.3 of the Risk Assessment. • *Item 15: Quantified other uncertainties in the groundwater or surface water impact modelling conducted for the activity?* Groundwater modelling uncertainty and sensitivity analysis are considered in Section 6.10 of the published Groundwater Impact Assessment (EIS Appendix F). • *Item 16: Considered strategies for monitoring actual and reassessing predicted take of water throughout the life of the project, and how these requirements will be accounted for?* The proponent is committed to monitoring and reporting groundwater extraction for the project. Monitoring and reporting of water production volumes is included as a minimum impact consideration in Section 3.7.2 of the Water Monitoring Plan (EIS Appendix G3).

EIS cross-reference	Correction
Appendix J2, Table 16	The descriptions of habitat for Australasian Bittern and Rufous Bettong are incorrect. Habitat for Australasian Bittern should be described as permanent freshwater wetlands with tall, dense vegetation, particularly Bullrushes (*Typha* spp.) and Spikerushes (*Eleocharis* spp.). Habitat for Rufous Bettong should be described as a variety of forests from tall, moist eucalypt forest to open woodland, with a tussock grass understorey. A dense cover of tall native grasses is the preferred shelter.
Appendix L, Section 5.2.5, Table 5-8	The table incorrectly states the NSW emission concentration standard includes five per cent O_2. This should state three per cent O_2.
Appendix M, Section 5.1.3	The text incorrectly states that the Leewood power generation facilities was assessed as two halls, each with four gas engines and one standby. This should state the facility was modelled as ten operating gas engines plus two standby gas engines.

EIS cross-reference	Correction
Appendix M, Section 5.2.2	The text incorrectly states that construction of Bibblewindi is expected to start mid-2016 with a duration of nine months.
Appendix M, Section 5.3.1	The text incorrectly states that construction of the field is expected to start in 2016 with a duration of approximately 20 years. Both statements should have read: ‘Subject to obtaining the required regulatory approvals, and a financial investment decision, construction of the project is expected to commence around early/mid 2018, with first gas scheduled for 2019/2020. Progressive construction of the gas processing and water management facilities would take around three years and would be undertaken between approximately early/mid-2018 and early/mid-2021. The gas wells would be progressively drilled during the first 20 or so years of the project.’ In relation to project timing, as set out in Chapter 6 (Project description) of the EIS (refer to Section 6.1.4), the project schedule proposed an indicative construction start date of around early/mid 2018, with first gas scheduled for around 2019/20. Acknowledging the current project schedule, it is likely that an indicative construction start date would be around mid/late 2019 with first gas scheduled for around 2021/22.
Appendix Q, Section 5.4	The text incorrectly states that the pilot and safety flares would have a blue flame. This should read that both the pilot and safety flares would have an orange flame.

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