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Report prepared for

AACo Northern Australian Beef Ltd

Livingstone Beef Plant

Odour Impact Assessment

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Glossary

Term	Definition
Units of measurement	
s	second
min	minute
h	hour
d	day
yr	year
t	tonne
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)
Nm^3/s	normalised cubic metres per second (0^oC, 1 Atm)
Sm^3/s	standard cubic metres per second (25^oC, 1 Atm)
km/h	kilometres per hour
Atm	atmosphere (unit of air pressure)
^oC	degrees Celsius
K	Kelvin (unit of temperature)
OU	Odour Units

Other abbreviations	
Approved Methods	Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (DEC, 2005)
BOM	Bureau of Meteorology
CALMET	Meteorological pre-processor and diagnostic 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
EA	Environment Assessment
EIA	Environment Impact Assessment
EIS	Environment Impact Statement
EMP	Environmental Management Plan
NT EPA	Northern Territory Environmental Protection Authority
OEH	NSW Office of Environment and Heritage (formerly Department of Environment and Conservation [DEC])
OER	Odour Emission Rate – total source rate of odour emission per second ($OU.m^3/s$ or OU/s)
SOER	Specific Odour Emission Rate – OER by unit area ($OU.m^3/m^2/s$ or $OU/ m^2/s$)
TAPM	The Air Pollution Model developed the Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Statistical terms

%ile	percentile
IOA	Index of agreement
MAE	Mean absolute error
PCC	Pearsons correlation coefficient
RMSE	Root Mean Square Error

Scientific terms

Boundary layer	The layer of the atmosphere from the Earth's surface to the level where the frictional influence is absent.
Mesoscale	Atmospheric phenomena having horizontal scales ranging from approximately 10 to 100s of kilometres, including thunderstorms, squall lines, fronts, precipitation bands in tropical and extratropical cyclones and topographically generated weather systems such as mountain waves and sea and land breezes.
Odour detection threshold	The highest dilution factor at which the sample has a probability of 0.5 of eliciting with certainty, the correct perception that an odour is present.
Odour unit	The number of times that a sample of odour must be diluted to reduce its concentration to its detection threshold. One odour unit is that concentration of odorant at standard conditions that elicits a physiological response form a panel (detection threshold) equivalent to that elicited by one Reference Odour Mass (ROM), evaporated in one cubic metre of neutral gas at standard conditions.
Pasquill-Gifford Scheme	Stability classification widely used in atmospheric dispersion models to define the turbulent state of the atmosphere.
Synoptic scale	General weather patterns that occur at the scale of 100s to 1000s of kilometres such as the migration of high and low pressure systems.

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Executive Summary

Air Environment Consulting (AEC) was commissioned by Australian Agricultural Company Pty Limited (AACo) on behalf of Northern Australia Beef Limited (NABL) in November 2014 to undertake an air quality impact assessment of the Livingstone Beef Plant for the development's works approval. The plant is situated in Livingstone in the Northern Territory (NT), approximately 30 kilometres southeast of Darwin. This original commission, presented in the report titled *AEC, 2015. Report prepared by Air Environment Consulting for AACo Northern Australian Beef Limited – Livingstone Beef Plant, Air Quality Impact Assessment, 26 March 2015, Brisbane, Australia*, assessed the potential for impacts to local air quality based on a range of air and odour emission estimates for sources at the plant.

At the time of the initial assessment, the plant was being commissioned and only operating at approximately 10 percent production capacity. Consequently, a planning-type odour dispersion modelling assessment was conducted to determine the source to receptor dispersion relationships and evaluate the potential range of odour emissions that would comply with the odour impact assessment criterion. An investigation was also conducted based on worst-case odour emissions, extracted from AEC's database of source emissions at similar facilities, to determine the level of odour impact if the plant was not operated according to best practice or under optimum conditions in terms of odour generation. Under these conditions, it was considered possible that odour nuisance in the local community was unlikely, but could occur if not well managed. The initial report also determined that an investigation of odour emissions was required to more accurately predict the impact of odour from the NABL facility and recommended that an odour emissions audit be undertaken once full operating capacity and plant commissioning was achieved.

Following the issuance of the Air Quality Impact Assessment report on 26 March 2015, the NABL plant continued to operate and the cattle processing rate gradually increased. During this time, several complaints were received by the Northern Territory Environmental Protection Authority (NT EPA) from local residents in response to odour nuisance, that was alleged to have been caused by NABL operations. On 17 August 2015, NTEPA issued NABL with a *Notice to Carry Out an Environmental Audit Program* pursuant to section 48 of the *Waste Management and Pollution Control Act*. The Notice included a request to conduct an odour impact assessment including a review of odour generating activities and sources, a review of general processes, housekeeping and odour control technology efficacy and suitability, an odour emissions audit, and odour dispersion modelling and impact assessment based on the aforementioned air quality impact assessment (AEC, 2015).

The odour impact assessment, which forms the basis of this report, was based on odour emission rate and source characteristic information collected during a site odour emissions audit conducted between 16 and 30 September 2015. The dispersion modelling study combines the site-specific details of the NABL operations and surrounding environment including odour emissions, topography, land use and the location of sensitive receptors with predicted local meteorology evaluated against local observed meteorology, in accordance with the methods promulgated in the *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (DEC, 2005)*. The current operating and odour emissions scenario, as determined during the site odour audit, was assessed against the NSW odour impact assessment criterion of 3 OU, 99th percentile, 1-second average based on local population density.

The key odour sources included in the assessment were the:

1. Lairage i.e. live animal receipt, holding yards and AQIS area,
2. Waste product handling and processing, i.e, the rendering building, hides building, paunch, DAF sludge and tallow storage,

3. Wastewater handling and treatment, i.e, the DAF, Lamella, effluent storage and solids treatment, irrigation water storage tank and sumps,
4. Disposal of treated effluent water by spray irrigation, and
5. Odour control units, i.e, the biofilter treating rendering cooker exhaust gases.

The odour impact assessment determined that odour emissions associated with the wastewater treatment plant and the spray irrigation of poorly treated effluent were likely to be the principle cause of the odour complaints receive by NT EPA, and which initiated the notice to conducted this assessment. The assessment determined that significant ground-level odour concentrations in exceedence of the odour impact assessment criterion (3 OU, 99th percentile, 1-second average) were likely at sensitive receptor locations around the NABL site, primarily due to the spray irrigation source, but also combined with the similar odour character of the wastewater treatment plant emissions to increase the impact.

The assessment also determined that the lairage odour sources also had the potential to cause odour nuisance at sensitive places beyond the site's southern boundary, however this finding is associated with some uncertainty in the calculation of odour emissions. Odour emissions associated with cattle handling activities could be mitigated through the environmental management procedures and include general housekeeping and regular cleaning of surfaces when cattle are removed from the pen. Housekeeping may comprise prevention of water spills and leaks during the dry season as the odour emissions audit showed that the wet surface released ten times more odour than the dry surface. During the wet season, holding yard pen floors should be cleaned of manure regularly to prevent material from anaerobic decomposition and excessive odour release. Similarly, the AQIS floor area should be cleaned as cattle are removed from holding pens.

The assessment determined that the rendering plant operations were not expected to cause odour nuisance above the impact assessment criterion at sensitive places, however, there were several activities identified that could be managed to significantly reduce odour emissions from the area. This included covering some sources with lids, or extracting ventilation air to the biofilter for treatment.

Based on these investigations, an upgraded wastewater treatment pond system was designed and assessed as part of the mitigation strategy for the NABL site. The four pond wastewater treatment system is expected to significantly reduce odour emissions associated with wastewater treatment and most significantly, reduce the odour emissions from the spay irrigation area. The assessment determined that cumulative ground-level odour concentrations associated with the existing stage 1 and proposed stage 2 wastewater treatment systems, and the spray irrigation of the treated effluent with improved water quality, would have a low risk of causing odour nuisance at any sensitive places in the local area.

Further recommendations and mitigation measures have been made for consideration in the environment management plan. The odour management plan should include:

- Maintenance of plant processes and equipment, including odour control units such as the biofilter.
- Cleaning and good housekeeping practices.
- Management of the wastewater treatment plant within its design criteria.
- Ambient odour monitoring, including.
    - Ambient odour intensity measurement.
    - Ambient odour concentration measurement.
    - Ambient monitoring of odorous gases.

- Weather monitoring and application of information in decision-making.
- Odour complaint recording and management.

1 Introduction

AEC was commissioned by AACo on behalf of NABL in September 2015 to undertake an odour impact assessment of the Livingstone Beef Plant. The plant is situated in Livingstone in the Northern Territory (NT), approximately 30 kilometres southeast of Darwin.

The commission was established in response to the issuance on 17 August 2015 by NTEPA to NABL of a *Notice to Carry Out an Environmental Audit Program* pursuant to section 48 of the Northern Territory Government's *Waste Management and Pollution Control Act*. The Notice requested an audit program be conducted to include a review of odour generating activities and sources, a review of general processes, housekeeping and odour control technology suitability and efficacy. The notice also stated that an odour emissions audit of the Livingstone plant be undertaken and used to assess the potential for odour impact in the local area using the odour dispersion model and impact assessment approach developed by AEC in their initial air quality impact report titled *AEC, 2015. Report prepared by Air Environment Consulting for AACo Northern Australian Beef Limited – Livingstone Beef Plant, Air Quality Impact Assessment, 26 March 2015, Brisbane, Australia*.

This report documents the methods, results, conclusions and recommendations of the odour impact assessment of the NABL abattoir and rendering plant in Livingstone, NT. The assessment combines the site-specific details of the NABL operations and surrounding environment including odour emissions, topography, land use and the location of sensitive receptors with predicted local meteorology evaluated against local observed meteorology, in accordance with the methods promulgated in the *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (DEC, 2005)* to assess the potential for odour impact. The predicted ground-level odour concentrations were assessed against the NSW odour impact assessment criterion of 3 OU, 99^{th} percentile, 1-second average based on local population density.

The key odour sources included in the assessment were the:

1. Lairage i.e. live animal receipt, holding yards and AQIS area,
2. Waste product handling and processing, i.e, the rendering building, hides building, paunch, DAF sludge and tallow storage,
3. Wastewater handling and treatment, i.e, the DAF, Lamella, effluent storage and solids treatment, irrigation water storage tank and sumps,
4. Disposal of treated effluent water by spray irrigation, and
5. Odour control units, i.e, the biofilter treating rendering cooker exhaust gases.

2 Overview of the Assessment Methodology

The odour impact assessment is based on a dispersion modelling study that combines the site-specific details of the project, as detailed in AEC (2015), with an odour emissions audit conducted by Airlabs Environmental (2015) at the Livingstone Beef Plant in September 2015.

The following approach to the odour impact assessment has been adopted:

- Selection of a representative year of regional meteorology for simulation.
- Development of a meteorological dataset using the CSIRO's prognostic meteorological model TAPM and the CALMET diagnostic meteorological model, that represents the three-dimensional wind flows and temperature profiles of the atmosphere in the region.
- Conduct of a site visit by AEC to design the odour emissions audit program for collection of relevant data for inclusion in the dispersion model and impact assessment.
- Undertaking of the odour emissions audit program by Airlabs Environmental and reporting for inclusion in the assessment.
- The three-dimensional wind field generated by CALMET, the results of the odour audit (Airlabs Environmental, 2015) and source characteristic information collected by AEC and Airlabs Environmental during their site visits and supplemented by information from NABL, were input to the CALPUFF air dispersion model to predict ground-level odour concentrations in the local area and at the most affected receptors.

The assessment was carried out in accordance with the following NSW legislation and guidance documents:

- *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2005)*,
- *Generic Guidance and Optimum Model Settings for the CALPUFF modelling system for Inclusion into the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW, Australia (2011)*,
- *Technical Framework - Assessment and Management of Odour from Stationary Sources in NSW*, (2006), and
- *Technical Notes - Assessment and Management of Odour from Stationary Sources in NSW* (2006).

The key site operations and odour sources investigated during the site visit included the following process areas:

1. Lairage, i.e. live animal receipt, holding yards and AQIS area,
2. Slaughter and processing, i.e, the kill floor operations, boning, packaging and cold storage,
3. Waste product handling and processing, i.e, the wet rendering building and cooker building, hides building, paunch, DAF sludge and tallow handling and storage,
4. Wastewater handling and treatment, i.e, the DAF, Lamella, effluent storage pit, balance tanks, sludge handling, irrigation water storage tank and sumps,
5. Disposal of treated effluent water by spray irrigation, and
6. Odour control units, i.e, the biofilter treating rendering cooker exhaust gases.

Odour impacts have been assessed on the basis of odour type and character, in accordance with the NSW odour criterion and guidance documents. On this basis, it considered that odour from different sources, with different characters, are not additive and the ground-level odour concentrations do not accumulate so that the odour unit concentrations can be summed to produce a total aggregated ground-level odour concentration. They can, however, be aggregated in terms of the frequency of occurrences in which odour from the facility causes an impact above the odour criterion. This cumulative odour impact frequency above the criterion was investigated in the assessment.

In regard to cumulative odour impacts of other sources in the region, a review of land use in the surrounding area indicated that the Wellard Darwin Integrated Livestock Export Facility, a cattle feedlot, is situated to the north of the NABL site. This is currently a small facility but has recently prepared an Environmental Impact Assessment including a Level 1 Odour Impact Assessment (EnviroAg, 2015) for a significant expansion of its capacity. The current facility is considered to be well separated from the NABL site and cumulative odour impacts are very unlikely to occur due to the unlikelihood of simultaneous plume merging from both sites. It is acknowledged that residences between the NABL and Wellard sites may experience low levels of cattle-type odour under various wind conditions from time to time. As a result, a cumulative modelling-based odour impact assessment of the Wellard facility has not been conducted in this report.

Notwithstanding this, the EnviroAg (2015) Level 1 Odour Impact Assessment indicates that the proposed fully expanded Wellard site buffer of 497 metres would overlap on the NABL site in the vicinity of the current NABL northern irrigation area and the proposed site of the stage 2 wastewater treatment ponds. It is also noted that the Level 1 S-Factor based Odour Impact Assessment report does not consider odour impact from their proposed anaerobic pond wastewater treatment system and the irrigation of primary treated effluent between the Wellard feedlot and the Stuart Highway. It is expected that this would provide a significant cumulative impact with respect to the frequency in which odour is detected with the NABL wastewater treatment and irrigation system, in that localised area, and should be considered not by the existing NABL operations but the yet to be approved and built Wellard operation.

3 Project Overview

3.1 Project description

NABL are operating a beef cattle slaughter and processing plant at Livingstone, approximately 30 km southeast of Darwin. The site is situated on the western side of the Stuart Highway, south of Livingstone, at the point in which the rail line and highway converge and run parallel to one another.

The plant operates two shifts between 7am and 1am the following day, with a downtime period between 1am and 7am daily. Approximately 8 or 9 road trains will deliver up to 1,050 head between 7am and 7pm each day for processing, with all cattle on site the night before their processing the following day. Each shift will process up to 525 head per day. The lairage area has a holding capacity of 1,050 head, while the Australian Quarantine Inspection Service (AQIS) yard area has a holding capacity of 525 head.

3.2 Site odour investigation

AEC Director, Andrew Balch, conducted an inspection of the NABL site on 15 and 16 September 2015. Andrew accompanied Ian Brash (Technical Manager, Airlabs Environmental), Glenn Bulloch (NABL Assistant Plant Manager) and Yeresha Herath (NABL Environmental Officer) on an inspection of the plant to identify the odour sources to be monitored and assessed. The inspection of plant production processes identified the key odour emission sources, as described in Table 3-1. Based on this identification of the emission sources, a sampling plan was prepared by AEC, as presented in Table 3-2, and provided to Airlabs Environmental, VIPAC and the project auditor, V&C Environment Consultants, for approval.

Since the commissioning of the plant and the receipt of odour complaints, several changes were made to various production and treatment processes to improve process efficiency and mitigate the odour complaints. These included, but may not be limited to:

- Bypassing of the Lamella in the wastewater treatment plant
- Bypassing of the In-ground storage tank in the wastewater treatment plant,
- Discontinuing with the use of the southern irrigation area, and
- Commissioning of the northern irrigation area.

As the odour sampling was conducted during the dry season, the First Flush Dam was dry with no water in storage.

Table 3-1 Site processes and odour emission release pathway

Emission source	Process unit	Process description and emission release	Considered to be a source of odour
Lairage	– Live animal receival area – Holding pens	– Open to atmosphere.	Yes
	– AQIS yard	– Open to atmosphere.	Yes
Animal processing	– Animal slaughter, boning, packaging and cold storage.	– Building is sealed and ventilation air is considered to be very low in odour.	No
Waste product handling and processing	– Rendering area. By-product processing. Separated in to two sections.	– Wet rendering building – pre-cooker handling and treatment, building is naturally ventilated and open to atmosphere. – Red Fan Press - Screw Conveyor – Red Fan Press - Tank/Sump – Raw materials bin	Yes
		– - Cooker building - Cooker in cooker building has point source exhaust air collection and extraction to the biofilter for abatement.	No
	– Hides building. Hides salting and preservation.	– There is no emissions collection and treatment. – Building is naturally ventilated and open to atmosphere. – Not considered to be an odorous activity.	No
	– Paunch storage and transfer	– Paunch stored in open bin.	Yes
	– Tallow storage and transfer	– Tallow stored in two fixed roof tanks. – Tank headspace is vented to atmosphere as tank fills.	Yes
	– Meat meal hammer meal vent, storage and transfer	– Air exhausted from hammer mill cyclone vent. Meat meal transferred to trucks for transfer.	Yes
Biofilter	– Odour control unit treating odour emissions extracted from the rendering cooker	– Open to atmosphere. – Earthy odour	Yes
Wastewater handling, treatment and storage	– DAF (Dissolved Air Flotation tank) for removal of suspended solids and effluent clarification	– DAF tank is open on top. – DAF is located within wastewater treatment building. Building structure has roof with no walls. – Building is naturally ventilated and open to atmosphere.	Yes
	– DAF Sludge Decanter	– Small bin holding DAF sludge.	Yes
	– DAF Sludge Storage Storage Bins	– DAF sludge stored on hook bins.	Yes

Emission source	Process unit	Process description and emission release	Considered to be a source of odour
		– Contra shear scrapings also placed in bin	
	– Lamella for further solids removal and clarification	– Lamella is no longer in use	No
	– Irrigation water storage tank	– Treated effluent is stored in a single fixed roof tank. – Tank headspace is vented to atmosphere as tank fills.	Yes
	– Green sump	– Green side wastewater treatment plant entry point – Open concrete ground level tank.	Yes
	– Common sump	– Red side wastewater treatment plant entry point – Open concrete ground level tank.	Yes
	– First Flush Dam	– Open dam. – No water in dam during dry season when sampling occurred.	No
	– In-ground tank	– No longer in use.	No
	– Equalising Tanks (2)	– Sealed. No vent. Overflow goes to Common Sump.	No
Disposal of treated wastewater	– Spray irrigation	– Effluent water is applied to the paddocks to the north of the facility within the site boundary. – Water is sprayed into the air for disposal via evaporation and ground infiltration.	Yes

Table 3-2 Sampling program

Location/process	Emission source type	Sampling method	Actual no. of samples/ source	Issues /access/ production requirements
Receival and Holding Yards	Fugitive / Area (surface)	Flux chamber	4	--
AQIS Yard	Volume (fugitive)	Vacuum chamber	2	- Representative number of animals in the area and condition of area.
Red Fan Press: Screw Conveyor	Volume (fugitive)	Vacuum chamber	1	--
Red Fan Press: Tank/Sump	Volume (fugitive)	Vacuum chamber	1	--
Raw Material Bin	Volume (fugitive)	Vacuum chamber	2	--
Wet Rendering Building	Volume (fugitive)	Vacuum chamber	2	- Production levels during sampling. - Building odour spatial and temporal variability. - Measuring building ventilation rates.
Rendering Cooker Room	--	--	0	- Not considered odorous during scoping site visit. All odour emissions collected and treated in biofilter.
Biofilter	Area (active net outflow)	Flux chamber	6	--
Meat Meal Hammer Mill Cyclone Wall Vent	Point source (Wall vent)	Vacuum chamber	2	- Elevated wall vent.
Tallow transfer and storage	Point source - vent	Vacuum chamber	2	Overflow vents. Only vents during filling.
Hides building	Volume (fugitive)	--	0	Not considered odorous during scoping site visit.
Green Sump	Area source	Flux chamber	2	Water level below ground surface level.
Common Sump	Area source	Flux chamber	2	Water level below ground surface level.
Equalising Tanks (2)	--	--	0	No vent. Overflow goes to Common Sump.
DAF Inlet End	Area source	Flux chamber	2	- Production levels during sampling. - DAF tank odour spatial and temporal variability.
DAF Outlet End	Area source	Flux chamber		- Production levels during sampling. - DAF tank odour spatial and temporal variability.
Lamella	Volume (fugitive)	--	0	Not in use anymore.
In-ground tank	Volume (fugitive)	--	0	Not in use anymore.
Irrigation tank	Volume (fugitive)	Vacuum chamber, sample tank vent	2	- Tank vents headspace to atmosphere.

Location/process	Emission source type	Sampling method	Actual no. of samples/ source	Issues /access/ production requirements
Spray irrigation	Fugitive: - Volume (spray evaporation)	Emissions based on DAF flux chamber sample SOERs	See DAF samples	Two source issues: 1. Water sprayed into air and evaporated (volume source) 2. Water lying on ground (area source) Samples were also collected downwind of source but results were inconclusive.
First Flush Dam	Area source (liquid surface)	--	0	No water in dam. Do not sample.
DAF Sludge Decanter Fresh material	Area source	Flux chamber	1	High concentration, small area source.
Sludge Storage (Hook) Bin on aged sludge (near WWTP)	Area source	Flux chamber	1	High concentration, small area source.
Sludge Storage (Hook) Bin with Contra Shear Scrapings – Day old (near WWTP)	Area source	Flux chamber	1	High concentration, small area source.
Paunch storage bins, Fresh material (near WWTP)	Area source	Flux chamber	1	--
Paunch storage bins, Day old material (near WWTP)	Area source	Flux chamber	1	--

Three key changes were made to the sampling methodology proposed by AEC:

- The biofilter was sampled using an Isolation Flux Chamber rather than a Witch's Hat.
- The Irrigation Tank water was not sampled and tested for application to the Spray Irrigation Area odour emission rate. An alternative approach was taken to sample ambient air at five distances downwind of the spray irrigation area and calculate the odour emission rate using back trajectory modelling (i.e. back calculation of the source emissions based on the measured odour concentration downwind). This method proved inconclusive and consequently, the specific odour emission rate of the DAF outlet was used to model the irrigation plots as an area source.
- For the AQIS building sampling, it was proposed to sample the air from within the source and calculate the flow through the cross sectional area of the building. An alternative approach was taken to sample ambient air at two distances downwind of the AQIS building and calculate the odour emission rate using back trajectory modelling (i.e. back calculation of the source emissions based on the measured odour concentration downwind).

4 Odour Emissions

This section details the odour emission source characteristics and emission rates configured in the air dispersion model. The result of the odour emissions audit conducted by Airlabs (2015) is presented in Appendix A.

4.1 Odour emission inventory calculation

Several adjustments to the odour emission rates and source characteristics were made by AEC in agreement with the project auditor, Vic Natoli, due to the methods used in the odour sampling and other complexities observed during the site odour emissions audit. These included:

- Odour emission rates for the AQIS area were calculated by the back trajectory modelling method, based on odour concentration sampling five metres downwind of the AQIS area and the wind velocity measured at the time of sampling. The back trajectory modeling was conducted using the Ausplume dispersion model. Based on the site conditions and time of sampling, a Pasquill-Gifford stability classification of B (very unstable) was assumed and a mixing height of 500 metres.
- Odour emission rates for the Spray Irrigation Area were to be calculated by the back trajectory modelling method, based on odour concentration sampling between the irrigation plots (two samples) and at downwind distance of 20, 200 and 400 metres downwind (one sample taken at each distance). However, there were several issues with this methodology, including:
  - — The sample odour concentrations measured were not consistent with the expected dispersion rates downwind. In addition to this, the sample concentration (sample no. AA34) was below the limit of detection of the olfactometer (24 OU).
  - — There was some discrepancy between the reported downwind distances from the source and the GPS coordinates recorded for the sampling locations.
  - — The observed wind directions and speeds at the sampling locations did not agree with observations at the site's automatic weather station (AWS) (based on hourly averages) during the second hour of sampling.
  - — The wind direction at the time of sampling was not consistent and regularly changing direction. Consequently, the sampling location may not have been downwind within the plume centerline during all samples.

  As an alternative, the specific odour emission rates applied to the Spray Irrigation Area modelling was based on the odour emissions measured at the outlet of the DAF. It is acknowledge that these odour emissions are relatively high and it is not known how the odour emitted from the wastewater changes between the DAF outlet, the Irrigation Tank and Spray Irrigation Plot. Notwithstanding that, there is no wastewater treatment process between the DAF and irrigation, and consequently, the odour emissions are expected to remain fairly constant. This approach was adopted to represent a worst-case odour emissions scenario for the irrigation as it has been observed that the irrigation of under-treated effluent is likely to be the source of the odour complaints received by NT EPA. Consequently, assuming the irrigated water released possesses the same level of odour as the water at the DAF outlet is considered to be a reasonable assumption.

  The calculated specific odour emission rate was then applied to the wetted surface area, averaged over the entire irrigation plot area. It was noted that the sprays do not effectively reach every square metre of the irrigation plot area, and so the emissions are averaged of the entire area. Irrigation is currently conducted in two plots (known as Plot C and Plot D), situate to the north of the NABL production plant and adjacent to the northern boundary along the rail line. It was assumed that, through water infiltration, runoff and evaporation, the specific odour emission rate of the irrigated surface will not be constant over the 24 hours of each day, and so the emissions were adjusted accordingly to account for the odour diminishing over several hours to a baseline level assumed to be approximately 10 percent of the peak emission. This hourly variability of specific odour emission rates over 24 hours is illustrated in Figure 4-1.

- The biofilter was sampled using an Isolation Flux Chamber. When using an Isolation Flux Chamber to sample from an odour source with a net air outflow, such as a biofilter or wastewater aeration tank, the additional sweep air into the chamber provided by the source outflow must be taken into consideration to adjust the specific odour emission rate. To achieve this, a constant mean outflow across the biofilter surface was assumed based on the design inlet airflow of 10,000 m^3/h and the bed surface area of 430.56 m^2. This airflow through the surface area of the Isolation Flux Chamber was added to the clean air sweep air in the calculation of the biofilter specific odour emission rates.
- The calculation of the odour emission rate of the Raw Material Bin was based on the wind velocity across the surface of the bin opening, observed and recorded during the sampling, rather than the observed rise rate of air from within the bin. It was assumed a venturi effect pulls the air from the bin, or put another way, the wind mixes within the bin and is released to atmosphere. This is likely to be a very conservative estimate, as the rate of mixing is not expected to be equivalent to the wind speed under all conditions. In addition to that, the maximum odour emission rate of the two samples collected was used in the model.
- As specified in the Australian standard, AS4323.3 (2001), Airlabs Environmental (2015) reported all odour emission rates at *normal temperature* (i.e. 0°C). However, olfactometry testing is conducted at room temperature, nominally 25°C, and it is more appropriate to assess the impact of odour concentrations at actual source temperature based on the conversion from the temperature at which the sample is tested. Consequently, all odour emission rates used in the modelling were adjusted based on testing at *standard temperature* (i.e. 25°C). This has the effect of slightly increasing the reported test odour concentration (in OU).

The odour source samples have been prepared into an odour emissions inventory and presented in Table 4-1. Several sources were sampled to gather odour emissions information for various operating conditions. These data were then combined in various ways to model each source or combination of sources, as presented in Section 4.2.

The odour emissions inventory presented in Table 4-1 clearly shows that the Spray Irrigation Area is the primary source of the odour and likely to be responsible for the odour complaints generated by the NABL operations. This is due to the proximity of the previously used southern irrigation area to sensitive receptors adjacent to NABL's southern boundary and to the poor quality of the effluent water that was irrigated. The Irrigation Tank is also a significant source of odour and also reflects the odour in the effluent being irrigated.

Other important odour sources are the AQIS area and the Raw Material Bin at the Rendering Plant. The AQIS area odour emissions appear to be very high and may be a function of their calculation method, i.e. through their calculation by back trajectory modelling of downwind odour sample collection. It was reported that there was approximately 450 head of cattle in the AQIS area at the time of sampling and NABL indicated that the area is kept clean after cattle pass through. Anecdotal comments from the sampling team at the time of sampling indicated that the odour in the AQIS area was low. The mean odour concentration of 46 OU, measured five metres downwind of the area, supports this observation. The key point to make in terms of the lairage area as a whole is the significant discrepancy between the AQIS and Holding Yard odour emission rate. Even assuming wet surface conditions, the Holding Yard odour emission rate appears to be quite low. This may be a function of good housekeeping and low production capacity at the time of sampling.

Also of note is the relatively low odour emission rate of the Wet Rendering Building by comparison to the Raw Materials Bin. Material processed through the Raw Materials Bin is further processed in several open top processes in the Wet Rendering Building. The odour emissions may have been a function of the throughput of the plant on the day of sampling, as odour was considered to be higher, than that measured, on the day of the initial site investigation.

It should also be noted that the Spray Irrigation Area is inherently difficult from which to sample odour emissions. The odour emission rate applied to the Spray Irrigation Area is based on the DAF specific odour emission rate. While this is not an unreasonable assumption as the DAF water, via the Irrigation Tank, is spray irrigated, it is not well understood what other factors affect the water quality and release of odour between the DAF and the spray nozzles, including inside the Irrigation Tank. Notwithstanding this, the odour impact predicted by the dispersion model supports the complaints data, see Section 7.5.

Table 4-1 Current odour emissions inventory

Odour source	Odour emission rate (OU/s)	Proportion of total plant emissions (%)
Lairage		
Cattle receival and holding yards, maximum during wet season	682	0.6%
AQIS Area	10,586	9.0%
Rendering Area		
Red fan press: tank/sump	71	0.1%
Red fan press: screw conveyor	609	0.5%
Raw material bin	7,475	6.4%
Wet rendering building	956	0.8%
Meat meal hammer mill cyclone wall vent	962	0.8%
Tallow transfer & storage tanks 1 and 2	2	0.0%
Biofilter	741	0.6%
Wastewater treatment area		
Green Sump	7	0.01%
Common Sump	5	0.005%
DAF	81	0.1%
DAF sludge decanter	3	0.003%
Irrigation Tank	5,991	5.1%
Sludge storage bins	321	0.3%
Paunch storage bins	7	0.01%
Spray Irrigation	88,640	75.7%
Total plant odour emissions	**117,140**	**100.0%**

4.2 Configuration of odour sources in the dispersion model

The Meat Meal Hammer Mill Cyclone wall vent and the Tallow Tank vents were sampled as point source emission with a sample vacuum chamber (indirect drum and pump sampling method). While these require a conventional sampling method, the sources were not standard vertical vent or stack emission sources. The Cyclone Wall vent is a short horizontal vent protruding from the Rendering Building wall, in the space between the Rendering Building and the Hides Building. The Tallow Tank vents comprise a duct venting the headspace from the top of the tank, down the side of the tank and releasing the emission at near ground level.

All other fugitive sources were sampled using the Isolation Flux Chamber method based on the Australian standard AS4323.4 (2009).

Fugitive odour emissions are released from various ground level sources open to atmosphere such as the lairage areas, open wastewater tanks, spray irrigation fields, open buildings and fixed roof tank vents as they fill and breathe. The two Tallow Tank emission vents comprise a vertical down directed duct near ground level on each tank, and consequently, these have been combined in the model as a volume source. The source characteristics configured in the dispersion model are separated into volume and area source categories in Table 4-2 and Table note: Coordinates are in Universal Transverse Mercator (UTM), equivalent to Map Grid of Australia (1994).
Odour emission rate in table does not include peak to mean factor applied in the model.

Table 4-3, respectively. The hourly variability of the Spray Irrigation area specific odour emission rates over 24 hours is illustrated in Figure 4-1.

The source characteristics and emission rate of the only source modelled as a point source, the Meat Meal Hammer Mill Cyclone wall vent, are presented in Table 4-4.

Table 4-2 Fugitive volume source characteristics

Odour source	Source centre coordinates		Dimension characteristics		Effective height (m)	OER (OU/s)	Hours of operation
	Easting	Northing	σy	σz			
Red fan press sump	725.955	8593.857	0.5	0.5	1	71	7am - 6pm
Red fan press screw conveyor	725.950	8593.854	0.5	0.5	1	609	7am - 6pm
Raw material bin	725.941	8593.861	1.3	1.2	5	7,475	7am - 6pm
Wet rendering building	725.928	8593.857	5.8	1.2	5	956	7am - 6pm
Tallow tanks 1 & 2 combined	725.894	8593.851	0.12	0.23	0.5	2.3	Continuous
Biofilter	725.891	8593.876	6.42	0.34	1.5	741	Continuous
Irrigation tank	725.794	8593.872	3	0.7	2.8	5,991	Continuous

Table note: Coordinates are in Universal Transverse Mercator (UTM), equivalent to Map Grid of Australia (1994).
Odour emission rate in table does not include peak to mean factor applied in the model.

Table 4-3 Fugitive area source characteristics

Odour source	Area source southwest corner		Length (m)	Width (m)	Height (m)	σz	SOER (OU/m^2/s)	Hours of operation
	Easting	Northing						
AQIS area	725.926	8593.737	30	55	0	1	6.42	Continuous
Holding pens (mean) during dry season	725.858	8593.715	127.4	42.3	1	0.5	0.03	Continuous in dry season

Odour source	Area source southwest corner Easting	Area source southwest corner Northing	Length (m)	Width (m)	Height (m)	σz	SOER (OU/m²/s)	Hours of operation
Holding pens (mean) during wet season	725.858	8593.715	127.4	42.3	1	0.5	0.13	Continuous in wet season
WWTP Green sump	725.827	8593.869	(Diameter 3.65 m)		0	0	0.66	4am - 10pm
WWTP Common sump	725.830	8593.876	(Diameter 3.7 m)		0	0	0.50	4am - 10pm
DAF	725.807	8593.887	10.5	4.1	2.05	0.48	1.88	4am - 10pm
Paunch storage bin (fresh)	725.811	8593.906	2.75	2.3	0.95	0.22	0.65	Continuous
Paunch storage bin (aged)	725.812	8593.898	5.5	2.3	0.95	0.22	0.20	Continuous
DAF sludge decanter bin (fresh)	725.808	8593.889	0.9	0.9	1.0	0.23	1.52	Continuous
DAF sludge storage (fresh)	725.803	8593.907	2.65	2.0	0.8	0.19	1.52	Continuous
DAF sludge storage (aged)	725.804	8593.899	5.3	2.0	0.8	0.19	0.38	Continuous
Contra shear scrapings (aged)	725.802	8593.913	1.33	2.0	0.8	0.19	116.70	Continuous
Spray irrigation Plot C	725.208	8594.781	L shape, 340 m x 250 m to give an area of 70,174 m²		0.0	1	2.77 (max) Hourly variable	see Figure 4-1
Spray irrigation Plot D	725.200	8594.630	470	150	0.0	1	2.77 (max) Hourly variable	see Figure 4-1

Table note: Coordinates are in Universal Transverse Mercator (UTM), equivalent to Map Grid of Australia (1994).
WWTP: wastewater treatment plant.
Odour emission rate in table does not include peak to mean factor applied in the model.

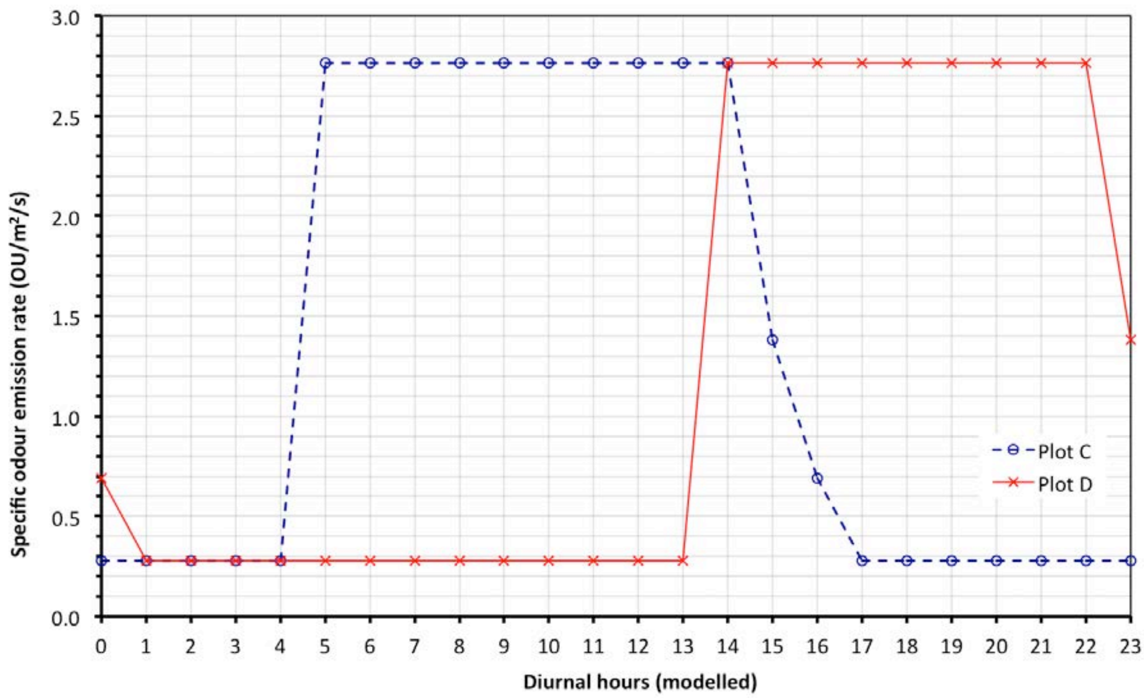

Figure 4-1 Diurnal time series of Spray Irrigation specific odour emission rates used in the modelling (OU/m²/s)

Table 4-4 Stack source characteristics

Odour source	Source coordinates		Stack height (m)	Stack diameter (m)	Stack velocity (m/s)	Stack gas temperature (°C)	OER (OU/s)	Hours of operation
	Easting	Northing						
Meat meal hammer mill cyclone wall vent	725.920	8593.834	3	0.44	9.58	64.5	962	7am - 6pm

Table note: Coordinates are in Universal Transverse Mercator (UTM), equivalent to Map Grid of Australia (1994). Odour emission rate in table does not include peak to mean factor applied in the model.

The NSW Approved Methods approach prescribes the use of a peak to mean factor to account for peak ground-level odour concentrations based on hourly averaged model time steps due to meteorological variability within each hour. The factor is designed to account for the discrepancy between the hourly averaged model time step and the peak ground-level odour concentration, effectively the nose-response time, of human receptors, which is assumed to be one second. DEC (2005, p.25, Table 6.1) presents peak to mean factors for a range of source types for varying atmospheric stability conditions. A peak to mean factor has been applied to the emission rate of each odour source modelled, based on the information in DEC (2005), and the following assumptions:

- Far field impacts have been considered only, due to the relationship between the source dimensions and the substantial separation distance between the source and the sensitive receptors, generally greater than 800 metres.
- A conservative approach was taken by selecting the highest peak to mean factor under all meteorological conditions for each type of source, typically Pasquill-Gifford stability classes A to D. Consequently, the worst case peak to mean factor (based on Pasquill-Gifford stability classes A to D) was applied to the worst case meteorological conditions for fugitive and short wake-affected stack sources (typically Pasquill-Gifford stability classes E and F).
- The point sources are all wake-affected.

Consequently, the following peak to mean factors have been applied:

- Point source: 2.3,
- Area source: 2.3, and
- Volume source: 2.3.

5 Legislative Requirements, Context and Air Quality Assessment Criteria

5.1 Legislative framework for air quality and odour impact assessment

Odour is the primary pollutant of concern in regard to the NABL facility. At the request of the NT EPA, the NSW air quality and odour impact assessment framework and guidance has been used as the basis of the impact assessment. The NSW odour impact assessment legislative framework and impact assessment criteria are discussed in this section.

5.2 Relevant NSW statutory requirements for the protection of the air environment

In accordance with *Part 5 of the Protection of the Environment Operations (Clean Air) Regulation (2010)*: *Emission of Air Impurities from Activities and Plant*, the statutory methods that are to be used for modelling and assessing emissions of air pollutants from stationary sources are outlined in the *Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (2005)* (DEC, 2005). The Approved Methods provides guidance on the air quality impact assessment process including the:

- Preparation of emission inventories,
- Preparation of meteorological data,
- Quantification and accounting for background concentrations and cumulative impact assessment,
- Dispersion modelling methodology,
- Presentation and interpretation of dispersion model predictions, and
- Impact assessment criteria and assessment outcomes.

The Approved Methods also prescribes two levels of impact assessment:

1. Level 1 – screening-level dispersion modelling technique using worst case input data.
2. Level 2 – refined dispersion modelling technique using site-specific input data.

The assessment levels are designed so that the second level of assessment should be more accurate than the first, but that the first level is more conservative than the second. The intention of the assessment level system is not to conduct a level two assessment upon completion of a level one assessment, particularly if the level one assessment adequately demonstrates that the development is not expected to cause an impact to the air environment in relation to the impact assessment criteria.

In accordance with the guidance provided in the DEC (2005), the assessment of key plant infrastructure for the project has been conducted as a level two impact assessment through the use of site-specific input data, including:

- Local terrain and land use,
- Actual locations of sensitive receptors,
- TAPM prognostic model simulations over the region,
- Configuration of the CALPUFF dispersion model using site-specific emission source characteristics, dimensions and coordinate locations,
- Odour emission rate estimates based on site-specific sampling data.

5.3 Odour assessment framework

In addition to the Approved Methods (DEC, 2005), the principal document that sets out the framework for the management and assessment of odour impacts in NSW is the *Technical Framework: Assessment and Management of Odour from Stationary Sources in NSW (2006) (the Framework)*. The framework aims to *protect the environment and community from the impacts of odour emissions while promoting fair and equitable outcomes for the operators of activities that emit odour* (DEC, 2006).

In order to equitably manage odour in the community, the framework recognises that (DEC, 2006):

- *Sustainable land-use planning and management is needed to avoid odour impacts, because land uses will change over time to meet altered industry and societal needs;*
- *Avoiding odour impacts is a shared responsibility between operators and local land-use planners. However, the operator of an activity that emits odour must ultimately be responsible for managing odour impacts of the operation beyond its boundary; and*
- *Emissions of odour may not be preventable from some activities. "No odour" is not a realistic objective.*

The key principles of the odour management framework include:

- **Planning to prevent and minimise odour** including consideration of the compatibility of the proposal with existing and future nearby land uses to ensure the best possible environmental outcomes;
- **Use of a range of strategies to manage odour** depending on the type of odour sources, the characteristics of the odour emissions i.e. frequency, intensity, duration and character and the impact of emissions; and
- **Ongoing environmental improvement** due to the dynamic nature of land use. Existing activities must be prepared to undertake measures to minimise their odour impacts if conflicts arise and should adopt a risk management approach that provides contingency for possible future land use changes.

The odour management framework establishes three levels of impact assessment in order that an appropriate level of odour investigation can be carried out depending on whether the proposed odour-emitting activity is new, modified or existing.

- **Level 1 Assessment**: is a simple screening-level technique based on generic parameters for the type of activity and site. It requires minimal data and uses simple equations designed to indicate the likely extent of any odour impact. It may be used to assess site suitability and odour mitigation measures for new or modified activities.
- **Level 2 Assessment**: is a screening-level dispersion modelling technique, using worst-case input data (rather than site-specific data). It is more rigorous and more realistic than a Level 1 assessment. It may be used to assess site suitability and odour mitigation measures for new, modified or existing activities.
- **Level 3 Assessment**: is a refined-level dispersion modelling technique using site-specific input data. This is the most comprehensive and most realistic level of assessment available. It may be used to assess site suitability and odour mitigation measures for new, modified or existing activities.

In accordance with the guidance provided in the Odour Framework, this assessment has been conducted as a Level 3 odour impact assessment.

5.3.1 Odour impact assessment criteria

The NSW impact assessment criterion for complex mixtures of odours has been *designed to take into account the range of sensitivity to odours within the community and to provide additional protection for individuals with a heightened response to odours. This is achieved by using a statistical approach dependent upon population size. As the population density increases, the proportion of sensitive individuals is also likely to increase, indicating that more stringent criteria are necessary in these situations*. (DEC 2005)

The following equation can be used to determine the appropriate odour impact assessment criterion. This equation has been used to determine the criteria summarised in Table 5-1, and as shown in the Approved Methods (DEC, 2005, pp. 37-38):

$$\text{Impact assessment criterion (ou)} = \frac{(log10\,(population) - 4.5}{-0.6}$$

Table 5-1 Impact assessment criteria for complex mixtures of odorous air pollutants (nose-response-time average, 99th percentile)

Population of affected community	Impact assessment criteria for complex mixtures of odorous air pollutants (ou)
Urban (≥~2000) and/or schools and hospitals	2.0
~500	3.0
~125	4.0
~30	5.0
~10	6.0
Single rural residence (≤~2)	7.0

Table note: Source: DEC (2005)

The NABL facility is situated in a relatively sparsely populated, semi-rural setting surrounded by very low density ‘acreage’, residential properties. With the exception of the spray irrigation area to the south of the plant that is no longer used as it was potentially the source of the odour complaints received by NT EPA, the minimum separation distance between the main plant emission sources and the nearest sensitive receptor (a residential property to the north) is 800 metres. Based on the identification of sensitive receptors using aerial images of the local area, the distances between many of these receptors and the potential number of people at each location, the area surrounding the plant is not considered to be urban nor have a population greater than 2,000 people. The local population is expected to be less than 500 people, providing for an odour impact assessment criterion of not greater than 3 OU.

Odour impact assessment criteria used in the impact are presented in Table 5-2.

Table 5-2 Odour impact assessment criteria used in the assessment

Pollutant	Averaging period	Statistic (percentile)	Assessment criterion	Source
Odour	1-second	99.0th	3 OU	EPA (2001)[1]

Table note: [1] The source is the original document in which the criterion was promulgated.

5.3.2 Approach to odour impact assessment

DEC (2005) outlines the application of the odour impact assessment criterion for complex mixtures of odorous air pollutants as follows:

1. *At the nearest existing or likely future off-site sensitive receptor.*
2. *The incremental impact (i.e. the predicted impact due to the source alone) must be reported in odour units, as peak concentrations (i.e. approximately 1-second average) in accordance with the peak to mean factors outlined in Section 6 of DEC (2005) and as the:*
    a. *100th percentile of dispersion model predictions for Level 1 impact assessments, or*
    b. *99th percentile of dispersion model predictions for Level 2 impact assessments.*

For this Level 2 assessment, the predicted incremental 99th percentile 1-second average ground-level odour concentration at the most affected off-site sensitive receptor has been assessed against the 3 OU criterion for each odour source alone. It should be noted that the assessment criterion is a dispersion modelling-based method for assessing individual odour sources. The majority of the odour sources at the NABL facility have different odour characters and are not considered to be additive in their impact. Consequently, some of the sources have been grouped together based on the odour characters, as presented in Table 6-1. By assessing the odour sources in this way, the problematical areas of the plant can be identified under different operational, emission and meteorological conditions.

6 Odour Impact Assessment Methodology

6.1 Selection of a representative year of meteorology

The dispersion model meteorology that was developed for the initial NABL air quality impact assessment (AEC, 2015) was used for the odour impact assessment. This comprised of a one-year period between 1 September 2011 and 31 August 2012. The analysis for the selection of the representative year of meteorology conducted in AEC (2015) is presented in this report as Appendix B.

6.2 Terrain and land use

The land use surrounding the NABL plant was classified entirely as mixed rangeland, mainly comprising grass fields with scrubby low trees. This was equivalent to the CALMET meteorological model land use category 33.

The topography in the surrounding area was gently sloping from the eastern side of the meteorological domain to the west. There is a narrow ridge running along a north-south axis near the eastern edge of the domain. A topographic map of the CALMET model domain is presented in Figure 6-1.

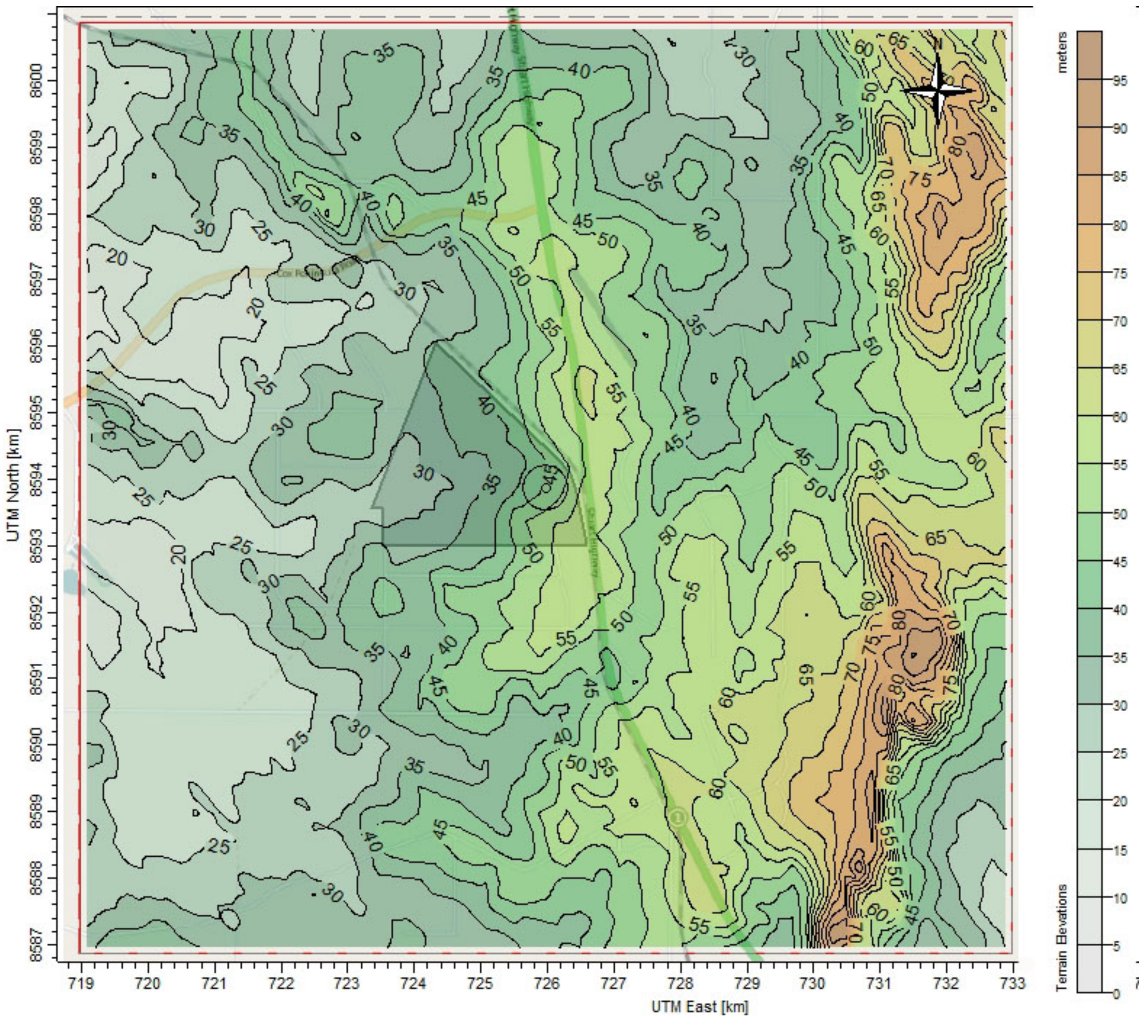

Figure 6-1 Topographic map of the regional terrain used in the CALMET meteorological and CALPUFF dispersion models

6.3 Meteorological modelling

The meteorological file used in the air dispersion model was developed using the TAPM-CALMET two-stage model suite. TAPM was run to develop a three-dimensional simulation of the atmosphere in the region for direct input to the CALMET model. CALMET was then used to downscale the regional meteorological profile developed using TAPM to incorporate the local geography. The CALMET output file is formatted for use in the CALPUFF dispersion model.

6.3.1 TAPM prognostic meteorological model

The Air Pollution Model (TAPM) was developed by CSIRO for use in simulating regional meteorological and air pollution events. TAPM is a coupled synoptic-scale prognostic meteorological and air dispersion modelling system designed to operate on a standard desktop computer.

The model requires synoptic meteorological information inputs for the region of interest that are generated by a global model similar to the large-scale models used to forecast the weather. TAPM incorporates re-analysed and validated synoptic weather forecast data at a resolution of approximately 75 km and at elevations of between 100 m and 5,000 m above the surface with regionally-specific terrain, land use, soil moisture content and soil type, to simulate the meteorology of a region as well as at a specific location.

TAPM was configured as follows:

- Mother domain of 30 km with 3 nested daughter grids of 10 km, 3 km and 1 km,
- 25 x 25 grid points for all modelling domains,
- 25 vertical levels from the surface up to 8,000 m above the ground,
- Centre coordinates were: cx = 726225 m; cy = 8594213 m,
- TAPM defaults for terrain, land use and sea surface temperatures,
- Default options selected for advanced meteorological inputs,
- Year modelled: 1 September 2011 to 31 August 2012, and
- Meteorological observations were not assimilated.

A summary of the model performance is presented in Appendix A.

6.3.2 CALMET diagnostic meteorological model

CALMET is an advanced non-steady-state diagnostic three-dimensional meteorological pre-processor for the CALPUFF dispersion model. The model is capable of operating in three key modes by:

1. Assimilating surface and upper air meteorological observations from multiple sites within the modelling domain,
2. Initialisation by three-dimensional gridded meteorological information supplied by a prognostic model such as TAPM, or
3. A hybrid mode whereby three-dimensional gridded data from TAPM is effectively ‘nudged’ through the assimilation of local surface observations.

For this assessment, CALMET was configured in ‘No observations’ mode due to the lack of automatic weather station (AWS) data collected within the model domain and surrounding local area.

CALMET was set up as the fifth nest in the meteorological simulation at a grid resolution of 200 m. A 200 m CALMET grid resolution was considered appropriate for the simulation and is the minimum resolution able to be configured using the Lakes Environmental *CalpuffView* software package used in the modelling assessment.

The TAPM prognostic grid data was used by the CALMET diagnostic model as an 'initial guess' before making adjustments to the local wind fields for the kinematic effects of terrain, slope flows, blocking effects and three-dimensional divergence minimisation. The coupled approach improves the mesoscale prognostic simulation generated by TAPM with the refined local-scale land use and terrain capabilities of CALMET. The CALMET output provides a complete set of three-dimensional wind fields, temperature profiles and other important meteorological variables throughout the atmosphere for application in the simulation of plume dispersion.

CALMET was configured as follows:

- Model domain area of 14 km x 14 km based on 70 grid points at a resolution of 200 m,
- 11 vertical levels with cell face heights at 0 m, 20 m, 40 m, 80 m, 160 m, 320 m, 640 m, 1200 m, 2000 m, 2500 m, 3000 m, 4000 m,
- Year modelled: 1 September 2011 to 31 August 2012,
- TAPM generated prognostic meteorological inputs as a CALTAPM.M3D file used as an 'initial guess' field only,
- Wind field options guided by the recommendations outlined in the *Generic Guidance and Optimum Model Settings for the CALPUFF modelling system for Inclusion into the Approved Methods for the Modelling and Assessment of Air Pollutants in NSW, Australia (2011)*,
- Cloud cover calculated from prognostic relative humidity,
- Terrain radius of influence of 5 km, and
- No observations mode.

The CALMET meteorological grid domain is illustrated in Figure 6-2.

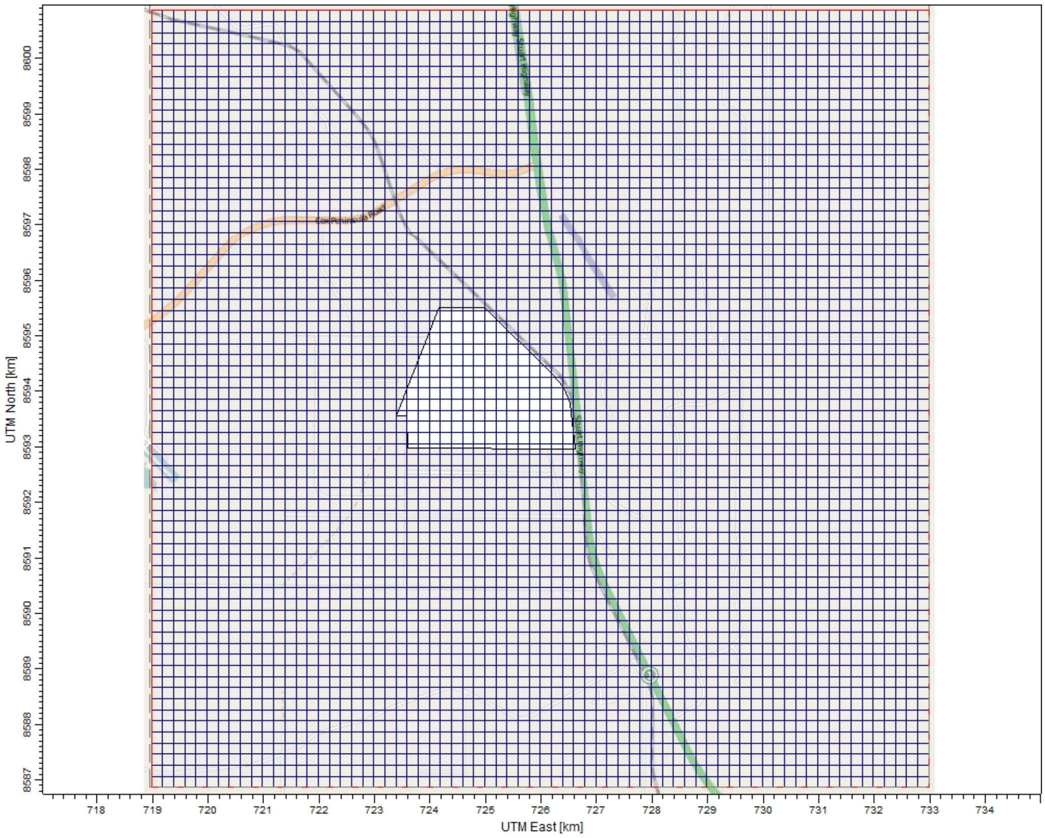

Figure 6-2 CALMET meteorological model grid domain

6.3.3 Meteorological Model Performance Evaluation

A detailed analysis of the meteorological modelling suite performance evaluation is presented in Appendix C.

6.4 Analysis of dispersion meteorology

This section outlines the analysis of the meteorology used in the CALPUFF model that is important to the dispersion of air pollutants and the generation of air quality impacts.

6.4.1 Wind direction and speed

The annual distribution of wind direction and speed at the site used in the model is presented as a wind rose diagram in Figure 6-3, while the seasonal and daily breakdown of winds is presented Figure 6-4 and Figure 6-5, respectively. The seasonal breakdown is based on the conventional three month seasons, even though it is recognised that the Northern Australian region has two distinct seasons, wet and dry. The distribution indicates that there are two dominant wind flows in the project region from the northwest and southeast.

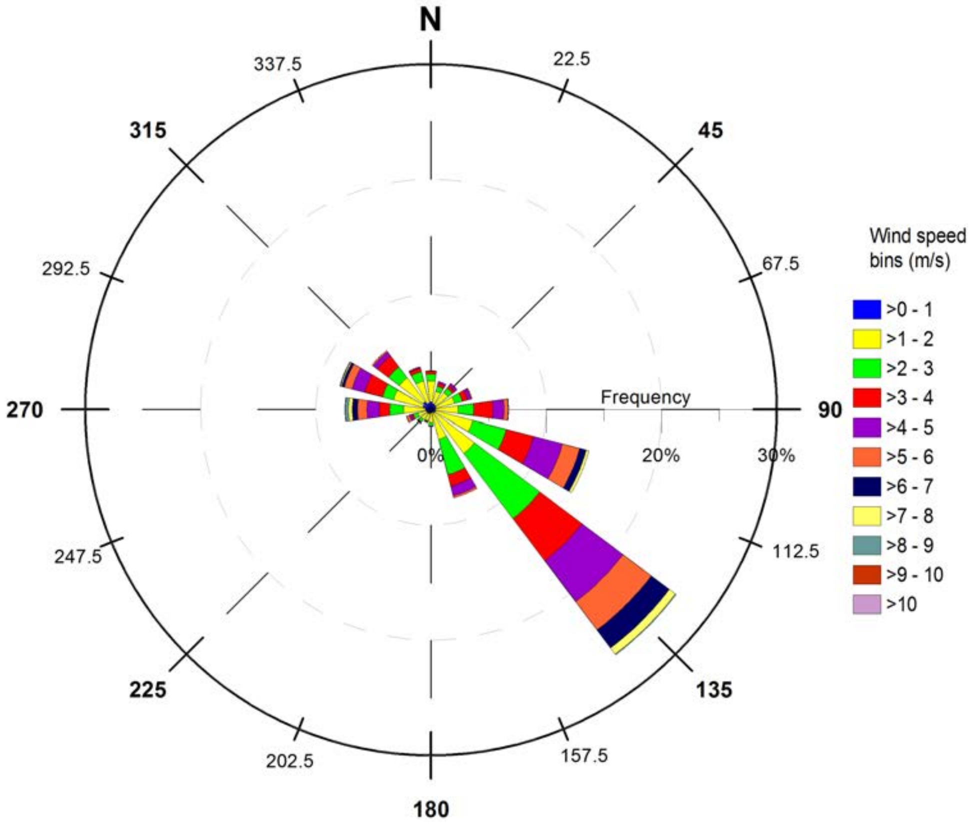

Figure 6-3 Annual frequency distribution of modelled wind speed and direction at the site

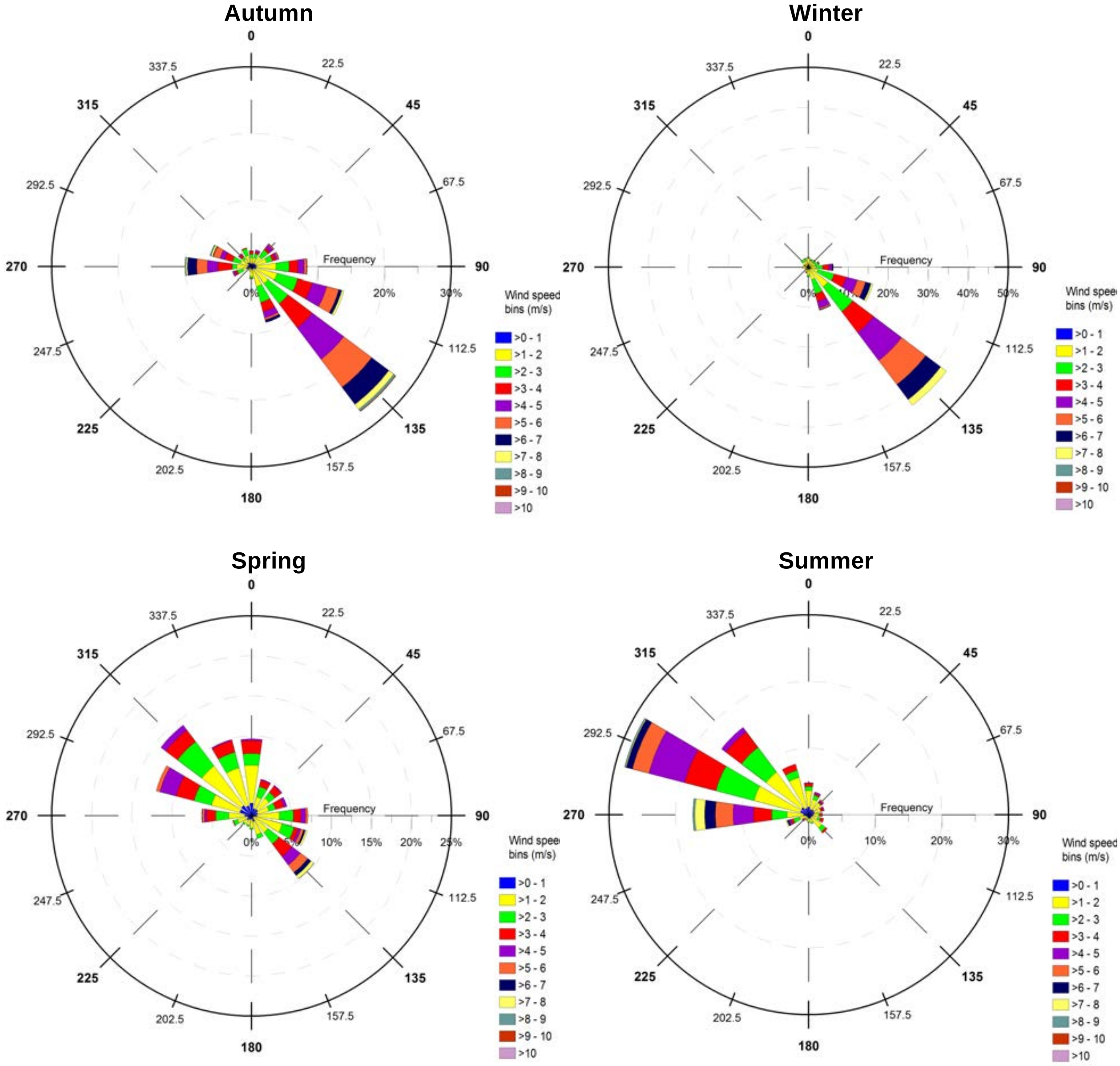

Figure 6-4 Seasonal frequency distribution of modelled wind speed and direction at the site

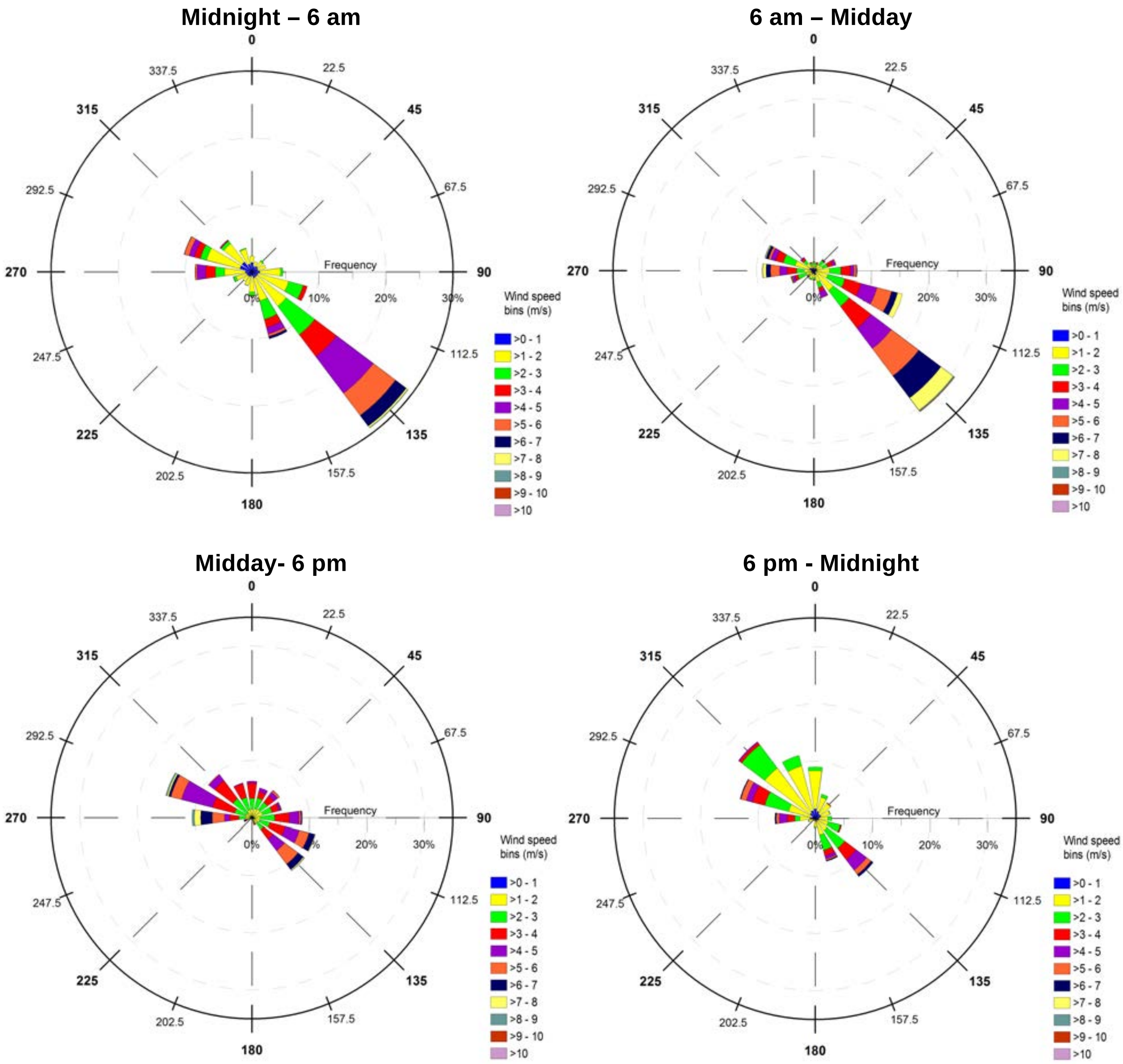

Figure 6-5 Diurnal frequency distribution of modelled wind speed and direction at the site

6.4.2 Atmospheric stability and mixing height

Stability is a term applied to the properties of the atmosphere that govern the acceleration of the vertical motion of an air parcel. The acceleration is positive in an unstable atmosphere (turbulence increases), zero when the atmosphere is neutral and negative (deceleration) when the atmosphere is stable (turbulence is suppressed). There are six main atmospheric stabilities designated as A (highly unstable or convective), B (moderately unstable), C (slightly unstable), D (neutral), E (slightly stable) and F (stable). This is known as the Pasquill-Gifford stability classification and is widely used in atmospheric models to define the turbulent state of the atmosphere.

Unstable conditions (Class A-C) are characterised by strong solar heating of the ground that induces turbulent mixing in the atmosphere close to the ground, and usually results in material from a plume reaching the ground closer to the source than for neutral conditions or stable conditions. This turbulent mixing is the main driver of dispersion during unstable conditions. Dispersion processes for neutral conditions (Class D) are dominated by mechanical turbulence generated as the wind passes over irregularities in the local surface, such as terrain features and building structures. During the night, the atmospheric conditions are neutral or stable (Class D, E and F). During stable conditions, plumes from short stacks or fugitive releases will be subject to minimal atmospheric turbulence. A plume released below an inversion layer during stable conditions that has insufficient vertical momentum or thermal buoyancy to penetrate the inversion will be trapped beneath it and result in elevated ground-level concentrations. Conversely, a plume that is hotter than its surroundings and emitted above, or is able to penetrate the nocturnal inversion through momentum, will remain relatively undiluted, and will not reach the ground unless it encounters elevated terrain.

The frequencies of Pasquill-Gifford stability classes for the wet and dry seasons, and based on the CALMET model, are presented in Figure 6-6. For this assessment the wet season was considered from October to April. Generally the wet season is considered from November to April but the rainfall for October on average was similar to April and consequently was considered 'wet'.

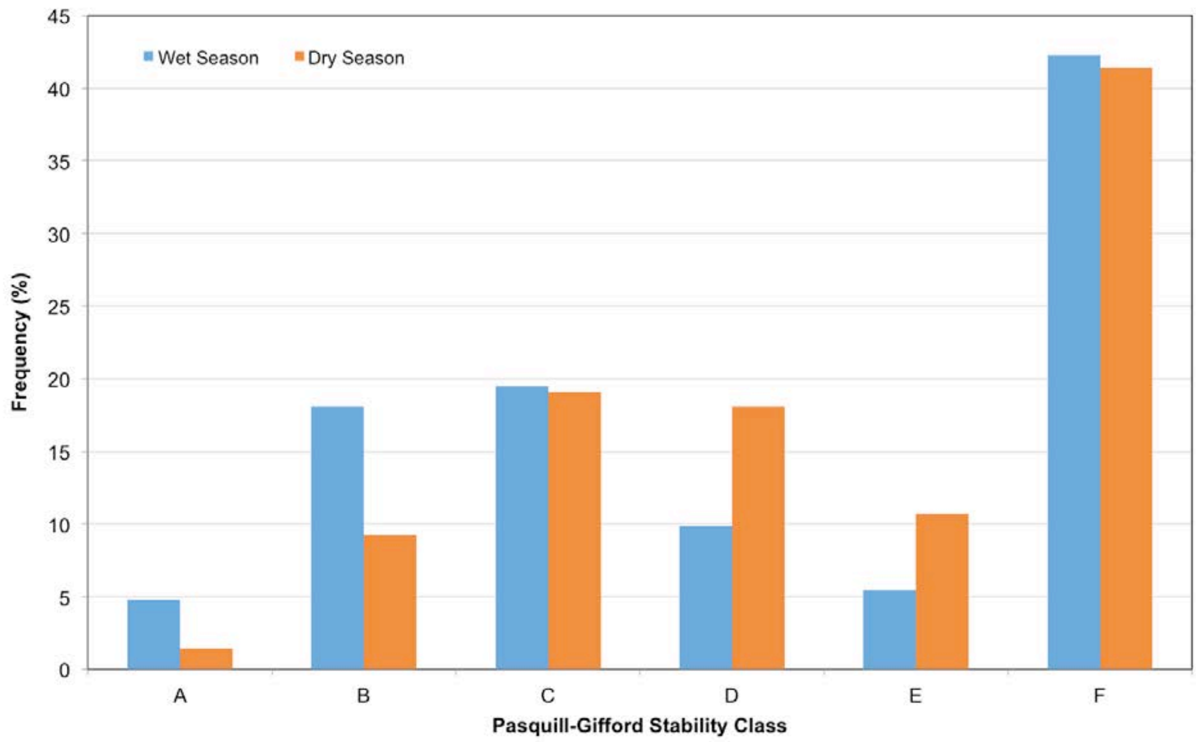

Figure 6-6 Frequency distribution of hourly atmospheric stability classifications at the site during the wet and dry seasons

The relationship between atmospheric stability and the wind direction is explored in Figure 6-7.

All odour emission sources at the facility are fugitive releases and dispersion from these types of sources is typically poor during light wind stable atmospheric conditions.

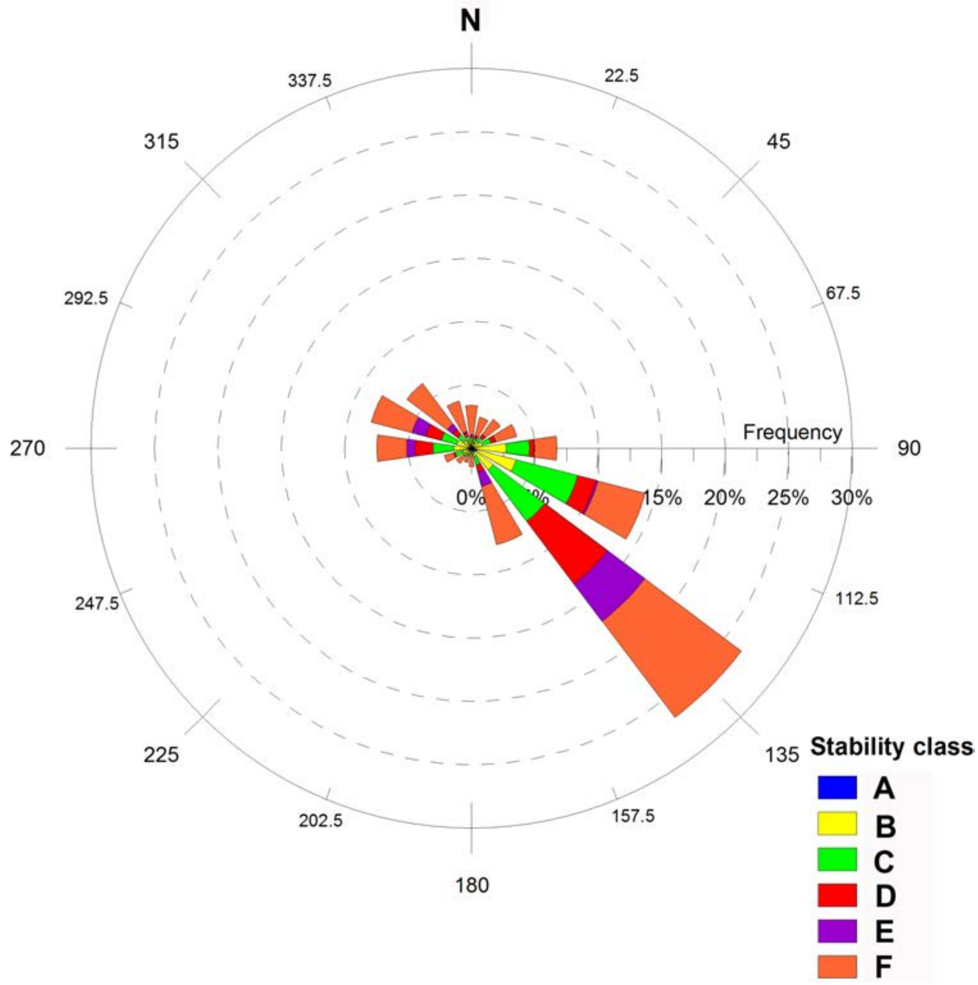

Figure 6-7 Stability classification rose diagram illustrating the relationship between hourly wind direction and Pasquill-Gifford stability class

The mixing height refers to the height above ground within which the plume can mix with ambient air. During stable atmospheric conditions at night, the mixing height is often quite low. During the day, solar radiation heats the air at ground level and causes the mixing height to rise through the growth of convection cells. The air above the mixing height during the day is generally colder. The growth of the mixing height is dependent on how well the air can mix with the cooler upper levels of air and therefore depends on meteorological factors such as the intensity of solar radiation and wind speed. During strong wind speed conditions the air will be well mixed, resulting in a high mixing height.

The hourly distributions of mixing height at the site from the CALMET model are presented as a box and whisker plot in Figure 6-8 and Figure 6-9 for the wet and dry seasons.

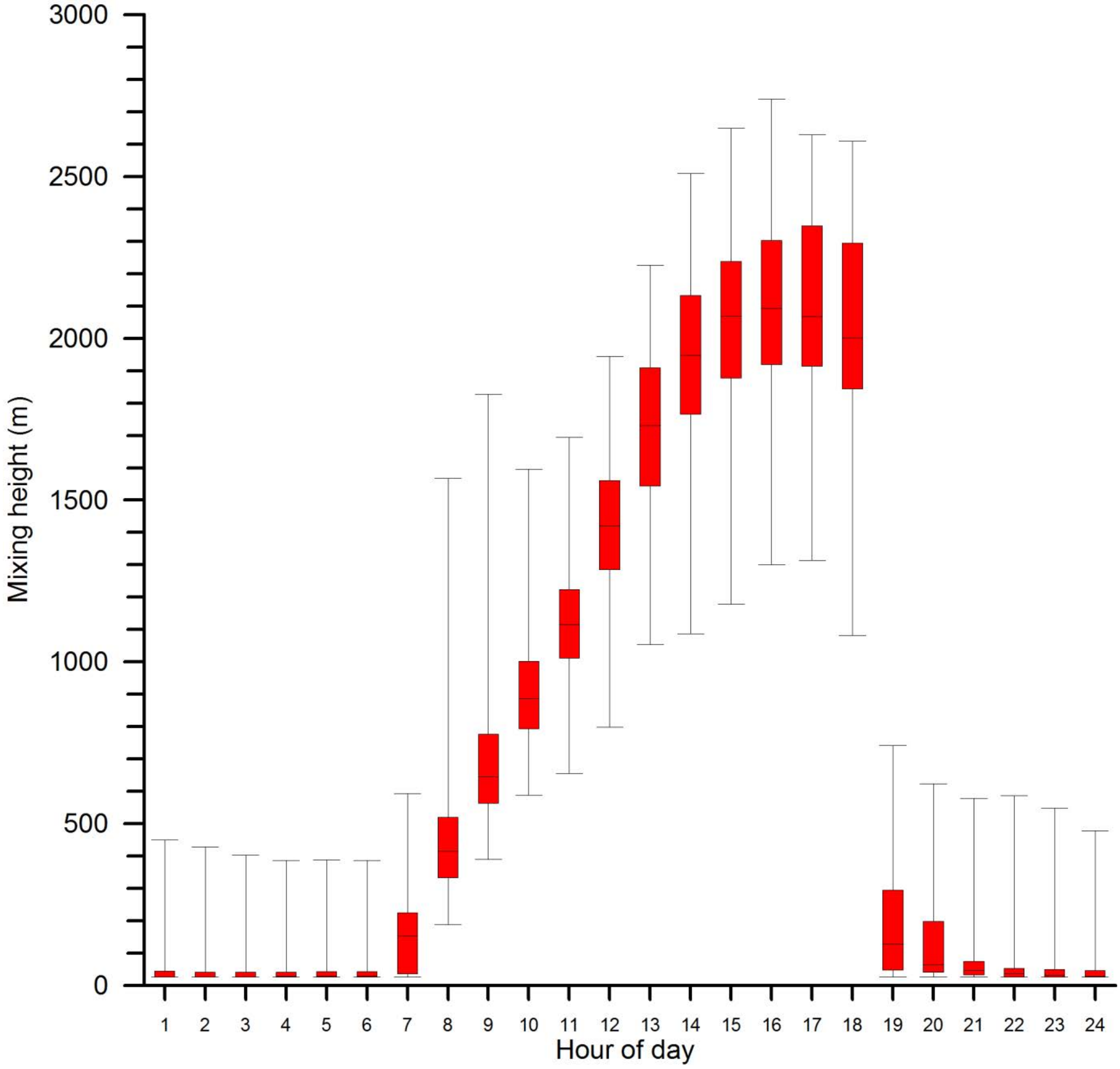

Figure 6-8 Distribution of hourly mixing heights at the site during the wet season

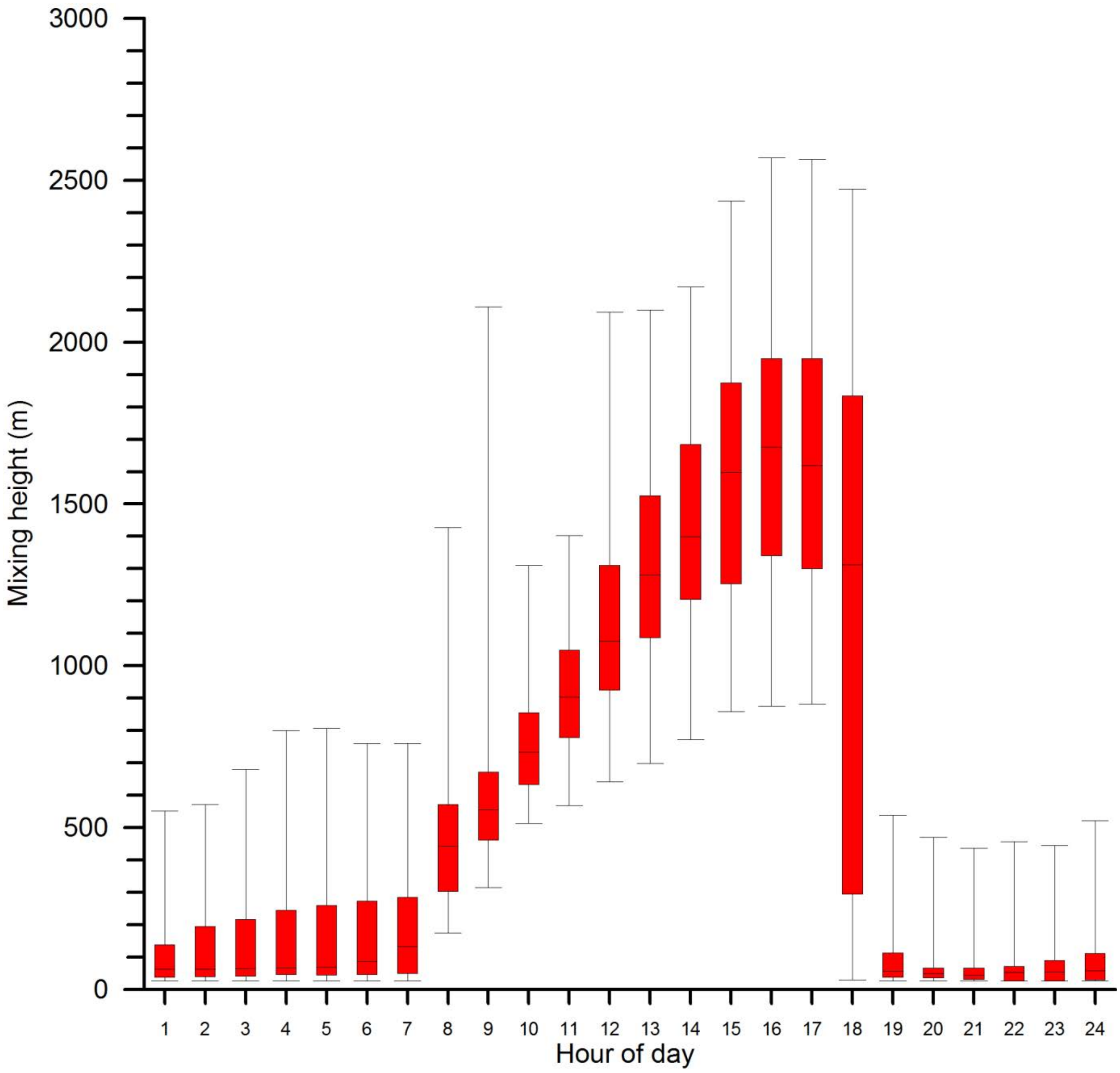

Figure 6-9 Distribution of hourly mixing heights at the site during the dry season

6.5 Dispersion modelling

6.5.1 CALPUFF dispersion model

Atmospheric dispersion modelling was carried out using the CALPUFF dispersion model, a non-steady-state, Lagrangian puff dispersion model accepted for use by all environmental regulators across Australia for application in environments where wind patterns and plume dispersion is strongly influenced by complex terrain and the land-sea interface. While the regional terrain surrounding the site appears to be gently sloping and not too complex, the standard definition of complex terrain is a situation where the local terrain has a higher elevation than stack sources at the facility being assessed. The CALPUFF dispersion model is also the preferred model for simulating odour dispersion due to limitations in steady-state Gaussian models such as Ausplume to model light winds and causality effects.

The CALPUFF dispersion model was used to predict ground-level odour concentrations downwind of the facility. The domain size used in the CALPUFF model was the same as the CALMET model

(14 x 14 km) with a nesting factor of 2. Consequently, the CALPUFF model's sampling grid was at a resolution 100 m by 100 m.

6.5.2 Location of sensitive receptors

The 29 nearest sensitive receptors in all directions from the site were identified from aerial images and included in the dispersion model. Figure 6-10 shows the CALPUFF sampling grid resolution, the site and plant boundaries, and the location of the 29 sensitive receptors. Figure 6-11 shows a close up of the receptors and their identification.

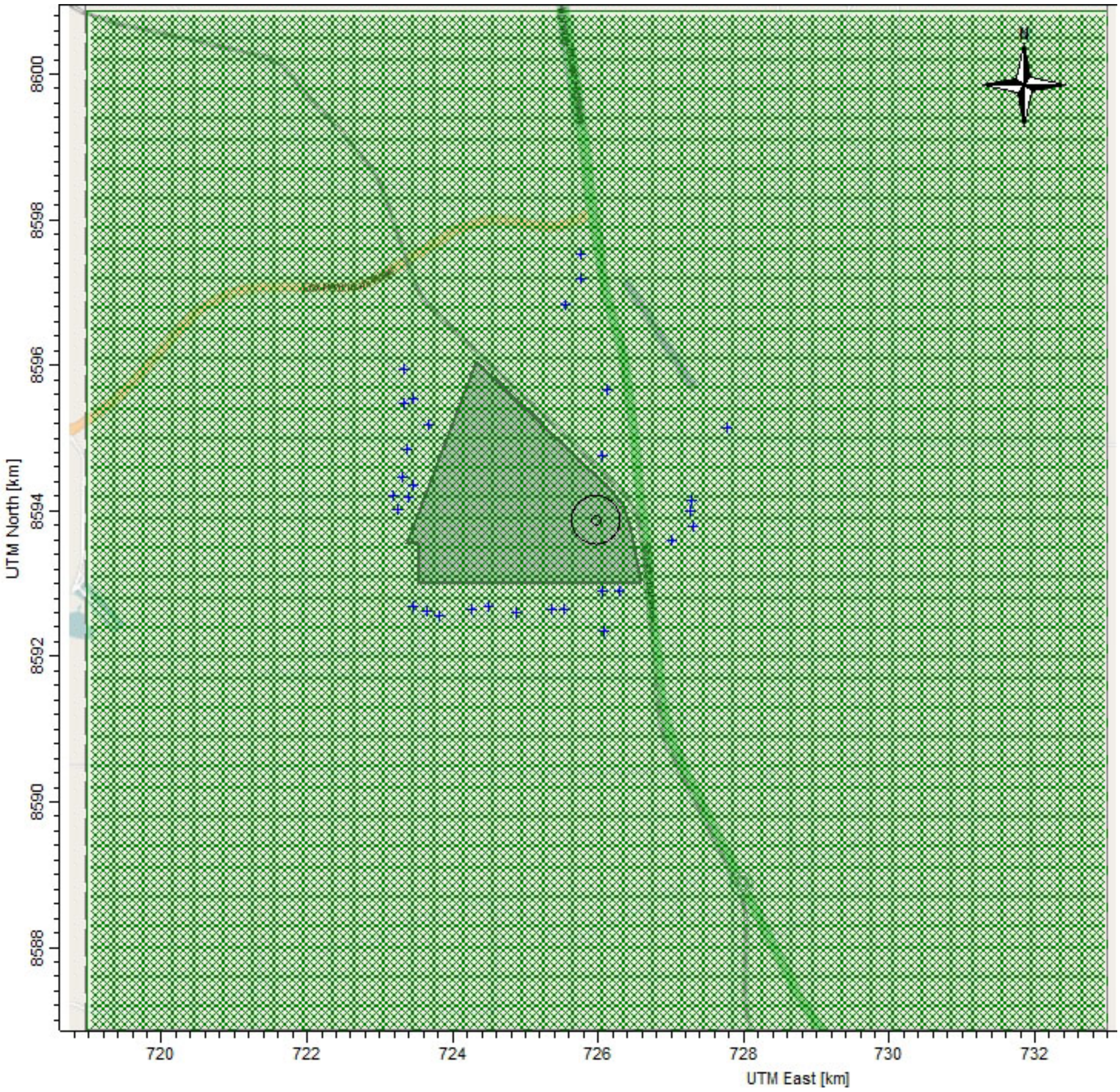

Figure 6-10 Map of the CALPUFF sampling grid, site and plant boundaries and nearest discrete receptors configured in the model

Figure note: The NABL plant is situated within the circle marker at the eastern side of the site.

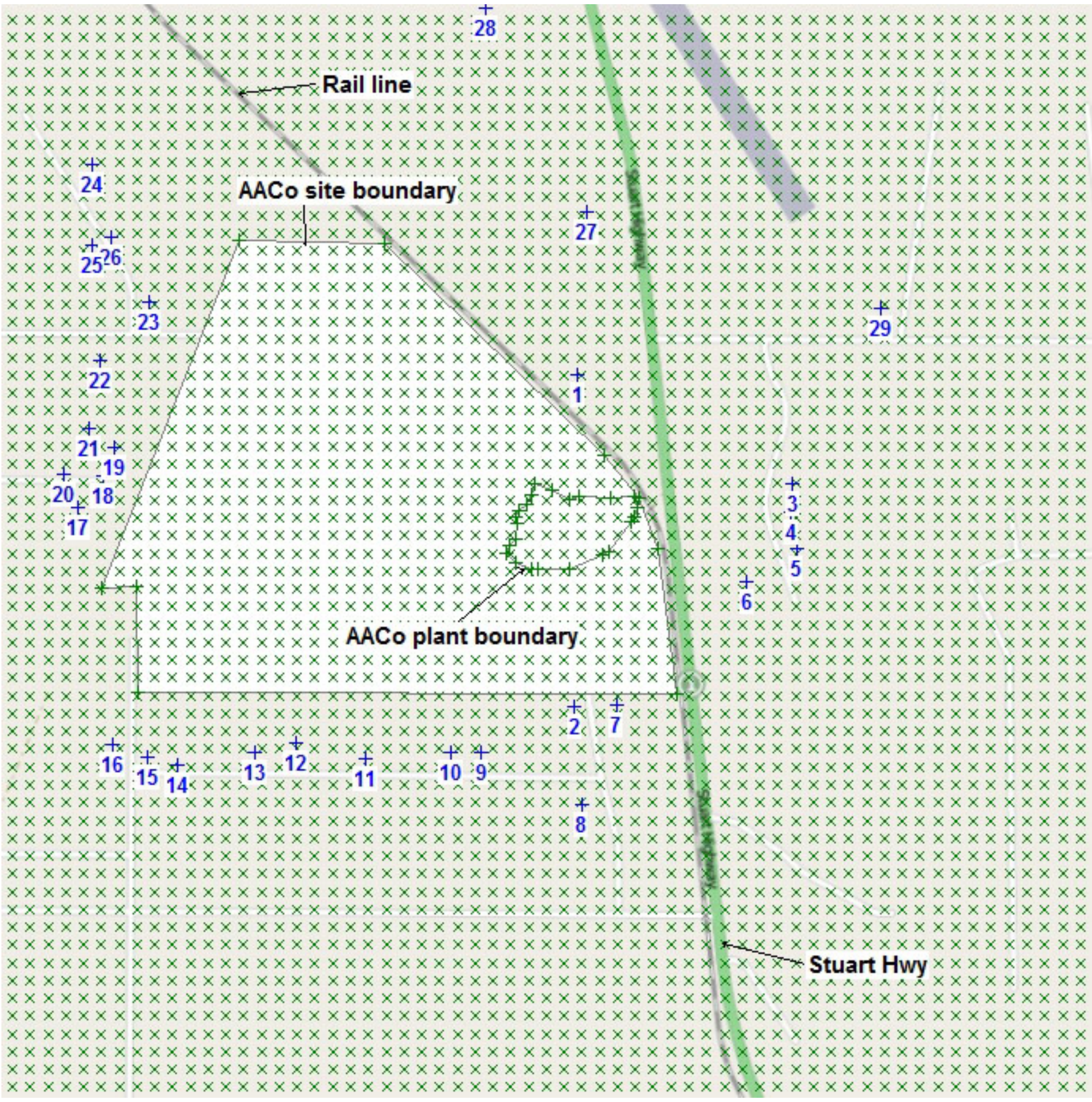

Figure 6-11 Local sensitive receptors and the CALPUFF sampling grid

6.6 Assessment scenarios and cumulative impacts

Odour impact has been assessed based on the cumulative ground-level odour concentrations of sources with similar odour character and emission source type. Based on differences in odour character, intensity and hedonic tone at concentrations above the odour detection threshold, different sources will stand out and be recoginsed independently of one another. Consequently, the odours have been combined in this way.

In AEC's experience, odour sources such as the Lairage, can be clearly recognised from the rendering or wastewater odour. Similarly, the biofilter will have an earthy odour that is quite different from these sources. It is not considered appropriate to aggregate the predicted ground-level odour concentrations from the biofilter with the wastewater treatment plant or Lairage. These odours are composed of a different suite of odorous chemical compounds and cannot simply be added together to provide a meaningful odour impact.

Notwithstanding this, the frequency of odour impact that exceeds the odour criterion (i.e. 3 OU) may be aggregated to determine the frequency of occurrence that an odour from an NABL source impacts a sensitive place. This has been investigated in the assessment.

The odour emission source combinations modelled and assessed in the impact assessment are presented in Table 6-1.

Table 6-1 Odour source assessment combinations based on similar odour character and source type

Cumulative odour groups	Source
Holding yards across wet and dry seasons	Holding pens during dry season Holding pens during wet season AQIS yard
Rendering plant	Red fan press sump Red fan press screw conveyor Raw material bin Wet rendering building Tallow tanks 1 & 2 combined Meat meal hammer mill cyclone
Biofilter	Biofilter
Waste handling bins	Paunch storage bins (fresh and aged material) DAF sludge decanter (fresh DAF sludge) DAF sludge storage bins (fresh and aged material with aged Contra Shear Scrapings)
Wastewater treatment plant area	Green sump Common sump DAF Irrigation tank
Spray irrigation areas	Plot C Plot D
Wastewater treatment plant and Spray irrigation areas combined	Green sump Common sump DAF Irrigation tank Plot C Plot D

7 Impact Assessment

The impact assessment is presented as a series of odour concentration isopleths, illustrating the predicted maximum and 99th percentile, 1-second average ground-level odour concentrations across the region surrounding the NABL site.

The contour plots presented show the area within a seven kilometre radius around the plant centre (near the Biofilter). The NABL site boundary is shown as the grey line and shaded area in the centre of the plots, while the black outer circle (near the centre of the plot) envelopes the production plant and the inner black circle is near the plant centre.

The blue crosses on the plot represent the innermost ring of identified sensitive receivers in all directions from the plant. It is assumed that these receptors will be the most affected by odour dispersion from ground level fugitive sources.

7.1 Lairage - Holding yards and AQIS area

Predicted maximum and 99th percentile ground-level odour concentrations for lairage emission sources including the holding yards and AQIS area are presented in Figure 7-1 and Figure 7-2, respectively.

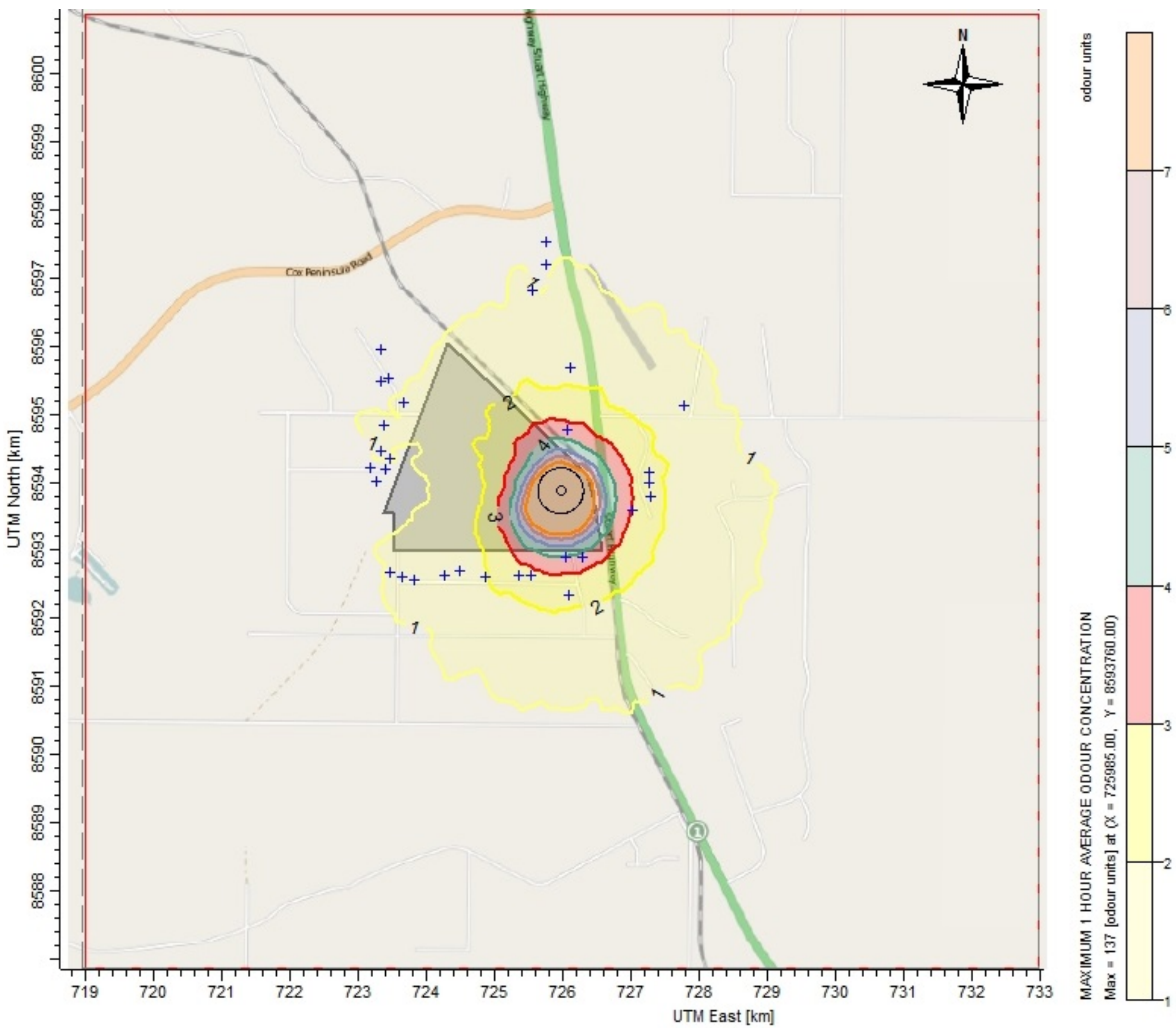

Figure 7-1 Predicted maximum ground-level odour concentrations for the holding yards and AQIS area

Assessment scenario: Holding yards and AQIS area	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

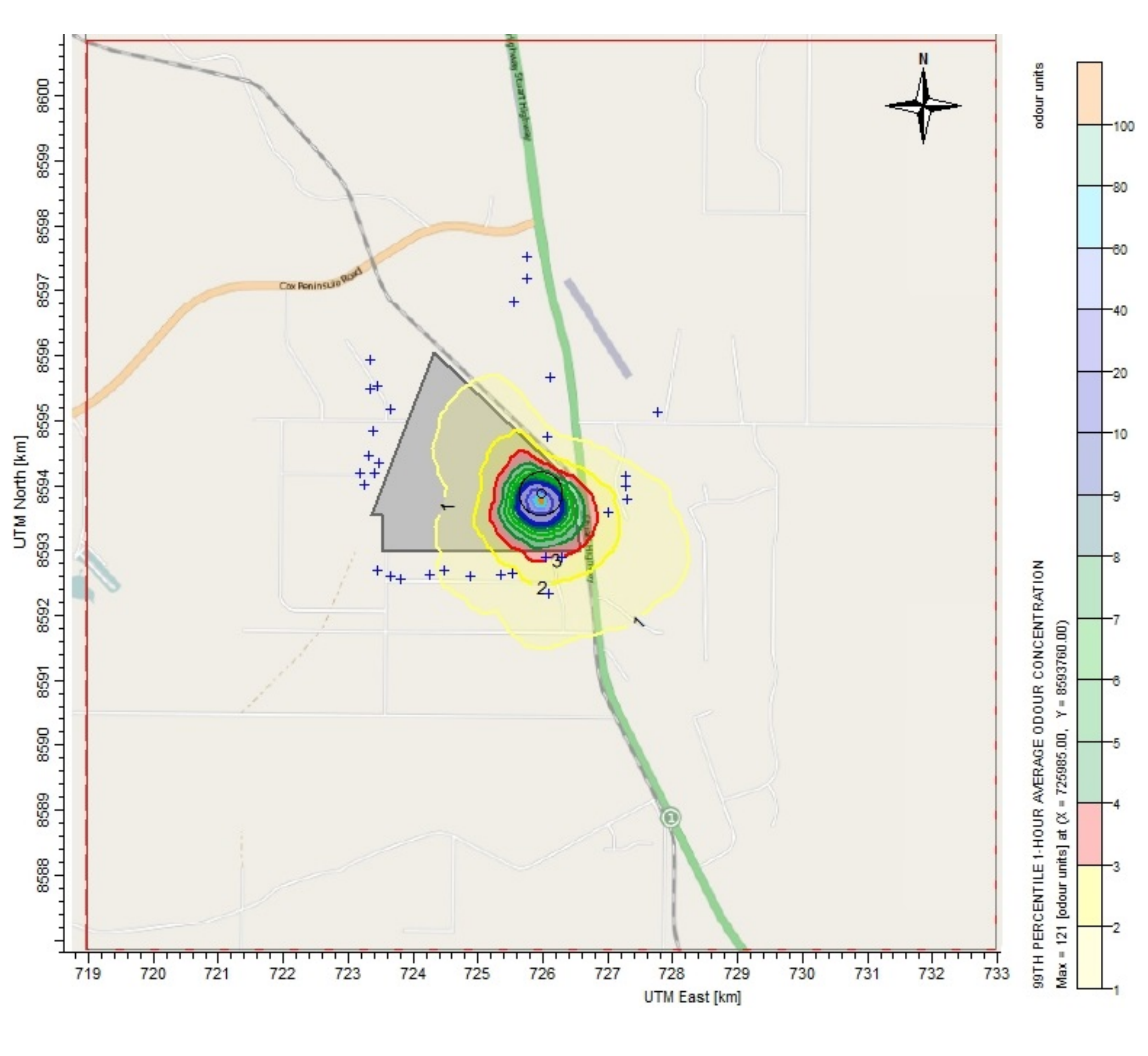

Figure 7-2 Predicted 99th percentile ground-level odour concentrations for the holding yards and AQIS area

Assessment scenario: Holding yards and AQIS area	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

7.2 Rendering area

Predicted maximum and 99th percentile ground-level odour concentrations for the rendering area (wet rendering building, raw materials bin, red fan sump, red fan screw conveyor, tallow tanks 1 & 2 and meat meal hammer mill cyclone) are presented in Figure 7-3 and Figure 7-4, respectively.

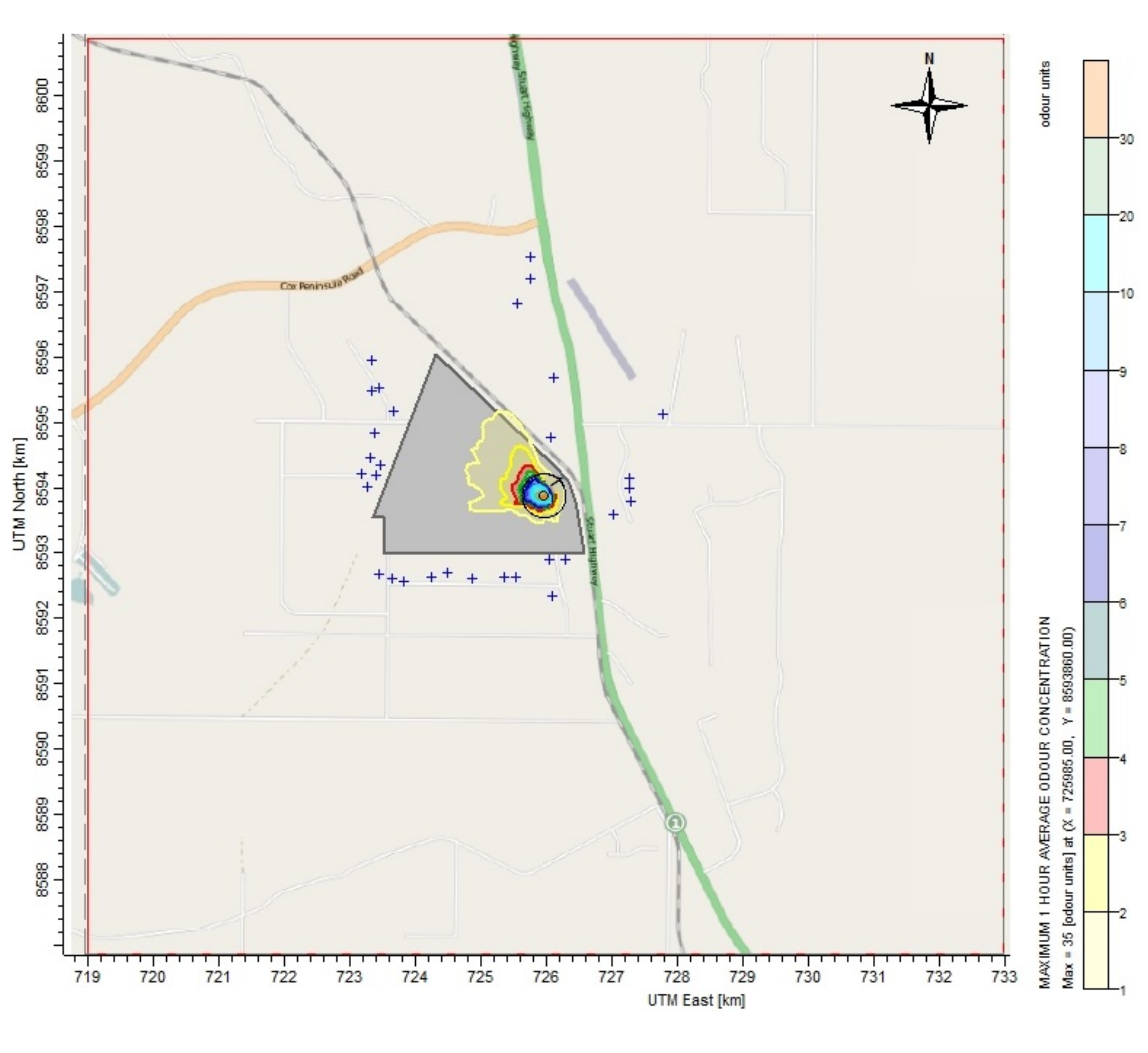

Figure 7-3 Predicted maximum ground-level odour concentrations for the wet rendering plant area and meat meal hammer hill vent

Assessment scenario: Rendering area	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

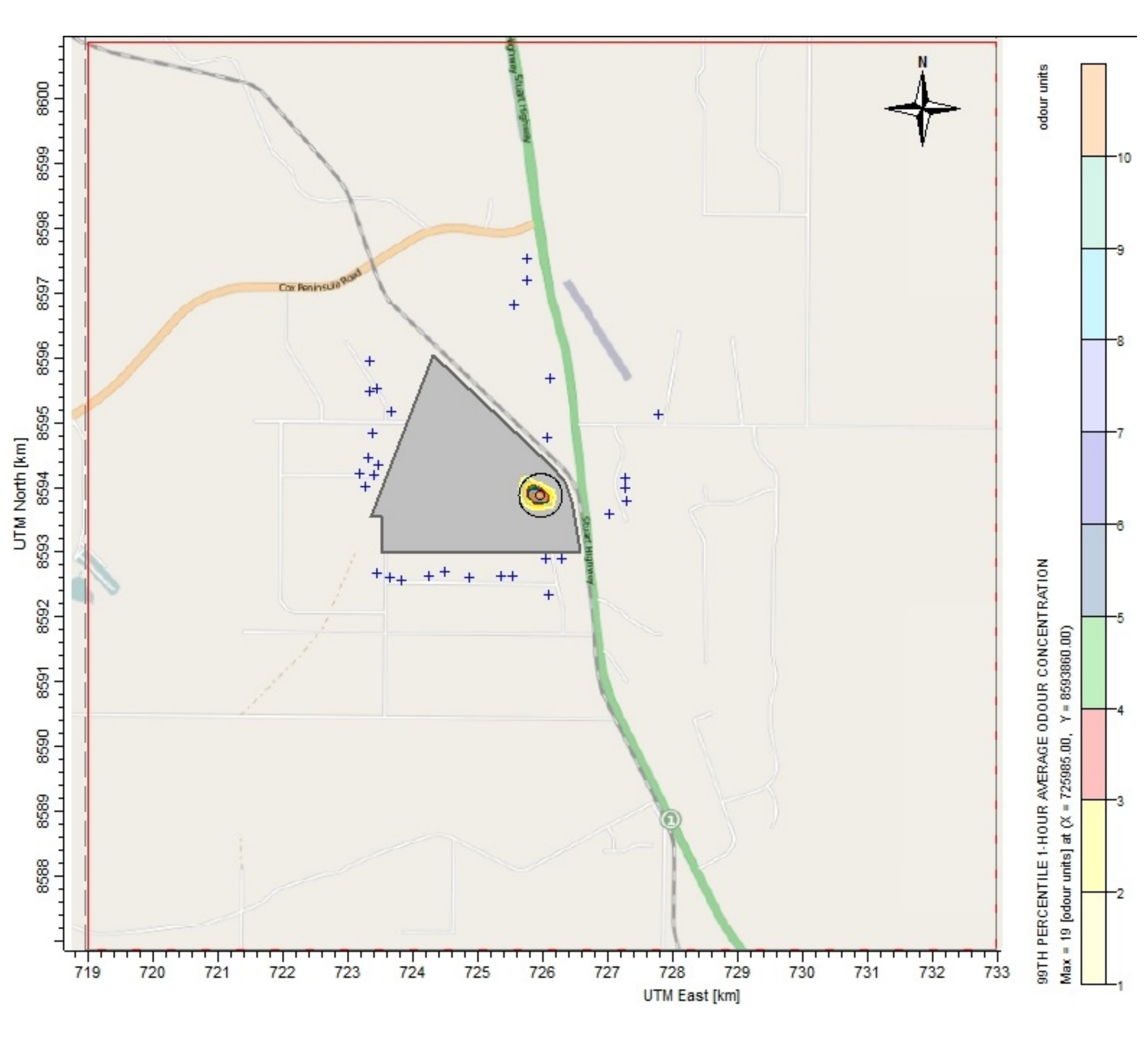

Figure 7-4 Predicted 99th percentile ground-level odour concentrations for the wet rendering plant area and meat meal hammer hill vent combined

Assessment scenario: Rendering area	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

7.3 Biofilter

Predicted maximum and 99th percentile ground-level odour concentrations for the biofilter are presented in Figure 7-5 and Figure 7-6, respectively.

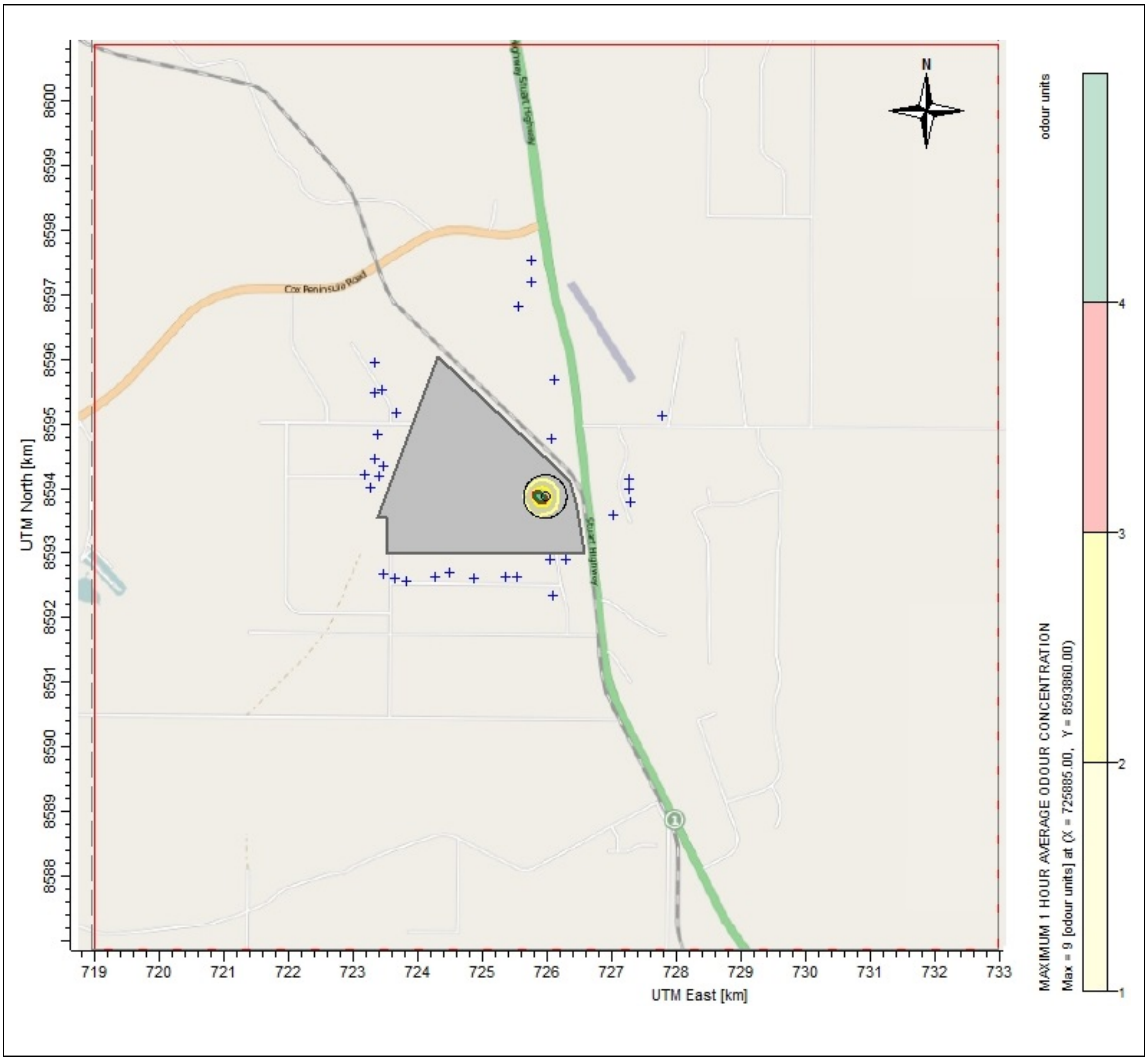

Figure 7-5 Predicted maximum ground-level odour concentrations for the biofilter treating rendering cooker emissions

Assessment scenario: Biofilter	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

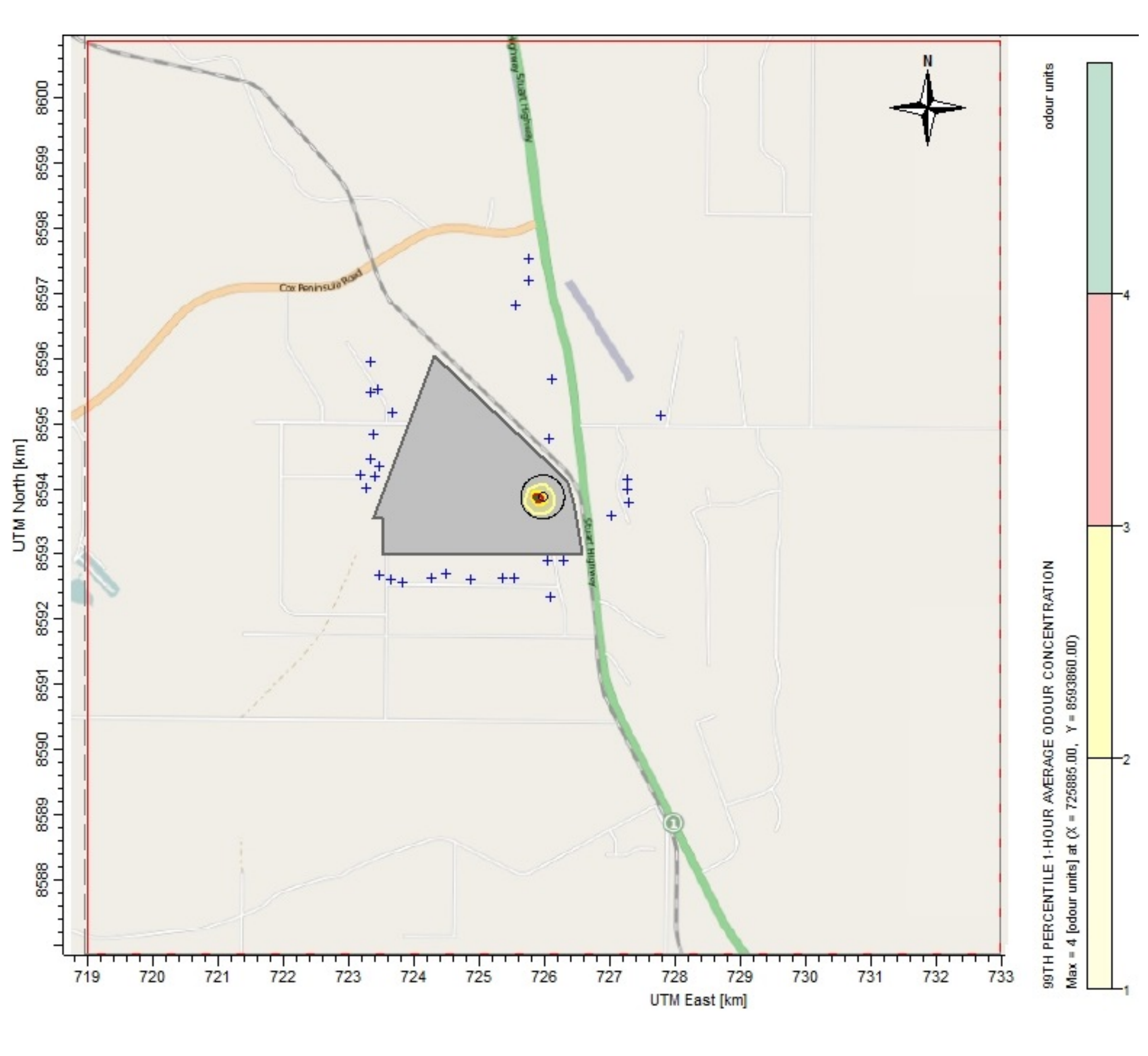

Figure 7-6 Predicted 99th percentile ground-level odour concentrations for the biofilter treating rendering cooker emissions

Assessment scenario: Biofilter	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

7.4 Wastewater Treatment Plant area

Predicted maximum and 99th percentile ground-level odour concentrations for the wastewater treatment plant area (green sump, common sump, DAF and irrigation tank) are presented in Figure 7-7 and Figure 7-8, respectively.

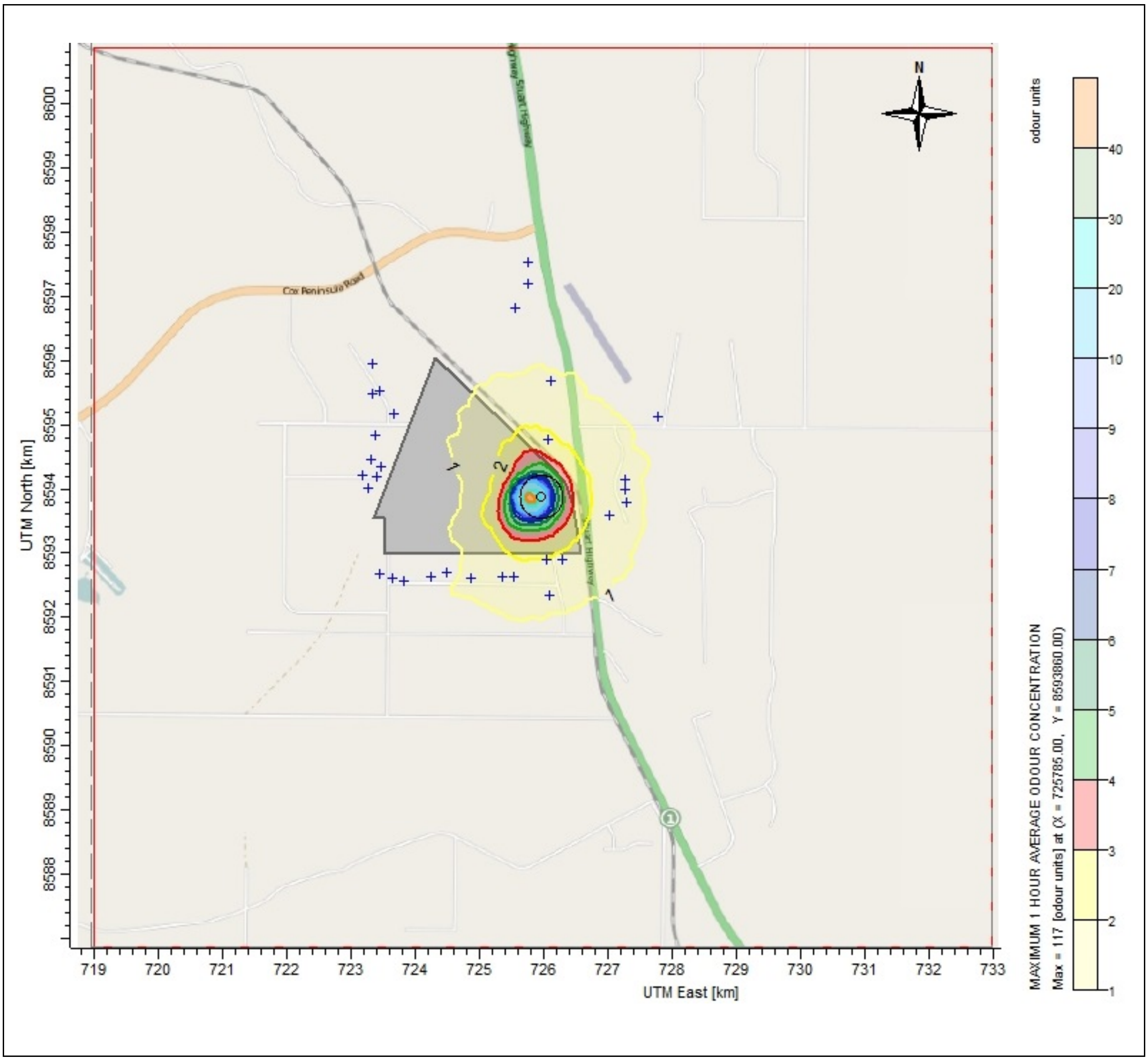

Figure 7-7 Predicted maximum ground-level odour concentrations for the wastewater treatment plant including DAF, sumps and irrigation water storage tank

Assessment scenario: WWTP area	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

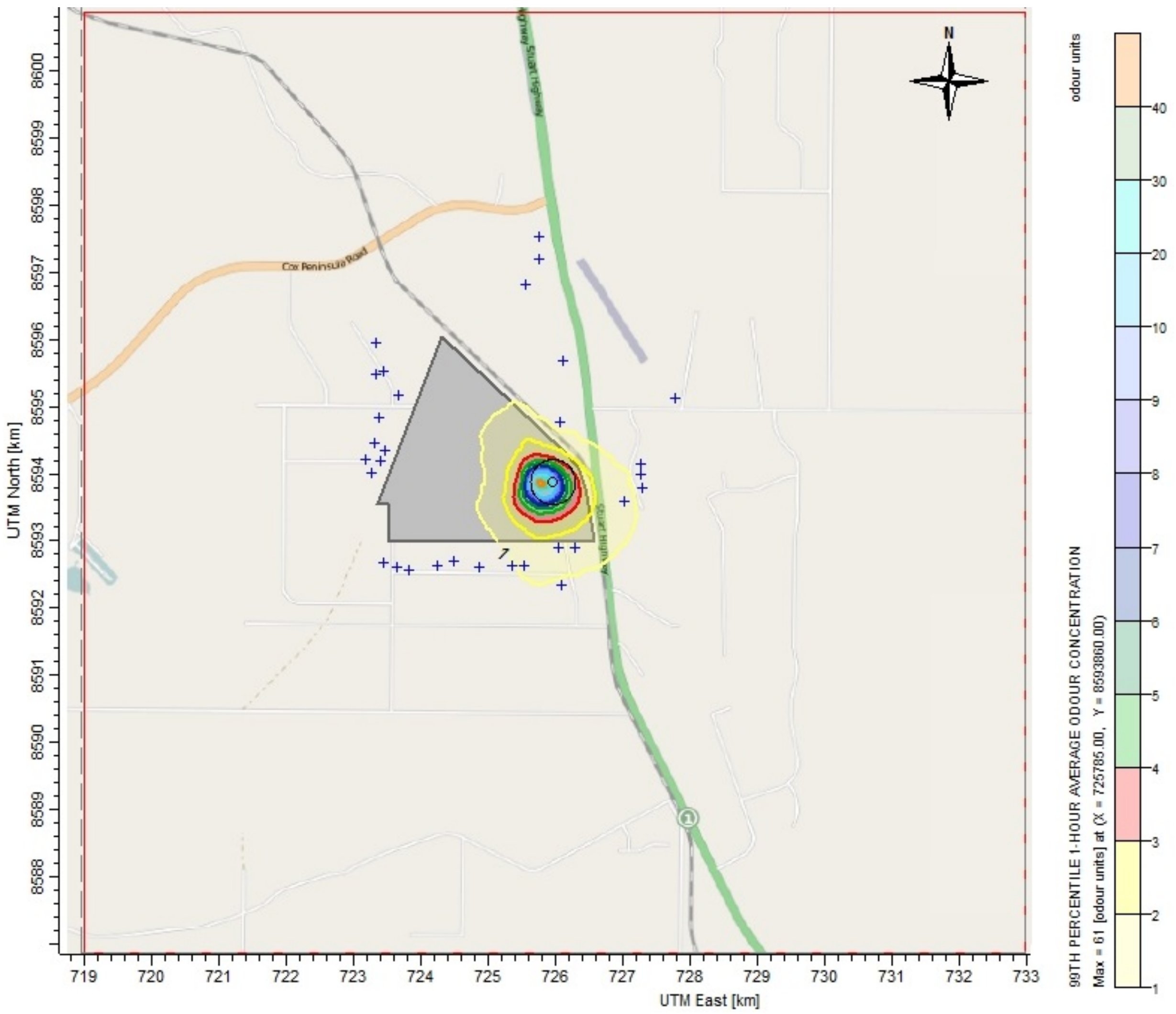

Figure 7-8 Predicted 99th percentile ground-level odour concentrations for the wastewater treatment plant including DAF and irrigation water storage tank

Assessment scenario: WWTP area	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

7.5 Spray irrigation area

Predicted maximum and 99th percentile ground-level odour concentrations for the spray irrigation area are presented in Figure 7-9 and Figure 7-10, respectively.

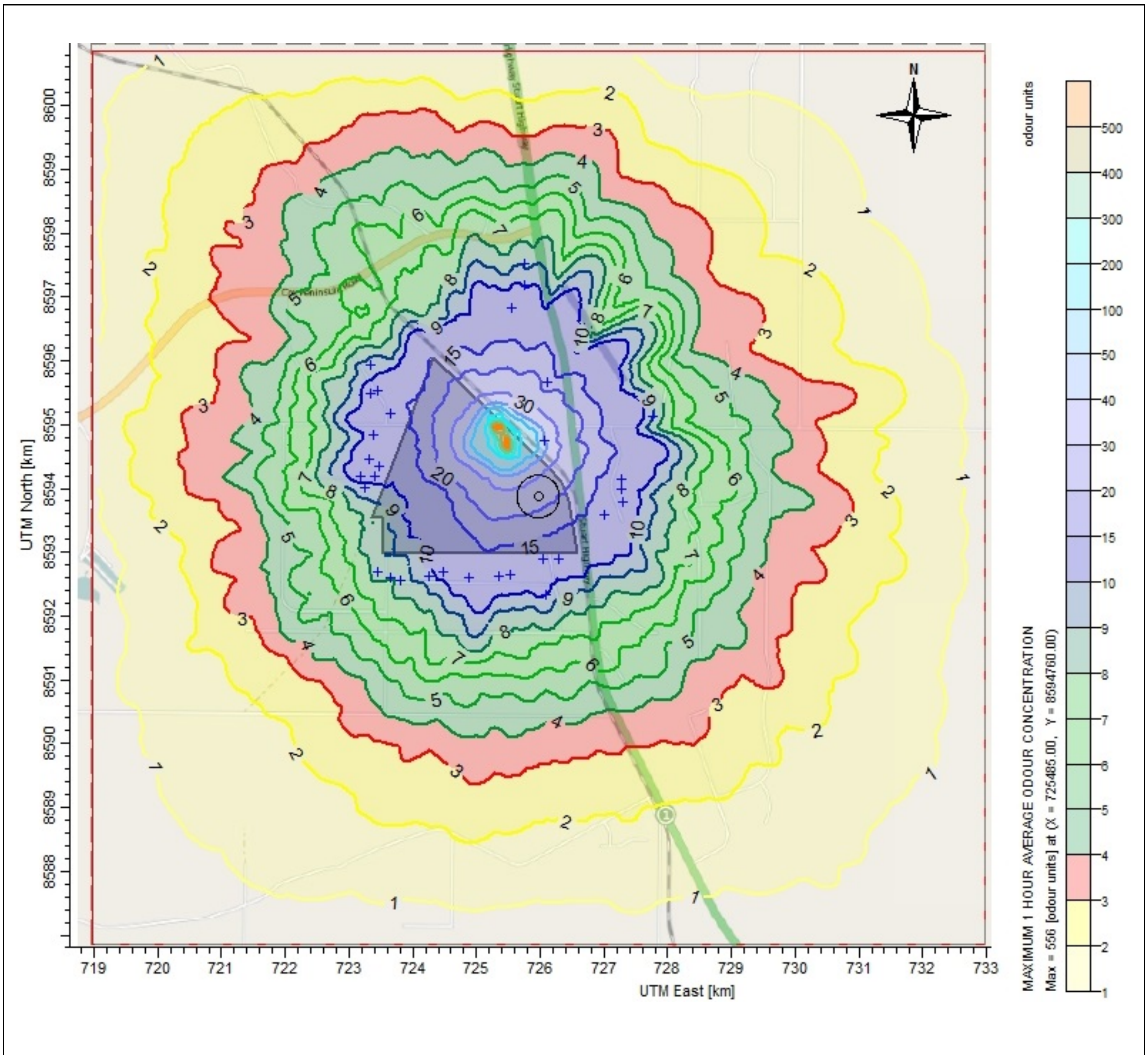

Figure 7-9 Predicted maximum ground-level odour concentrations for the spray irrigation area only

Assessment scenario: Spray irrigation area	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

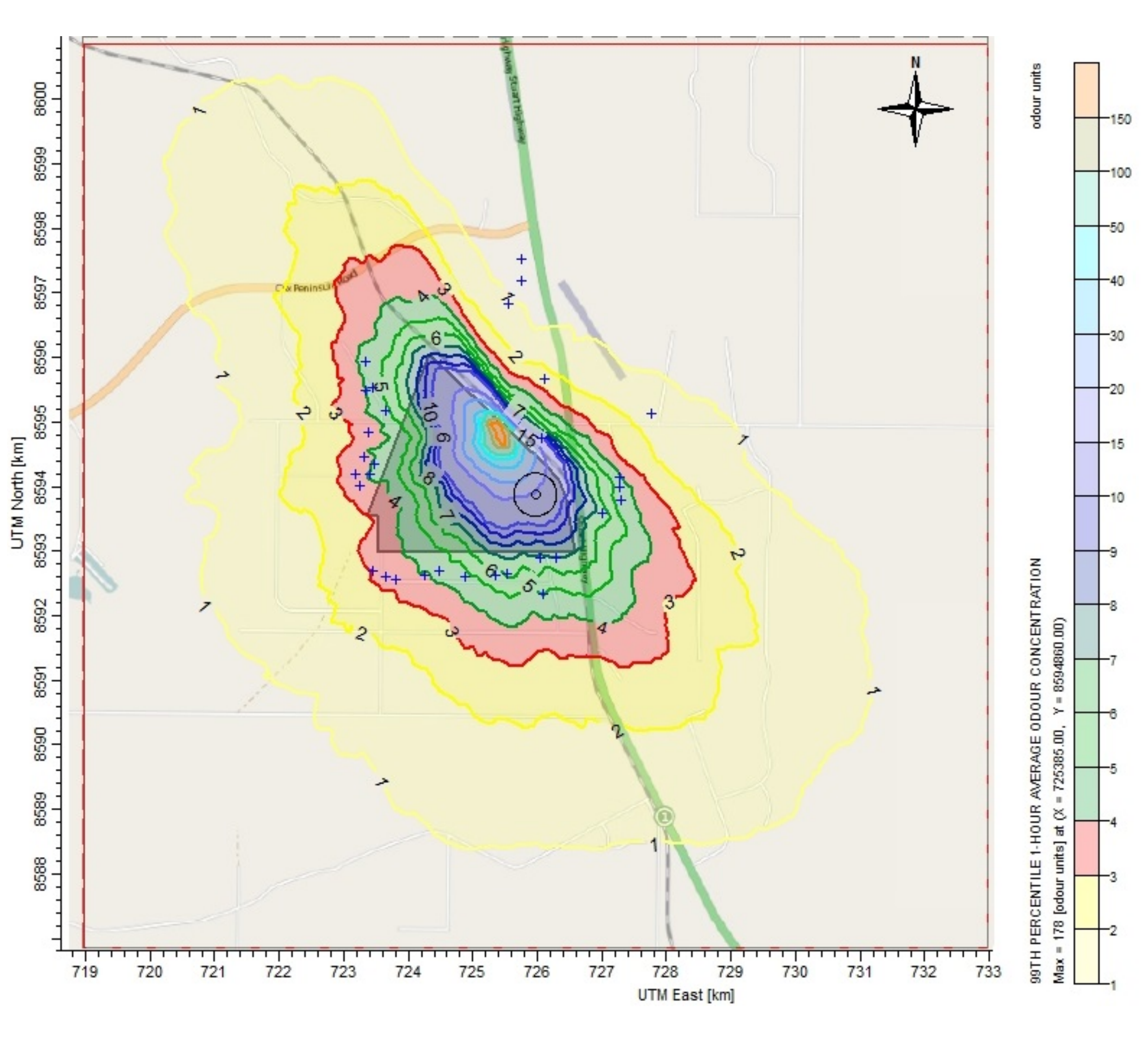

Figure 7-10 Predicted 99th percentile ground-level odour concentrations for the spray irrigation area only

Assessment scenario: Spray irrigation area	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

7.6 Wastewater treatment plant and spray irrigation areas combined

Predicted maximum and 99th percentile ground-level odour concentrations for the wastewater treatment plant and spray irrigation area combined are presented in Figure 7-11 and Figure 7-12, respectively.

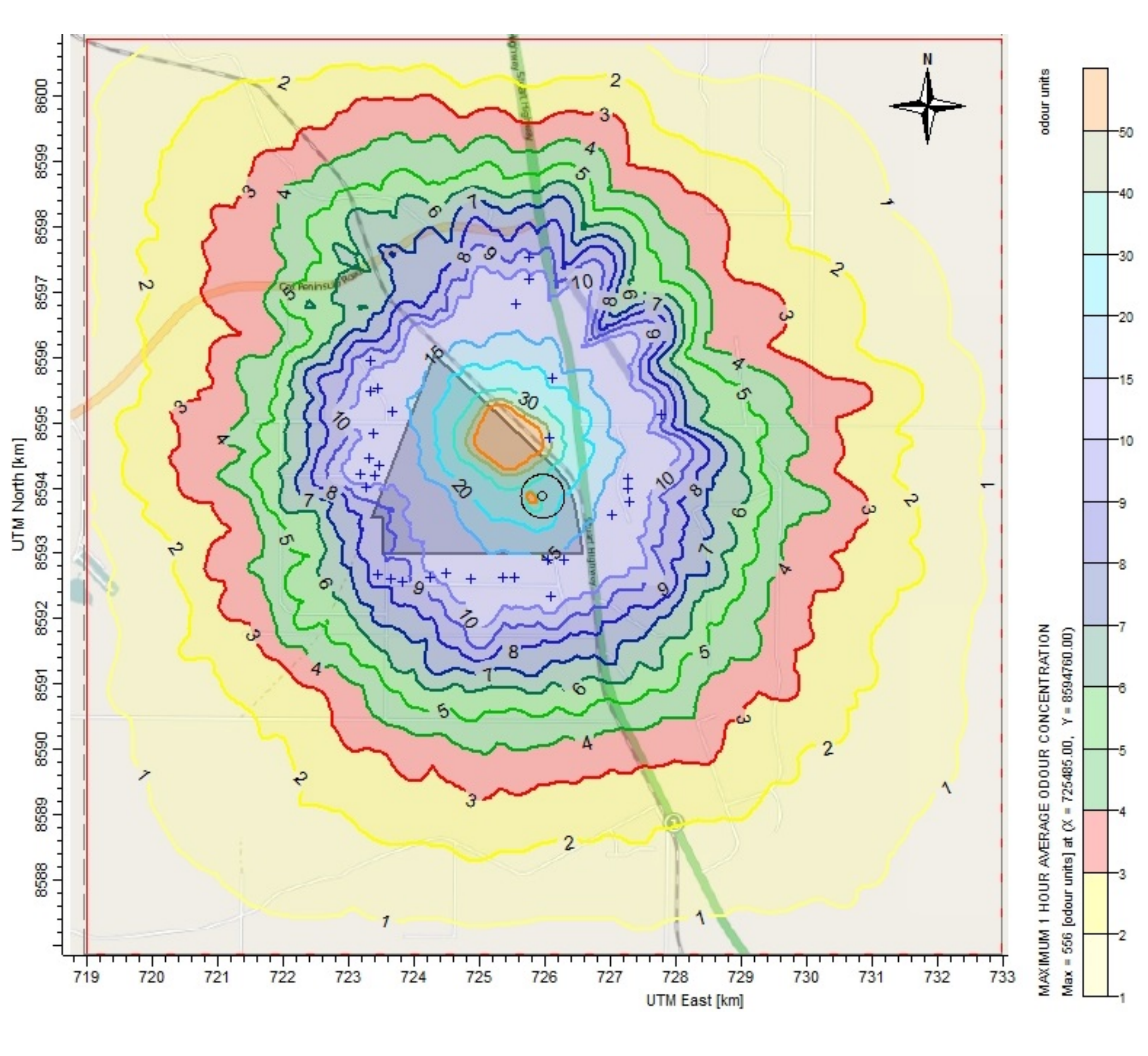

Figure 7-11 Predicted maximum 1-second average ground-level odour concentrations for the wastewater treatment plant and spray irrigation area

Assessment scenario: WWTP and spray irrigation area	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

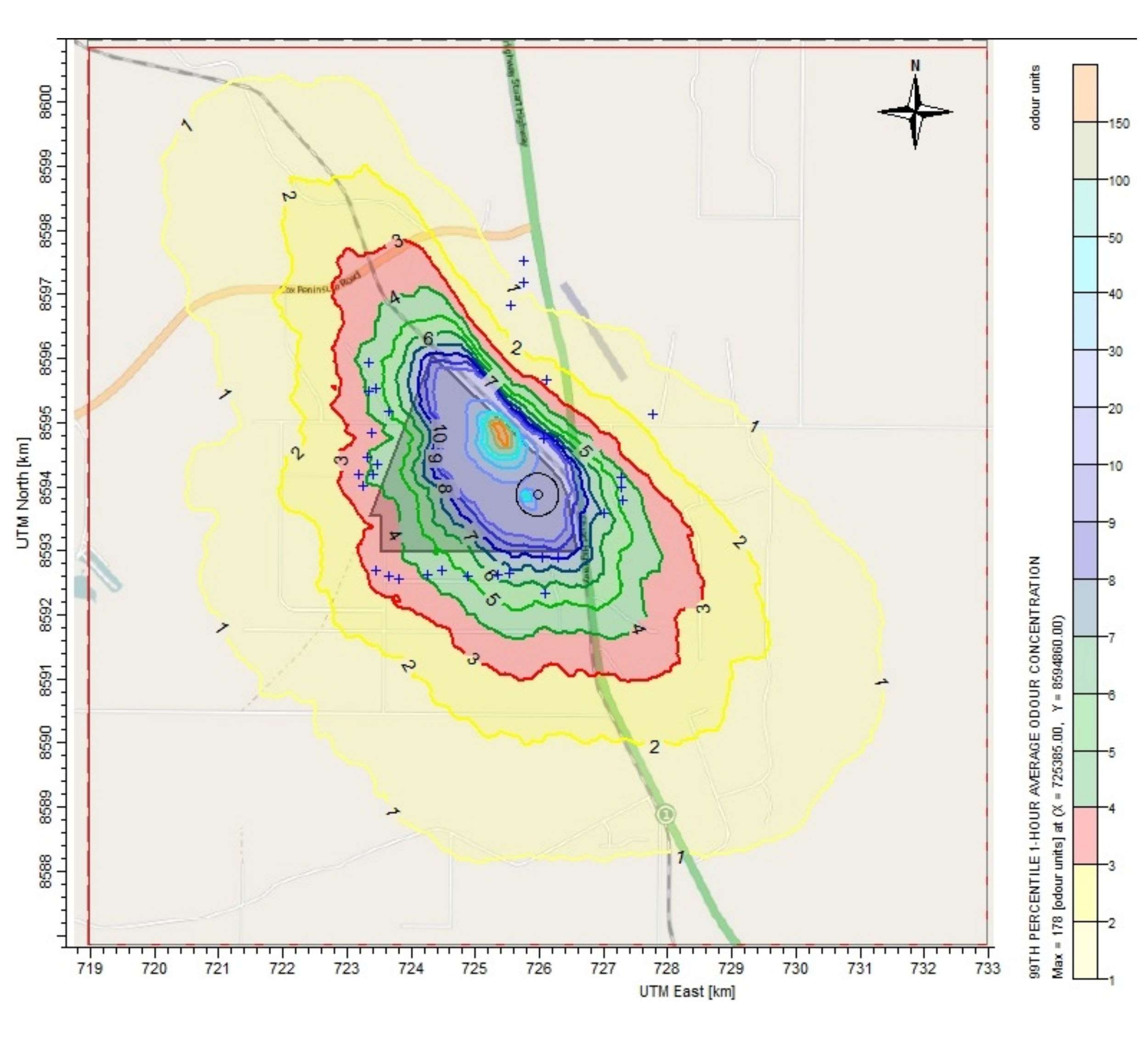

Figure 7-12 Predicted 99th percentile 1-second average ground-level odour concentrations for the wastewater treatment plant and spray irrigation area

Assessment scenario: WWTP and spray irrigation area	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

7.7 Waste management area

Predicted maximum and 99th percentile ground-level odour concentrations for the waste management area (paunch storage bin, DAF sludge decanter, DAF sludge storage and contra shear scrapings) are presented in Figure 7-13 and Figure 7-14, respectively.

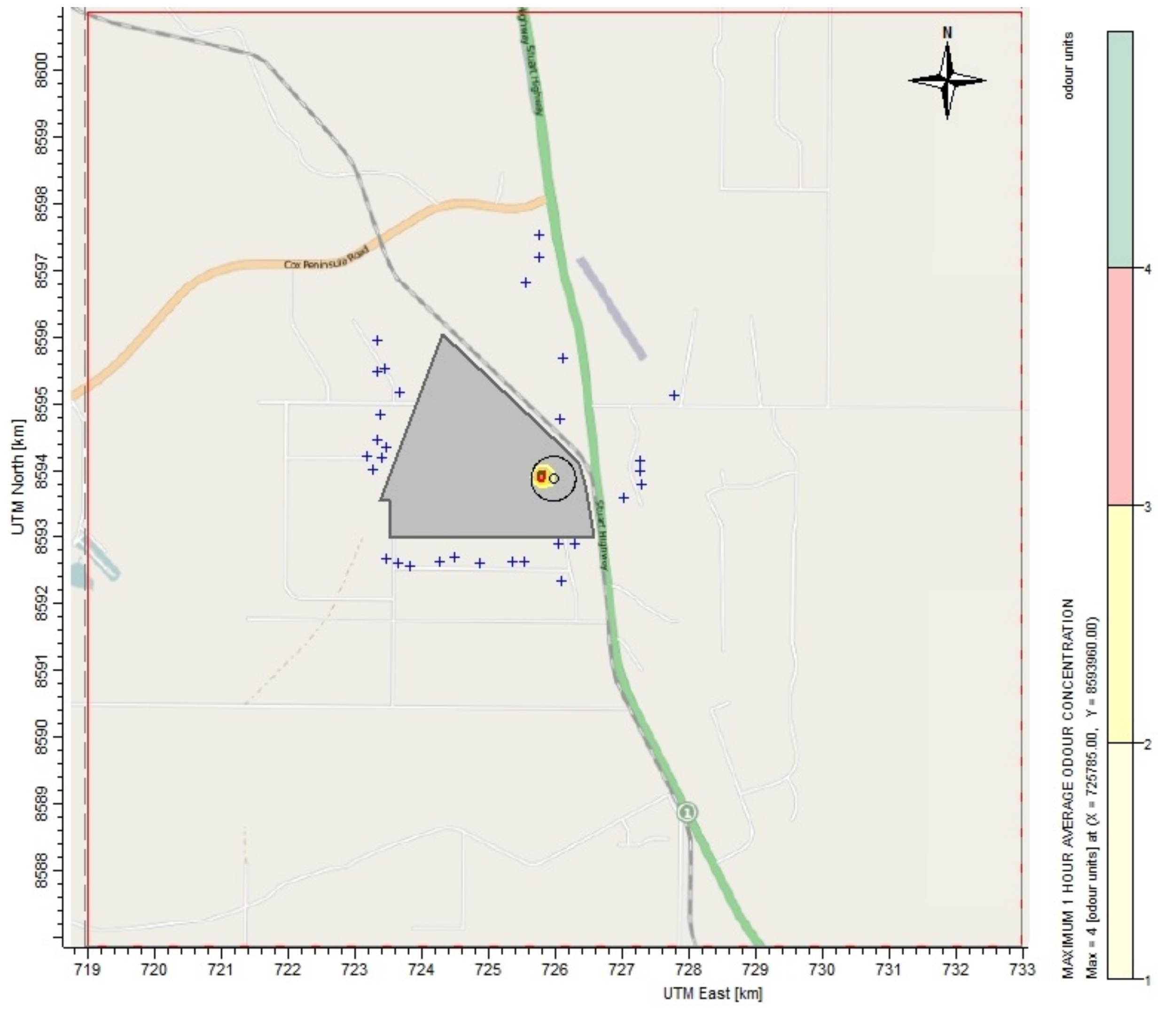

Figure 7-13 Predicted maximum ground-level odour concentrations for the waste management area

Assessment scenario: waste storage bins	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

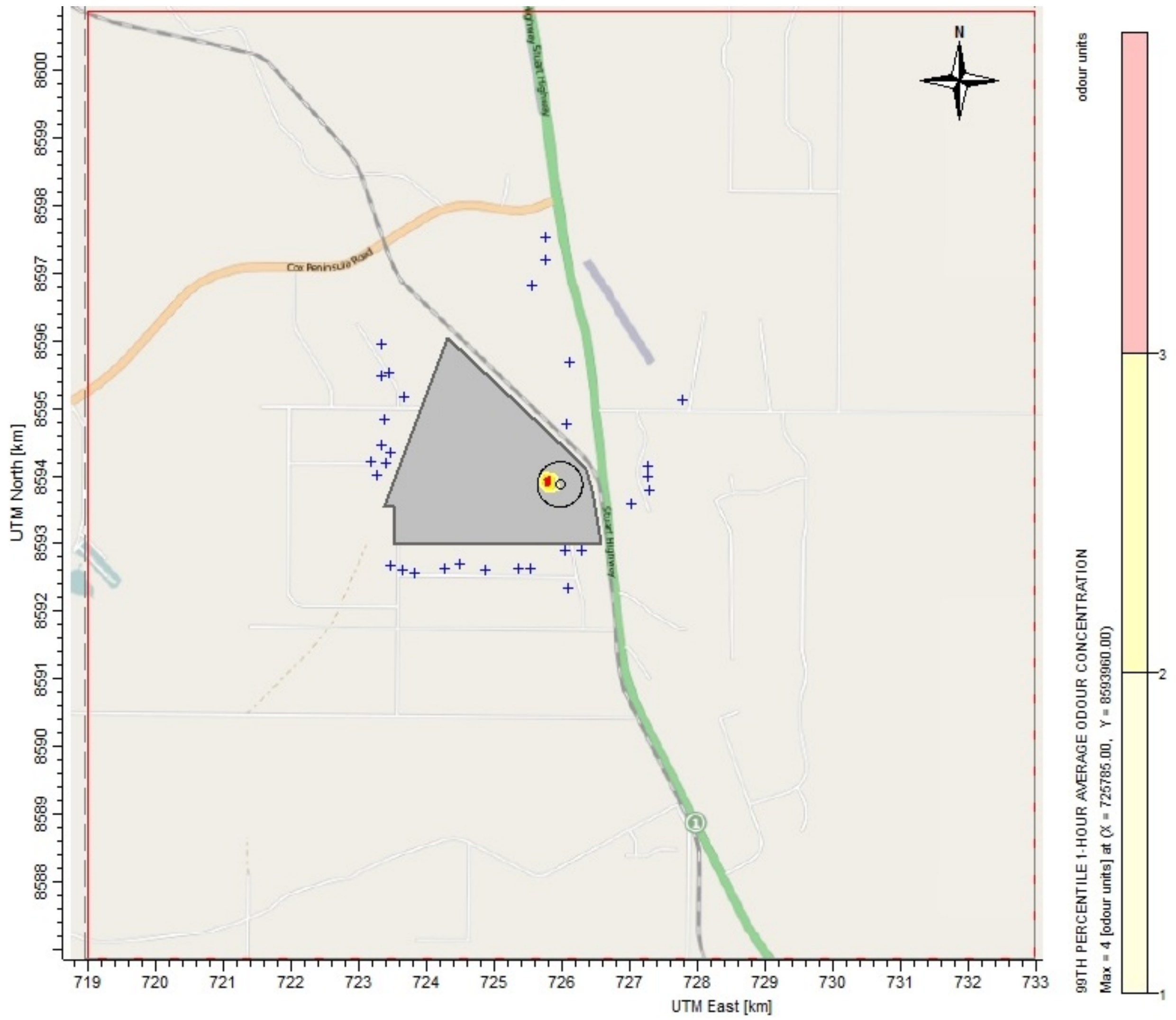

Figure 7-14 Predicted 99th percentile 1-second average ground-level odour concentrations for the waste management area

Assessment scenario: waste storage bins	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

The ground-level concentration isopleths have been summarized in Table 7-1. The results show the receptors in which the odour criterion is predicted to be exceeded (i.e. 3 OU, 99th percentile, 1-second average), and the predicted highest concentration.

Table 7-1 Predicted exceedences of the odour impact assessment criterion by source

Odour source	Receptor	Predicted 99th percentile ground-level odour concentration	Predicted highest ground-level odour concentration
Lairage	R2	3.2	3.9
	R7	3.0	3.7
Wastewater treatment plant and spray irrigation combined	R1	10.3	40.1
	R7	8.4	13.5
	R2	8.0	14.4
	R6	6.6	12.9
	R9	6.5	12.6
	R10	6.3	12.0
	R8	5.8	11.2
	R11	5.0	11.5
	R4	4.9	11.8
	R23	4.9	12.9
	R5	4.8	11.7
	R26	4.6	11.6
	R12	4.5	10.8
	R24	4.4	9.5
	R3	4.3	13.0
	R13	4.2	9.7
	R18	4.1	11.4
	R19	4.1	12.5
	R25	4.1	11.1
	R21	3.9	11.2
	R17	3.7	9.5
	R20	3.7	11.0
	R22	3.6	10.8
	R14	3.5	8.5
	R15	3.5	8.3
	R16	3.2	8.5
Rendering area		No exceedences	
Waste management area		No exceedences	
Wastewater treatment plant in isolation		No exceedences	
Biofilter		No exceedences	

8 Interpretation of Odour Impacts

The odour impact assessment has identified the following:

- The most significant source of odour predicted in the area surrounding the NABL site is the wastewater treatment and spray irrigation area sources. Combined, sources with a wastewater type odour character were predicted to exceed to the odour impact assessment criterion at almost all of the receptors identified in the areas nearest the plant and in all directions.
- The majority of the elevated ground-level odour concentration impacts were predicted in the evening between sunset and midnight. This is likely to the time when residents are at home and complain about odour nuisance.
- When considered individually, the wastewater treatment plant was not predicted to exceed the odour impact assessment criterion.
- In its current location adjacent to the northern boundary of the plant (at the time of the odour sampling program), the spray irrigation area, was predicted to generate significant odour impacts at almost all of the receptors identified in the areas nearest the plant and in all directions. Offsetting this area of odour impact based on the southern spray irrigation area used during the first half of 2015, it is likely that the spray irrigation was responsible for the odour complaints received by NT EPA.
- The Lairage area was predicted to slightly exceed the odour impact assessment criterion at the nearest receptors adjacent to the site's southern boundary (R2 and R7). Further monitoring is recommended of the holding yards and AQIS source as this results may be very conservative due to the over-estimation of the odour emission rate through the sampling methodology used. Based on conservative, but standard, buffer calculations for level 1 cattle feedlot assessment, the separation of the NABL lairage areas and the receptors to the south would be considered sufficient. This indicates that the model's prediction of ground-level odour concentrations associated with the lairage may be an over-estimate.
- All other odour sources including the rendering plant area, biofilter and waste management area (i.e. the DAF sludge and paunch storage bins) were predicted to be well below the odour impact assessment criterion.
- The biofilter is operating well and is unlikely to require the use of the odour neutralising sprays situated around the walls of the cells.

9 Recommendations for Odour Mitigation

The odour impact assessment determined that the treatment and irrigation of wastewater was likely to be the primary contributor to odour nuisance in the local community. The lairage area was also determined to be a potential source of odour nuisance, however due to the uncertainty of the odour testing and emission calculating methods, this source was considered to be of a secondary importance in the odour mitigation strategy. The assessment and site investigations also determined that several simple plant housekeeping instructions, noted in the site environmental management plan, were not being observed. By following the site environmental management plan, further reduction of odour emissions could easily be achieved, particularly for localised odour on the site. Further, the incorporation of some other mitigation and management options would significantly reduce the potential risk of odour nuisance in the local community.

Based on the findings of the odour impact assessment and other investigations in regard to the odour complaints received by NT EPA, a new wastewater treatment plant design has been developed. This treatment system would operate downstream of the current DAF and irrigation tank system, by further treating the water from the irrigation tank in a series of ponds as follows:

- Covered anaerobic lagoon (gas beneath the cover would be extracted for use)
- Aeration cell 1
- Aeration cell 2, and
- Settling pond.

The proposed wastewater treatment system would be situated to the east of the northern irrigation area and adjacent to the site's northern boundary along the rail line. The system would operate continuously throughout the year.

Based on this design, further odour dispersion modelling was conducted using odour emission rates from the AEC database. A range of wastewater treatment pond specific odour emissions rates from similar abattoir and rendering plant operations in Australia were presented in AEC (2015). The odour emissions used in the mitigation scenario modelling are presented in Table 9-1. The odour emissions used, were considered to be in the middle of the distribution of aeration pond sources and it is expected that a well managed wastewater treatment pond system would achieve lower odour emissions than those used in the assessment. The specific odour emission rates have been selected as a conservative approach and the same emission rate was used for each of the two aeration cells and the settling pond. The specific odour emission rates would be expected to diminish as the quality of the treated water improved through the pond system. The specific odour emission rate of the covered anaerobic lagoon is based on an uncovered pond with a specific odour emission rate of 4 OU/m^2/s, with 99 percent capture efficiency from the cover and gas extraction system.

The predicted ground-level odour concentrations for the upgraded wastewater treatment and spray irrigation option are presented as concentration isopleths in Figure 9-1 to Figure 9-6.

Table 9-1 Odour emissions used in the mitigation modelling

Odour source	Area source southwest corner		Length (m)	Width (m)	Height (m)	σz	SOER ($OU/m^2/s$)	Hours of operation
	Easting	Northing						
Covered anaerobic lagoon	726.066	8594.280	84.5	48.5	0	1	0.04	Continuous
Aeration cell 1	726.115	8594.226	48.5	45.0	0	1	0.16	Continuous
Aeration cell 2	726.151	8594.257	34.5	34.5	0	1	0.16	Continuous
Settling pond	726.177	8594.230	32.5	26.5	0	1	0.16	Continuous
Spray irrigation Plot C	725.208	8594.781	L shape, 340 m x 250 m to give an area of 70,174 m²		0	1	0.16 (max) Hourly variable	Same profile as Figure 4-1
Spray irrigation Plot D	725.200	8594.630	470	150	0	1		

Table 9-2 presents the same odour emissions inventory as presented in Table 4-1, with the addition of the proposed wastewater treatment system and other potential mitigation options.

Table 9-2 Current and potential future mitigation scenario odour emissions inventory

Odour source	Odour emission rate (OU/s)	Proportion of total plant emissions (%)	Potential odour mitigation scenario (OU/s)	Proportion of total plant emissions (%)
Lairage				
Cattle receival and holding yards, maximum during wet season	682	0.6%	682	2.8%
AQIS Area	10,586	9.0%	10,586	44.0%
Rendering Area				
Red fan press: tank/sump	71	0.1%	0	0.0%
Red fan press: screw conveyor	609	0.5%	0	0.0%
Raw material bin	7,475	6.4%	0	0.0%
Wet rendering building	956	0.8%	0	0.0%
Meat meal hammer mill cyclone wall vent	962	0.8%	0	0.0%
Tallow transfer & storage tanks 1 and 2	2	0.0%	0	0.0%
Biofilter	741	0.6%	741	3.1%
Wastewater treatment area				
Green Sump	7	0.01%	7	0.03%
Common Sump	5	0.005%	5	0.02%
DAF	81	0.1%	81	0.3%
DAF sludge decanter	3	0.003%	3	0.01%
Irrigation Tank	5,991	5.1%	5,991	24.9%
Sludge storage bins	321	0.3%	0	0.0%
Paunch storage bins	7	0.01%	0	0.0%
Spray Irrigation	88,640	75.7%	5,120	21.3%

Odour source	Odour emission rate (OU/s)	Proportion of total plant emissions (%)	Potential odour mitigation scenario (OU/s)	Proportion of total plant emissions (%)
Proposed stage 2 wastewater treatment plant expansion				
Covererd anaerobic lagoon	0	0.0%	163.93	0.7%
Aeration cell 1	0	0.0%	349.2	1.5%
Aeration cell 2	0	0.0%	190.44	0.8%
Settling pond	0	0.0%	137.8	0.6%
Total plant odour emissions	**117,140**		**24,057**	

The updated odour emissions inventory based on potential mitigation options shows how the plant odour emissions could be significantly abated. The wastewater treatment and irrigation system is estimated to be reduced by 82,679 OU/s, a reduction of more than 87%.

The lairage area was also determined to be a significant source of odour, and while there is some uncertainty in this finding, this area is predicted to be the primary source of odour once the wastewater treatment odour mitigation strategy is implemented. Odour emissions associated with the lairage area are expected to be mitigated through the implementation of the management plan including general cleaning and housekeeping.

Although the rendering plant area is a lower priority, mitigation of its odour emissions could be easily achieved through the following:

- Replacement of the lid on the red fan press,
- Replacement of the lid on the red fan press screw conveyor,
- Covering of the raw material bin or extraction of air from the bin and treatment in the biofilter,
- Enclosing of the rendering building and outside area and extraction of the air for treatment in the biofilter, and
- Ducting of the meat meal hammer mill cyclone vent to the biofilter for treatment.

This would virtually eliminate the rendering plant odour emissions, providing a reduction to total plant odour emissions of 10,073 OU/s, based on the emissions measured during the assessment.

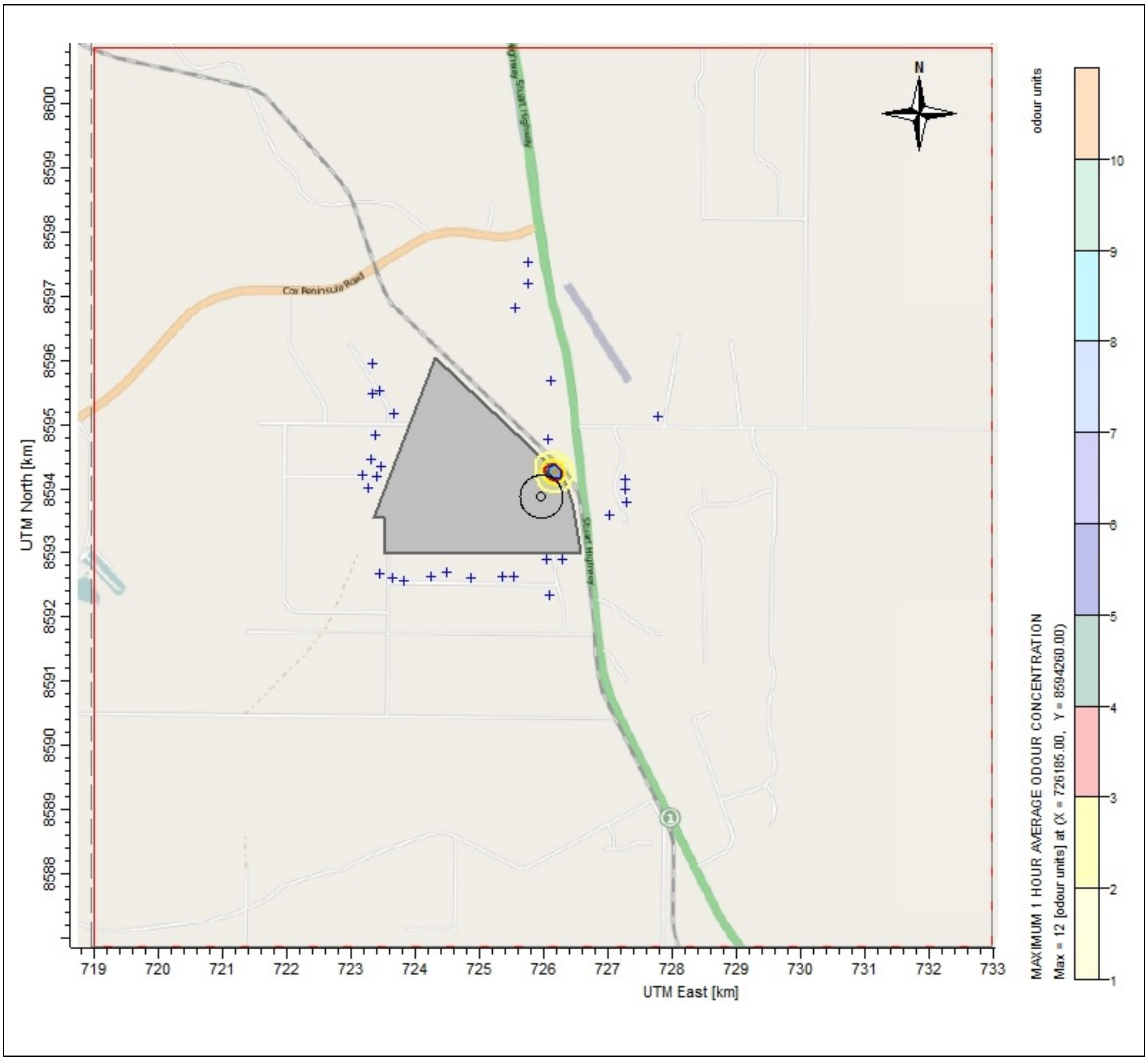

Figure 9-1 Predicted maximum ground-level odour concentrations for the proposed stage 2 wastewater treatment pond system in isolation

Assessment scenario: Stage 1 and 2 ponds	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

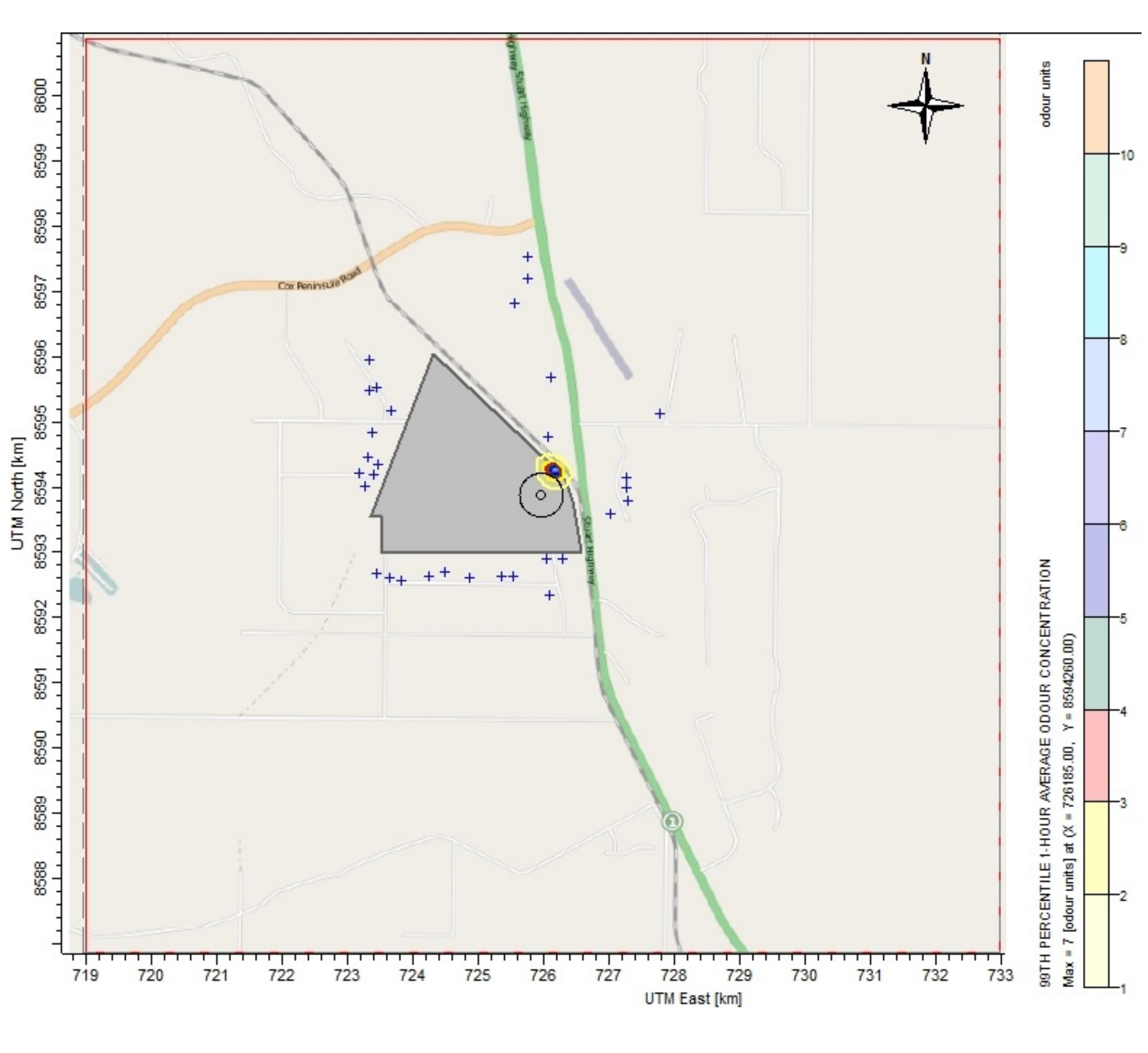

Figure 9-2 Predicted 99th percentile ground-level odour concentrations for proposed stage 2 wastewater treatment pond system in isolation

Assessment scenario: Stage 1 and 2 ponds	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

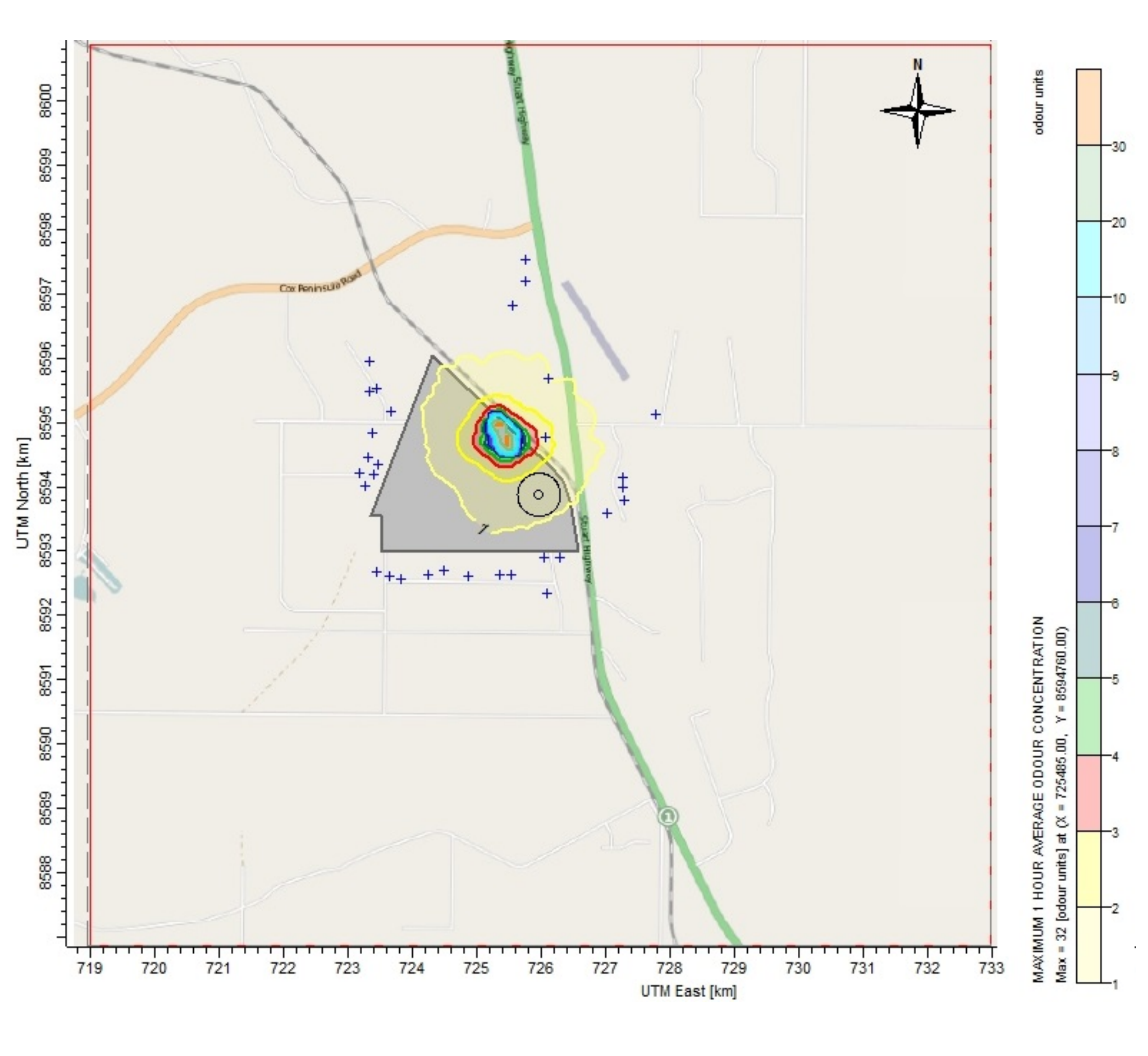

Figure 9-3 Predicted maximum ground-level odour concentrations for the spray irrigation system based on improved water quality from the proposed stage 2 wastewater treatment pond system

Assessment scenario: Spray irrigation after stage 2 upgraded wastewater treatment	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

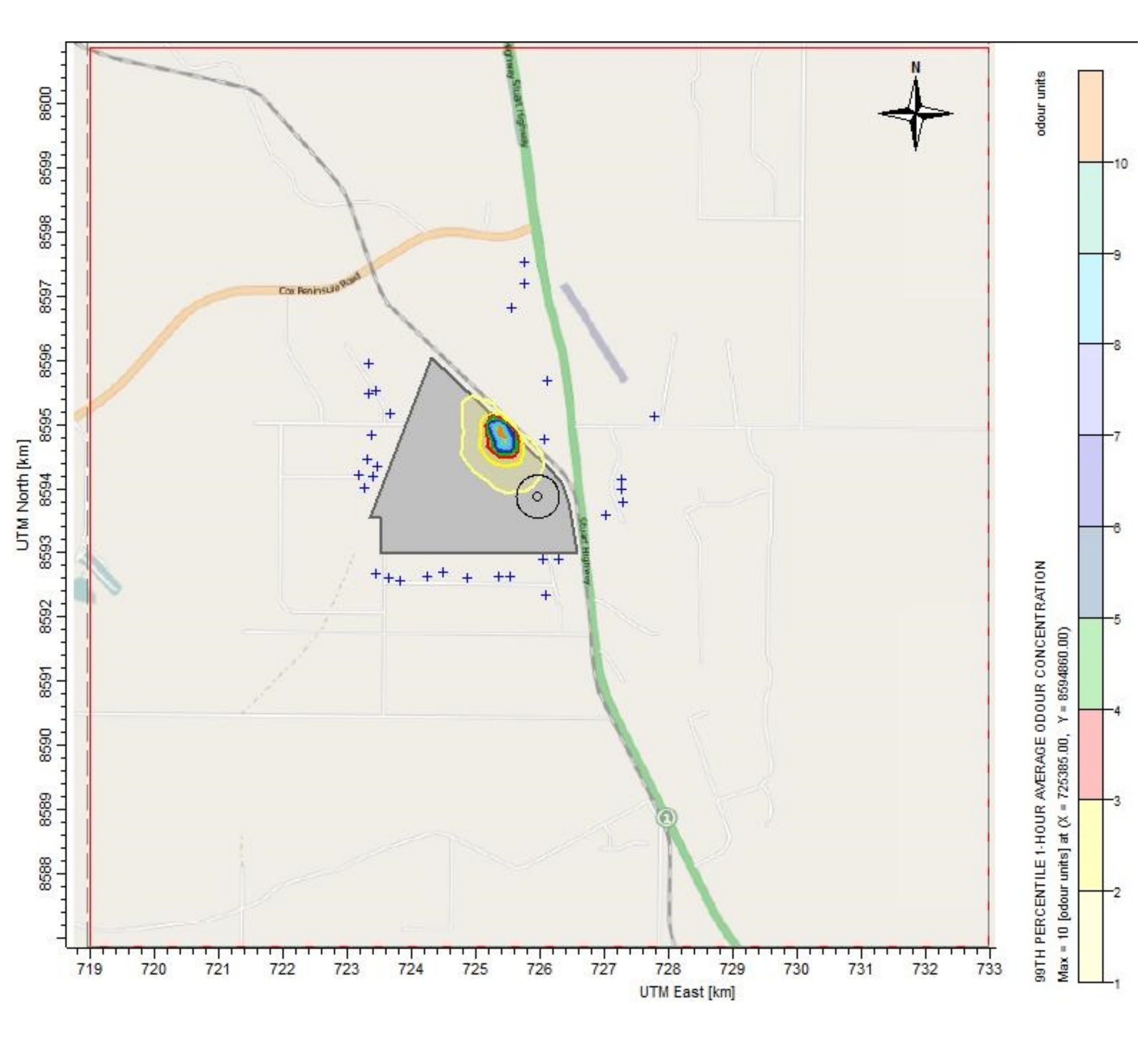

Figure 9-4 Predicted 99th percentile ground-level odour concentrations for the spray irrigation system based on improved water quality from the proposed stage 2 wastewater treatment pond system

Assessment scenario: Spray irrigation after stage 2 upgraded wastewater treatment	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

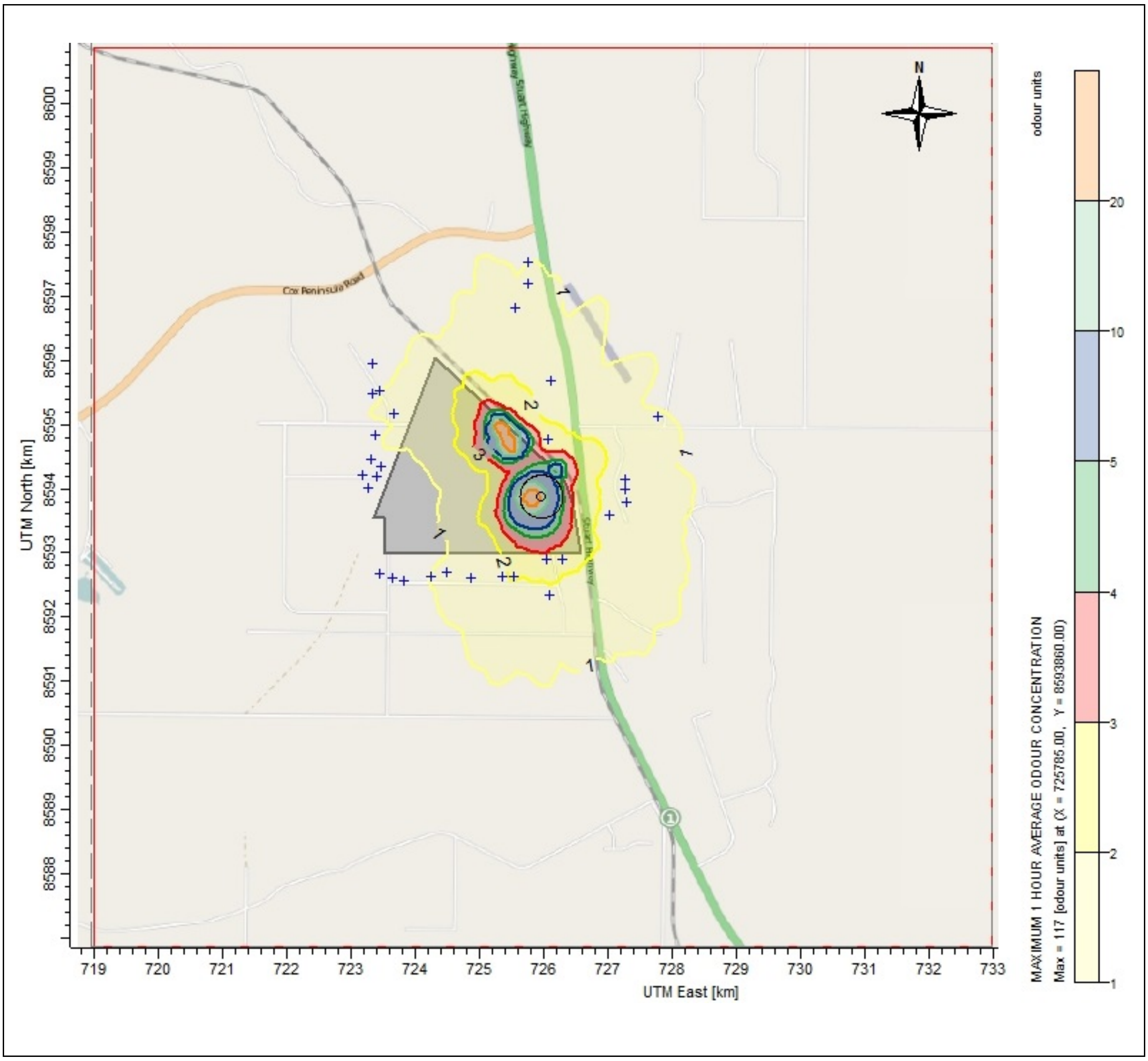

Figure 9-5 Predicted maximum ground-level odour concentrations for the existing wastewater treatment plant, proposed stage 2 wastewater treatment pond system and spray irrigation system based on improved water quality

Assessment scenario: Stage 1 & 2 ponds, spray irrigation and the WWTP area	Units: Odour Units (OU)
Contours: Predicted maximum, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

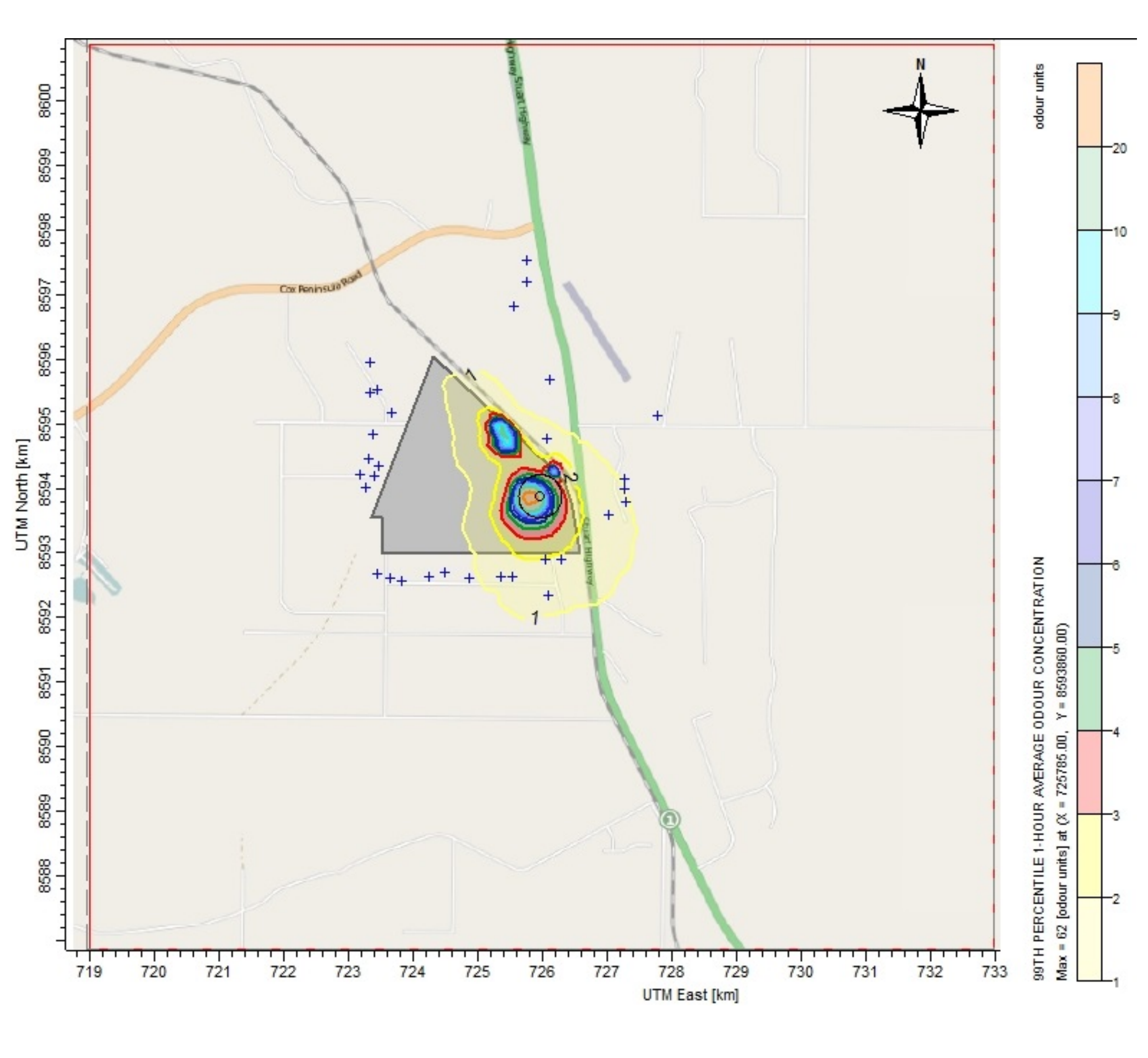

Figure 9-6 Predicted 99th percentile ground-level odour concentrations for the existing wastewater treatment plant, proposed stage 2 wastewater treatment pond system and spray irrigation system based on improved water quality

Assessment scenario: Stage 1 & 2 ponds, spray irrigation and the WWTP area	Units: Odour Units (OU)
Contours: Predicted 99th percentile, 1-second average	Assessment criterion: 3 OU (red line)
Data source: CALPUFF	Prepared by: L. Jackson and A. Balch
Location: NABL, Livingstone, NT	Date: 26 November 2015

10 Conclusions and Recommendations

The odour impact assessment determined that odour emissions associated with the wastewater treatment plant and the spray irrigation of poorly treated effluent were likely to be the principle cause of the odour complaints receive by NT EPA, and which initiated the *Notice to Carry Out an Environmental Audit Program* of 17 August 2015. The assessment determined that significant ground-level odour concentrations in exceedence of the odour impact assessment criterion (3 OU, 99th percentile, 1-second average) were likely at sensitive receptor locations around the NABL site, primarily due to the spray irrigation source, but also combined with the similar odour character of the wastewater treatment plant emissions.

The assessment also determined that the lairage odour sources also had the potential to cause odour nuisance at sensitive places beyond the site's southern boundary, however this finding is associated with some uncertainty in the calculation of odour emissions. Odour emissions associated with cattle handling activities would be mitigated through the environmental management procedures and include general housekeeping and regular cleaning of surfaces when cattle are removed from the pen. Housekeeping may comprise prevention of water spills and leaks during the dry season as the odour emissions audit showed that the wet surface released ten times more odour than the dry surface. During the wet season, holding yard pen floors should be cleaned of manure regularly to prevent material from anaerobic decomposition and excessive odour release. Similarly, the AQIS floor area should be cleaned as cattle are removed from holding pens.

The assessment determined that the rendering plant operations were not expected to cause odour nuisance above the impact assessment criterion at sensitive places, however, there were several activities identified that could be managed to significantly reduce odour emissions from the area. This included covering some sources with lids, or extracting ventilation air to the biofilter for treatment.

Based on these investigations, an upgraded wastewater treatment pond system has been designed and assessed as part of the mitigation strategy for the NABL site. The four pond wastewater treatment system is expected to significantly reduce odour emissions associated with wastewater treatment and most significantly, reduce the odour emissions from the spay irrigation area. The assessment determined that cumulative ground-level odour concentrations associated with the existing stage 1 and proposed stage 2 wastewater treatment systems, and the spray irrigation of the treated effluent with improved water quality, would have a low risk of causing odour nuisance at any sensitive places in the local area.

In addition to the recommendations and mitigation measures discussed above, the following odour management protocols are recommended for consideration in the environment management plan. The odour management plan should include, but not be limited to, the following scope of work:

- **Maintenance of plant processes and equipment.** It is an offence for an operator of a site to cause air pollution (including odour nuisance) through their failure to maintain and operate plant and equipment in an efficient and proper manner. Equipment failure and poor maintenance is a common cause of odour events that lead to odour nuisance and complaints. Plant and equipment should be designed to minimize the generation and emission of odour and it's proper maintenance should, in general, ensure that odour impact does not occur.
- **Cleaning and good housekeeping practices.**
  - All plant areas should be maintained including being kept clean and free from material that has the potential to generate odour and other emissions (e.g. dust).

- Doors of buildings that are mechanically ventilated and air extracted for treatment should be kept closed to assist the efficiency of the ventilation system and reduce fugitive odour releases.
- Air collection system extraction ducts should not be obstructed and should be routinely cleaned and maintained. Duct pressure and airflow rates should also be checked routinely to ensure proper and efficient function.
- The biofliter should be maintained according to the design specifications, and include a schedule of routine odour, moisture and airflow testing. The biofilter media should also be remediated routinely to prevent it from drying out and forming channels or chimneys that allow untreated emissions to be released.

- **Management of the wastewater treatment plant within its design criteria.** Wastewater treatment processes and water quality should be routinely monitored and managed in order to operate the treatment plant within it design criteria. Wastewater and its treatment processes are often a significant source of odour at abattoirs and rendering plants if operations and management deviate from the design strategy and process. The assessment has shown that due to the volume of wastewater to be disposed of via spray irrigation and the large area over which the recycled water is to be irrigated, poor water quality that increases the water's odour emissions has the potential to generate odour impacts due the spray drift and the transfer of odour to the air through evaporation.
- **Ambient odour monitoring.** A routine ambient odour monitoring program is recommended to understand the dispersion of odour from the site under various meteorological conditions. The odour monitoring program can also be used to respond to odour complaints from the local residences.
  - **Ambient odour intensity measurement.** A modified German VDI3940 approach is recommended, whereby a suitably trained and qualified person tracks and sniffs the air downwind of the plant to record odour intensity in accordance with the seven point scale promulgated in the method.
  - **Ambient odour concentration measurement.** In addition to the measurement of ambient odour intensity, a less subjective method using a Field Olfactometer (such as the Scentroid SM100i Personal Intelligent Field Olfactometer) is recommended. The Field Olfactometer can be routinely used by a suitably trained and qualified person to test the concentration of odour, both directly from the source on site, and in the ambient air downwind of the source, at the boundary or any sensitive place. The Field Olfactometer could be used to benchmark odour emissions from plant emission sources and record changes in management performance over time. When coupled with a static hood, the Field Olfactometer could be used to monitor the performance of the biofilter and determine whether any malfunctions have occurred.
  - **Ambient monitoring of odorous gases.** Once the stage 2 wastewater treatment system is commissioned, it is recommended that low concentration gases in the ambient air downwind of the ponds and irrigation area be monitored. A Scentroid Scentinal Ambient Air Monitor is recommended to monitor up to 20 gases at part per million and part per billion concentrations. The Scentinal is specifically designed to monitor a range of odorous gases and other wastewater and waste product off-gases. The gas concentrations measured can also be combined with Field Olfactometer measurements to train a built-in learning algorithm to monitor the odour concentration of the gases. The Scentinal can measure up to 20 gases including hydrogen sulfide,

ammonia, total reduced sulfur, methane, carbon dioxide, nitrogen dioxide, total VOCs, and sulfur dioxide.

- **Weather monitoring.** Regular analysis of the AWS wind data in combination with an odour complaints register would provide key information in identifying any future odour issues at the site. The AWS data could also be used to run a real time odour dispersion model or be used to inform management of the most appropriate time and location to irrigated the fields.
- **Odour complaint recording and management**. Odour complaints by the local community should be recorded and promptly investigated. A complaint register can be set up and managed in accordance with the method prescribed in the NSW odour framework. It is important for the management team of a significant local business that has the potential to generate odour emissions to remain proactive and responsive to the concerns and complaints of the local community.

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Appendix A
Airlabs Environmental
Odour Emission Audit Report

DATE OF REPORT: 26TH OCTOBER, 2015

Att: Michelle Clifton
Consulting Scientist
Vipac Engineers & Scientists Ltd
Level 2, 146 Leichhardt Street,
Spring Hill QLD 4000 Australia

TEST REPORT NO. SEP15166.1

ODOUR MONITORING PROGRAM CONDUCTED AT THE AACO - LIVINGSTONE BEEF FACILITY IN LIVINGSTONE VALLEY

DATE OF SAMPLING: 16TH – 30TH SEPTEMBER, 2015

ACCREDITATION:

This laboratory is accredited by the National Association of Testing Authorities (NATA).
NATA Accredited Laboratory No. 15463.
Accredited for compliance with ISO/IEC 17025:2005.
This document shall not be reproduced, except in full.

AUTHORISATION:

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LABORATORY MANAGER

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INTRODUCTION

Airlabs Environmental Pty Ltd was commissioned by Vipac Engineers & Scientific to conduct an odour monitoring program at the AACo Livingstone Beef facility in Livingstone Valley. Odour sampling was conducted throughout the processing facility.

All sampling was conducted on 16th – 30th September 2015.

QUALITY STATEMENT

Airlabs is committed to providing the highest quality data to all our clients, as reflected in our ISO 17025 (NATA) accreditation. This requires strict adherence to and continuous improvement of all our processes and test work. Our goal is to meet or exceed the QA/QC requirements as set by our clients and appropriate governmental entities and to insure that all data generated is scientifically valid, defensible and of known measurement uncertainty following the best available testing methods.

TEST METHOD

Odour

Sample Collection

Odour samples were collected using the 'lung-in-the-box' technique in accordance with the Australian/New Zealand Standard 4323.3:2001 'Stationary Source Emissions – Part 3: Determination of Odour Concentration by Dynamic Olfactometry'. The sample was drawn through a Teflon tube that fed into a Nalophan sample bag.

Area source samples were first isolated using a 'Five Senses' AC'SCENT emissions isolation flux hood in accordance with the Australian/New Zealand Standard 4323.4:2009 'Area Source Sampling – Flux Chamber Technique'. The flux hood comprised a stainless steel constructed isolation flux chamber with a surface area of 0.13m^2. The flux hood has a stainless skirt which ensures that the surface area enclosed by the hood is isolated.

The flux hood was operated using the standard operating parameters as specified in AS/NZS 4323.4:2009 for a USEPA Chamber. These were as follows:

Sweep Air Flow = 5 lpm.
Sweep Air Velocity = 5.1 m/s.
Sample flow rate = 2.5 lpm (max).

Sample Analysis

Odour samples were analysed in accordance with the Australian/New Zealand Standard 4323.3 'Stationary Source Emissions – Part 3: Determination of Odour Concentration by Dynamic Olfactometry'.

Odour concentrations were determined using a dynamic olfactometer operating in the forced choice mode with a step factor of 1.5. The odour panellists were all familiar with the procedure and specially selected in accordance with the Australian Standard criteria. The total number of dilutions of the sample at which 50 percent of all responses of the panellists confirmed odour detection is reported as the panel threshold, and is expressed in odour units (OU).

Two ports were available to each panel member; one presenting the odorous gas and one presenting a neutral reference gas (carbon-scrubbed air). Each sample was analysed three times. Individual threshold estimates for each panel member were determined and the corresponding odour concentrations were calculated, with the average response of the second and third analyses reported. The precision of results obtained by these techniques lies statistically within the 95% confidence interval.

AREA SOURCE EMISSION RATE

The area source zone flux emission rate (F_i) is calculated from:

$F_i = C_i Q / A_c$

where:
F_i = zone atmospheric contaminant flux emission rate (OU/m^2.s)
C_i = zone chamber atmospheric contaminant concentration (OU/m^3)
Q = chamber flow rate (m^3/s – wet basis)
A_c = area enclosed by chamber (m^2)

For aerated surfaces the flow rate Q is the chamber flow rate (sweep air) + surface air flow.

The total area source emission rate (E) is calculated from:

$E = \sum F_i A_i$

where:
E = area source emission rate (OU/s);
F_i = zone flux emission rate (i = 1,2,3,…..n);
Ai = zone area (m^2)

The flux hood was operated using the standard operating parameters as specified in AS/NZS 4323.4:2009 for a USEPA Chamber. These were as follows:

Sweep Air Flow = 5 lpm
Sweep Air Velocity = 5.1 m/s
Equilibration Time = 24 mins
Sample flow rate = 2.5 lpm (max)

DEFINITIONS

'OU/m^3'	Odour concentration in odour units per wet cubic meter of air at STP. It should be noted that the units OU/m^3 and OU have the same meaning, and are frequently interchanged.
'STP'	Standard temperature and pressure (0°C and 101.325 kPa).
'OU/m^2.s'	Odour flux emission rate in odour units per square meter of surface area per second.
'<'	Less than. The value stated is the analytical limit of detection.

RESULTS

Company AACo – Livingstone Beef

Date of Test 16th September, 2015

Testing Officer I. Brash

Table 1: Odour Results for Samples Collected on Wednesday 16th September 2015

Sampling Location	Description	Our Sample Number	Dilution Ratio	Sample Time	Analysis Time	Odour Conc (OU/m^3, wet)	Odour Conc (Corrected for Dilution) (OU)	Gas Temperature for Point Sources (°C)	Velocity (m/s)	Volumetric Flowrate (Nm^3/s, wet) for Point Sources	Area (m^2) for Area Sources	Odour Emission Rate of Flux Hood for Area Sources ($OU/m^2.s$)	Odour Emission Rate of Source (OU/s)
DAF sludge decanter fresh material	Normal Operation – Bin full ready to be decanted into main skip	AA01	neat	12:54	17/09/15 11:50	2,746	2,746	N/A	N/A	N/A	0.748	1.52	1.14
Paunch storage bin, fresh material (near WWTP)	Normal Operation – Bin full ready to be decanted into main skip	AA02	neat	13:28	17/09/15 12:22	1,177	1,177	N/A	N/A	N/A	1.07	0.653	0.697
DAF unit – Inlet sample	Normal Operation	AA03	neat	14:18	17/09/15 12:49	1,560	1,560	N/A	N/A	N/A	1.25 (inlet area)	0.861	1.08
DAF unit – Inlet sample	Normal Operation	AA04	neat	14:23	17/09/15 13:06	1,420	1,420	N/A	N/A	N/A	1.25 (inlet area)	0.783	0.979
DAF unit – Outlet sample	Normal Operation	AA05	neat	15:03	17/09/15 13:28	4,786	4,786	N/A	N/A	N/A	1.75 Outlet area)	2.64	4.62
DAF unit – Outlet sample	Normal Operation	AA06	neat	15:08	17/09/15 13:50	5,241	5,241	N/A	N/A	N/A	1.75 Outlet area)	2.89	5.06
DAF Sludge storage bin with contra shear scrapings – few days old (near WWTP)	Normal Operation – Full bin at least 5 days old	AA07	20:1	15:53	17/09/15 14:11	10,070	211,500	N/A	N/A	N/A	1.21	116.7	141

RESULTS CONTINUED

Company AACo – Livingstone Beef

Date of Test 17th September, 2015

Testing Officer I. Brash

Table 2: Odour Results for Samples Collected on Thursday 17th September 2015

Sampling Location	Description	Our Sample Number	Dilution Ratio	Sample Time	Analysis Time	Odour Conc (OU/m³, wet)	Odour Conc (Corrected for Dilution) (OU)	Average Gas Temperature for Point Sources (°C)	Velocity (m/s)	Area (m²) for Area Sources	Volumetric Flowrate (Nm³/s, wet) for Point Sources	Odour Emission Rate of Flux Hood for Area Sources (OU/m².s)	Odour Emission Rate of Source (OU/s)
Red fan press: tank/sump	Open sump	AA08	neat	08:44	18/09/15 10:55	372	372	32.1	0.26	0.748	0.174	N/A	64.7
Red fan press: screw conveyor	Open transfer bin – Hatch removed	AA09	neat	09:08	18/09/15 11:17	1,072	1,072	37.0	0.27	2.19	0.521	N/A	558
Raw material bin	Product in bin being screwed to conveyor	AA10	neat	09:43	18/09/15 11:38	339	339	32.0 (ambient temperature)	1.3 (Average wind speed)	17.4	-	N/A	-
Raw material bin	Product in bin being screwed to conveyor	AA15	neat	14:18	18/09/15 12:00	284	284	35.7 (ambient temperature)	1.1 (Average wind speed across bin)	17.4	-	N/A	-
Wet rendering building – centre of process area	Normal Operation with large roller door 70% closed	AA11	neat	10:10	18/09/15 12:20	260	260	35.0 (Air @ door opening)	0.41 (Air flow thru opening)	6.91 (Large door opening area)	2.51	N/A	653
Wet rendering building – near shredders	Normal Operation with large roller door 70% closed	AA12	neat	10:27	18/09/15 12:44	217	217	35.5 (Air @ door opening)	0.66 (Air flow thru opening)	6.91 (Large door opening area)	4.06	N/A	881
Paunch storage bin, aged material (near WWTP)	Normal Operation – Bin full ready to be pickup for disposal	AA13	neat	11:53	18/09/15 13:50	372	372	N/A	N/A	13.2	N/A	0.203	2.68

RESULTS CONTINUED

Company AACo – Livingstone Beef

Date of Test 17th September, 2015

Testing Officer I. Brash

Table 3: Odour Results for Samples Collected on Thursday 17th September 2015

Sampling Location	Description	Our Sample Number	Dilution Ratio	Sample Time	Analysis Time	Odour Conc (OU/m³, wet)	Odour Conc (Corrected for Dilution) (OU)	Average Gas Temperature for Point Sources (°C)	Velocity (m/s)	Area (m²) for Area Sources	Volumetric Flowrate (Nm³/s, wet) for Point Sources	Odour Emission Rate of Flux Hood for Area Sources (OU/m².s)	Odour Emission Rate of Source (OU/s)
Meat meal hammer mill cyclone wall vent	Normal Operation fan running – Product being blown out of vent)	AA16	neat	14:37	18/09/15 14:21	748	748	64.5	9.58	0.139	1.074	N/A	803
Meat meal hammer mill cyclone wall vent	Normal Operation fan running – Product being blown out of vent)	AA17	neat	14:50	18/09/15 14:43	625	625	64.5	9.58	0.139	1.074	N/A	671
Sludge storage (hook) bin, aged material (near WWTP)	Normal Operation – Bin full ready to be decanted into main skip	AA18	neat	15:29	18/09/15 15:10	681	681	N/A	N/A	13.2	N/A	0.376	4.96
Irrigation Tank	Normal Operation – effluent being transferred from DAF unit outlet	AA14	5:1	13:26	18/09/15 15:33	11,090	66,540	44.0	0.30	0.319	0.101	N/A	6,722

RESULTS CONTINUED

Company AACo – Livingstone Beef

Date of Test 18th September, 2015

Testing Officer I. Brash

Table 4: Odour Results for Samples Collected on Friday 18th September 2015

Sampling Location	Description	Our Sample Number	Dilution Ratio	Sample Time	Analysis Time	Odour Conc (OU/m^3, wet)	Odour Conc (Corrected for Dilution) (OU)	Average Gas Temperature for Point Sources (°C)	Velocity (m/s)	Area (m^2) for Area Sources	Volumetric Flowrate (Nm^3/s, wet) for Point Sources	Odour Emission Rate of Flux Hood for Area Sources ($OU/m^2.s$)	Odour Emission Rate of Source (OU/s)
Downwind AQIS Undercover Concrete Yard	Approx. 450 animals	AA19	neat	08:43	19/09/15 08:29	52	52	32.0 (ambient temperature)	1.3 (Average wind speed)	Yard area?	-	N/A	-
Downwind AQIS Undercover Concrete Yard	Approx. 450 animals	AA20	neat	08:55	19/09/15 08:29	40	40	32.0 (ambient temperature)	1.3 (Average wind speed)	Yard area?	-	N/A	-

RESULTS CONTINUED

Company AACo – Livingstone Beef

Date of Test 29th September, 2015

Testing Officer I. Brash

Table 5: Odour Results for Samples Collected on Tuesday 29th September 2015

Sampling Location	Description	Our Sample Number	Dilution Ratio	Sample Time	Analysis Time	Odour Conc (OU/m³, wet)	Odour Conc (Corrected for Dilution) (OU)	Gas Temperature for Point Sources (°C)	Velocity (m/s)	Volumetric Flowrate (Nm³/s, wet) for Point Sources	Area (m²) for Area Sources	Odour Emission Rate of Flux Hood for Area Sources (OU/m².s)	Odour Emission Rate of Source (OU/s)
Bio-filter – fourth quadrant	Normal Operation	AA21	neat	10:07	30/09/15 11:16	150	150	N/A	N/A	N/A	352	0.0838	29.5
Bio-filter – first quadrant	Normal Operation	AA22	neat	11:02	30/09/15 11:39	124	124	N/A	N/A	N/A	352	0.0695	24.5
Bio-filter – fifth quadrant	Normal Operation	AA23	neat	11:33	30/09/15 12:04	180	180	N/A	N/A	N/A	352	0.101	35.6
Bio-filter – third quadrant	Normal Operation	AA24	neat	12:09	30/09/15 12:25	311	311	N/A	N/A	N/A	352	0.173	60.9
Bio-filter – sixth quadrant	Normal Operation	AA25	neat	12:41	30/09/15 12:46	407	407	N/A	N/A	N/A	352	0.226	79.6
Bio-filter – second quadrant	Normal Operation	AA26	neat	13:12	30/09/15 13:10	105	105	N/A	N/A	N/A	352	0.0583	20.5
Tallow transfer & storage tanks – L/H	Normal Operation – Tanks constantly being filled during rendering	AA27	neat	13:38	30/09/15 14:00	406	406	32.7	0.30	0.00219	0.00817	N/A	0.889
Tallow transfer & storage tanks – R/H	Normal Operation – Tanks constantly being filled during rendering	AA28	neat	13:49	30/09/15 14:25	681	681	33.0	0.24	0.00175	0.00817	N/A	1.19
Irrigation Tank	Normal Operation – effluent being transferred from DAF unit outlet	AA29	5:1	14:26	18/09/15 14:56	2,275	13,650	45.2	0.24	0.0657	0.319	N/A	897

RESULTS CONTINUED

Company AACo – Livingstone Beef

Date of Test 29th September, 2015

Testing Officer I. Brash

Table 6: Odour Results for Samples Collected on Tuesday 29th September 2015 Continued

Sampling Location	Description	Our Sample Number	Dilution Ratio	Sample Time	Analysis Time	Odour Conc (OU/m^3, wet)	Odour Conc (Corrected for Dilution) (OU)	Gas Temperature for Point Sources (°C)	Velocity (m/s)	Volumetric Flowrate (Nm^3/s, wet) for Point Sources	Area (m^2) for Area Sources	Odour Emission Rate of Flux Hood for Area Sources ($OU/m^2.s$)	Odour Emission Rate of Source (OU/s)
Spray Irrigation	Between Irrigation	AA30	neat	17:39	01/10/15 10:05	105	105	31.0 (ambient temperature)	0.90 (Average wind speed)	-	26,880 (approx.)	N/A	-
Spray Irrigation	Between Irrigation	AA31	neat	18:09	01/10/15 10:29	75	75	31.0 (ambient temperature)	0.90 (Average wind speed)	-	26,880 (approx.)	N/A	-
Spray Irrigation – 20m Downwind	Irrigating – Started 18:12	AA32	neat	18:20	01/10/15 10:52	444	444	30.5 (ambient temperature)	1.0 (Average wind speed)	-	26,880 (approx.)	N/A	-
Spray Irrigation – 200m Downwind	Irrigating – Started 18:12	AA33	neat	18:35	01/10/15 11:16	124	124	30.5 (ambient temperature)	1.0 (Average wind speed)	-	26,880 (approx.)	N/A	-
Spray Irrigation – 400m Downwind	Irrigating – Started 18:12	AA34	neat	18:48	01/10/15 11:28	<24	<24	30.7 (ambient temperature)	0.85 (Average wind speed)	-	26,880 (approx.)	N/A	-

RESULTS CONTINUED

Company	AACo – Livingstone Beef
Date of Test	30th September, 2015
Testing Officer	I. Brash

Table 7: Odour Results for Samples Collected on Wednesday 30th September 2015

Sampling Location	Description	Our Sample Number	Dilution Ratio	Sample Time	Analysis Time	Odour Conc (OU/m^3, wet)	Odour Conc (Corrected for Dilution) (OU)	Gas Temperature for Point Sources (°C)	Velocity (m/s)	Volumetric Flowrate (Nm^3/s, wet) for Point Sources	Area (m^2) for Area Sources	Odour Emission Rate of Flux Hood for Area Sources ($OU/m^2.s$)	Odour Emission Rate of Source (OU/s)
Receival and holding yards – Upwind Sample 1	Pen 37 - No animals but used the day before.	AA35	neat	09:38	01/10/15 12:30	49	49	N/A	N/A	N/A	Pen 37= 384 (approx.)	0.0224	8.60
Receival and holding yards – Upwind Sample 2	Pen 37 - No animals but used the day before.	AA36	neat	10:07	01/10/15 12:54	81	81	N/A	N/A	N/A	Pen 37= 384 (approx.)	0.0466	17.9
Receival and holding yards – Downwind Sample 1	Pen 38 - No animals but used the day before.	AA37	neat	10:36	01/10/15 13:15	260	260	N/A	N/A	N/A	Pen 37= 384 (approx.)	0.15	57.6
Receival and holding yards – Downwind Sample 2	Pen 38 - No animals but used the day before.	AA38	neat	11:06	01/10/15 13:37	180	180	N/A	N/A	N/A	Pen 37= 384 (approx.)	0.103	40
Green Sump	Normal Operation – effluent flowing in to sump	AA39	neat	12:19	01/10/15 14:01	1,177	1,177	N/A	N/A	N/A	10.5	0.664	6.97
Green Sump	Normal Operation – effluent flowing in to sump	AA40	neat	12:22	01/10/15 14:25	976	976	N/A	N/A	N/A	10.5	0.551	5.79
Common Sump	Normal Operation – effluent flowing in to sump	AA41	neat	13:15	01/10/15 14:46	742	742	N/A	N/A	N/A	10.8	0.416	4.49
Common Sump	Normal Operation – effluent flowing in to sump	AA42	neat	13:19	01/10/15 15:11	742	742	N/A	N/A	N/A	10.8	0.500	5.40

Appendix B

Selection of a Representative Year of Meteorology for the Modelling Assessment

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1 Methodology for the Assessment of Meteorological Inter-annual Variability

1.1 Review and selection of regional meteorological observations

The nearest available automatic weather stations (AWS) to the project area that are operated by the Bureau of Meteorology are located at:

- Middle Point (26 km to the northeast), and
- Darwin Airport (38 km to the north-northwest).

Meteorological data from both stations were reviewed to determine its suitability for use in the air quality modelling. The data was analysed to select a representative year for the modeling, to provide information on local dispersion conditions and to determine whether the data was suitable for assimilation into the meteorological model or for evaluating the meteorological model's performance.

The review determined the following:

- The Middle Point AWS is 12 km closer to the site than the Darwin Airport AWS.
- While Middle Point AWS is closer to the site, it is significantly further inland from the coast than Darwin Airport AWS and the site. The site is approximately 16 km from the nearest edge of Port Darwin (upper reaches of the Middle Arm area). The Middle Point station is approximately two and half times (38 km) further away from the harbour. The Darwin Airport AWS is between five and ten kilometres from the coast in the south, west and northerly directions.
- The review of Middle Point AWS data observed a significant proportion of calm wind conditions, and more importantly, a predominant frequency of winds blowing from the north (0°). On other evidence, the regional winds were expected to have a dominant northwest (wet) and southeast (dry) seasonal flow component that was not evident at the Middle Point site. Consequently, a significant portion of the Middle Point data was considered to be erroneous due to localised effects or monitoring station error.

As a result of the review, the Middle Point station data was determined to be unsuitable to be used in the selection of a representative year for the modeling or to evaluate the meteorological model's performance. The Darwin Airport AWS data has been used to select the most representative year for the meteorological modelling.

1.2 Analysis of regional meteorological observations

Meteorological data recorded at Darwin Airport AWS were analysed to determine a representative year for use in the dispersion modelling assessment. The meteorological parameters, dataset time period and analysis conducted are summarised in Table 1-1.

Table 1-1 Meteorological data assessed at Darwin Airport AWS

Parameter	Time period assessed	Data	Analysis
Wind speed	1 September 2008 – 31 August 2013	Hourly data points from AWS	Comparisons of: • Frequency distributions (as probability density functions) as year on year and each year against the mean of all five years; • Frequency distribution anomaly (as a %) from the mean of all five years; • Correlation statistics (R^2).
Wind direction			
Wind vector U component			
Wind vector V component			
Air temperature			
Dew point temperature			
Surface atmospheric pressure			
Rainfall	September 2008 – August 2013	Annual and monthly totals (mm)	Comparison of monthly and annual rainfall totals
El Nino Southern Oscillation	2008 – 2014	Annual classification	SOI classification and strength

The selection process was based on determining which years provided the closest representation of the average state of the climate based on the variation of each meteorological parameter from the mean and each other year. For meteorological modelling and air quality assessment purposes, the key parameters that influence pollutant dispersion are wind speed, wind direction, atmospheric stability and mixing height, with stability a function of the atmosphere's vertical temperature profile and the wind speed. Notwithstanding this, these parameters can be strongly influenced by the overall state of the climate including the El Nino Southern Oscillation (ENSO), solar exposure, cloud cover and rainfall and the resulting soil and atmospheric moisture content. In general, the analysis considered the following:

- A year with a moderate or strong ENSO classification should be avoided, where possible.
- A year with anomalously low or high rainfall should be avoided, where possible.
- The distributions of wind speed and direction should be as close to the mean distribution as possible, both in terms of the frequencies of low, moderate and high wind speeds, and in the overall correlation statistics. This includes the analysis of wind in its U and V vector components.
- The distributions of temperature should be as close to the mean distribution as possible, in terms of low nocturnal and daytime high temperatures.
- The distributions of dew point temperature should be as close to the mean distribution as possible.
- The distributions of mean sea level atmospheric pressure should be as close to the mean distribution as possible.

2 Analysis of Meteorological Inter-annual Variability

2.1 Wind speed

The annual and mean frequency distributions (probability density function [pdf]) of wind speed and the anomaly of each year to the mean of the five-year period, September 2008 to August 2013, are presented in Figure 2-1 and Figure 2-2, respectively.

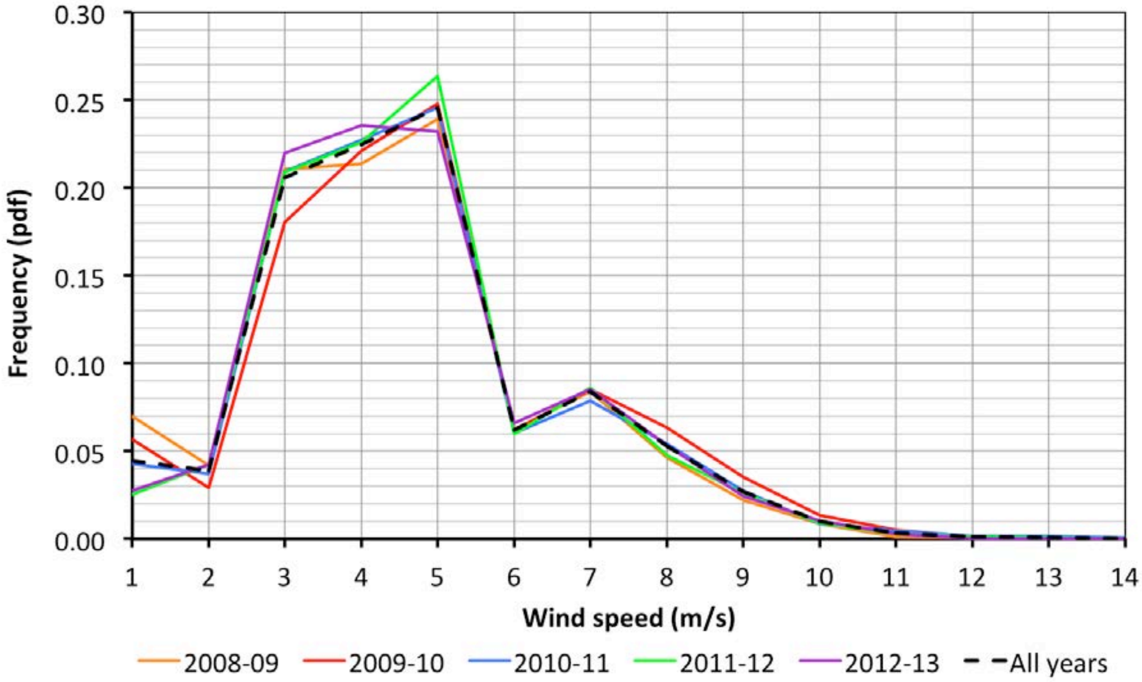


Figure 2-1 Comparison of annual observed wind speed frequency distributions to the mean

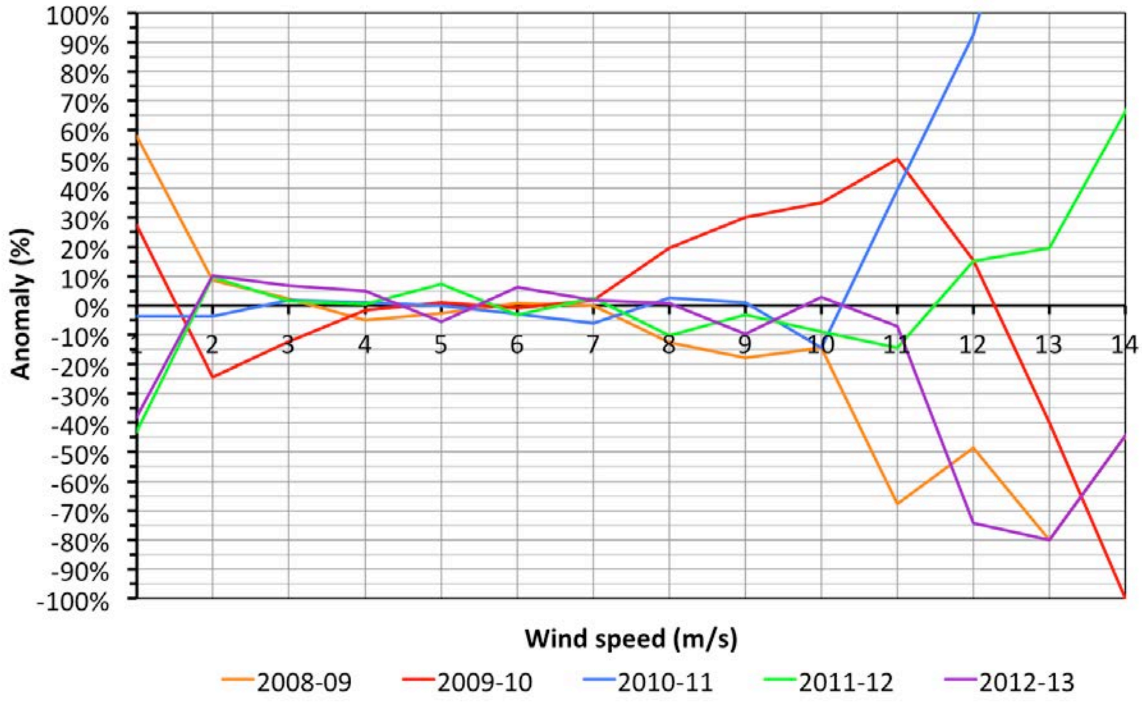


Figure 2-2 Annual observed wind speed frequency distribution anomaly from the mean

The R^2 correlation statistics for each year on year, and each year versus the mean of all years, are summarised in Table 2-1.

Table 2-1 Correlation coefficients matrix of the distributions of wind speed

Years	2008-09	2009-10	2010-11	2011-12	2012-13	All years
2009	1					
2010	0.9924	1				
2011	0.9958	0.9947	1			
2012	0.9907	0.9914	0.9974	1		
2013	0.9895	0.9866	0.9969	0.9949	1	
All years	0.9959	0.9956	0.9998	0.9976	0.9966	1

2.2 Wind direction

The annual and mean frequency distributions (probability density function [pdf]) of wind direction and the anomaly of each year to the mean of the five-year period, September 2008 to August 2013, are presented in Figure 2-3 and Figure 2-4, respectively.

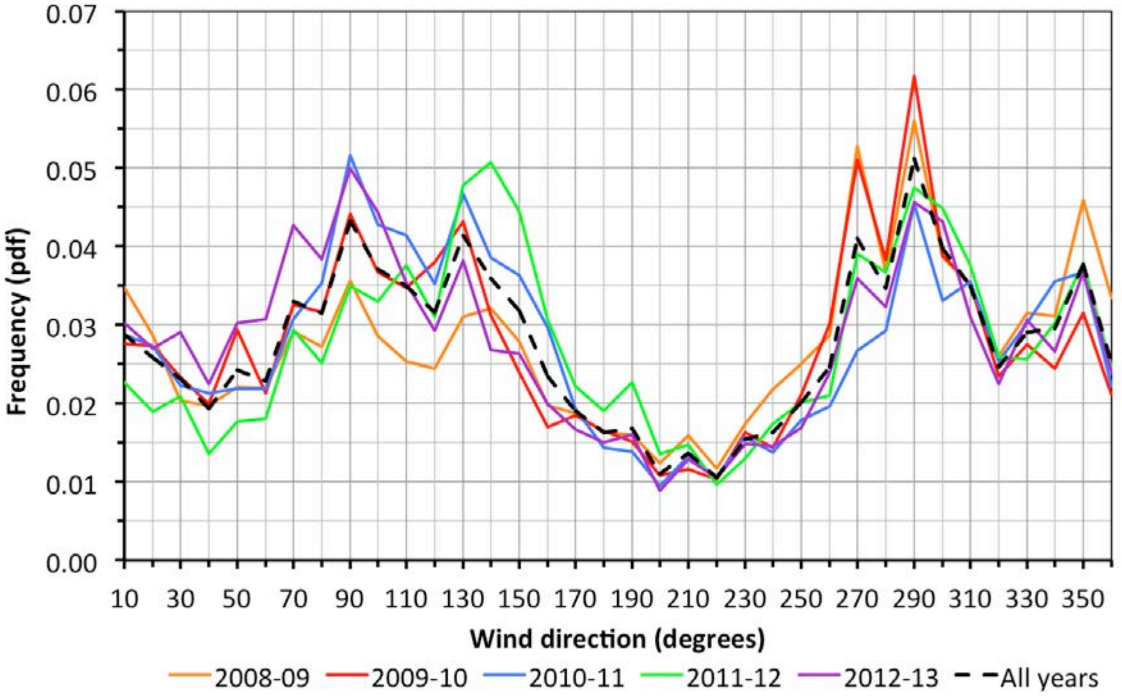


Figure 2-3 Comparison of annual observed wind direction frequency distributions to the mean

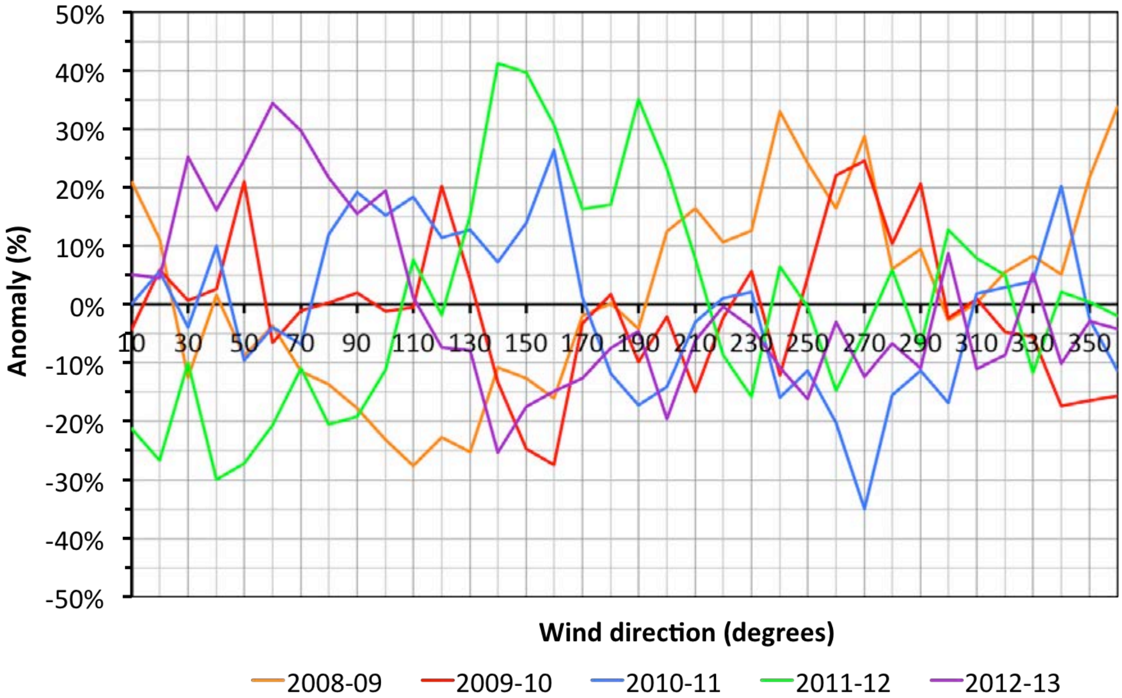


Figure 2-4 Annual observed wind direction frequency distribution anomaly from the mean

The R^2 correlation statistics for each year on year, and each year versus the mean of all years, are summarised in Table 2-2.

Table 2-2 Correlation coefficients matrix of the distributions of wind direction

Years	2008-09	2009-10	2010-11	2011-12	2012-13	All years
2009	1					
2010	0.8520	1				
2011	0.6494	0.7907	1			
2012	0.7213	0.7581	0.8238	1		
2013	0.7295	0.8661	0.8559	0.6762	1	
All years	0.8693	0.9436	0.9133	0.8825	0.9127	1

2.3 Temperature

The annual and mean frequency distributions (probability density function [pdf]) of temperature and the anomaly of each year to the mean of the five-year period, September 2008 to August 2013, are presented in Figure 2-5 and Figure 2-6, respectively.

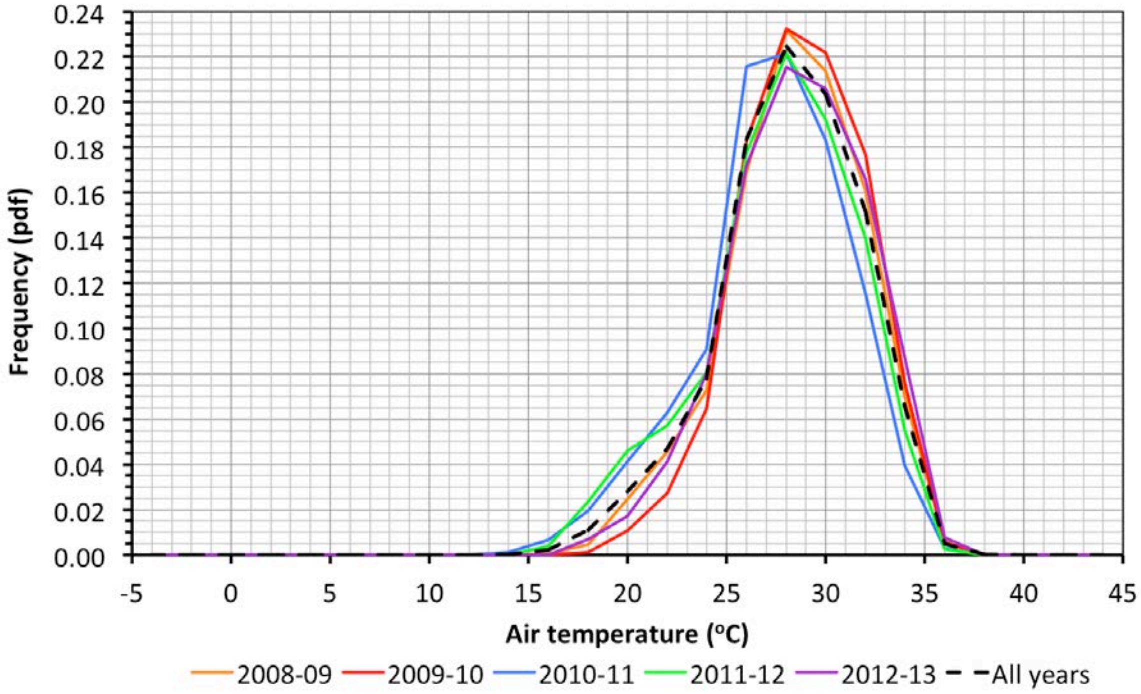


Figure 2-5 Comparison of annual observed temperature frequency distributions to the mean

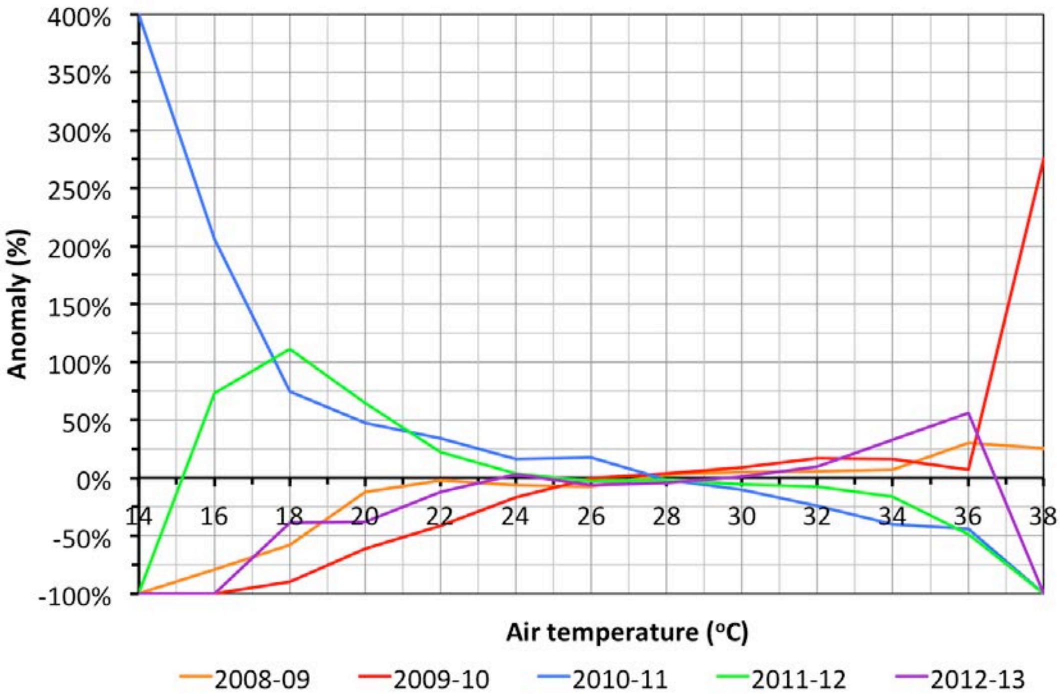


Figure 2-6 Annual observed temperature frequency distribution anomaly from the mean

The R^2 correlation statistics for each year on year, and each year versus the mean of all years, are summarised in **Error! Reference source not found.**.

Table 2-3 Correlation coefficients matrix of the distributions of temperature

Years	2008-09	2009-10	2010-11	2011-12	2012-13	All years
2009	1					
2010	0.9967	1				
2011	0.9703	0.9598	1			
2012	0.9920	0.9825	0.9891	1		
2013	0.9970	0.9966	0.9639	0.9865	1	
All years	0.9980	0.9940	0.9827	0.9964	0.9956	1

2.4 Dew point temperature

The annual and mean frequency distributions (probability density function [pdf]) of the dew point temperature are presented in Figure 2-7.

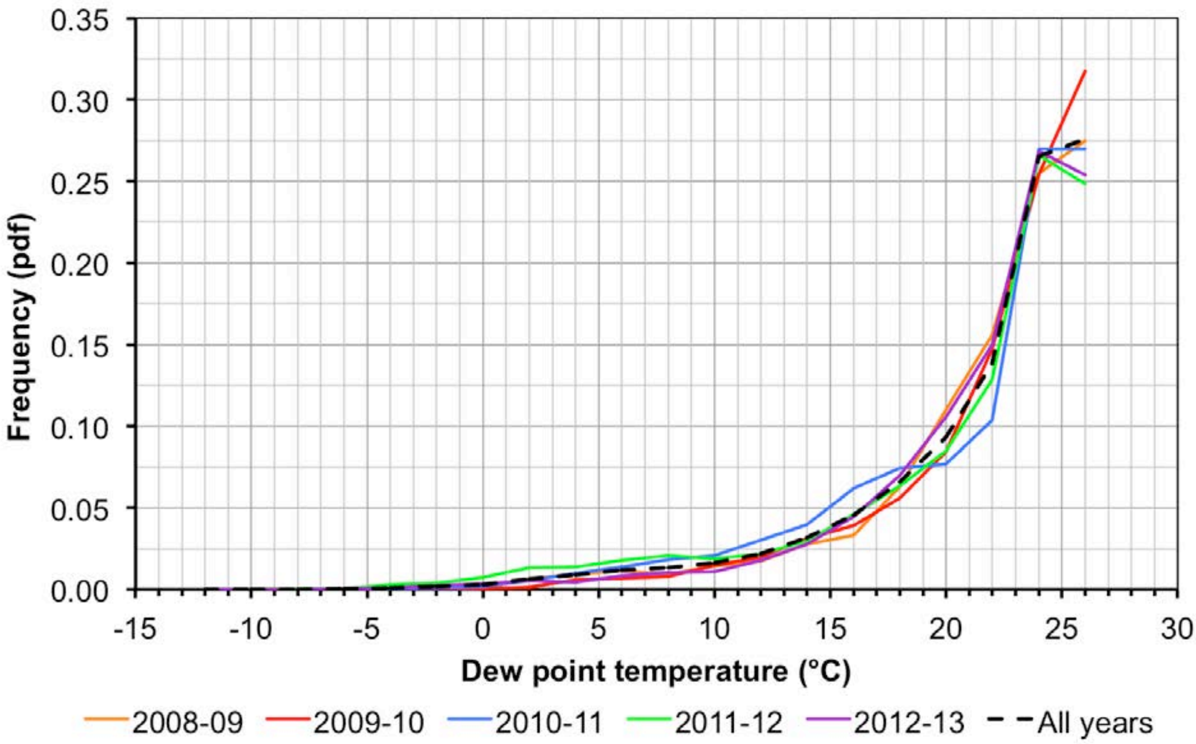


Figure 2-7 Comparison of annual observed temperature frequency distributions to the mean

The R^2 correlation statistics for each year on year, and each year versus the mean of all years, are summarised in Table 2-4.

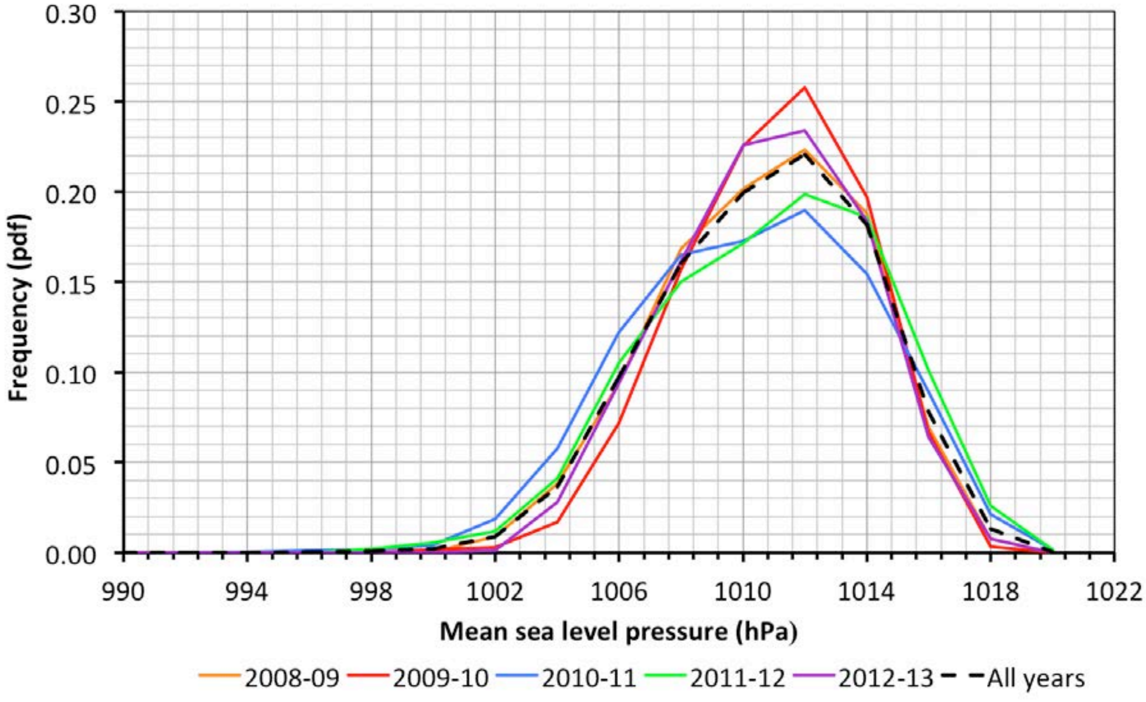
Table 2-4 Correlation coefficients matrix of the distributions of dew point temperature

Years	2008-09	2009-10	2010-11	2011-12	2012-13	All years
2009	1					
2010	0.9926	1				
2011	0.9806	0.9841	1			
2012	0.9923	0.9869	0.9933	1		
2013	0.9968	0.9860	0.9846	0.9958	1	
All years	0.9965	0.9938	0.9929	0.9976	0.9961	1

2.5 Surface atmospheric pressure

The annual and mean frequency distributions (probability density function [pdf]) of mean sea level pressure are presented in Figure 2-8.

Figure 2-8 Comparison of annual observed mean sea level pressure frequency distributions to the mean



The R^2 correlation statistics for each year on year, and each year versus the mean of all years, are summarised in Table 2-5.

Table 2-5 Correlation coefficients matrix of the distributions of mean sea level pressure

	2008-09	2009-10	2010-11	2011-12	2012-13	All years
2009	1					
2010	0.9913	1				
2011	0.9827	0.9542	1			
2012	0.9879	0.9707	0.9883	1		
2013	0.9967	0.9953	0.9729	0.9786	1	
All years	0.9992	0.9908	0.9854	0.9915	0.9966	1

2.6 Rainfall

Monthly rainfall totals for the five-year period between September 2008 and August 2013 are presented in Figure 2-9.

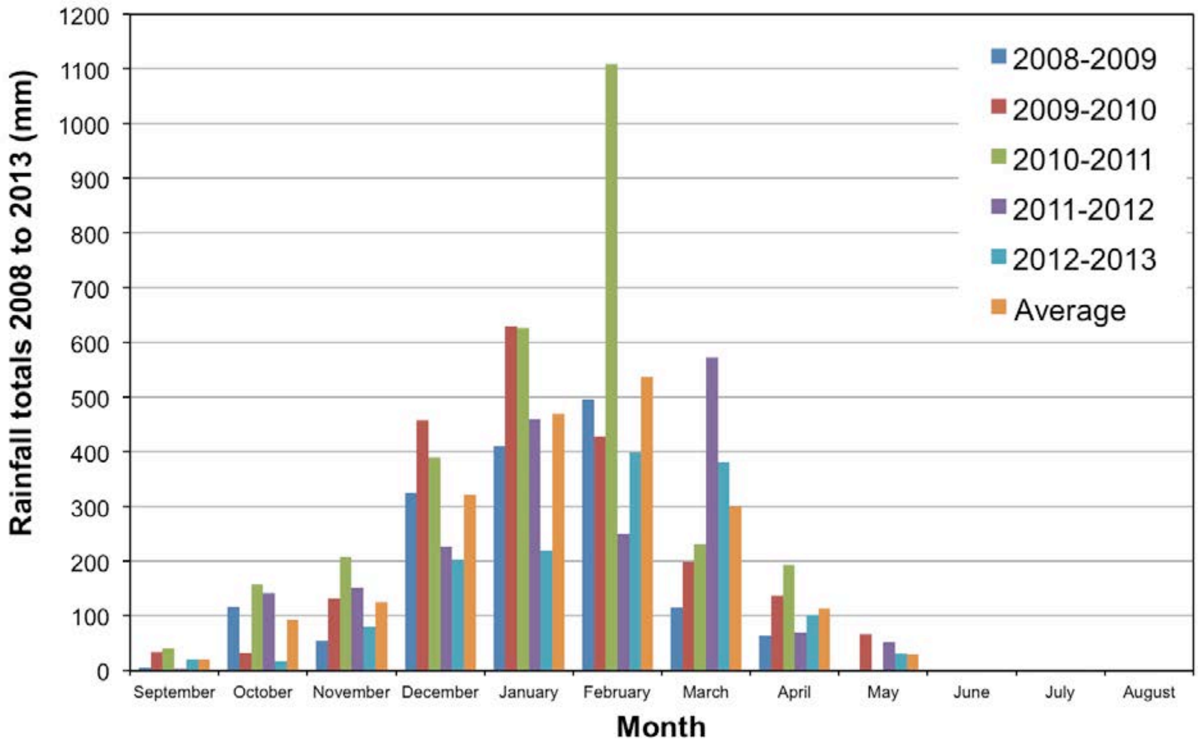


Figure 2-9 Total monthly rainfall anomaly from the mean during the period 2008 to 2013

2.7 El Niño Southern Oscillation

The El Niño Southern Oscillation (ENSO) classification and strength according to the Bureau of Meteorology for the period 2008 – 2014, are presented in Table 2-6.

Table 2-6 El Niño Southern Oscillation classifications

Year	Classification
2008-09	La Nina (weak)
2009-10	El Nino (moderate)
2010-11	La Nina (strong)
2011-12	La Nina (weak)
2012-13	Neutral
2013-14	Neutral

3 Conclusion

The correlation statistics for each meteorological parameter assessed were ranked and aggregated to determine a representative year for the meteorological modelling. The statistic rankings are presented in Table 3-1.

Table 3-1 Rankings of correlation statistics for meteorological parameters

Period	Wind Speed	Wind Direction	Temperature	Dew point	Wind Vector U	Wind Vector V	Mean sea-level pressure	Aggregate ranking	Final rank
2008-09	4	5	1	2	5	4	1	22	4
2009-10	5	1	4	4	2	1	4	21	3
2010-11	1	2	5	5	4	3	5	25	5
2011-12	2	4	2	1	1	5	3	18	1
2012-13	3	3	3	3	3	2	2	19	2

The analysis found that the:

- There was very little variability between the years for wind speed with all years having an R2 correlation of greater than 0.99 to the mean of all years. The year 2010-11 was the highest rank for wind speed correlation but was the only year with a stong La Nina. The year 2011-12 was ranked second.
- There was more variability between years for wind direction. The highest ranked year was 2009-10, which was also a moderate El Nino year.
- The year 2008-09 had the closest correlation in terms of air temperature and 2011-12 was the closest correlation of dew point temperature.
- The year 2011-12 had the highest correlation of the U component of the wind but the lowest correlation of the V component.
- The year 2008=09 had the highest correlation for mean sea-level pressure.
- None of the years consistently mirrored the mean monthly rainfall pattern. The strong La Nina of 2010-11 received more than twice the monthly rainfall for February, significantly higher than average rainfall in January but lower than average rainfall in March.
- The year 2010-11 was characterised by a strong El Nino.

Based on this assessment, the year September 2011 to August 2012 was selected as a representative period for the meteorological modelling simulation.

Appendix A
Evaluation of Meteorological Model Performance

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1 Methodology for the Evaluation of Meteorological Model Performance

1.1 Approach to the meteorological modelling

The meteorological modelling was conducted as a two-stage process once the year to model was selected. The modelling sequence was as follows:

1. Run TAPM in default mode with a standard mother domain with three nested daughter grids at 30 km, 10 km 3 km, and 1 km grid cell resolution. Evaluate output.
2. Run CALMET in No Observations mode using three-dimensional output from TAPM as an 'initial guess' in the Step 1 Wind Field. Evaluate output.

The analysis presented in this section is the model performance evaluation for steps 1 and 2.

1.2 Approach to the performance evaluation

For the evaluation of the TAPM model's performance in simulating the wind fields in the region, two statistical techniques were used:

1. Comparison of the distributions of key meteorological parameters through presentation of the modelled versus observed probability density functions for the BoM AWS site at Noonamah –
    a. Wind speed,
    b. Wind direction,
    c. Temperature,
    d. Relative humidity, and
    e. U and V vector wind components.

This analysis provides for the evaluation of the model's ability to predict the correct distributions of important parameters and is a reasonable approach to evaluating meteorological model performance.

2. Correlation of the observed and predicted wind speeds on a time and space basis including –
    a. Mean,
    b. Standard deviation,
    c. Pearson Correlation Coefficient,
    d. Index of Agreement,
    e. Root Mean Square Error (RMSE),
    f. Systematic Root Mean Square Error,
    g. Unsystematic Root Mean Square Error,
    h. Skill_E,
    i. Skill_V, and
    j. Skill_R.

This analysis is more stringent and provides for the evaluation of the model's ability to predict the correct conditions during each hour of the day. In general for a model such as TAPM, it is unrealistic to expect that the model will accurately predict the surface conditions at a specific point in space at the exact same time. The model is a regional-scale model that is skilled at computing the fluid dynamics of general synoptic-scale atmospheric circulations and predicting phenomena such as sea breezes, land breezes, large scale terrain affected flows and temperatures based on variable synoptic inputs, terrain, soil type and land use influences.

To evaluate the model's ability to predict the correct wind direction for each hour of the day, wind speed must be included in the analysis. Consequently, the entire wind field is broken down into its vector components, U and V.

1.3 Correlation statistics for observed and predicted meteorology

Balch (2009) summarised the following statistical approach for the evaluation of meteorological model performance based on the methods described by Chang and Hanna (2005) and Wilmott (1982).

Root mean square error (RMSE)

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(P_i - O_i)^2}$$

Where:

N = number of observed and predicted hours in analysis (i.e. one year)
P = hourly prediction
O = hourly observation

The RSME can be described as the standard deviation of the difference for hourly predicted and observed pairings at a specific point. The RMSE is a quadratic scoring rule, which measures the average magnitude of the error. The difference between predicted and corresponding observed values are each squared and then averaged over the sample. Finally, the square root of the average is taken. Since the errors are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This means the RMSE is most useful when large errors are particularly undesirable. Overall, the RSME is a good overall measure of model performance, but since large errors are weighted heavily (due to squaring), its value can be distorted. RMSE is equal to the unit of the values being analysed i.e., an RMSE of 1.2 for wind speed = 1.2 m/s.

Systematic root mean square error ($RMSE_S$)

$$\text{RMSE}_S = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\hat{P}_i - O_i)^2}$$

Where:

N = number of observed and predicted hours in analysis (i.e. one year)
$\hat{P}$ = mean of predictions
O = hourly observation

The $RMSE_S$ is calculated as the square root of the mean square difference of hourly predictions from the regression formula and observation pairings, at a specific point. The regressed predictions are taken from the least squares formula. The $RMSE_S$ estimates the model's linear (or systematic) error. The systematic error is a measure of the bias in the model due to user input or model deficiency, i.e., data input errors, assimilation variables, and choice of model options. The $RMSE_S$ is a metric for the model's accuracy.

Unsystematic root mean square error ($RMSE_u$)

$$\mathrm{RMSE}_U = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\hat{P}_i - P_i)^2}$$

Where:

N = number of observed and predicted hours in analysis (i.e. one year)
$\hat{P}$ = mean of predictions
O = hourly prediction

The $RMSE_u$ is calculated as the square root of the mean square difference of hourly predictions from the regression formula and model prediction value pairings, at a specific point. The $RMSE_u$ is a measure of how much of the difference between predictions and observations result from random processes or influences outside the legitimate range of the model. This error may require model refinement, such as new algorithms or higher resolution grids, or that the phenomena being simulated cannot be fully resolved by the model. The $RMSE_u$ is a metric for the model's precision.

Ultimately, for good model performance, the RMSE should be a low value, with most of the variation explained in the observations. Here, the systematic error $RMSE_s$ should approach zero and the unsystematic error, $RMSE_{u,}$ should approach the RMSE since:

$$\mathrm{RMSE}^2 = \mathrm{RMSE}_S^2 + \mathrm{RMSE}_u^2$$

Mean error and mean absolute error

The Mean Error (ME) is simply the average of the hourly modelled values minus the hourly observed values. It contains both systematic and unsystematic errors and is heavily influence by high and low errors.

The Mean Absolute Error (MAE) measures the average magnitude of the errors in a set of predictions, without considering their direction. It measures accuracy for continuous variables. Expressed in words, the MAE is the average of the absolute values of the differences between predictions and the corresponding observation. The MAE is a linear score, which means that all the individual differences are weighted equally in the average. The MAE and the RMSE can be used together to diagnose the variation in the errors in a set of predictions. The RMSE will always be larger or equal to the MAE; the greater difference between them, the greater the variance in the individual errors in the sample. If the RMSE = MAE, then all the errors are of the same magnitude. Both the MAE and RMSE can range from 0 to ∞. They are negatively-oriented scores, i.e., lower values are better.

Index of agreement

The Index of Agreement (IOA) is defined as:

$$\mathrm{IOA} = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i - O_{mean}| + |O_i - O_{mean}|)^2}$$

The IOA is calculated using a method described in Willmott (1982). The IOA can take a value between 0 and 1, with 1 indicating perfect agreement. The IOA is the ratio of the total RMSE to the sum of two differences, i.e., the difference between each prediction and the observed mean, and the difference between each observation and observed mean. From another perspective, the IOA is a measure of the match between the departure of each prediction from the observed mean and the departure of each observation from the observed mean. A value of 0.5 is considered acceptable and >0.6 is considered good performance for time and space predictions.

Where:

N is the number of observations,

P_i are the hourly model predictions,

O_i are the hourly observations,

O_{mean} is the observed observation mean, and $\hat{P}_i = a + bO_i$ is the linear regression fitted with intercepts a and slope b.

Skill measures

Skill measure statistics are given in terms of a score, rather than in absolute terms. A model's skill can be measured by the difference in the standard deviation of the modelled and observed values (Chang and Hanna, 2004).

The **Skill_E (se)** is indicative of how much of the standard deviation in the observations is predicted to be due to random/natural processes (unsystematic) in the atmospheric boundary layer. i.e., turbulence/chaos. For good model performance, the value for Skill_E should be less than one, i.e.:

SKILL_E = (RMSE_U/ STDEV OBS) < 1 shows skill

Skill_V (sv) is ratio of the standard deviation of the model predictions to the standard deviation of the observations. For good model performance, the value for Skill_V should be close to one, i.e.:

SKILL_V = (STDEV_MOD/ STDEV _OBS) close to 1 shows skill

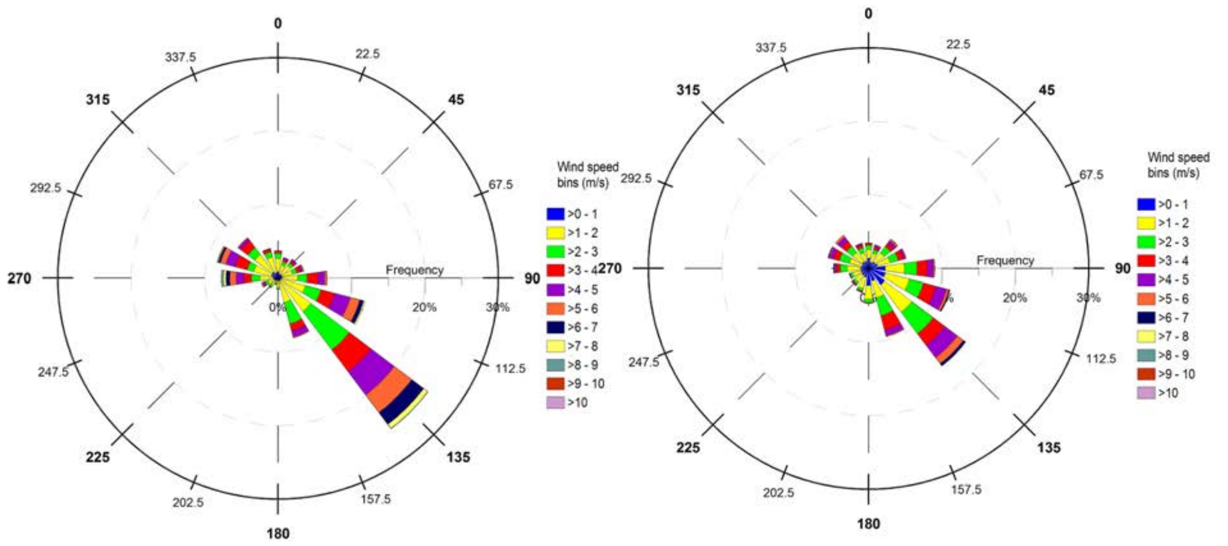
SKILL_R (sr) takes into account systematic and unsystematic errors in relation to the observed standard deviation. For good model performance, the value for Skill_E should be less than one, i.e.:

SKILL_R = (RMSE/ STDEV _OBS) < 1 shows skill

2 TAPM Model Performance Evaluation

AEC (2015) presented a evaluation of the TAPM model's performance based on a comparison with observations at Darwin Airport. In this section, the same model output has been evaluated against the BOM Noonamah station dataset.

A comparison of TAPM predicted and observed meteorology is presented in this section. The wind rose diagrams for the TAPM predicted and AWS observed wind distributions are presented in Figure 2-1. The winds are based on observations and model predictions at the location of the BOM Noonamah AWS.



TAPM predicted AWS Observations

Figure 2-1 Distributions of wind speed and direction, as a wind rose diagram, for the TAPM predicted and BOM AWS datasets

The comparison of the distributions of meteorological variables is presented as probability density function plots for wind speed, wind direction, temperature, relative humidity, the vector U wind and vector V wind components in Figure 2-2 to Figure 2-9, respectively.

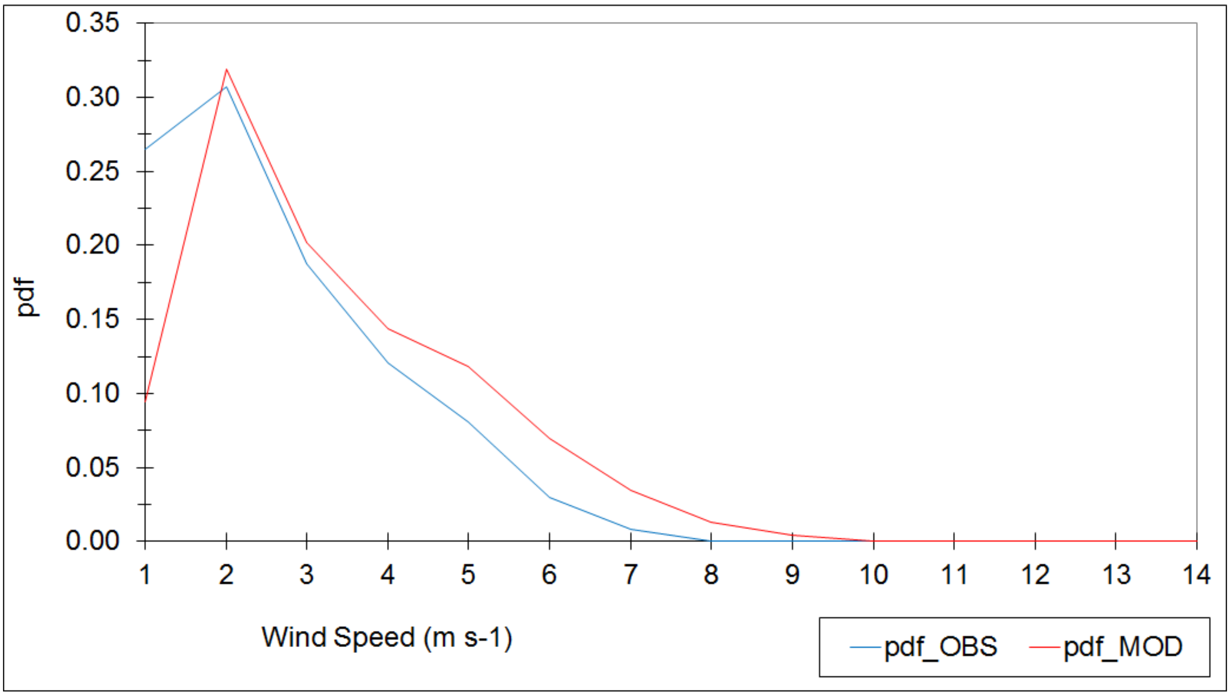


Figure 2-2 Frequency distributions of observed versus TAPM predicted (modelled) wind speed

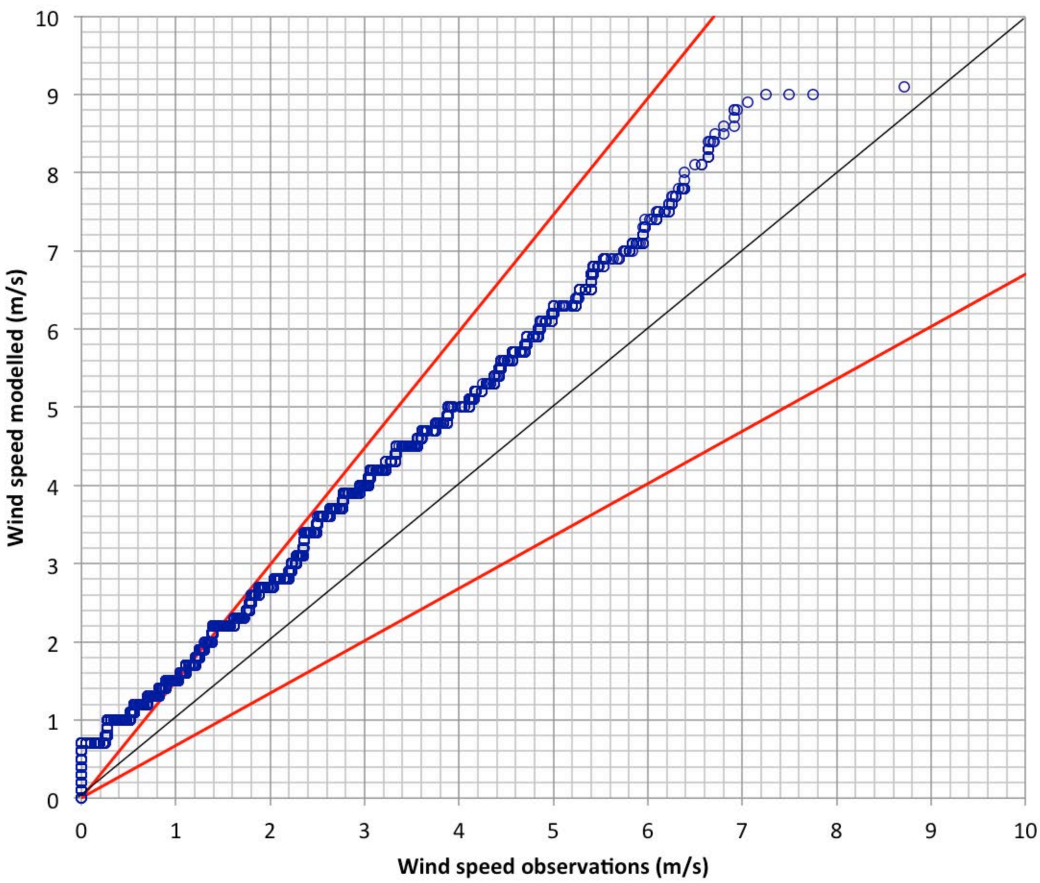


Figure 2-3 Quantile-quantile plot relationship between observed and TAPM predicted (modelled) wind speed

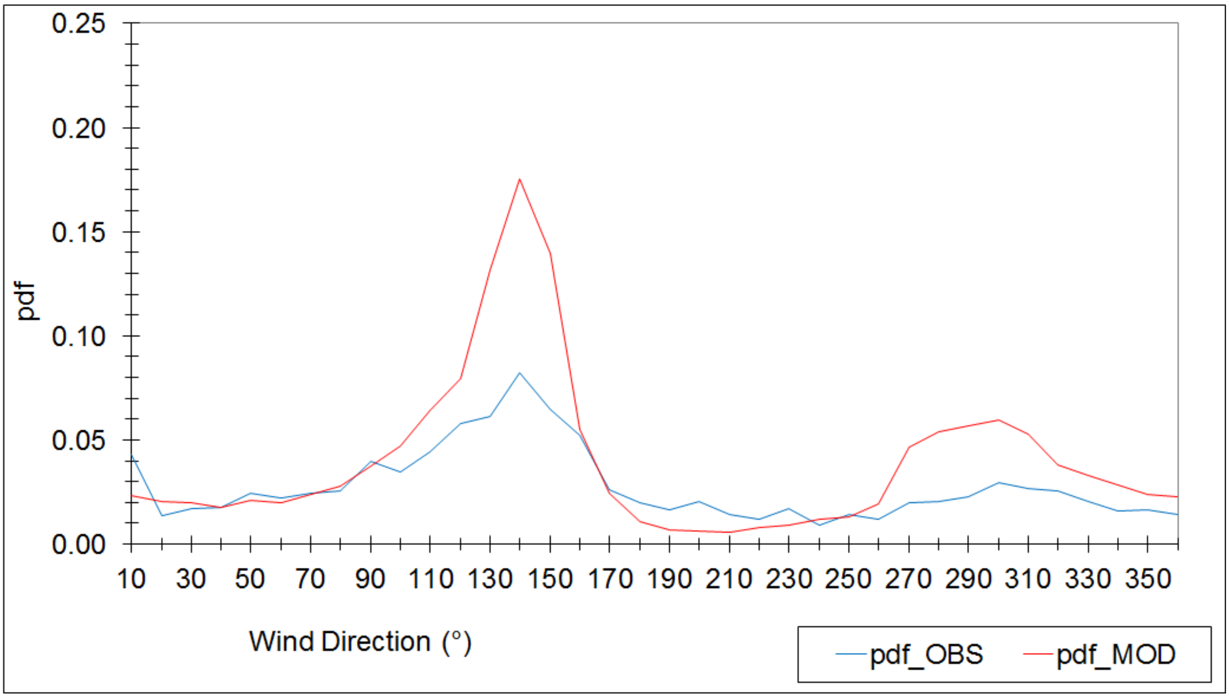


Figure 2-4 Frequency distributions of observed versus TAPM predicted (modelled) wind direction

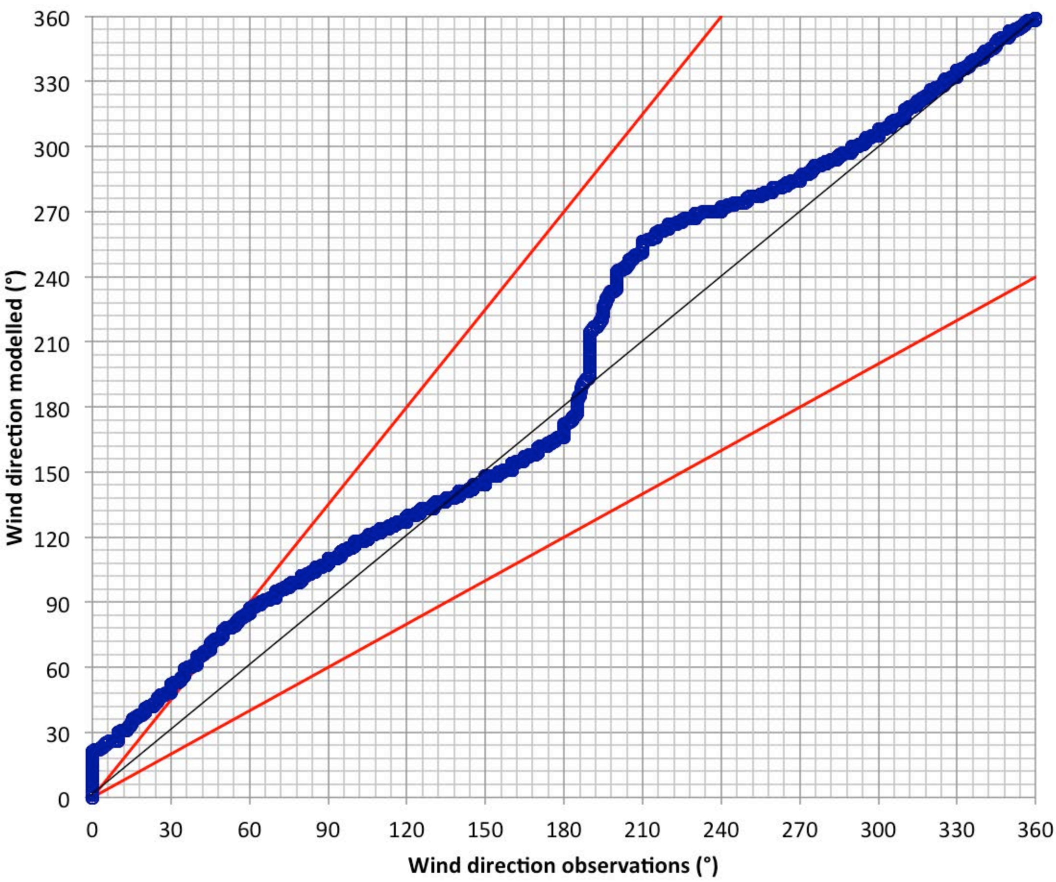


Figure 2-5 Quantile-quantile plot relationship between observed and TAPM predicted (modelled) wind direction

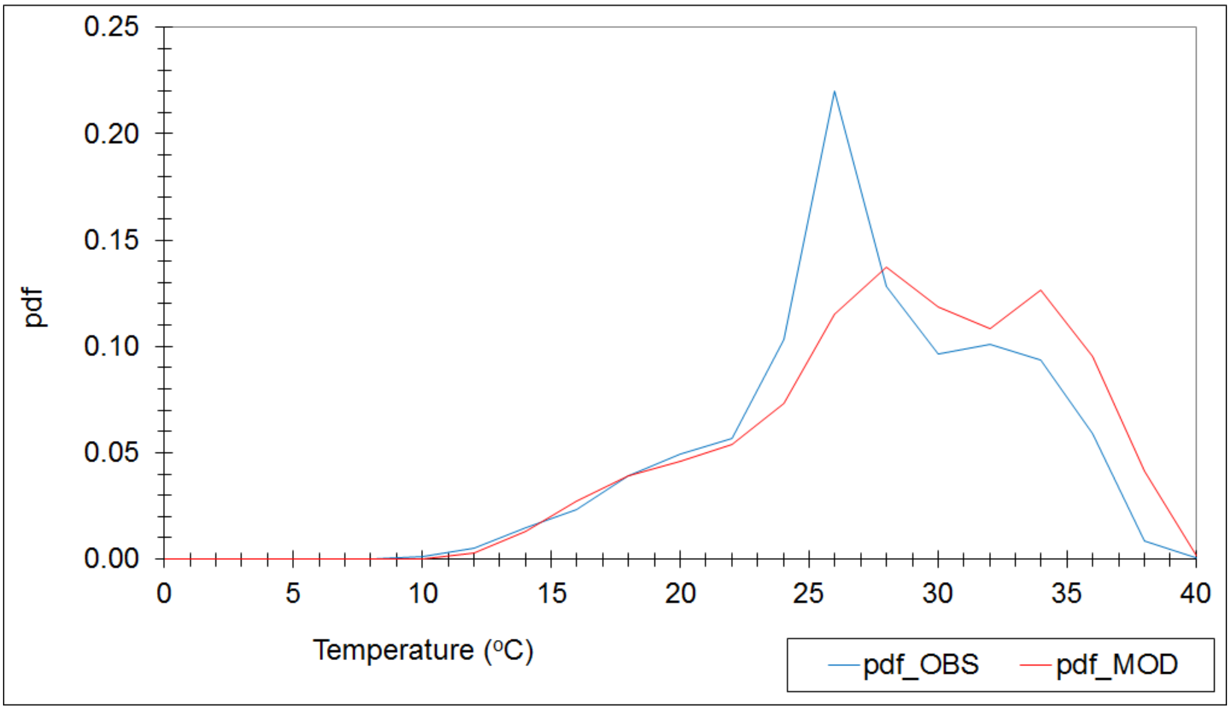


Figure 2-6 Frequency distributions of observed versus TAPM predicted (modelled) surface air temperatures

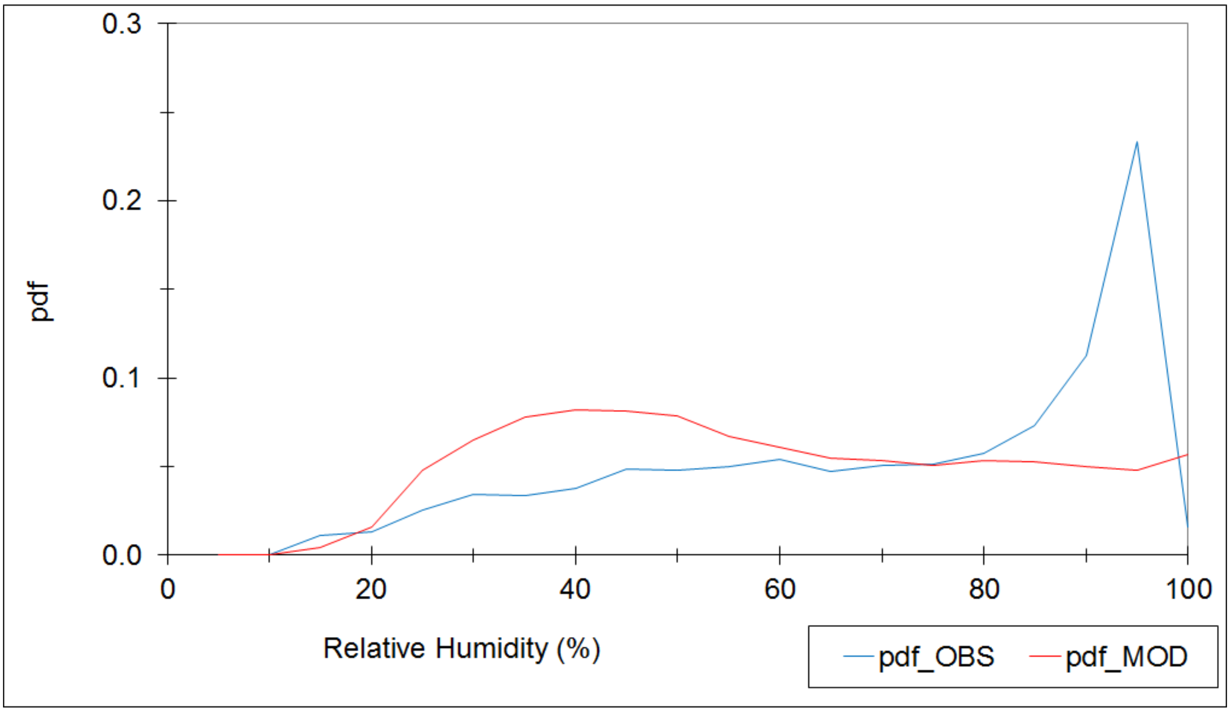


Figure 2-7 Frequency distributions of observed versus TAPM predicted (modelled) relative humidity

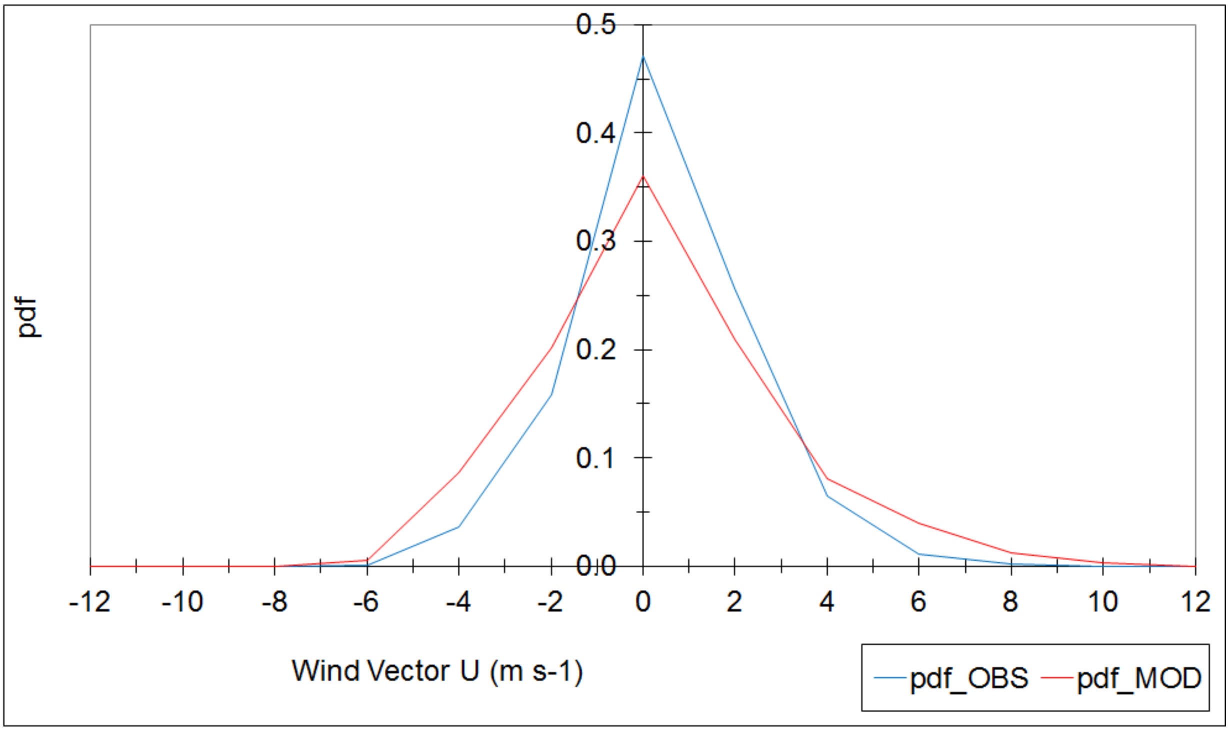


Figure 2-8 Frequency distributions of observed versus TAPM predicted (modelled) wind vector component U

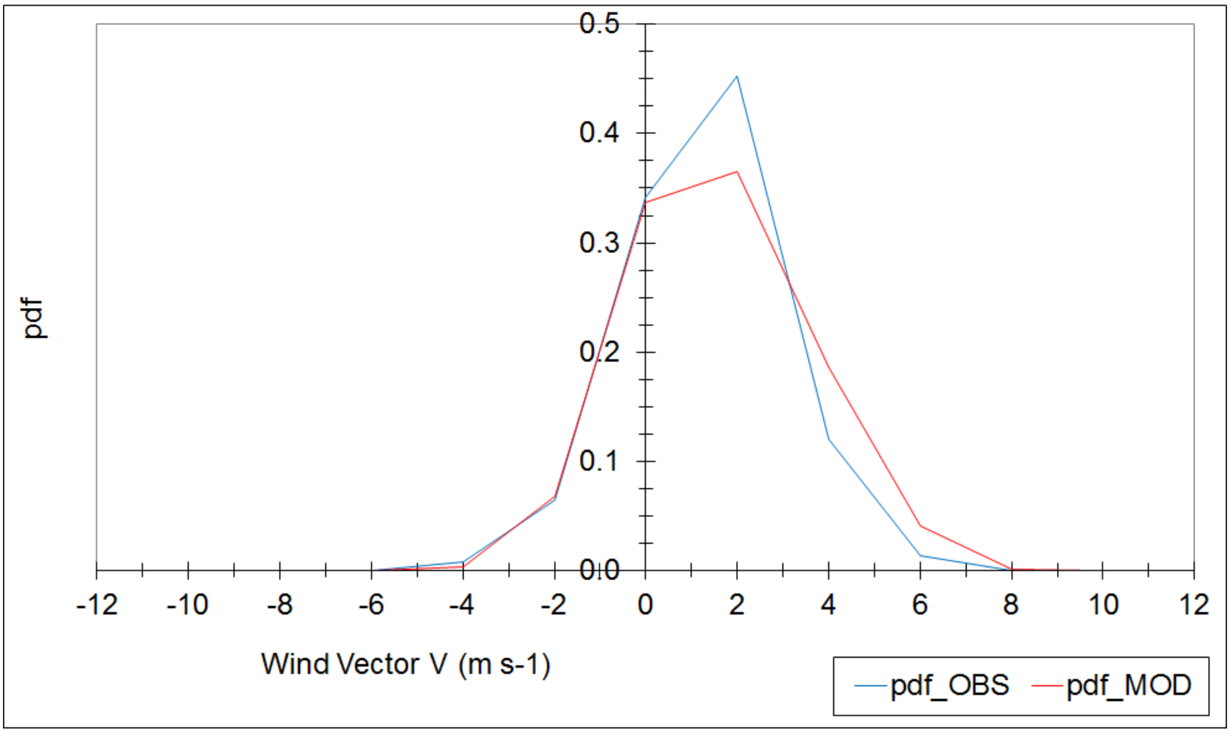


Figure 2-9 Frequency distributions of observed versus TAPM predicted (modelled) wind vector component V

Descriptive statistics for the modelled and observed winds are presented in Table 2-1. Correlation statistics for the performance of TAPM when compared to the observations at Noonamah AWS are summarised in Table 2-2.

Table 2-1 Descriptive statistics for meteorological observations and TAPM model predictions

Descriptive Statistics	Wind speed		Wind direction		Temperature		U Vector wind		V Vector wind	
	AWS OBS	TAPM MOD	AWS OBS	TAPM MOD	AWS OBS	TAPM MOD	AWS OBS	TAPM MOD	AWS OBS	TAPM MOD
Average	2.0	2.9	159	174	26.2	27.5	-0.6	-0.7	0.3	0.6
Standard deviation	1.4	1.7	94	93	5.3	5.9	1.8	2.6	1.6	1.8
Minimum	0.0	0.0	0	0	9.3	9.9	-8.4	-7.4	-5.9	-5.1
Maximum	8.7	9.1	360	359	38.5	39.0	7.2	9.0	6.4	6.1

Table 2-2 Correlation statistics for TAPM meteorological model performance

Statistics	Wind speed	Wind direction	Temperature	U vector wind	V vector wind
Root Mean Square Error	1.5	107.4	2.7	1.7	1.4
Systematic Root Mean Square Error	0.8	63.1	1.3	0.3	0.5
Unsystematic Root Mean Square Error	1.2	86.8	2.4	1.6	1.4
Index of Agreement	0.78	0.64	0.94	0.84	0.81
$Skill_e$	0.84	0.92	0.45	0.90	0.86
$Skill_v$	1.18	0.99	1.10	1.44	1.17
$Skill_r$	1.02	1.14	0.51	0.92	0.90
Mean Absolute Error	1.15	67.86	2.10	1.30	1.12

The data indicates the following:

- TAPM under-predicts the frequency of light winds at Noonamah in the 0 – 1 m/s range but performs very well in predicting the frequency of winds greater than 1 m/s. This is unusual for TAPM v4, which commonly over-predicts the distribution of light winds. This was the case when the model was compared with Darwin Airport observations. Notwithstanding this, the assessment has investigated the highest 1% and the maximum ground-level odour concentrations. The under-estimation of light winds the Noonamah region is unlikely to affect the prediction of the highest impacts.
- TAPM performs reasonably well in predicting the shape (i.e. the dominant northwesterly and southeasterly seasonal flow) of the distribution of wind direction but the comparison against observations at Noonamah suggests TAPM overestimates the peaks in the distribution. The dominant northwesterly and southeasterly seasonal flow in northern Australia is a function of the shifting Inter-Tropical Convergence Zone (ITCZ) and associated Australian monsoon trough over the continent. This generates southeasterly trade winds during the dry season and a return flow northwesterly wind during the monsoon (or wet season) (Sturman and Tapper, p.64). The significant scatter in the AWS observations may be due to localised obstacles, terrain and/or sea breeze effects that are not easily resolved by the regional-scale (1 kilometre resolution) of the meteorological model. Further inland at the site, the wind pattern is expected to more closely follow the synoptic flow predicted by TAPM. Installation of an AWS at the NABL site would provide a useful means to confirm the local wind patterns for air quality management and model evaluation.
- TAPM performs reasonably well in predicting surface air temperatures. However, TAPM tends to slightly over-predict the frequency of temperatures above 28°C, and under-predicts the frequency of temperatures between 23 – 28°C.

- TAPM tends to over-predict the frequency of relative humidity between 25-60% and under-predict the frequency of humidity greater than 60%.
- TAPM performs reasonably well in predicting the general shape of the distributions of the U and V vector wind components but over-predicts the peakedness of the distributions.

The correlation statistics indicate the following:

- The RMSE and MAE statistics indicate a slightly poor performance. However it is not expected that TAPM will predict the exact wind speed and direction in time and space,
- All IOA values are >0.6, which indicates good model performance for time and space pairings.
- $Skill_e$ values are all <1, which indicates good model performance, and suggests that variability in the observations is due to natural, unsystematic processes.
- $Skill_v$ values for wind speed and direction are reasonably close to 1, which indicates good model performance. However, the $Skill_v$ values for the U vector component of the wind indicate that perhaps the model does not perform well in predicting the correct wind speed and direction together, in the same hour.
- $Skill_r$ values for wind speed and direction are close to but slightly greater than 1, indicating slightly poor performance. However, the $Skill_r$ values of temperature, and the U and V vector components of the wind are well below 1, indicating good model performance.

3 Conclusion

The meteorological model evaluation indicates that TAPM has performed reasonably well in predicting the regional flows and the distributions of each meteorological parameter, and that the statistical scores are generally within the range expected of a good dispersion model. Consequently, it is considered that TAPM is suitable for use in the modelling study. Some of the anomalies and inconsistencies illustrated in the model's performance evaluation may be explained by the location and performance of the AWS when comparing the observations to a regional meteorological model.

The TAPM output has been used as an input to the CALMET meteorological pre-processor to down-scale the meteorology to the local scale within a seven kilometre radius of the NABL facility. There are no meteorological monitoring stations situated within the CALMET domain with a full year of data. NABL has installed an AWS at the site, however it is yet to record a full year of data. The use of this data should be explored in the future. Consequently, further evaluation of the CALMET model performance was unable to be conducted. Notwithstanding this, CALMET was configured in 'No Observations' mode, with minimal change to the wind patterns expected.