Air Quality Assessment for the Proposed Yeelirrie Development Western Australia

Prepared for

BHP BILLITON

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FINAL

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Contents

Glossary

Term	Definition
BoM	Bureau of Meteorology
°C	degrees Celsius
CO	Carbon monoxide
CO_2	Carbon dioxide
DEC	Department of Environment and Conservation
ERMP	Environmental Review and Management Programme
km	kilometre
km/h	kilometre per hour
m	metre
m/s	metres per second
m^2	square metres
m^3	cubic metres
m^3/s	cubic metres per second
mg	milligram
Mtpa	Million tonnes per annum
NEPC	National Environment Protection Council
NEPM	National Environmental Protection Measure
NO_2	Nitrogen dioxide
NO_X	Oxides of nitrogen
NPI	National Pollutant Inventory
ou	Odour units
PM	Particulate matter (fine dust)
$PM_{2.5}$	Particulate matter with aerodynamic diameter less than 10 microns
PM_{10}	Particulate matter with aerodynamic diameter less than 2.5 microns
SO_2	Sulfur dioxide
t	tonnes
tpa	tonnes per annum
TSF	Tailings storage facility
TSP	Total suspended particles
µg/m^3	micrograms per cubic metre
µm	microns
UOC	Uranium oxide concentrate
UO_42H_2O	Uranium peroxide
US EPA	United States Environment Protection Agency

Executive Summary

BHP Billiton Yeelirrie Development Company Pty Ltd proposes to develop an open pit uranium mine and associated processing facility at Yeelirrie in the Northern Goldfields region of Western Australia, approximately 420 km north of Kalgoorlie and 60 km west of Mt Keith. The proposed Yeelirrie development would produce approximately 3,500 tpa of uranium peroxide ($UO_4.2H_2O$), more commonly referred to as uranium oxide concentrate (UOC), through the development and operation of an open pit mine and on-site Metallurgical Plant.

Katestone Environmental has been commissioned by BHP Billiton to undertake an air quality impact assessment as part of the ERMP for the proposed Yeelirrie development. The air quality impact assessment investigated the potential for impacts associated with mining operations for a scenario representing a stage in the development that is likely to result in the highest ground-level concentrations at the closest sensitive receptors. The assessment used meteorological and dispersion models to assess the emissions (TSP, PM_{10}, $PM_{2.5}$ and dust deposition) from the proposed Yeelirrie development in isolation (operationally contributed) and with the inclusion of ambient background levels of dust representative of the region. The ground-level concentrations due to emissions associated with onsite power generation (diesel generators) were also assessed and include nitrogen dioxide (NO_2), sulfur dioxide (SO_2) and carbon monoxide (CO).

The cumulative air quality impact assessment indicates that the air quality criteria for $PM_{2.5}$, PM_{10}, TSP and dust deposition are achieved at any sensitive receptor due to the operation of the mine. Assessment of SO_2, NO_2 and CO indicates that the relevant air quality criteria are met at all sensitive receptors due to emissions from the onsite power generation.

1. Introduction

Katestone Environmental has been commissioned by BHP Billiton to undertake an air quality impact assessment as part of the Environmental Review and Management Programme (ERMP) for the proposed Yeelirrie development in Western Australia.

BHP Billiton Yeelirrie Development Company Pty Ltd proposes to develop an open cut uranium mine at Yeelirrie located approximately 420 km north of Kalgoorlie and 60 km west of its Mount Keith operations in the Murchison geologic region of Western Australia (Figure 1). The proposed Yeelirrie development will involve mining of up to 8 Mtpa of mineralised uranium ore using open cut mining techniques over an anticipated mine life of up to 30 years. Processing of the uranium ore will be carried out at the on-site Metallurgical Plant. The proposed Yeelirrie development will produce up to 3,500 tonnes per annum (tpa) of uranium oxide concentrate during the 30-year life of the project.

This report describes the methods and findings of an assessment of the potential impacts to the air environment due to construction and mining operations. The purpose of this assessment is to:

- Describe the climate, local meteorology and existing air environment in the development area
- Quantify emissions of dust (TSP, PM_{10} and $PM_{2.5}$) from all mine related sources
- Quantify emissions of other air pollutants from all mine related sources, including onsite power generation
- Conduct air dispersion modelling using accepted techniques
- Evaluate the incremental air quality impacts of the proposed Yeelirrie development on the air environment
- Evaluate the cumulative air quality impacts of the proposed Yeelirrie development on the air environment
- Present the results in relation to relevant ambient air criteria
- Recommend dust management and mitigation strategies where applicable

2. Project description

BHP Billiton Yeelirrie Development Company Pty Ltd proposes to develop an open pit uranium mine and associated processing facility at Yeelirrie in the Northern Goldfields region of Western Australia, approximately 420 km north of Kalgoorlie, 60 km west of Mt Keith, 70 km southwest of Wiluna and 110 km northwest of Leinster (Figure 1). The proposed Yeelirrie development would produce approximately 3,500 tpa of uranium peroxide ($UO_4.2H_2O$), more commonly referred to as uranium oxide concentrate (UOC), through the development and operation of an open pit mine and on-site Metallurgical Plant.

The key characteristics of the proposed development that are important to the air quality impact assessment are summarised in Table 1. A complete description of the proposed Yeelirrie development is included in the Project Description (BHP Billiton, 2010).

Table 1 Key characteristics of the proposed Yeelirrie development important to the air quality assessment

Element	Description
Project operating life	Up to 30 years
Nature of mineralisation	Shallow-depth alluvial deposit about 10 m below ground level with a thickness of between 1 – 7 m
Operations summary	Open pit mining and on-site processing of uranium mineralised ore to produce uranium oxide concentrate
Mining method	Conventional open pit mining using conventional open pit mining equipment such as excavators, front-end loaders and haul trucks
Mining rate	Up to 8 Mtpa of mineralised ore and non-mineralised material
Processing method	Alkali leach and direct precipitation
Production rate	Up to 3,500 tpa of uranium oxide concentrate
Tailings management	In-pit disposal to an engineered Tailings Storage Facility
Maximum electricity demand	12 MW
Average electricity consumption	72,000 MWh per annum
Maximum diesel demand	38,000 KL per annum (excluding product transport diesel)
Location of operation	Yeelirrie is located about 110 km northwest of Leinster, 60 km west of Mt Keith and about 420 km north of Kalgoorlie
Mineralisation footprint	Approximately 9 km in length and up to 1.5 km in width (averages about 1 km in width)
Project footprint	The proposed Yeelirrie development would result in the disturbance of up to 5,000 hectares within the nominated project area
Accommodation village	A village would be constructed about 20 km east of the Metallurgical Plant, with sufficient accommodation for up to 1,200 personnel
Quarry	A quarry supplying approximately 500,000 tonnes of basic raw material will be located about 8 km north of the Metallurgical Plant, covering an area up to 10 ha to a depth averaging 5 m

3. Assessment methodology

3.1 Overview

The potential impact of the proposed Yeelirrie development on the air environment was assessed by developing an air quality modelling system consisting of an:

1. Emissions model, using detailed source characteristics and operational activity data provided by BHP Billiton
2. Meteorological model, using regional and local meteorology, land use and terrain characteristics to represent the air environment for the development site
3. Dispersion model, combining the emissions model and meteorological model to predict the impact potential of the proposed Yeelirrie development on the air environment

Technical descriptions of the modelling components are presented in the following sections and in detail in Appendix A and B.

3.2 Climate assessment methodology

The proposed Yeelirrie development site lies on the western edge of the Great Victoria Desert in central Western Australia (WA) in the Murchison geologic region (Figure 1). Being an arid inland region the climate and weather are dominated by the exchange of energy between the land surface and the atmosphere. These predominantly local scale features are in turn modulated by the west coast trough, which dominates the southwest region of WA, and the Australian monsoon which dominates the northwest region of WA.

Fourteen years (1994 to 2009) of data were analysed from meteorological monitoring sites operated by the Bureau of Meteorology (BoM) to determine the large scale synoptic and regional weather patterns relevant to the air environment at the proposed Yeelirrie development site. Highly localised data gathered from a monitoring campaign undertaken in 1977 and 1981 are also referred to in developing a detailed understanding of the local air environment. These data have been supplemented with three-dimensional meteorological data from The Air Pollution Model (TAPMv4) developed by the CSIRO.

A summary of the Western Australian Climate is presented in Section 5.1. A comprehensive climate analysis is provided in Appendix C.

3.3 Modelling

3.3.1 Emissions model

Dust emissions from the proposed Yeelirrie development have been estimated based on representative emission factors from the National Pollutant Inventory (NPI) mining handbook and USEPA AP-42 documents and detailed source characteristics and operational activity data provided by BHP Billiton. Emissions have been estimated for one year of operations, based on operational activities at the mine that have the potential to cause the highest ground-level concentrations at the closest sensitive receptors.

Technical descriptions of the emissions model are outlined in Section 6 and in detail in Appendix A.

3.3.2 Meteorological model

The site specific meteorological data for this study was generated by coupling TAPM, a prognostic mesoscale model to CALMET, a diagnostic dispersion model. The coupled TAPM/CALMET modelling system was developed by Katestone Environmental to enable detailed air dispersion modelling capabilities for regulatory and environmental assessments. The modelling system incorporates synoptic, mesoscale and local atmospheric conditions, detailed topography and land use categorisation schemes to simulate synoptic and regional scale meteorology for input into pollutant dispersion models, such as CALPUFF. Complete details of the model configuration and analysis are provided in Appendix B.

As there are no site specific surface and upper air data to initialise the air dispersion model, a three dimensional meteorological dataset was required to assess the potential air quality impacts from the proposed Yeelirrie development. Five Bureau of Meteorology monitoring sites were assessed and found to be representative of the synoptic and regional scale meteorology of Western Australian and the Murchison geologic region (Appendix C). These sites where assimilated into the prognostic meteorological model (TAPM) to ensure that the frequency and distribution of the regional scale meteorology are represented in the model as accurately as possible (40 km radius of influence up to 150 m above ground-level). TAPM was run for a 5 year period beginning in December 2003 and ending in November 2008. The staggered start and end periods was intentional to ensure that seasonal components are continuous for analysis purposes.

TAPM was initialised with the following parameters:

- 50 by 50 mother domain at a horizontal resolution of 30 km
- 3 nested domains at a horizontal resolution of 10 km, 3 km and 1 km
- 25 vertical levels from 10 m to 8000 m
- Land use and terrain generated from AUSLIG 9 arc second database (TAPM default) and crosschecked against data provided by BHP Billiton from previous assessments
- Data assimilation site at Kalgoorlie, Geraldton, Laverton and Meekatharra

The three dimensional TAPM output was then used as input for CALMET the meteorological pre-processor for CALPUFF, the air dispersion model. CALMET was initialised at 1 km with land and terrain generated from the SRTM3 database and crosschecked with AUSLIG database and the data supplied by BHP Billiton. All datasets were found to be consistent. CALMET was situated within the TAPM 1 km domain and offset by 1 grid cell generating a 1 km horizontal resolution domain consisting of 48 by 48 grid nodes.

Spatial analysis of the terrain digital elevation model (DEM) was conducted to determine whether modelling meteorology at a horizontal resolution of less than 1 km was warranted. A 300 m DEM was generated and compared to the 1 km DEM for the inner most modelling domain. No significant difference was discernable between the 1 km DEM and the 300 m DEM (Figure 8). As land use remains the same throughout the inner most modelling domain increasing the terrain resolution would not improve the modelling results as all the terrain features in the region are well represented in the 1 km DEM.

A cluster analysis has been performed on the 5 year modelling dataset to compare the local data to the regional BoM sites. This was done to determine the model's capability of simulating the local atmospheric conditions experienced at the proposed Yeelirrie development site. The results of the cluster analysis of the modelled meteorology are presented in Appendix B. The modelled meteorology was found to accurately simulate the frequency and distribution of weather types found to occur at Yeelirrie. Modelled wind speeds tended to be slightly higher, and temperatures slightly lower than the Yeelirrie data might suggest; however, this may be due to data collection techniques.

The 5 year period from 2003 to 2008 was also analysed for any significant variation between the years. Modelled and monitored data were compared and found to be consistent between the years, indicating that any one year would be representative and therefore suitable for the assessment of air quality impacts. A twelve-month period from December 2007 to November 2008 was chosen to initialise the air dispersion model.

3.3.3 Dispersion model

Atmospheric dispersion modelling was carried out using the CALPUFF Version 6.4 dispersion model (EarthTec) to predict the ground-level concentrations of particulate matter, sulfur dioxide, carbon monoxide and nitrogen dioxide and dust deposition rates.

The CALPUFF dispersion model utilises the three-dimensional wind fields from CALMET to simulate the dispersion of air pollutants to predict ground-level concentrations across a gridded domain. CALPUFF is a non-steady-state Lagrangian Gaussian puff model containing parameterisations for complex terrain effects, overwater transport, coastal interaction effects, building downwash, wet and dry removal, and simple chemical transformation. CALPUFF employs the three dimensional meteorological fields generated from the CALMET model by simulating the effects of time and space varying meteorological conditions on pollutant transport, transformation and removal. CALPUFF contains algorithms that can resolve near-source effects such as building downwash, transitional plume rise, partial plume penetration, sub-grid scale terrain interactions, as well as the long range effects of removal, transformation, vertical wind shear, overwater transport and coastal interactions. Emission sources can be characterised as arbitrarily-varying point, area, volume and lines or any combination of those sources within the modelling domain.

Dust dispersion modelling was carried out for the scenario representing the operations at the mine likely to result in the greatest impacts to the air environment surrounding the proposed Yeelirrie development. The model was configured to assess the dispersion and predict the impact of TSP, PM_{10}, $PM_{2.5}$ and dust deposition within the modelling domain. For dust deposition modelling, a particle size distribution was included based on size fractions of TSP, PM_{10} and $PM_{2.5}$ reported for the various mine sources in AP-42.

The model was also configured to assess the dispersion and predict the impact of sulfur dioxide, nitrogen dioxide and carbon monoxide from the onsite diesel generators within the modelling domain.

Twelve months of modelled meteorological data was used as input for the dispersion model. This encompasses all weather conditions likely to be experienced in the region during a typical year (Appendix B). CALPUFF was nested down by a factor of 2 generating a 500 m horizontal resolution calculation grid for the prediction of ground-level concentrations.

Key features of CALPUFF used to stimulate dispersion are as follows:

- Domain area of 90 by 90 grid points at 500 m spacing
- 365 days (1 December 2007 to 30 November 2008)
- Dispersion coefficients calculated internally from sigma v and sigma w using micrometeorological variables
- Minimum turbulence velocity of sigma-v over land set to 0.2 m/s
- Minimum wind speed allowed for non-calm conditions 0.2 m/s

- Maximum mixing height 4600 m
- Minimum mixing height 20 m
- Dry deposition modelled as computed particle

All other options set to default.

3.4 Impact assessment

3.4.1 Air quality criteria

Air quality in Western Australia is assessed according to standards specified by the NEPM(Air) through the National Environmental Protection Council (Western Australia) Act 1996 (WA DEC, 1996). For other significant air pollutants not covered by the NEPM(Air), the Department of Environment and Conservation (DEC) adopts the World Health Organisation's Guidelines for Air Quality or air quality guidelines from other jurisdictions where appropriate, with appropriate amendments to suit the Western Australian context (Department of Environment, Government of Western Australia, 2004). Air quality criteria used in this assessment are presented in Section 4.

The air quality study includes an assessment of TSP, PM_{10}, $PM_{2.5}$ and dust deposition rates for one scenario representing a stage of the life of the mine with highest potential to impact the air environment. The cumulative ground-level concentrations (operationally contributed plus background) have been compared with the relevant air quality criteria.

The predicted increases in ground-level concentrations of nitrogen dioxide, carbon monoxide and sulfur dioxide have been compared with the relevant air quality criteria.

3.4.2 Background-levels for assessment

To determine the impact of a project upon the surrounding environment a representative background concentration for all assessed pollutants is required.

Monitoring of sulfur dioxide, nitrogen dioxide, carbon monoxide and particulates are currently carried out by the Department of Environment and Conservation (DEC) in the Perth metropolitan, southwest and Kalgoorlie regions of Western Australia. The network of monitoring stations have been selected to monitor wind-blown crustal material and smoke from bushfires, hazard reduction or stubble burning and wood-fired heaters in the industrial and residential areas of Western Australia.

A summary of the monitoring data recorded at the sites most representative of the proposed Yeelirrie development site is presented in Table 2 and Table 3.

Table 2 DEC monitoring data summary for the Perth metropolitan and southwest regions of Western Australia during 2008

Pollutant	Averaging Period	Monitoring station	Average	95th Percentile	75th Percentile	50th Percentile
Carbon monoxide	8-hour	Duncraig (north metropolitan region)	-	687 µg/m³ (0.6 ppm)	343 µg/m³ (0.3 ppm)	229 µg/m³ (0.2 ppm)
Nitrogen dioxide	1-hour	Rolling Green (outer east rural)	-	30.1 µg/m³ (0.016 ppm)	20.7 µg/m³ (0.011 ppm)	13.2 µg/m³ (0.007 ppm)
Sulfur dioxide	1-hour	Rockingham (south coast)	-	39.3 µg/m³ (0.015 ppm)	5.2 µg/m³ (0.002 ppm)	2.6 µg/m³ (0.001 ppm)
	24-hour		-	5.2 µg/m³ (0.002 ppm)	2.6 µg/m³ (0.001 ppm)	0.0 µg/m³ (0.000 ppm)
PM_{10}	24-hour	Caversham (north east metropolitan region)	-	26.1 µg/m³	17.1 µg/m³	12.9 µg/m³
$PM_{2.5}$	24-hour	Caversham (north east metropolitan region)	-	11.7 µg/m³	8.2 µg/m³	6.5 µg/m³
	Annual		7.1 µg/m³	-	-	-

Table note: Data source: Government of Western Australia Department of Environment and Conservation, 2008 Western Australia Air Monitoring Report (December 2009)

Table 3 DEC particulate (24-hour average PM_{10}) monitoring data summary for Kalgoorlie, Perth and Geraldton in Western Australia during 2006 and 2007

Monitoring station	Year	6th Highest (µg/m³)	99th Percentile (µg/m³)	95th Percentile (µg/m³)	90th Percentile (µg/m³)
Boulder Shire Yard, Kalgoorlie-Boulder	2006	43.7	55.2	33.6	26.5
	2007	53.2	59.6	37.9	33.7
Hannans Golf Club, Kalgoorlie-Boulder	2006	39.7	47.4	26.8	23.0
	2007	67.8	95.6	47.5	37.0
Geraldton	2006	46.6	48.6	40.0	35.4
	2007	77.5	87.2	44.7	36.4
Caversham, Perth	2006	35.8	38.4	29.3	26.4
	2007	37.2	39.7	30.3	26.1
Duncraig, Perth	2006	31.5	32.9	27.3	24.0
	2007	30.3	31.8	25.8	22.0

Table note: Data source: Government of Western Australia Department of Environment and Conservation, Ambient monitoring of particulate matter in Kalgoorlie, 2006 – 2007 Technical Report (May 2009)

Iluka Resources also currently conducts dust monitoring of PM_{10} (TEOM) at the Iluka North Mine Site at Eneabba, approximately 500 km southwest of the proposed Yeelirrie development site. Iluka Resources Midwest Annual Environmental report 2007 reported that, whilst the 24-hour average PM_{10} NEPM(Air) standard of 50 µg/m³ was exceeded on three occasions in the town of Eneabba, the 24-hour average ground-level concentrations for 2007 were generally lower than 30 µg/m³. The dust levels recorded at the Eneabba monitoring station would be higher than those occurring at the proposed Yeelirrie development site due to the close proximity of the Eneabba monitoring station to the Iluka North Mine.

The DEC monitoring stations are generally located within the urbanised coastal regions of Western Australia, with the closest monitoring station (Geraldton) located over 500 km west of the proposed Yeelirrie development site. The DEC monitoring stations are influenced by urban activities and industrial emission sources that tend to emit a higher proportion of fine particles to total suspended particles (TSP) than occurs in the natural environment. The sources of carbon monoxide, nitrogen dioxide and sulfur dioxide are also expected to be significantly greater than those in the pastoral Yeelirrie region. Consequently, measurements of particulates, CO, NO_2 and SO_2 at the DEC sites would be higher than those occurring at the proposed Yeelirrie development site, which is a significant distance from any industrialised, urban environments.

Notwithstanding this, a cumulative assessment of particulates has been conducted assuming background-levels presented in Table 4 based on the data from the DEC monitoring stations. The background levels are assumed to be constant across the region and have been added to each CALPUFF grid cell.

As there are no monitoring sites representative of the proposed Yeelirrie development site, values of 25 µg/m^3 and 10 µg/m^3 were chosen to represent the background 24-hour average concentrations of PM_{10} and $PM_{2.5}$ respectively. These values are based on the range of values shown in Table 3. Annual PM_{10} concentrations are taken as 50% of the 24 hour average following the relationship found at the Caversham monitor between the 95th percentile and the 50th percentile for PM_{10} and the annual $PM_{2.5}$ concentration are taken from the Caversham monitor as a conservative estimate.

There are currently no known measurements of TSP in the region. The standard conversion ratios detailed in the United States Environmental Protection Agencies (US EPA's) Compilation of Air Pollution Emission Factors Volume 1 (AP-42) and in the NPI Handbooks, have found that PM_{10} is usually 50% of the TSP concentration. In accordance with standard industry practice, this ratio has been employed for this assessment.

The estimates shown in Table 4 are based on the range of monitoring data from all the monitoring sites (Table 3), taking into account the station locations, localised influences and previous assessments by Katestone Environmental.

There are currently no monitoring of dust deposition levels in the surrounding region. The New South Wales DECCW (Department of Environment, Climate Change and Water Quality) states that, for the prevention of impacts to amenities, the predicted incremental increase in dust deposition levels due to the operation of a facility must not exceed the criteria of 2.0 g/m²/month (DECCW, 2008). Due to the absence of dust deposition monitoring data in the vicinity of the proposed Yeelirrie development, the assessment criteria specified by the NSW DECCW has been used in this assessment.

The background concentrations will provide a conservative estimate of the accumulative impact from the proposed Yeelirrie development. As the background estimates are based on monitoring data from regions subject to anthropogenic pollution sources as well as natural (fugitive) sources, the concentrations will be significantly higher than those likely to be experienced at Yeelirrie. Monitoring of ambient dust levels at the proposed Yeelirrie development site prior to and during operation of the mine will confirm background levels of particulates at the site.

This assessment has not included a background concentration for carbon monoxide, nitrogen dioxide or sulfur dioxide due to the lack of significant existing sources of these pollutants in the region, with all sources located greater than 60 km from the proposed Yeelirrie development site.

Table 4 TSP, PM_{10} and $PM_{2.5}$ concentrations used as background concentrations for the proposed Yeelirrie development

Pollutant	Averaging period	Concentration ($\mu g/m^3$)
TSP	24-hour	50
	Annual	25
PM_{10}	24-hour	25
	Annual	12.5
$PM_{2.5}$	24-hour	10
	Annual	7.1

3.4.3 Method for the Conversion of Oxides of Nitrogen to Nitrogen Dioxide

Nitric oxide (NO) emissions from the onsite diesel generators will undergo chemical transformation in the atmosphere to form nitrogen dioxide (NO_2). As NO_2 is more toxic than NO, it is important to quantify the transformation of NO to NO_2 to assess the predicted ground-level NO_2 concentrations against the air quality criteria. NO and NO_2 are collectively termed oxides of nitrogen (NO_X).

The actual degree of conversion of oxides of nitrogen to nitrogen dioxide in a plume will depend on atmospheric conditions at the time that the emissions occur. Measurements around power stations in Central Queensland show, under worst possible cases, a conversion of 25-40% of the nitric oxide to nitrogen dioxide occurs within the first 10 km of plume travel. During days with elevated background levels of hydrocarbons (generally originating from bush-fires, hazard reduction burning or other similar activities), the resulting conversion is usually below 50% in the first 30 km of plume travel (Bofinger et al, 1986).

For this assessment a conservative ratio of 30% conversion of the oxides of nitrogen to nitrogen dioxide has been assumed to estimate the ground-level concentrations of nitrogen dioxide resulting from the operation of the onsite diesel generators.

4. Air quality guidelines

The National Environmental Protection Council defines national ambient air quality standards and goals in consultation with, and agreement from, all state governments. These were first published in 1997 in the National Environmental Protection (Ambient Air Quality Measure (NEPM(Air)). The NEPM(Air) standards for the most significant pollutants that may arise from the proposed Yeelirrie development are presented in Table 5.

Table 5 National Environmental Protection (Ambient Air Quality) Measure standard

Pollutant	Averaging period	NEPM (Air) standard (µg/m³)	NEPM (Air) goal – maximum allowable exceedances
PM_{10}	24-hour	50	5 days per year
NO_2	1-hour	246	1 day per year
	Annual	62	None
SO_2	1hour	572	1 day per year
	24-hour	229	1 day per year
	Annual	57	None
CO	8-hour	11,000	1 day per year

For other significant air pollutants not covered by the NEPM(Air), the DEC adopts the World Health Organisation's Guidelines for Air Quality or air quality guidelines from other jurisdictions where appropriate, with appropriate amendments to suit the Western Australian context (Department of Environment, Government of Western Australia, 2004). Air quality guidelines for the most significant pollutants that may arise from the proposed Yeelirrie development are summarised in Table 6. Western Australia specifies a 24-hour average TSP guideline in the Environmental Protection (Kwinana) (Atmospheric Wastes) Policy 1999. In the Kwinana area, a 24-hour average standard of 90 µg/m³ (limit of 150 µg/m³) applies for an isolated residential dwelling.

Table 6 Relevant air quality guidelines

Pollutant	Averaging period	Air quality guidelines	Units	Source
Total suspended particulates (TSP)	24-hour	90	µg/m³	Kwinana
	Annual	90	µg/m³	NSW DECCW
Particulate matter less than 10 µm (PM_{10})	24-hour	50	µg/m³	NEPM
	Annual	25	µg/m³	WHO guideline
Particulate matter less than 2.5 µm ($PM_{2.5}$)	24-hour	25	µg/m³	NEPM advisory standard
	Annual	8	µg/m³	NEPM advisory standard
Dust deposition rate	Annual	2 [a]	g/m²/month	NSW DECCW[c]
		4 [b]		

Table note:

[a] Maximum increase in deposited dust level

[b] Maximum total deposited dust level
[c] Amenity dust guideline

5. Existing environment

5.1 Climate

The Western Australian climate varies significantly throughout the state. While the southern regions of Western Australia experience the four typical seasons (spring, summer, autumn and winter), in the northern areas of the state the seasons are generally described as either wet or dry. In addition, there is a reduction in rainfall and an increase in temperature extremes and variability with an increase in distance from the Western Australia coastline.

Seven Bureau of Meteorology (BoM) monitoring sites have been analysed in order to assess the climate of the proposed Yeelirrie development site at the synoptic, regional and local scale. The seven sites are considered to be representative of the large scale synoptic climate, the regional arid inland environment or the local environment of the proposed Yeelirrie development site (Table 7, Figure 2).

Table 7 Existing monitoring stations operated by the Bureau of Meteorology

Site	Type	Location	Monitoring period analysed	Data frequency	Distance and direction to proposed development site (approx Km)	Distance from site to WA coastline (approx km)
Geraldton Airport	Synoptic	28.80 °S 114.70 °E	1993-2009	1-hour	540 km SW	50 km
Kalgoorlie-Boulder Airport	Synoptic	30.78 °S 121.45 °E	1994-2008	1-hour	500 km SSE	600 km
Meekatharra Airport	Synoptic	26.61 °S 118.54 °E	1993-2008	1-hour	150 km NW	470 km
Laverton Airport	Synoptic	28.61 °S 122.42 °E	1991 - present	1-hour	300 km SE	760 km
Leinster	Regional	27.84 °S 120.70 °E	1994-2009	1-hour	105 km SE	595 km
Wiluna	Regional	26.59 °S 120.23 °E	2006 - present	9 am and 3 pm	70 km NNE	630 km
Yeelirrie	Local	27.28 °S 120.09 °E	2006 - present	6 am, 9 am, and 3M	20 km SE	600 km

The climate of Western Australia is strongly influenced by the size of the Australian land mass, as well as large scale synoptic processes such as warm/cold frontal systems, cut-off lows, the west coast trough, blocking highs, the southern annual mode, the Indian ocean dipole, cloud bands and tropical lows (Australian Government, 2008).

The inland areas of Western Australia show a predominance of east to southwest winds during spring and summer, shifting to a distinct alternating westerly and easterly flow during autumn and winter. While coastal locations record a high frequency of moderate to strong winds from the north-northeast to northeast during winter, shifting to winds predominantly from the south during spring and summer (Figure 3). The synoptic conditions responsible for these shifts in wind patterns were analysed using the K-means clustering algorithm to identify the main weather types across the region, with the results presented in Appendix C.

A detailed climate analysis was undertaken to ensure that the main weather types observed across the region surrounding the proposed Yeelirrie development are well represented in the meteorological fields used in the dispersion modelling for the air quality assessment. This analysis is presented in Appendix C.

5.2 Local terrain and land use

The land use of the Wiluna Shire in central Western Australia is predominantly pastoral rangeland, with regions of hummock grassland, woodland, shrubland and low open forest (Figure 4).

The uranium deposit occurs in carbonated sediments in the central drainage channel of a wide, flat and long valley that is flanked by granite breakaways of low topographic relief, some 50 to 100 metres and an elevation of 480 to 595 metres above sea level.

The current land uses of the proposed Yeelirrie development area are predominantly fenced pastoral land. Trial mining activities were performed in the area by Western Mining Corporation (WMC) between 1978 and 1983. The open-cut trial pits were closed in 1994 and decommissioned and revegetated in 2000 and 2004.

5.3 Sensitive receptors

The proposed Yeelirrie development site is located on the Yeelirrie pastoral property in the East Murchison pastoral region. This region is sparsely populated with homesteads approximately 30 km and more apart. The proposed Yeelirrie development site is relatively isolated, with the nearest receptors located more than 10 km from the ore body. The nearest sensitive receptors identified in the air quality impact assessment will be the Yeelirrie Pool, Accommodation village and Yeelirrie homestead located approximately 10.2 km, 15.6 km and 16.4 km, respectively, from the ore body. The nearest sensitive receptors to the proposed Yeelirrie development site are presented in Table 8 and Figure 5.

Table 8 Nearest sensitive receptors to the proposed Yeelirrie development site

Receptor	Distance and direction from ore body
Accommodation village	15.6 km southeast, adjacent to the Yeelirrie homestead
Yeelirrie homestead	16.4 km southeast
Ululla homestead	28.5 km north
No-Ilba homestead	38.1 km west-northwest
Albion Downs homestead	44.2 km west-southwest
Youno Downs	61.8 km west-northwest
Yeelirrie Pool	10.2 km northeast
Palm Springs	50.4 km east-southeast

5.4 Ambient air quality

Due to the remote location of the proposed Yeelirrie development, there are currently no long-term air quality monitoring stations in the region that monitor ambient dust levels. The area surrounding the proposed Yeelirrie development site is mostly pastoral rangeland with scattered residencies. The main regional dust source is wind erosion of exposed soil surfaces. The NPI database identifies a number of industrial sources within the central Western Australia region reporting emissions of PM_{10}, $PM_{2.5}$, sulfur dioxide, carbon monoxide and oxides of nitrogen. The existing industries within a 100 km radius of the proposed Yeelirrie development and the reported emissions of PM_{10}, $PM_{2.5}$, SO_2, CO and NO_X for the 2008 – 2009 year are presented in Table 9. The closest mining activity in the region is at Mount Keith approximately 60 km east of the proposed Yeelirrie development site.

With the exception of pastoral activities there are no significant nearby anthropogenic gaseous emission sources affecting air quality in the vicinity of the site. The predominant localised sources of dust are likely to be naturally occurring, associated with wind erosion of exposed areas of soil or land, particularly during dry periods. Air quality in the vicinity of the site is also affected by occasional bush fires and scrub fires.

Minor anthropogenic sources of dust are likely to come from vehicles passing on the nearby unsealed roads and any vehicular activity on the pastoral lease. Daily background-levels of dust are expected to be low and will vary significantly depending on location, topography, meteorological conditions and proximity to sources.

Table 9 Inventory of emission sources of particulate matter (as PM_{10} and $PM_{2.5}$), SO_2, CO and NO_X presented as total annual emission rates reported for 2008 – 2009 (NPI)

Faculty name	Locality	ANZSIC Class Name	Distance and direction from ore pit body	Total kg/year				
				PM_{10}	$PM_{2.5}$	SO_2	CO	NO_X
Gold fields Agnew Gold Mine	Leinster	Gold ore mining and processing	97 km southeast	1,545,900	7,359	709	42,302	107,779
Wiluna Operations	Wiluna	Gold ore mining and processing	64 km northeast	1,662,863	5,956	480	167,701	283,909
Leinster Nickel Operation	Leinster	Nickel mining and concentrating	93 km southeast	4,139,000	52,072	2,190	276,000	692,700
Mt Keith Nickel Operation	Wiluna	Nickel ore mining	56 km east	5,200,002	210,000	2,100	1,500,004	3,400,026
Cliffs Nickel Project	Sir Samuel	Nickel mining	53 km east	170,000	25,000	88	170,000	370,000
Wiluna Power Station	Wiluna	Diesel power station	66 km northeast	3,754	3,680	13	11,776	52,992
Lawlers Operations	Agnew	Gold ore mining	93 km southeast	939,210	7,000	830	50,130	112,560
Wiluna Compressor Station	8km NEE of Wiluna	Gas compressor station	72 km northeast	137	137	37	5,986	23,089
Magellan Lead Project	35km West of Wiluna	Lead mining and processing	62 km north	409,176	2,159	28	8,216	32,446
Jundee Operations	80km North of Wiluna	Gold ore mining and processing	110 km northeast	1,116,418	17,857	2,231	177,856	480,007
Leinster Power Station	Leinster	Electricity generation	101 km southeast	7,435	7,347	1,445	196,386	716,003
Lords Operations	Sand-stone	Gold ore mining	115 km southwest	256,617	982	163	7,208	14,760

Faculty name	Locality	ANZSIC Class Name	Distance and direction from ore pit body	Total kg/year				
				PM_{10}	$PM_{2.5}$	SO_2	CO	NO_X
Sandstone Operations	Sand-stone	Gold ore processing and power generation	115 km southwest	196,972	15,921	171	50,517	230,104
Cosmos Nickel Project	Leinster	Nickel mining and processing	68 km southeast	385,286	13,709	1,218	192,584	339,706

6. Emissions model

6.1 Sources of emissions

The vast majority of dust from mining activities consists of course particles (around 40 percent) and particles larger than PM_{10}, generated from natural activities such as mechanical disturbance of rock and soil materials by dragline or shovel, bulldozing, blasting and vehicles on dirt roads. Particles are also generated when wind blows over bare ground and different types of stockpiles (NSW DECC 2007). The potential sources of dust from the proposed Yeelirrie development are outlined in the following sections.

6.1.1 Construction

Construction has the potential to cause elevated levels of dust if not appropriately managed. Construction phase activities at the proposed Yeelirrie development site can be broadly described as:

- Preparation of the site for mining and the construction of the Metallurgical Plant, including the initial clearing of vegetation and stockpiling of topsoil for subsequent reuse
- Establishment of mine infrastructure
- Establishment of the quarry
- Commencement of pit dewatering
- Construction of initial water management infrastructure

Details of the above construction activities are outlined in the Project Description (BHP Billiton, 2010).

The major sources of dust during construction are expected to be earthworks, such as vegetation clearance, topsoil removal and storage.

6.1.2 Mining operations

The major source of dust emissions from conventional open-cut mining is the truck and excavator operation to remove overburden and ore. Sources of emissions associated with the extraction process include the following:

- Drilling and blasting of overburden and ore (minimal drilling and blasting required)
- Dozer ripping of overburden
- Excavator on overburden and ore and loading into trucks
- Transport of overburden and ore to stockpiles
- Dumping of overburden and ore to stockpiles
- Wind erosion of exposed pits and storage stockpiles
- Wind erosion from the quarry

The ore stockpiles will be around 50 m in length, 10 m in width and no higher than 20 m and will be managed so that stocks of high-grade material will be exposed for no more than 18 months and medium-grade materials up to twenty years. Low-grade materials and overburden may be exposed for the life of the operation, depending on the progress of rehabilitation activities and the economics associated with the processing of the lower-grade ore.

Mining will initially target areas of higher grade uranium ore, with the Metallurgical Plant continuing to treat ore from stockpiles until the economic material has been processed. In this assessment ore are defined as either very high grade (VHG), high grade (HG), medium grade (MG) or low grade (LG).

6.1.3 Metallurgical Plant

The dust emissions from the Metallurgical Plant will be minimal, with the leaching, precipitation, refining and packaging processes occurring within a closed environment. The predominant sources of dust emissions will be associated with the ore preparation phase, and will include:

- Dumping of ore to ROM stockpiles
- Wind erosion of ROM stockpiles
- Loading of ore into crushing unit by front end loader (FEL)
- Crushing unit
- Conveyor between crushing unit and semi autogenous grinding (SAG) mill
- Transfer points (crusher to conveyor and conveyor to SAG)
- SAG mill

6.1.4 On-site power generation

A series of diesel-fired electricity generators and local electricity transmission infrastructure will be installed to meet the proposed electricity demand of 12 Megawatts (MW) and an estimated average annual electricity consumption of around 72,000 MWh. Six diesel-fired generators will be installed at the Metallurgical Plant.

Emissions from the operation of the diesel-fired generators will include nitrogen dioxide, carbon monoxide, sulfur dioxide, hydrocarbons and particulates (PM_{10} and $PM_{2.5}$). Exhaust gases from the generators will be collected and conveyed via a waste heat boiler and blower fan to the carbonation stage of the Metallurgical Plant where the carbon dioxide content will be utilised to convert sodium hydroxide to sodium carbonate and bicarbonate. However, for this assessment it has been assumed that 100 percent of the exhaust emissions are released to the atmosphere to predict worse-case impacts.

Details of stack characteristics and the emission rates of SO_2, NO_2, CO, PM_{10} and $PM_{2.5}$ from the onsite diesel generators used in the dispersion modelling are presented in Appendix A.

6.2 Emission calculation

For the majority of dust producing activities the dust emission rate is dependent on the estimated quantities of overburden and ore to be extracted and processed. Mining will occur for up to 30 years at a rate of up to 8 Mtpa and would initially occur for 24-hours per day, with the subsequent mining schedule being as necessary to achieve production targets. The air quality assessment has assumed the maximum mining rate of 8 Mtpa with mining occurring 24-hours a day. The rate of ore throughput at the Metallurgical Plant has been modelled at 1.2 Mtpa.

Other factors are also important such as overburden and ore silt and moisture contents, particle size distribution, rainfall, wind speed and other mitigation measures that can be employed. The key factors that account for dust emissions have been accounted for in estimating dust emissions from the proposed Yeelirrie development, with a summary presented in Table 10.

Table 10 Summary of other key factors important for dust producing activities accounted for in emission calculations

Key factor	Unit	Value
Overburden density conversion	t/bcm	1.43
Ore density conversion	t/bcm	1.43
Overburden silt content	%	6.9
Ore silt content	%	6.9
Average overburden moisture content	%	15.0
Average ore moisture content	%	15.0
Mean wind speed	m/s	2.7 [1]
Rainfall	days/year	36 [2]

Table note:

[1] Average TAPM predicted wind speed at proposed Yeelirrie development site

[2] Number of days recording rainfall above 0.25 mm at Bureau of Meteorology station at Yeelirrie during 2008

The emission factors that have been used to calculate dust emission rates are reproduced in Appendix A. The emission factors are based on the factors developed by the US EPA (AP - 42) and National Pollutant Inventory Handbooks.

For this assessment, the working pit areas and stockpiles where excavation, loading and dumping activities are carried out during the modelled period are defined as 'active'. Any pit areas and stockpiles that were used in periods preceding the modelled period that will be subject to wind erosion are defined as 'inactive'.

6.3 Representative operations

The proposed mining sequence will preferentially target the highest grade ore within the ore body, as shown conceptually as Block 1 in Figure 6, and will then progress east and west. Once mining commenced in a block it would continue to full depth of up to 10 m, with mined voids subsequently used for in-pit tailings disposal. Ore and overburden from the open-pit operation will be extracted continuously 24 hours per day, 7 days per week.

The air quality impact assessment has assessed the emissions from the proposed Yeelirrie development during one year of mine operations. The scenario has been selected to represent the mining activities that will have the highest potential for causing offsite impacts. It has been assumed that the worse-case impacts, in terms of ground-level concentrations at nearest sensitive receptors, will occur during operation of the mine in the eastern end of the pit (Block 13, Figure 6). Mine activity in Block 13 will result in greater impacts due to the close proximity of the working pit to the receptors, the greater area exposed to wind erosion (Block 1 to Block 12), and the greater travelling distance from the active pit to the Metallurgical Plant. The level of dust emissions from the exposed areas can be reduced through various control mechanisms.

It has been assumed that 8.0 Mtpa of material is extracted from the active pit during the modelled period of one year. A breakdown of the extracted material into the various ore grades (VHG, HG, MG and LG), overburden and topsoil are presented in Table 11.

Table 11 Estimated tonnes of material extracted from open pit (Block 13) during assumed worse-case operation (one year)

Material	Tonnes extracted from open pit
VHG ore	222,723
HG ore	898,639
MG ore	2,011,301
LG ore	1,494,831
Overburden	2,974,919
Topsoil	397,586
Total	8,000,000

It has been assumed that 1.21 Mt of ore will be processed during the one year period. A breakdown of the processed ore into the various grades (VHG, HG and MG) is presented in Table 12.

Table 12 Estimated ore throughput at the Metallurgical Plant (tpa)

Material	Tonnes [1]
VHG ore	164,360
HG ore	500,000
MG ore	545,640
Total ore	1,210,000

Table note:
[1] Tonnes of material transferred from storage stockpiles to RoM stockpile and subsequently processed at Metallurgical Plant during modelled period

Fugitive dust emissions from storage stockpiles have been calculated based on information provided on the maximum dimensions of each stockpile (50 m length, 10 m width and 20 m height) and the tonnes of material extracted during the year. It has been assumed that the topsoil and overburden from the open pit will be stockpiled in the void from the previous pit (Block 12), the lower-grade ore will be stockpiled along the southern boundary of the open pit, the medium grade ore will be stockpiled along the northern boundary of the open pit, and the high grade and very high grade ore will be stockpiled nearest to the Metallurgical Plant.

It has been assumed that, since the modelled scenario is during the later stages of the mine operation, there will be no transfer of material from the quarry to the north of the Metallurgical Plant. There will; however, be fugitive dust emissions from this source.

Figure 7 illustrates the layout of the mine and Metallurgical Plant that has been represented in the modelled scenario, including the ore body, open pit, previously used pits, storage stockpiles, Metallurgical Plant and quarry.

Dust emission rates have been calculated using the detailed information on mining activities and standard metalliferous mining emission factors. These are provided in Appendix A, with a summary provided in Table 13.

Table 13 Estimated annual dust emission rates for the proposed Yeelirrie development during assumed worse-case operations

Emission source	Total dust emission rate (kg/annum)		
	TSP	PM_{10}	$PM_{2.5}$
Mining activities	1,215,900	482,017	64,002
Metallurgical Plant	146,909	46,309	5,166
Quarry	14,887	7,444	1,117
Generators	-	541	541
Total	1,377,696	536,310	70,825

6.4 Operational controls

A suite of best practice operational controls have been applied to the model. These controls are listed in Table 14.

Table 14 Operational controls employed as best practice and included in the dispersion modelling

Source	Control measure	Level of control
Active stockpiles [1]	Continuous watering using water cart and local ground water sources	50%
Topsoil stockpiles	Remain untreated to ensure viability of the soil by exposure to atmosphere and rain, covered with cleared vegetation to reduce wind erosion	99%
Inactive stockpiles [2]	Sealant product (e.g. Rainstorm Gluon 240) applied via water cart	90% (after 3 months of inactivity)
Working pit areas (active [3])	Continuous watering using water cart and local ground water sources	50%
Inactive pit areas [4]	Rehabilitated with original surface cover material appropriately stockpiled, followed by ripping and seeding with appropriate native vegetation	99%
Onsite haul Roads	Continuous watering using water cart and local ground water sources and road stabilisation product applied (Level 2 watering of > 2.0 litres/m²/hr)	75%
Metallurgical Plant (leaching, CCD and uranium recovery)	Enclosed	100%
Packaging area	Wet scrubber will be installed and area will be at negative pressure	100%

Table note:

[1] Active stockpiles refers to those where loading and/or dumping activities are carried out during the operational period
[2] Inactive stockpiles refers to those used previously, with no loading and/or dumping activities carried out during the operational period
[3] Active/working pit refers to the pit where excavation, loading, etc. activities are carried out during the operational period
[4] Inactive pit areas refers to those used previously, with no excavation, loading, etc. activities are carried out during the operational period

7. Dispersion meteorology for the site

This section presents a summary of the CALMET predicted wind speed, wind direction, stability class and mixing height for the proposed Yeelirrie development site during the modelled period (December 2007 to November 2008).

7.1 Wind speed and wind direction

Wind speed and wind direction are important aspects that can influence the emission rate of dust from the proposed Yeelirrie development. Exposed dust sources such as stockpiles and active pits will have higher dust emissions during strong winds than during light winds. The dust emissions will also have a greater radius of impact during periods of higher wind speeds due to the dust particles remaining suspended and getting carried further distances. The seasonal and diurnal variability in the wind speed and wind direction at the proposed Yeelirrie development site will result in variation in the areas impacted by the mine as well as the intensity of dust events.

The annual, diurnal and seasonal distributions of CALMET predicted winds at the proposed Yeelirrie development site are presented as wind roses in Figure 9, Figure 10 and Figure 11. The predominant winds from the east will transport dust to regions west of the proposed Yeelirrie development.

A summary of the annual, diurnal and seasonal frequency of wind speeds predicted by CALMET at the proposed Yeelirrie development site is shown in Table 15. The data show the winds are predominantly light to moderate at the proposed Yeelirrie development site, with approximately 36% of winds less than 2 m/s, and a further 44% of winds between 2 and 4 m/s. Dust emissions from wind erosion sources, such as exposed ground, dump sources and stockpiles, are essentially zero at low wind speeds and will remain so until the wind speed exceeds a threshold that is specific to the particular source, but is generally found to be above 5 – 6 m/s. CALMET predicts around 20% of the annual winds to be greater than 4 m/s. During the afternoon period (midday to 6pm), 37% of winds are predicted to be greater than 4 m/s, and during spring 29% of winds greater than 4 m/s.

Localised impacts from the proposed Yeelirrie development will be greater during light wind conditions due to the lower rate of dispersion from the site. Light winds (i.e. with speed less than 2 m/s) are predicted to account for 36% of the annual winds at the proposed Yeelirrie development site, with these winds occurring predominantly during the early morning (6am to midday) and autumn periods.

Table 15 Summary of wind speeds at proposed Yeelirrie development site as generated by CALMET

Period	Wind speed			
	< 2 m/s	2 – 4 m/s	4 – 6 m/s	> 6 m/s
Annual	36 %	44 %	18 %	2 %
Diurnal distribution				
Midnight to 6am	56 %	40 %	4 %	< 1 %
6am to midday	28 %	44 %	25 %	2 %
Midday to 6pm	14 %	48 %	33 %	4 %
6pm to midnight	46 %	44 %	10 %	< 1 %
Seasonal distribution				
Spring	31 %	41 %	24 %	5 %
Summer	24 %	49 %	26 %	1 %
Autumn	46 %	42 %	12 %	< 1 %
Winter	43 %	45 %	11 %	1 %

7.2 Atmospheric stability and mixing height

Stability classification is a measure of the stability of the atmosphere and can be determined from wind measurements and other atmospheric observations. The stability classes range from A class which represents very unstable atmospheric conditions that may typically occur on a sunny day to F class stability which represents very stable atmospheric conditions that typically occur during light wind conditions at night. Unstable conditions (Classes A to C) are characterised by strong solar heating of the ground that induces turbulent mixing in the atmosphere close to the ground. This turbulent mixing is the main driver of dispersion during unstable conditions. Dispersion processes for the most frequently occurring Class D conditions are dominated by mechanical turbulence generated as the wind passes over irregularities in the local surface. During the night, the atmospheric conditions are generally stable (often classes E and F).

Table 16 shows the percentage of stability classes at the proposed Yeelirrie development site for the 2007 – 2008 meteorological data used in the dispersion modelling, where Class A represents the most unstable conditions.

Table 16 Frequency of occurrence (%) of surface atmospheric stability at the proposed Yeelirrie development site under Pasquil-Gifford stability classification scheme

Pasquil-Gifford stability class	Classification	Frequency (%)
A	Extremely unstable	1.1
B	Unstable	12.0
C	Slightly unstable	19.1
D	Neutral	23.6
E	Slightly stable	8.6
F	Stable	35.5

The mixing height refers to the height above ground within which particulates or other pollutants released at or near ground can mix with ambient air. During stable atmospheric conditions, the mixing height is often quite low and particulate dispersion is limited to within this layer. During the day, solar radiation heats the air at the ground level and causes the mixing height to rise. The air above the mixing height during the day is generally cooler. The growth of the mixing height is dependent on how well the air can mix with the cooler upper level 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.

Mixing height information has been extracted from the CALMET simulation at the proposed Yeelirrie development site and is presented in Figure 12. The data shows that the mixing height develops around 9am, increases to a peak around 3pm before descending rapidly.

8. Results of dispersion modelling

This section presents the results of the air quality impact assessment for predicted ground-level concentrations of TSP, PM_{10}, $PM_{2.5}$, dust deposition, nitrogen dioxide, carbon monoxide and sulfur dioxide.

8.1 Particulates

Figure 13 to Figure 25 show the maximum predicted ground-level concentrations of TSP, PM_{10}, $PM_{2.5}$ and dust deposition from the proposed Yeelirrie development.

The predicted maximum 24-hour average and annual average ground-level concentrations of TSP, PM_{10} $PM_{2.5}$ and dust deposition due to operation of the mine at the nearest sensitive receptor locations are presented in Table 17. Results have been presented for the Yeelirrie Pool, Accommodation Village and Yeelirrie homestead. As the Accommodation Village and Yeelirrie homestead are in close proximity, predicted ground-level concentrations have been extracted from the same CALPUFF grid cell. All other sensitive receptors listed in Section 5.3, Table 8 are outside of the model domain. Ground-level concentrations at these receptors that are likely to occur due to the proposed Yeelirrie development are predicted to be well below the relevant air quality criteria for all pollutants assessed.

The ground-level concentrations of TSP, PM_{10} and $PM_{2.5}$ are presented with and without a background concentration. The ground-level concentrations of dust deposition are presented in isolation only and compared to the criteria of 2.0 g/m²/month in accordance with the NSW DECCW criteria.

The results of dispersion modelling of particulates from the proposed Yeelirrie development show:

- The predicted maximum 24-hour average ground-level concentrations of TSP, PM_{10} and $PM_{2.5}$ at the nearest sensitive receptors due to mine operations (with background) are predicted to be well below the relevant air quality criteria.

- The predicted annual average ground-level concentrations of TSP, PM_{10} and $PM_{2.5}$ at the nearest sensitive receptors due to mine operations (with background) are predicted to be well below the relevant air quality criteria.

- Incremental dust deposition rates outside the MLA boundary due to mine operations are predicted to be well below the air quality criteria of 2 g/m²/month.

Table 17 Predicted ground-level concentrations (µg/m³) of TSP, PM_{10} and $PM_{2.5}$ and dust deposition rate (g/m²/month) due to assumed worse-case operations at the proposed Yeelirrie development

Pollutant	Averaging Period	Air quality criteria	Accommodation village/ Yeelirrie homestead		Yeelirrie Pool	
			Operationally contributed	With background	Operationally contributed	With background
TSP	24-hour maximum	90	7.7	57.7	13.9	63.9
	Annual	90	0.2	25.2	0.6	25.6
PM_{10}	24-hour 6th highest [1]	50	3.5	28.5	7.3	32.3
	Annual	25	0.2	12.7	0.6	13.1
$PM_{2.5}$	24-hour maximum	25	1.9	11.9	3.2	13.2
	Annual	8	0.04	7.1	0.2	7.3
Dust deposition	Annual	2 [2]	0.002	-	0.009	-

Table note:

[1] 6th Highest 24-hour concentration presented for PM_{10} in accordance with NEPM criteria

[2] Dust deposition criteria of 2 g/m²/month is maximum increase in deposited dust level, no background assessed

8.2 Pollutants other than particulates

Figure 26 to Figure 31 show the predicted maximum ground-level concentrations of NO_2, CO and SO_2 due to emissions from the on-site diesel generators. As discussed in Section 6.1.4, the exhaust emissions from the diesel generators will be captured and conveyed for use at the Metallurgical Plant, however, this assessment has assumed a zero percent capture to predict worse-case impacts from the proposed Yeelirrie development.

The predicted maximum and annual average ground-level concentrations at the nearest sensitive receptor locations are presented in Table 18. Results have been presented for the Yeelirrie Pool, Accommodation Village and Yeelirrie homestead. As the Accommodation Village and Yeelirrie homestead are in close proximity, predicted ground-level concentrations have been extracted from the same CALPUFF grid cell. All other sensitive receptors listed in Section 5.3, Table 8 are outside of the model domain. Ground-level concentrations at these receptors that are likely to occur due to the proposed Yeelirrie development are predicted to be well below the relevant air quality criteria for all pollutants assessed.

The results of dispersion modelling of pollutants other than particulates show:

- The predicted maximum ground-level concentrations of nitrogen dioxide at the nearest sensitive receptors due to mine operations are predicted to be well below the relevant air quality criteria.

- The predicted maximum ground-level concentrations of carbon monoxide at the nearest sensitive receptors due to mine operations are predicted to be well below the relevant air quality criteria.

- The predicted maximum ground-level concentrations of sulfur dioxide at the nearest sensitive receptors due to mine operations are predicted to be well below the relevant air quality criteria.

Table 18 Predicted operationally contributed ground-level concentrations (µg/m³) due to diesel generators (Assume zero capture of generator emissions)

Pollutant	Averaging Period	Air quality criteria	Accommodation village/ Yeelirrie homestead	Yeelirrie Pool
Nitrogen dioxide	1-hour maximum	250	19.2	125.9
	Annual average	62	0.01	0.39
Carbon monoxide	8-hour maximum	11,000	0.4	4.2
Sulfur dioxide	1-hour maximum	570	0.9	5.5
	24-hour maximum	230	0.06	0.62
	Annual average	57	0.0006	0.02

9. Conclusions

An air quality assessment has been conducted as part of the Environmental Review and Management Programme (ERMP) for the proposed Yeelirrie development in Western Australia.

The air quality impact assessment investigated the potential for impacts associated with the proposed Yeelirrie development. A worse-case scenario has been selected to represent the mining operations that will have the potential to result in the highest ground-level concentrations at the closest sensitive receptors. The assessment used meteorological and dispersion models to predict the concentrations due to emissions (TSP, PM_{10}, $PM_{2.5}$ and dust deposition) from the proposed Yeelirrie development in isolation (operationally contributed) and with the inclusion of ambient background-levels of dust representative of the region. The predicted ground-level concentrations due to emissions of nitrogen dioxide, sulfur dioxide and carbon monoxide from the onsite diesel generators were also assessed.

The cumulative air quality impact assessment has shown the following:

- The predicted maximum 24-hour average ground-level concentrations of TSP, PM_{10} and $PM_{2.5}$ at the nearest sensitive receptors due to mine operations (with background) are predicted to be well below the relevant air quality criteria.

- The predicted annual average ground-level concentrations of TSP, PM_{10} and $PM_{2.5}$ at the nearest sensitive receptors due to mine operations (with background) are predicted to be well below the relevant air quality criteria.

- Dust deposition rates outside the MLA boundary due to mine operations are predicted to be well below the air quality criteria of 2 $g/m^2/month$.

An air quality impact assessment of the emissions from the onsite diesel generators was undertaken and has shown the following:

- The predicted maximum ground-level concentrations of nitrogen dioxide, carbon monoxide and sulfur dioxide at the nearest sensitive receptors due to mine operations are predicted to be well below the relevant air quality criteria.

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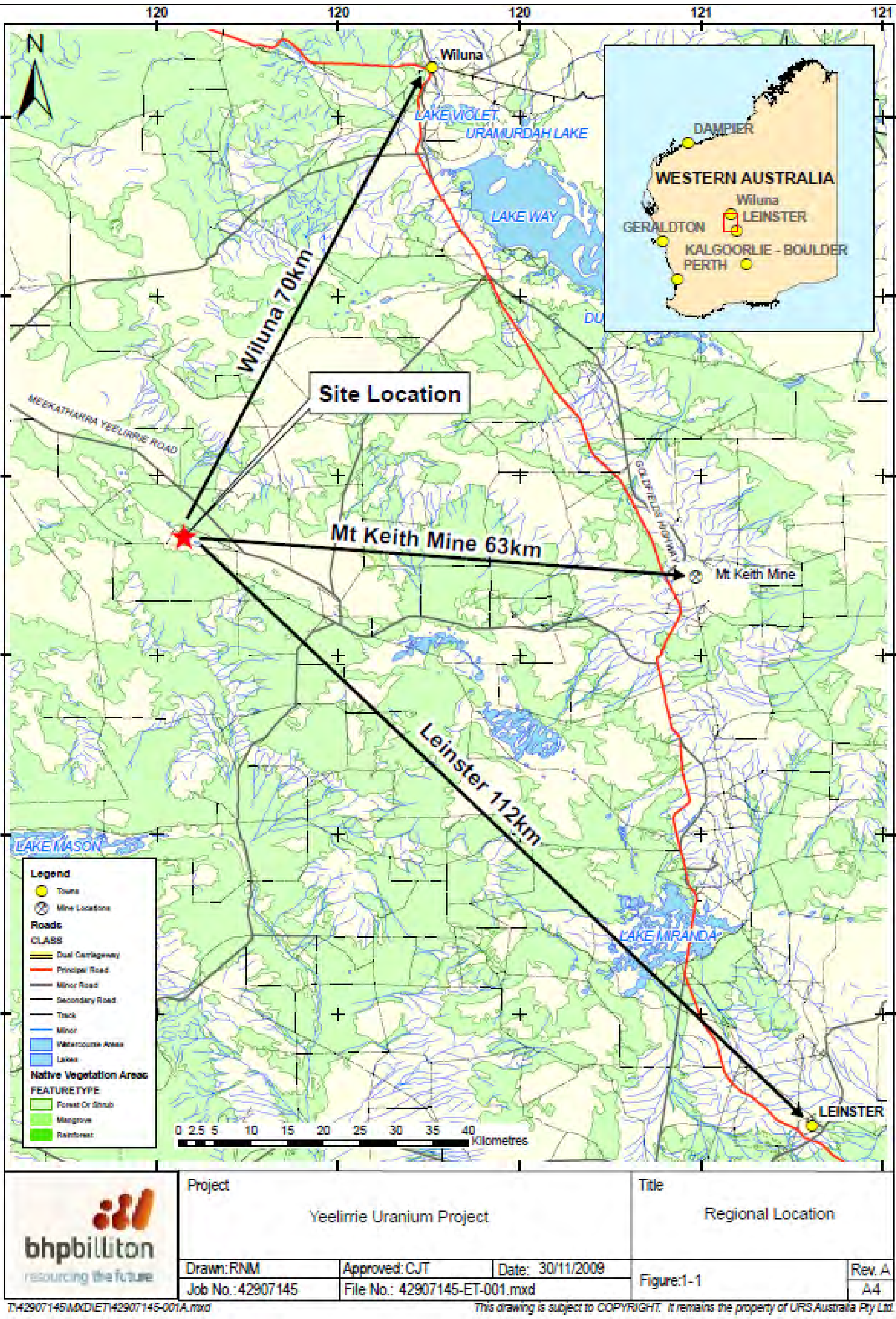


Figure 1 Proposed Yeelirrie development site location

Location: Yeelirrie, Western Australia	**Data source:** BHP Billiton	**Units:** Geographic coordinate system
Type: Aerial map	**Prepared by:** BHP Billiton	**Date:** Provided April 2010

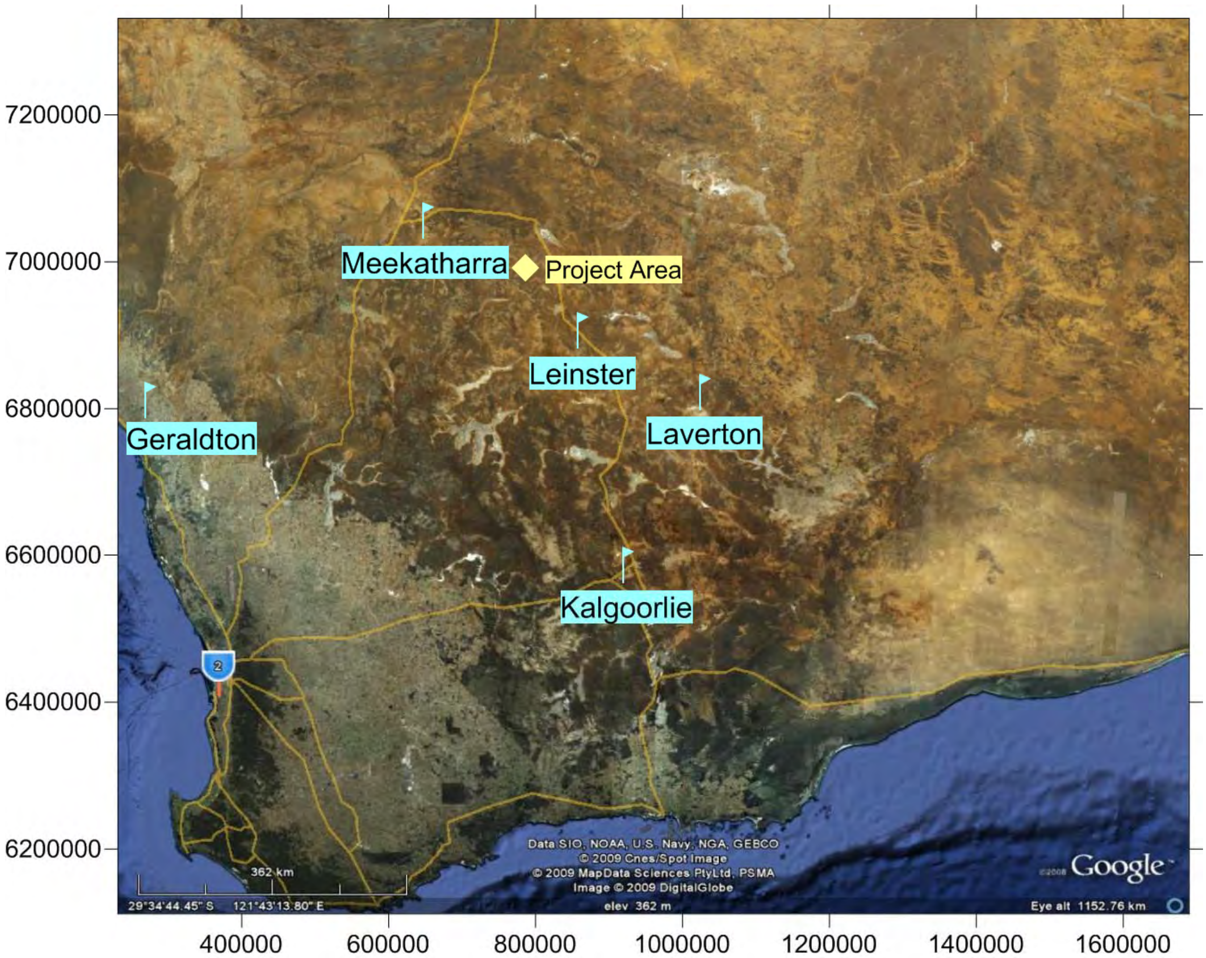


Figure 2 Bureau of Meteorology sites representative of large scale synoptic weather patterns

Location: Yeelirrie, WA	**Data source:** Surfer 9 and Google-Earth	**Units:** Global coordinates – WGS-84 GDA, Zone 50, km
Type: Aerial map	**Prepared by:** Sarah Menzel	**Date:** January 2011

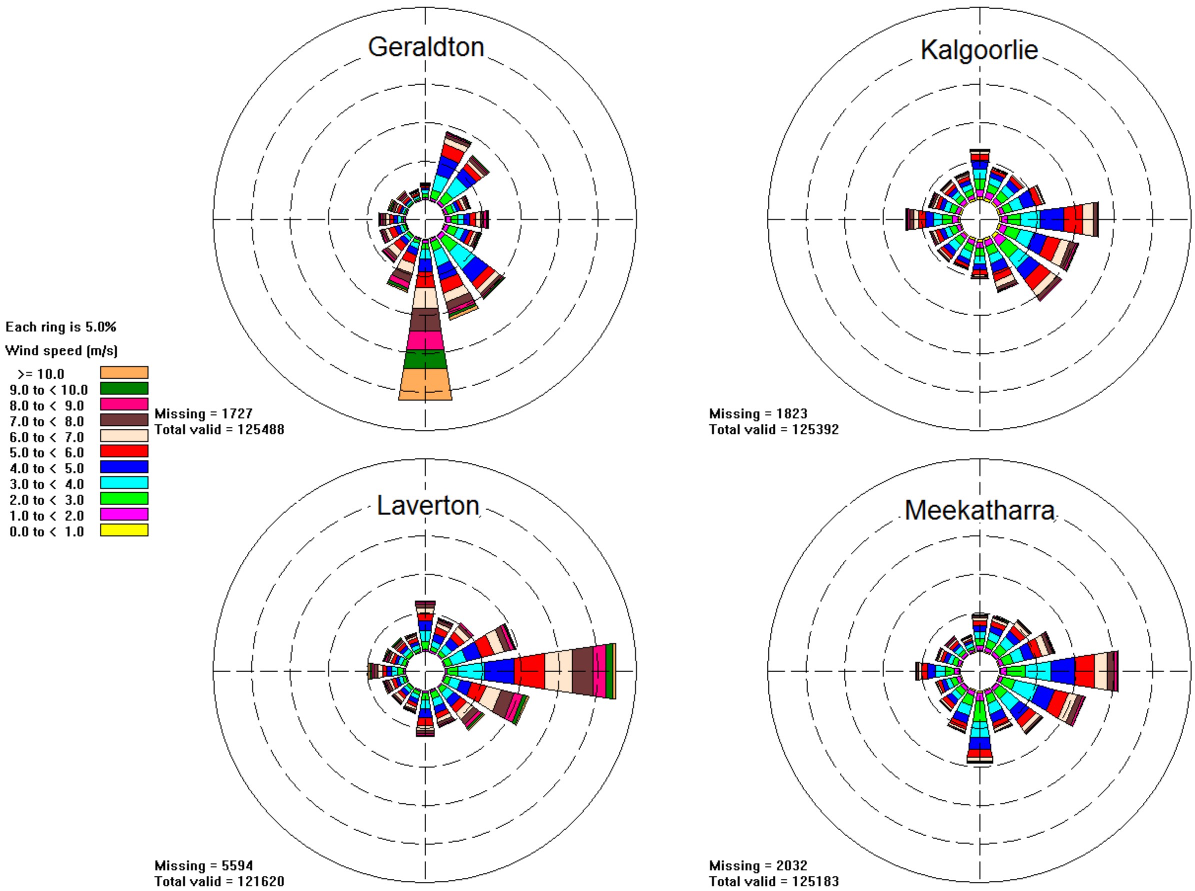


Figure 3 Annual wind roses for four synoptic sites

Location:	**Period:**	**Data source:**	**Units:**
Western Australia	1995 - 2009	Bureau of Meteorology	m/s and degrees
Type:	**Data frequency:**	**Prepared by:**	**Date:**
Wind rose	1 hour	Sarah Menzel	October 2010

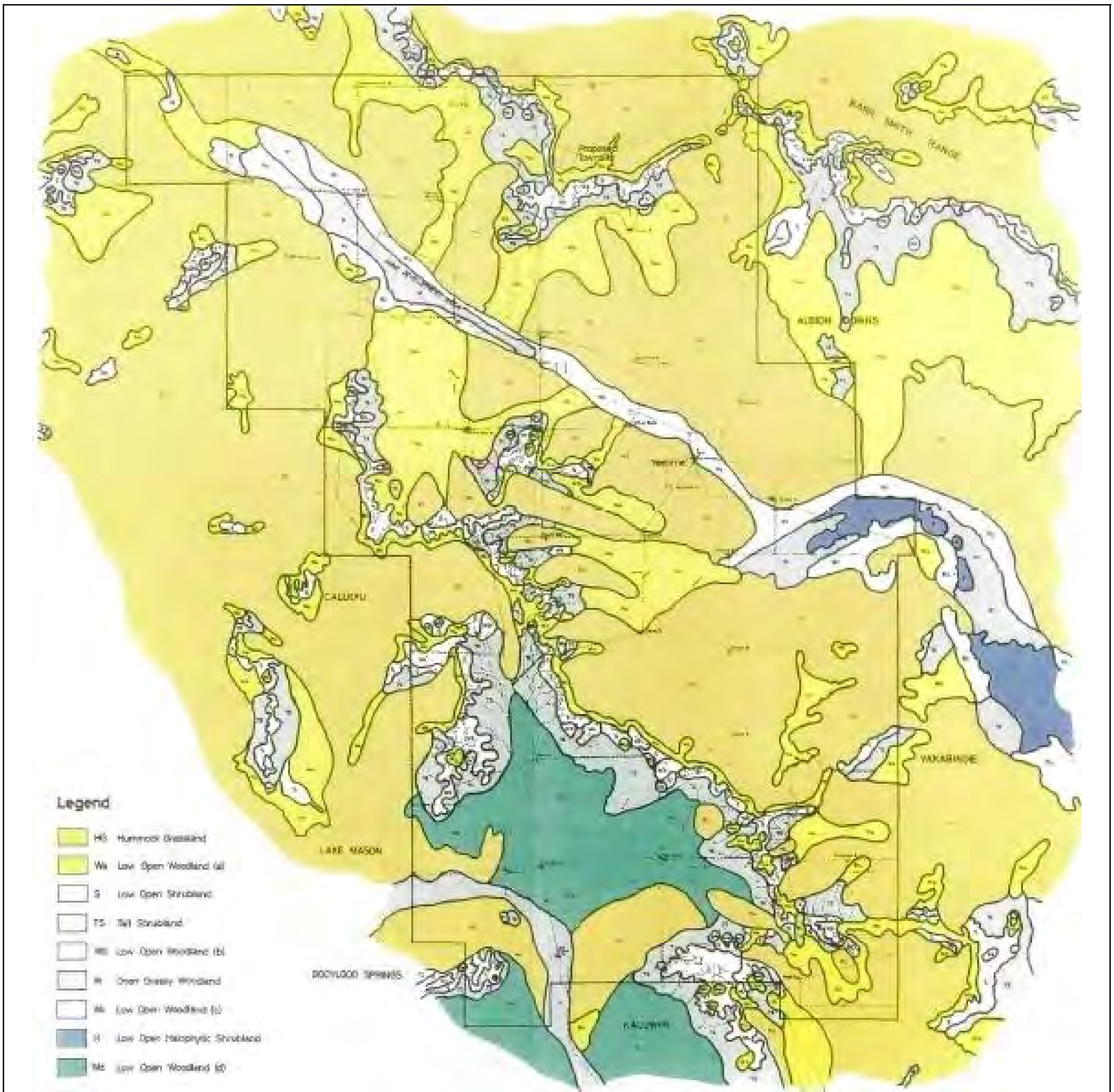


Figure 4 Proposed Yeelirrie development site vegetation

Location: Proposed Yeelirrie development site	**Data source:** BHP Billiton	**Units:** NA
Type: Aerial map	**Prepared by:** BHP Billiton	**Date:** Provided April 2010

Figure 5 Proposed Yeelirrie development site location and nearest sensitive receptors		
Location: Yeelirrie, Western Australia	**Data source:** BHP Billiton	**Units:** Km
Type: Arial map	**Prepared by:** BHP Billiton	**Date:** Provided January 2011

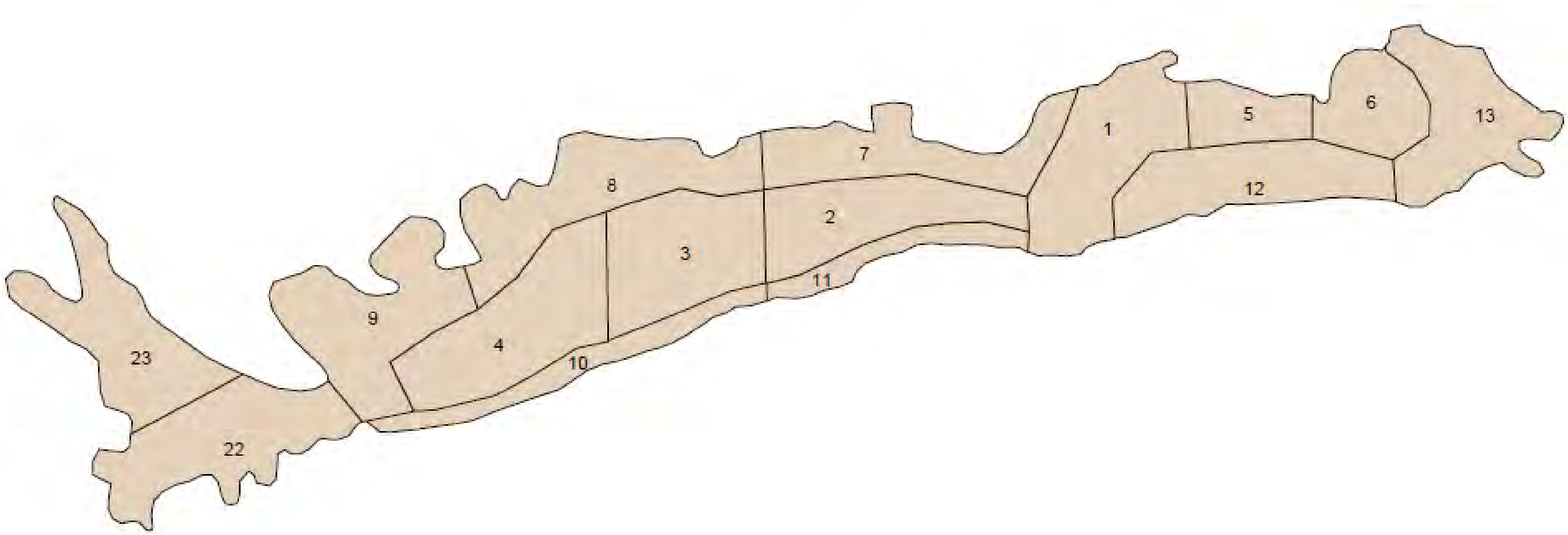


Figure 6 Proposed progressive mine sequence		
Location: Proposed Yeelirrie development site	**Data source:** BHP Billiton	**Units:** NA
Type: Diagram	**Prepared by:** BHP Billiton	**Date:** Provided April 2010

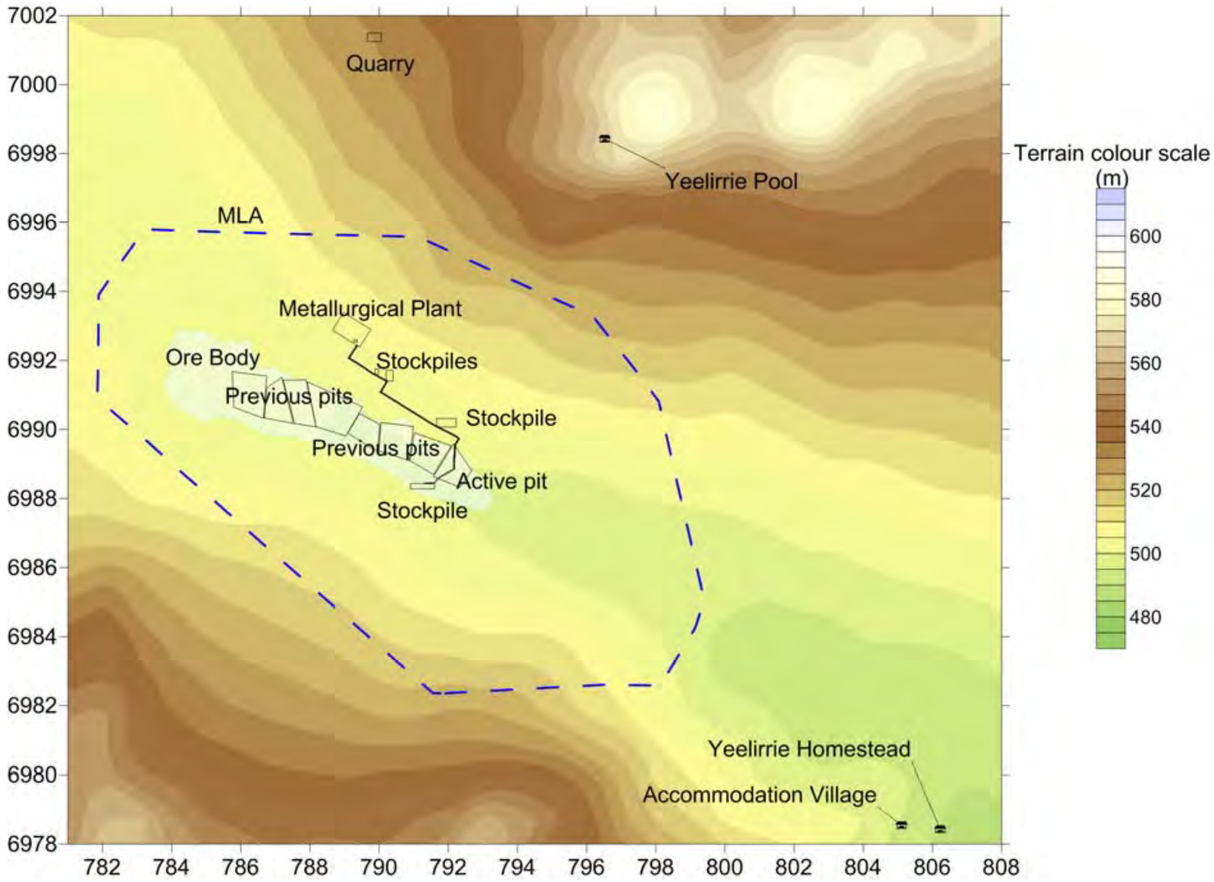


Figure 7 **Layout of mine and Metallurgical Plant during assumed worse-case operations, including active pit, previous pits, storage stockpiles, Metallurgical Plant, haul roads and quarry**

Location: Yeelirrie, WA	**Data source:** Surfer 9	**Units:** Global coordinates – WGS-84 GDA, Zone 50, km
Type: Aerial map	**Prepared by:** Sarah Menzel	**Date:** January 2011

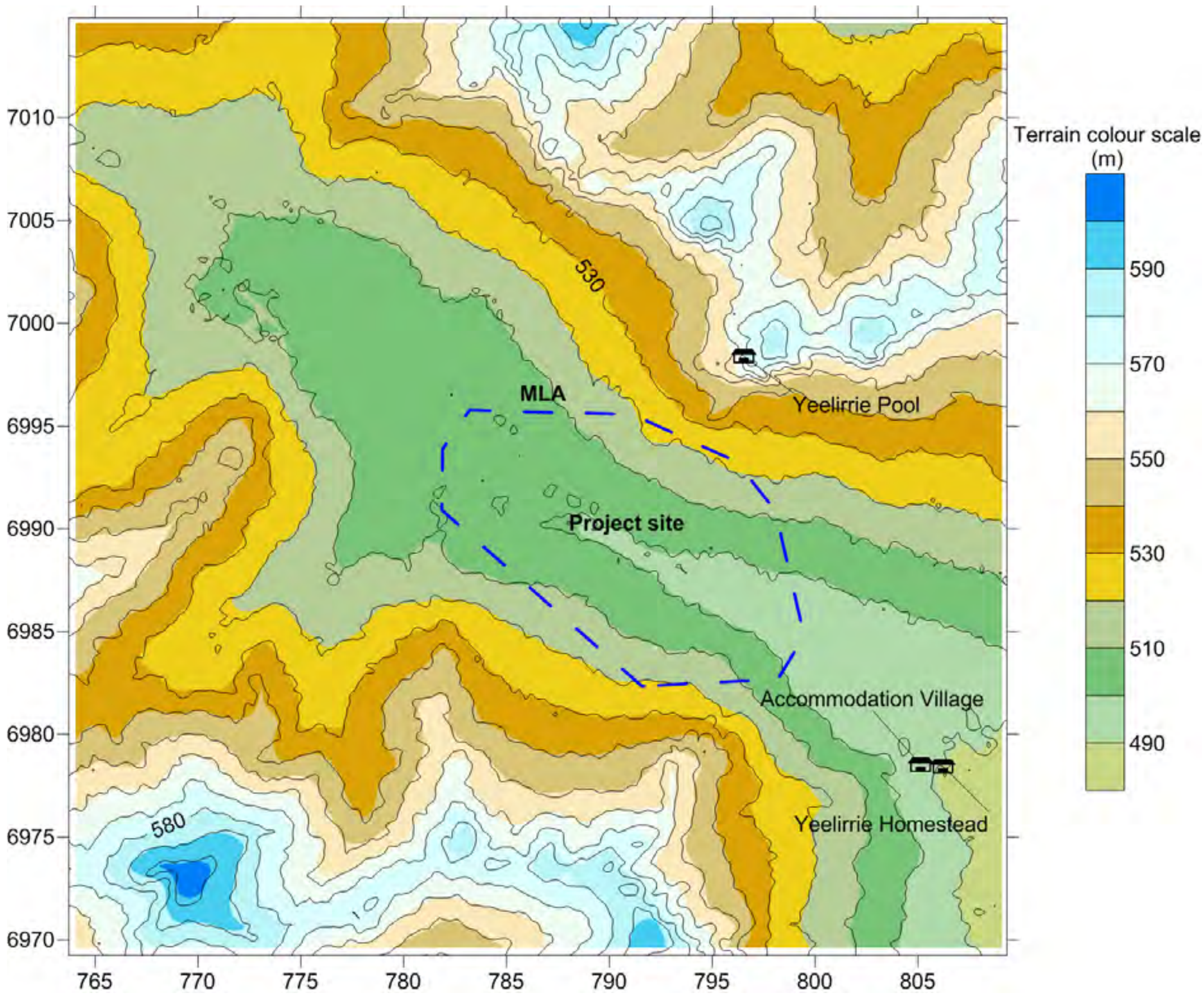


Figure 8	**Overlay of 300 m (black lines) and 1 km (colour shading) digital elevation models**	
Location: Proposed Yeelirrie development site	**Data source:** SRTM3	**Units:** Global coordinates – WGS-84 GDA, Zone 50, km
Type: 2d DEM	**Prepared by:** Sarah Menzel	**Date:** January 2011

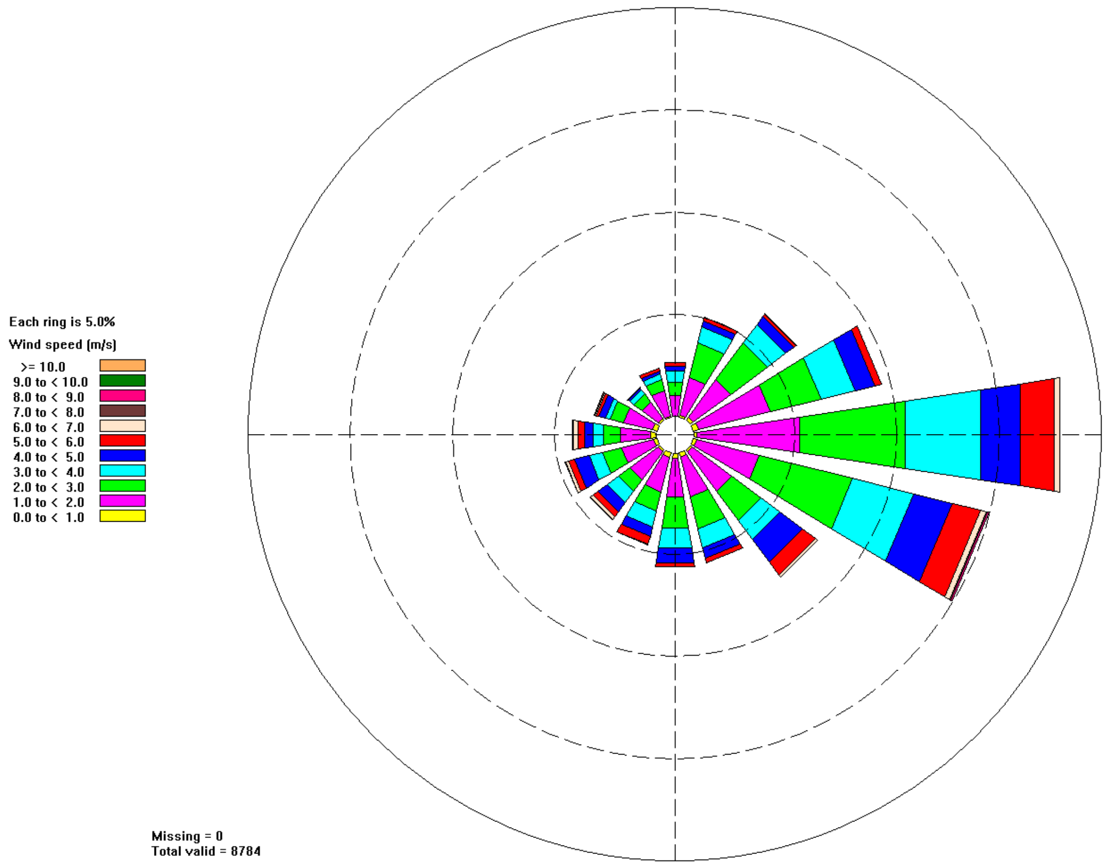


Figure 9 Predicted annual distribution of winds at the proposed Yeelirrie development site

Location: Proposed Yeelirrie development site	**Period:** One year	**Data source:** CALMET	**Units:** m/s and °
Type: Wind rose	8,784 hourly average records	**Prepared by:** Sarah Menzel	**Date:** October 2010

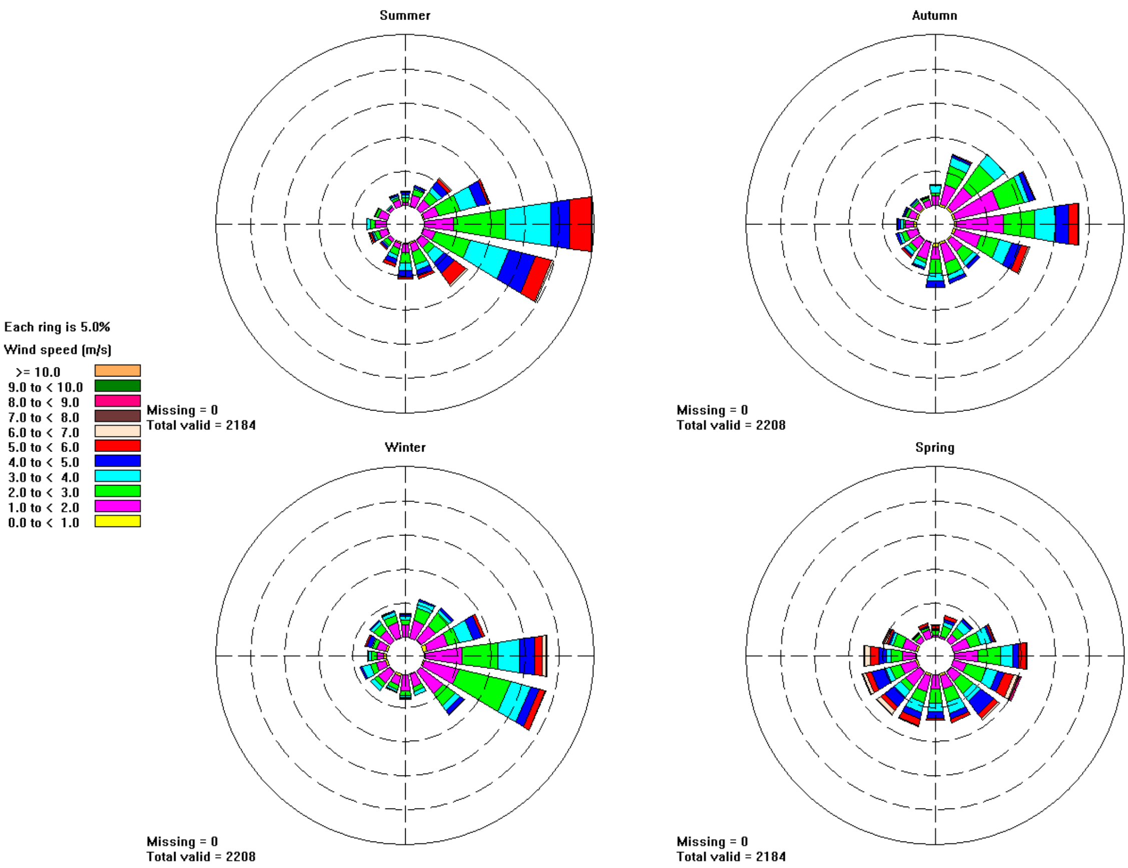


Figure 10 Predicted seasonal distribution of winds at the proposed Yeelirrie development site

Location: Proposed Yeelirrie development site	**Period:** December 2007 – November 2008	**Data source:** CALMET	**Units:** m/s and °
Type: Wind rose	8,784 hourly average records	**Prepared by:** Sarah Menzel	**Date:** October 2010

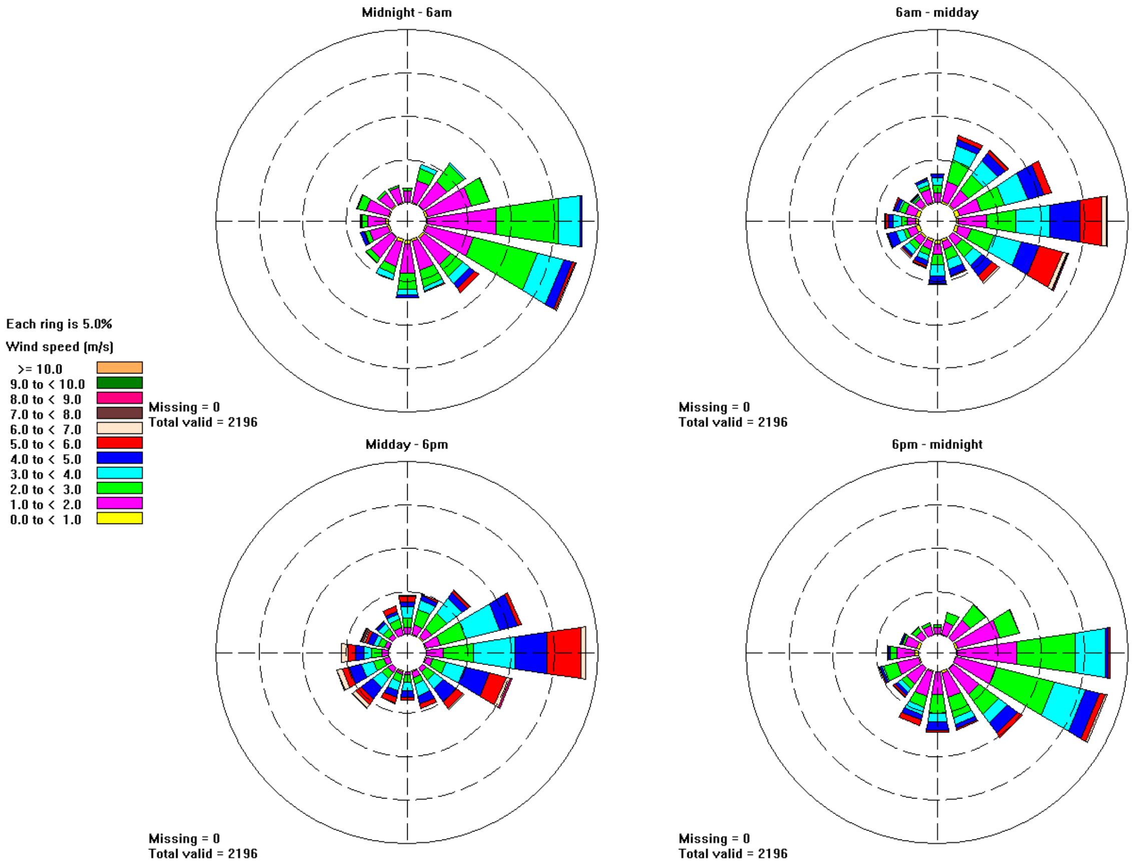


Figure 11 Predicted diurnal distribution of winds at the proposed Yeelirrie development site

Location: Proposed Yeelirrie development site	**Period:** December 2007 – November 2008	**Data source:** CALMET	**Units:** m/s and °
Type: Wind rose	8,784 hourly average records	**Prepared by:** Sarah Menzel	**Date:** October 2010

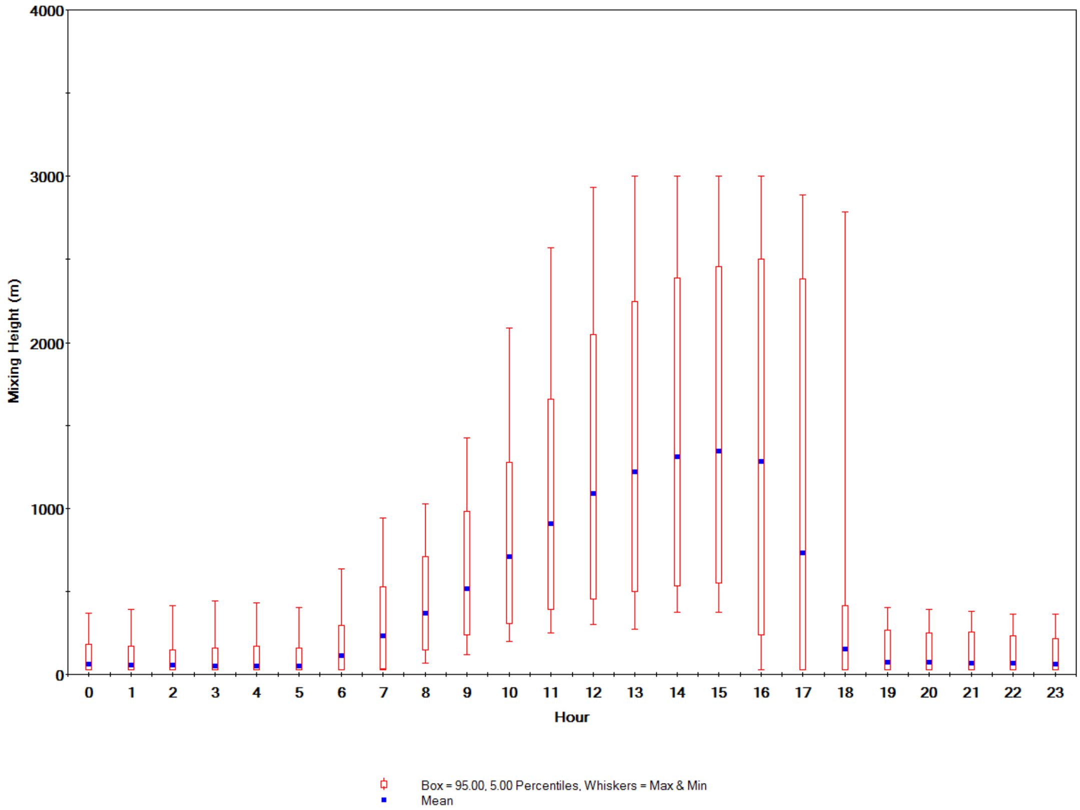


Figure 12 Diurnal profile of modelled mixing height at the proposed Yeelirrie development site

Location: Proposed Yeelirrie development site	**Period:** December 2007 – November 2008	**Data source:** CALMET	**Units:** m
Type: Box and whisker	**Averaging period:** 1-hour	**Prepared by:** Sarah Menzel	**Date:** October 2010

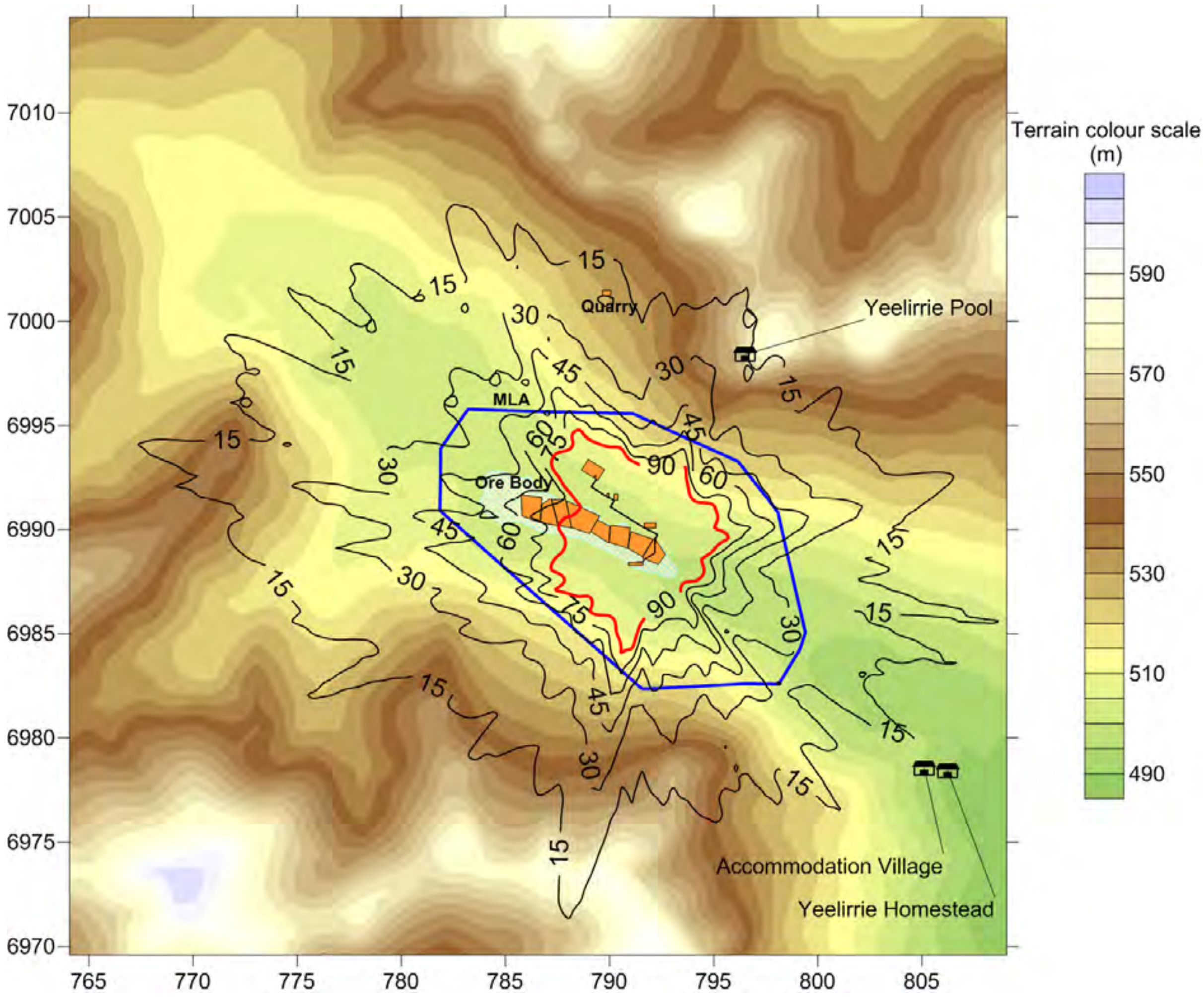


Figure 13 Predicted operationally contributed maximum 24-hour ground-level concentration of TSP

Location: Yeelirrie, WA	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, no background	**Standard:** 90 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

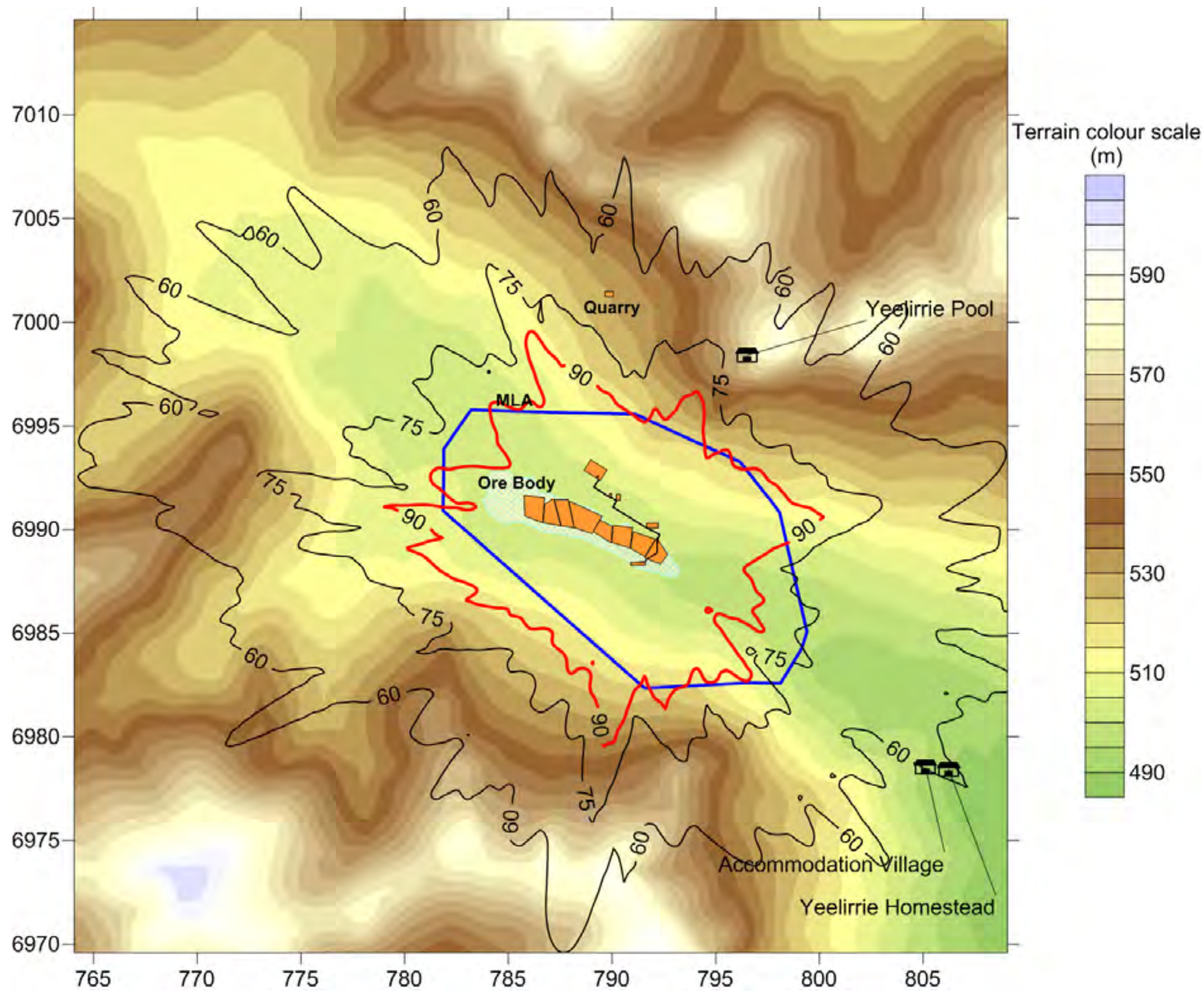


Figure 14 Predicted maximum 24-hour ground-level concentration of TSP with ambient background

Location: Yeelirrie, WA	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, with background of 50 µg/m³	**Standard:** 90 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

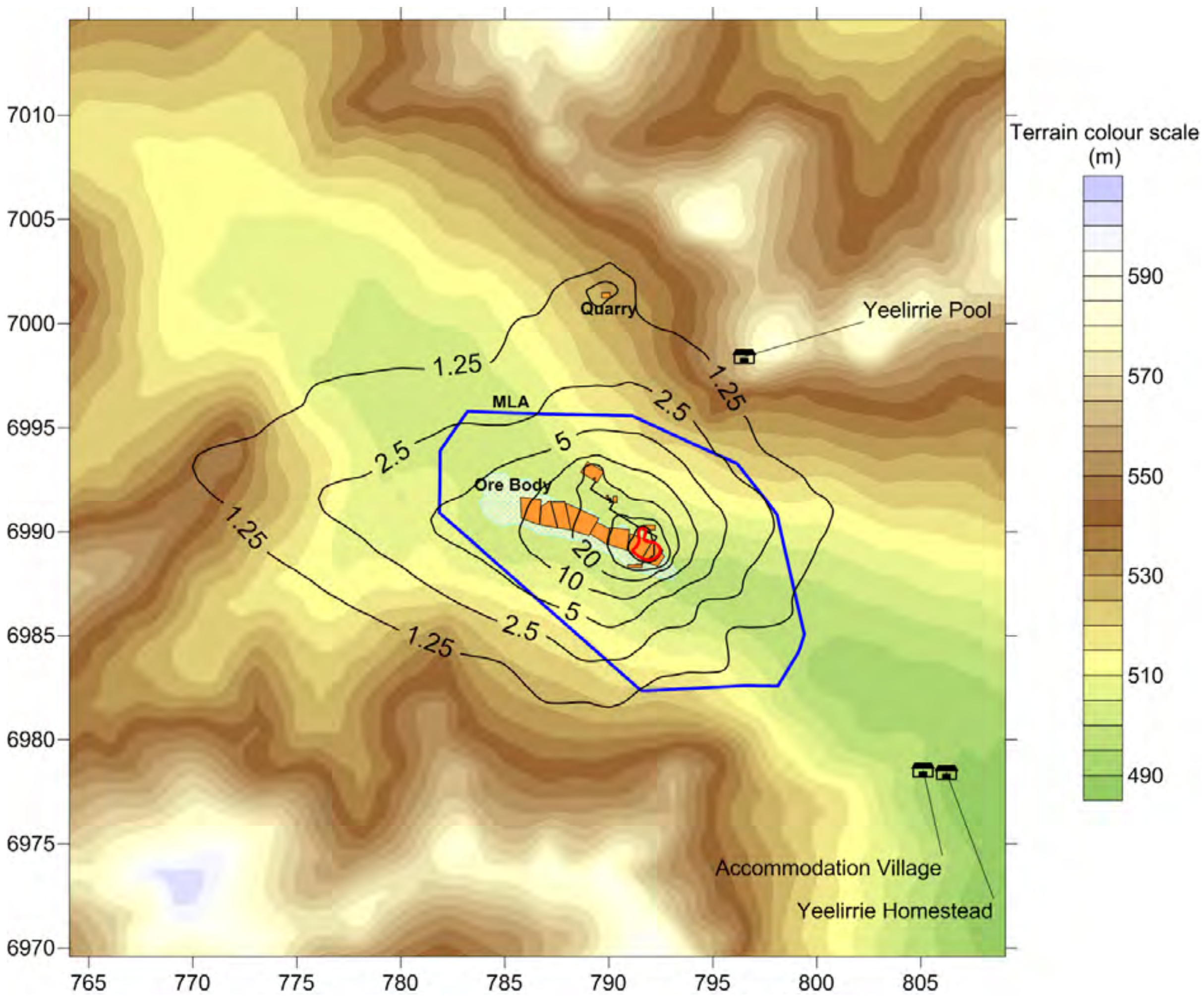


Figure 15	**Predicted operationally contributed annual ground-level concentration of TSP**

Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, no background	**Standard:** 90 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

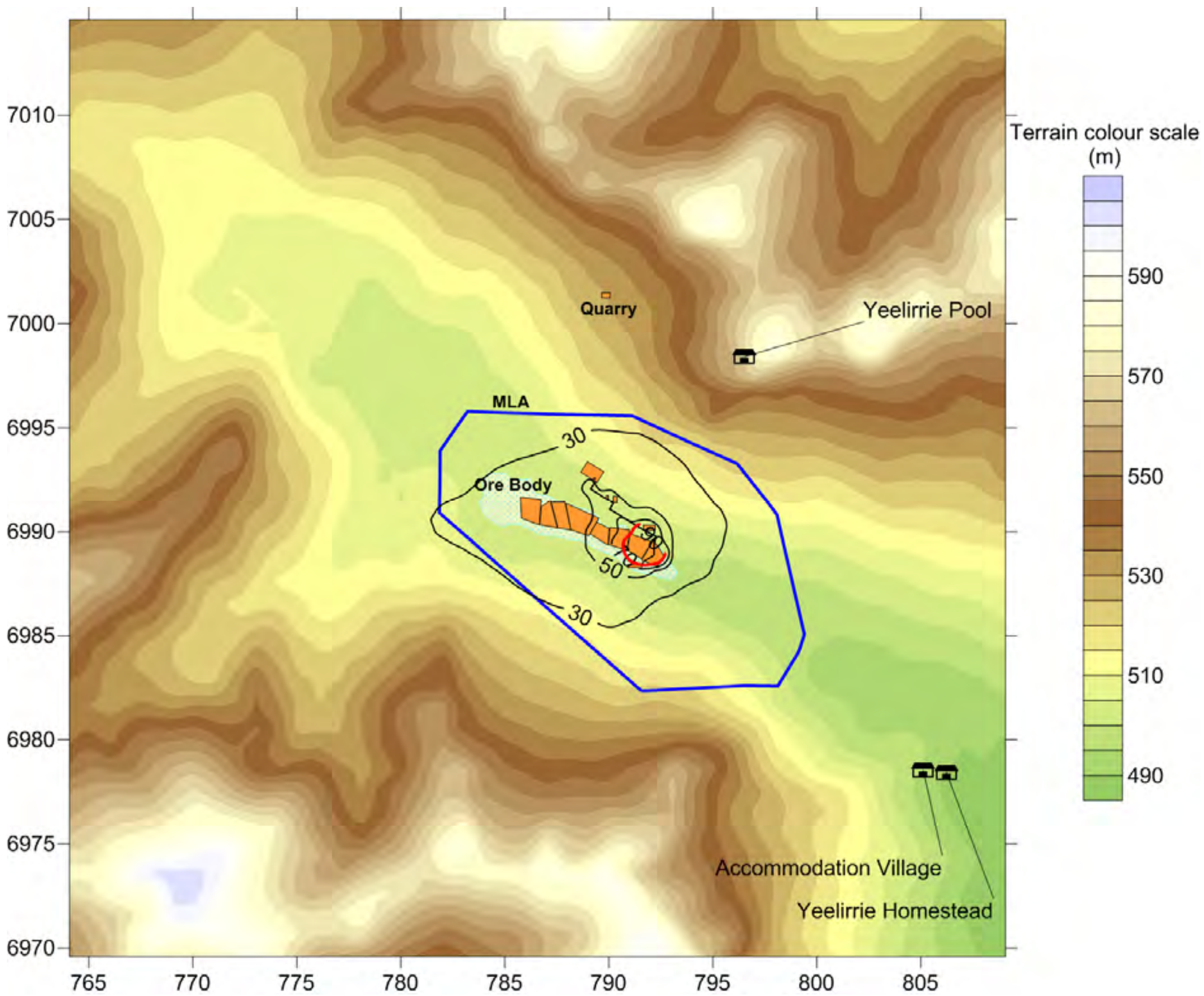


Figure 16	**Predicted annual ground-level concentration of TSP with ambient background**		
Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, with background of 25 µg/m³	**Standard:** 90 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

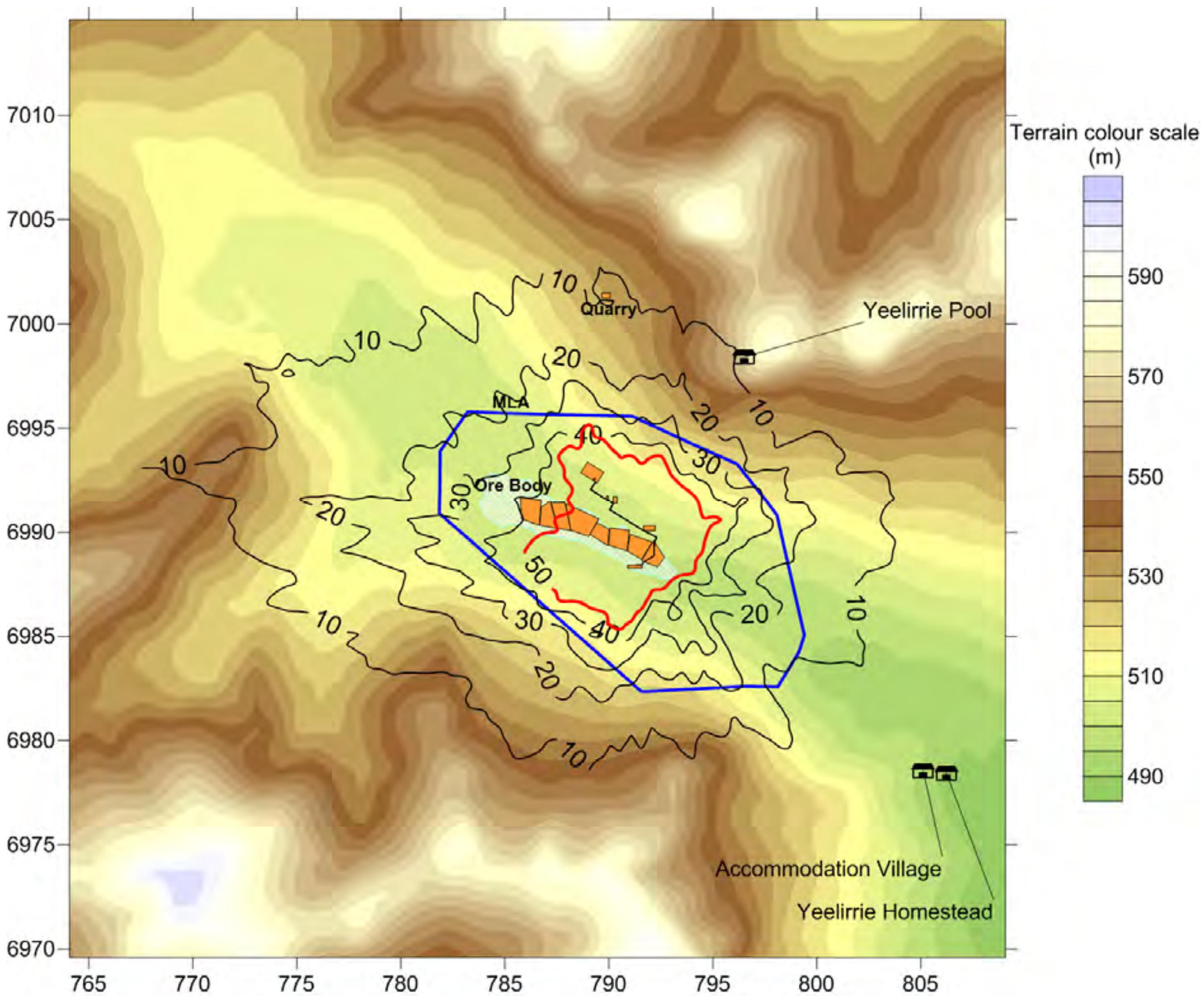


Figure 17	**Predicted operationally contributed 6th highest 24-hour ground-level concentration of PM_{10}**

Location: Yeelirrie, WA	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: 6th highest contours, no background	**Standard:** 50 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

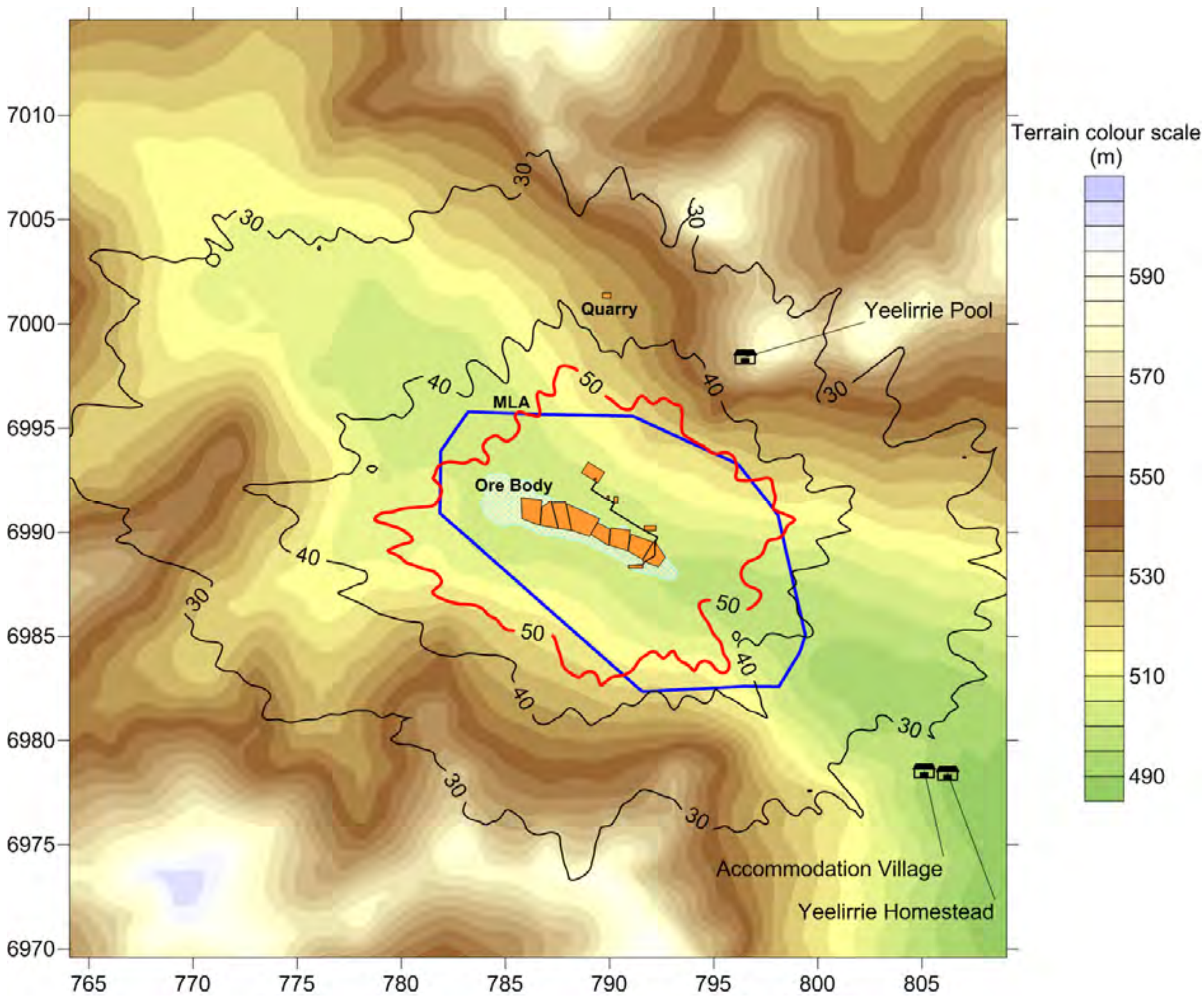


Figure 18 Predicted 6th highest 24-hour ground-level concentration of PM_{10} with ambient background

Location: Yeelirrie, WA	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: 6th highest contours, with background of 25 µg/m³	**Standard:** 50 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

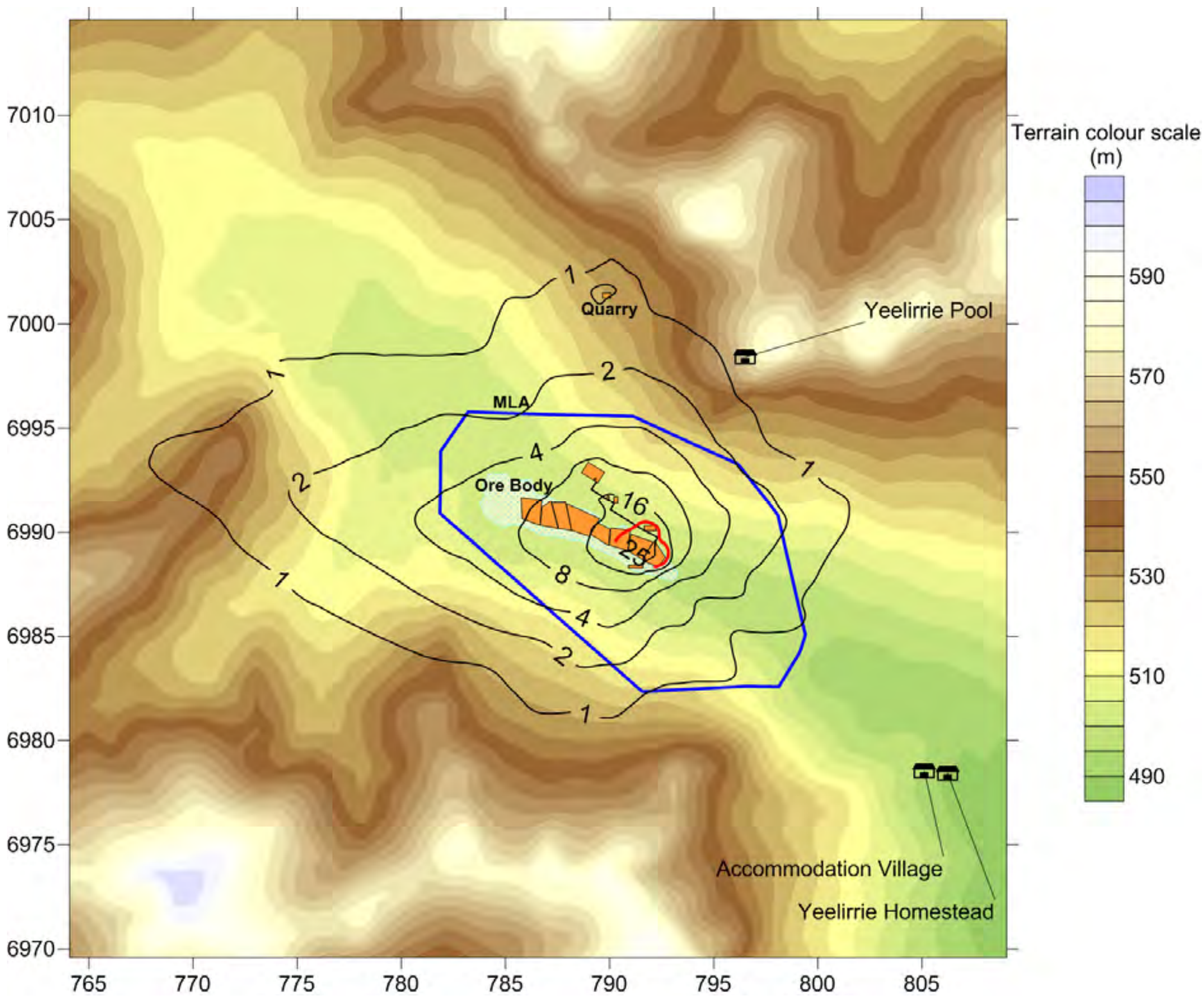


Figure 19	**Predicted operationally contributed annual ground-level concentration of PM_{10}**		
Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, no background	**Standard:** 25 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

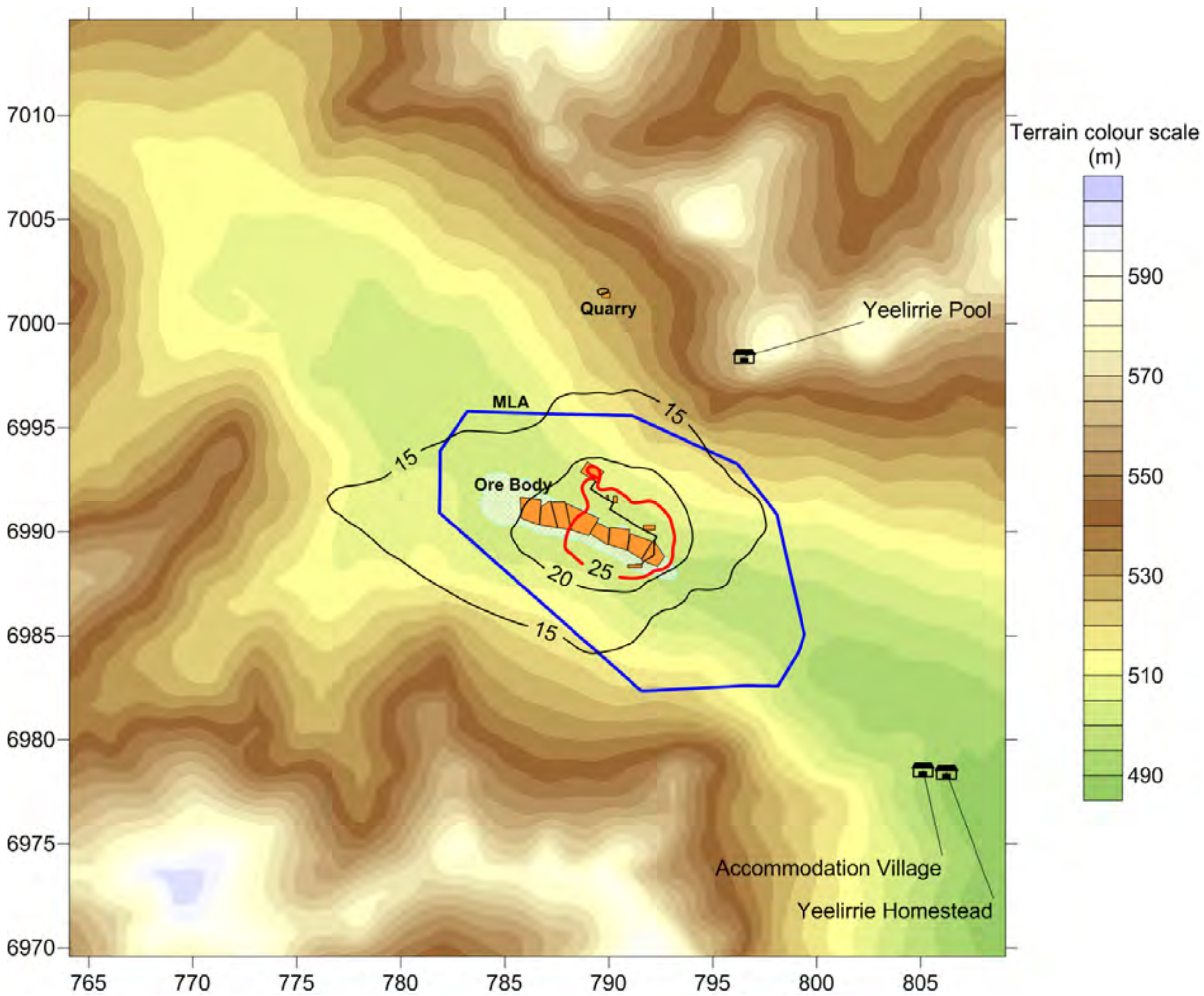


Figure 20 Predicted annual ground-level concentration of PM_{10} with ambient background

Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** $\mu g/m^3$
Type: Annual contours, with background of 12.5 $\mu g/m^3$	**Standard:** 25 $\mu g/m^3$	**Prepared by:** Sarah Menzel	**Date:** January 2011

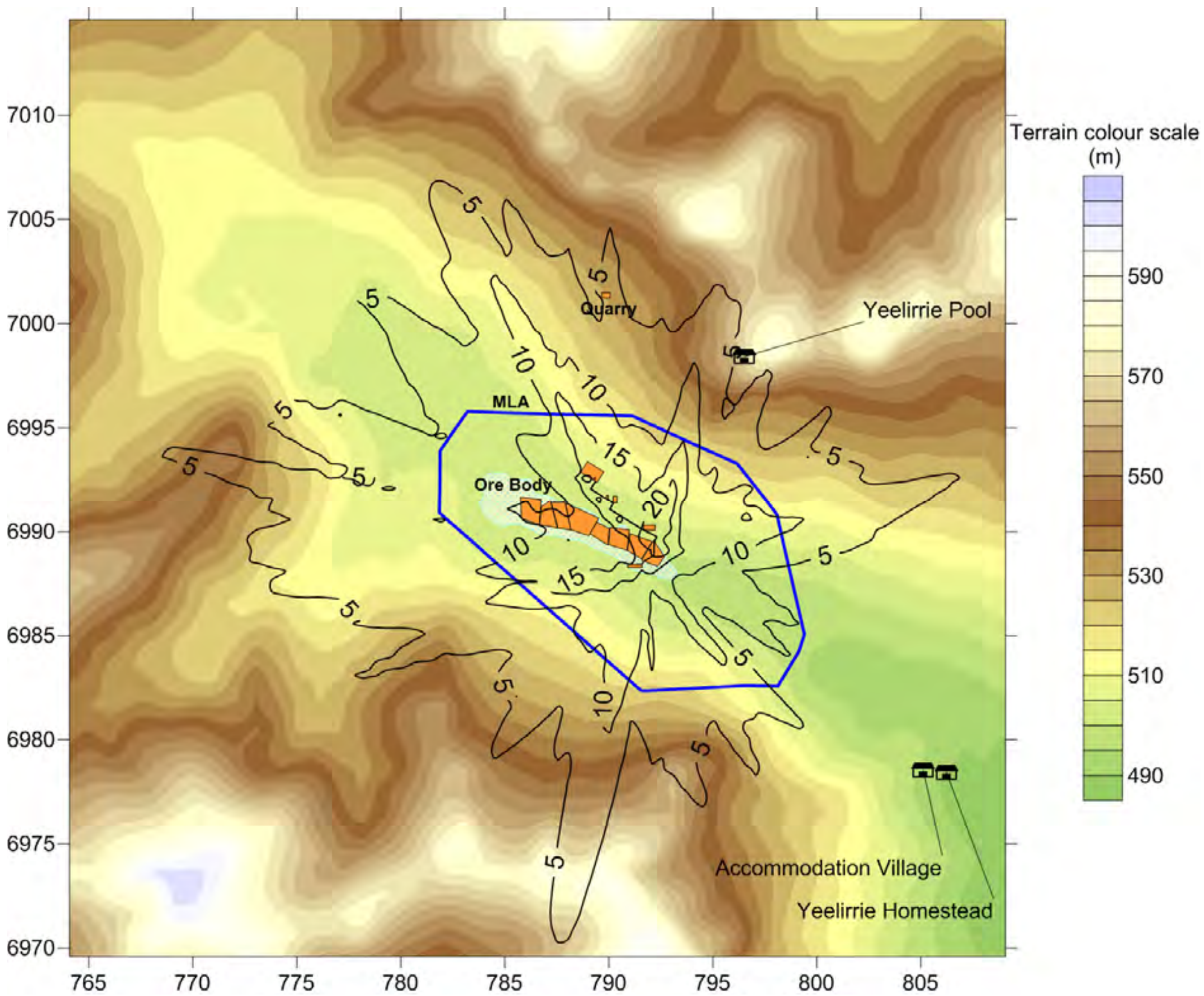


Figure 21 **Predicted operationally contributed maximum 24-hour ground-level concentration of $PM_{2.5}$**			
Location: Yeelirrie, WA	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, no background	**Standard:** 25 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

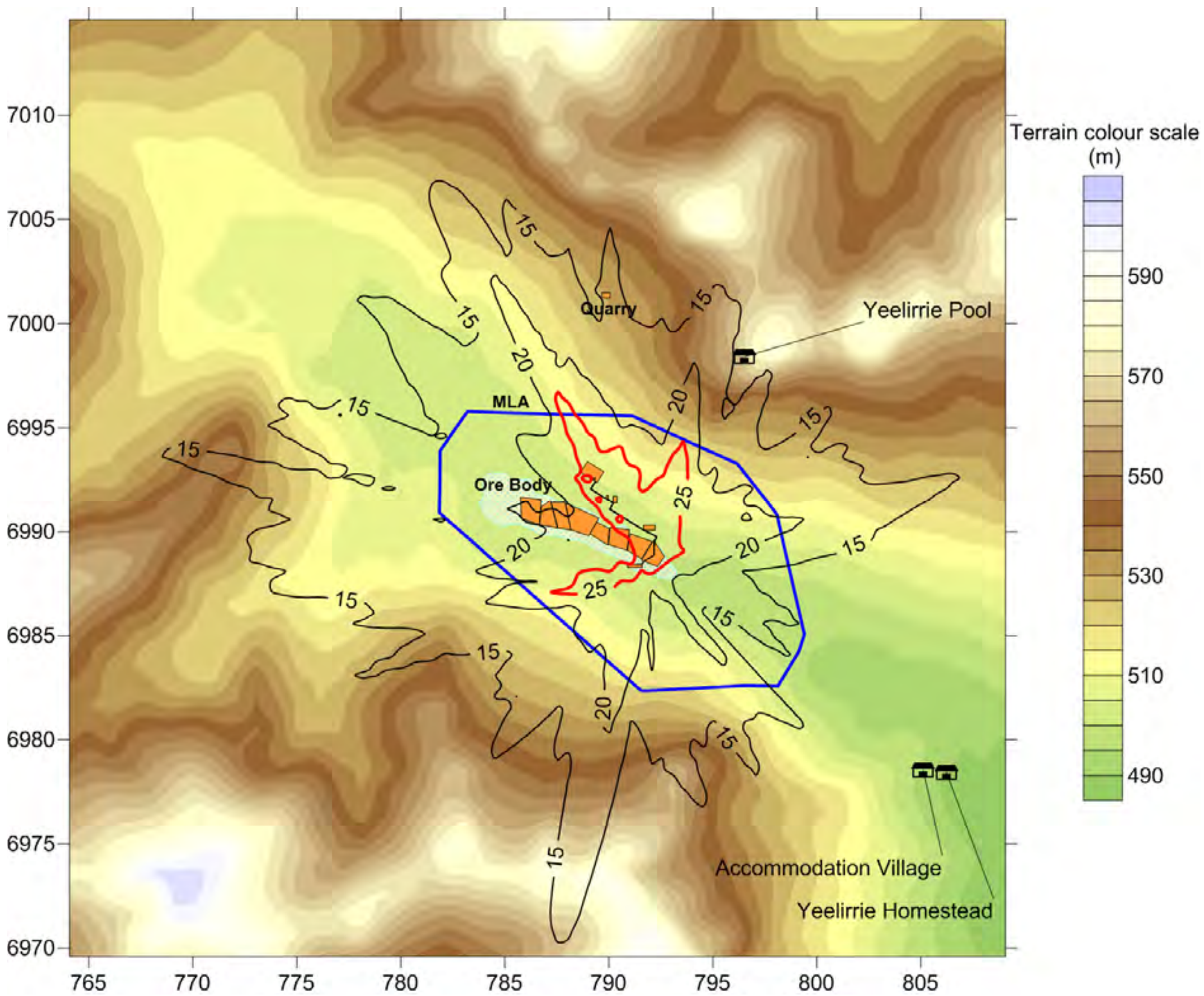


Figure 22 Predicted maximum 24-hour ground-level concentration of $PM_{2.5}$ with ambient background

Location: Yeelirrie, WA	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, with background of 10 µg/m³	**Standard:** 25 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

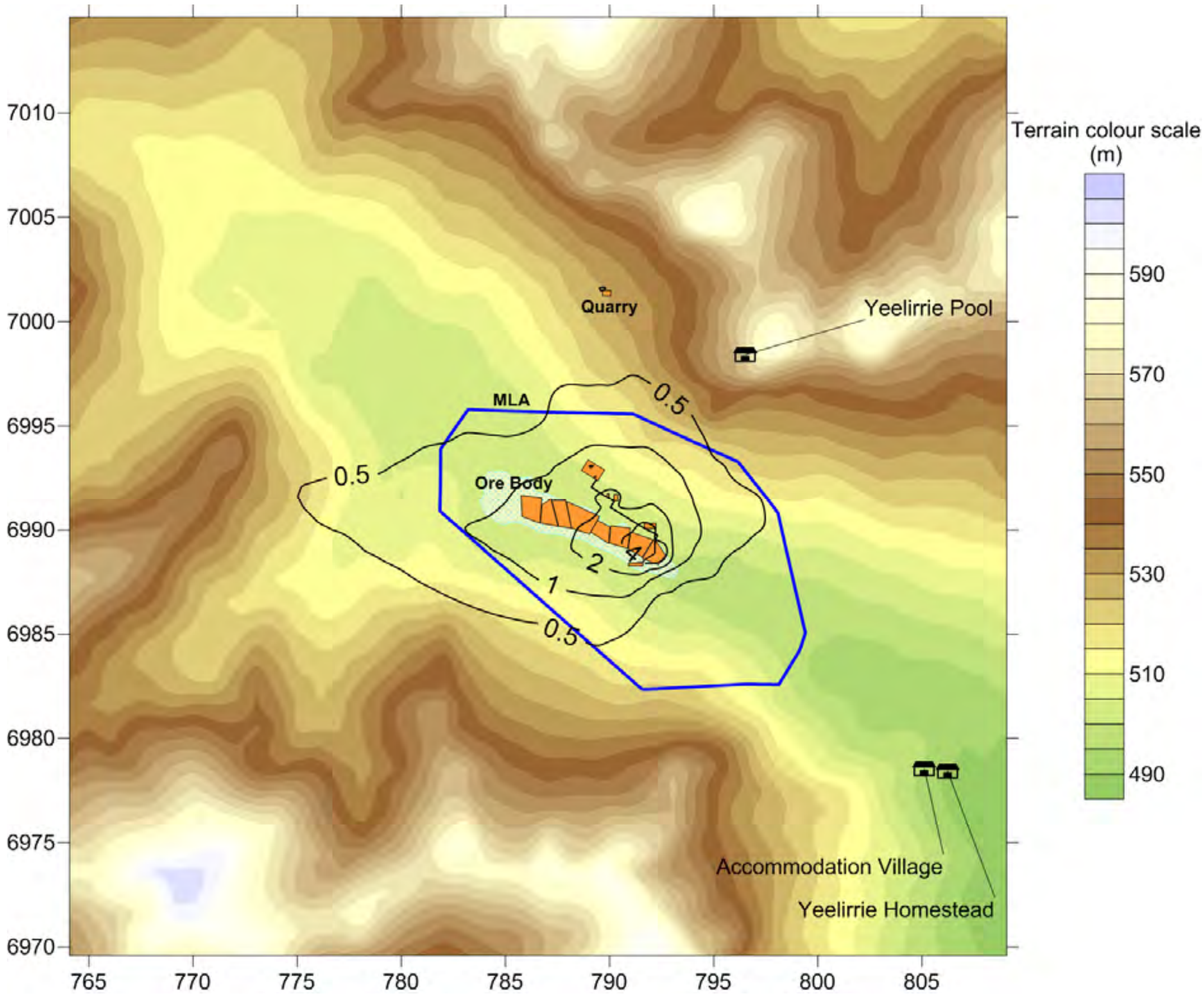


Figure 23 **Predicted operationally contributed annual ground-level concentration of $PM_{2.5}$**			
Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, no background	**Standard:** 8 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

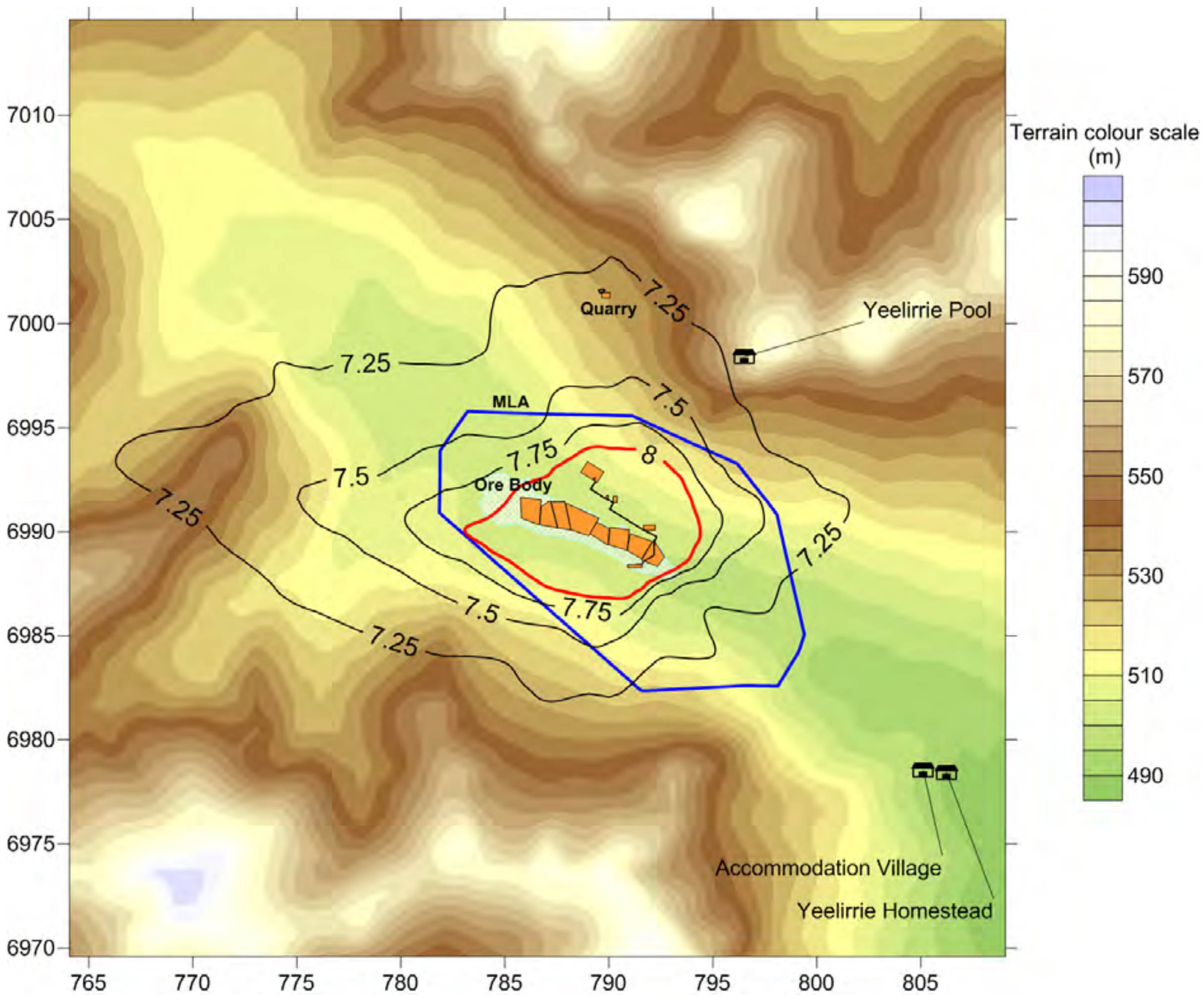


Figure 24 Predicted annual ground-level concentration of $PM_{2.5}$ with ambient background

Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, with background of 7 µg/m³	**Standard:** 8 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

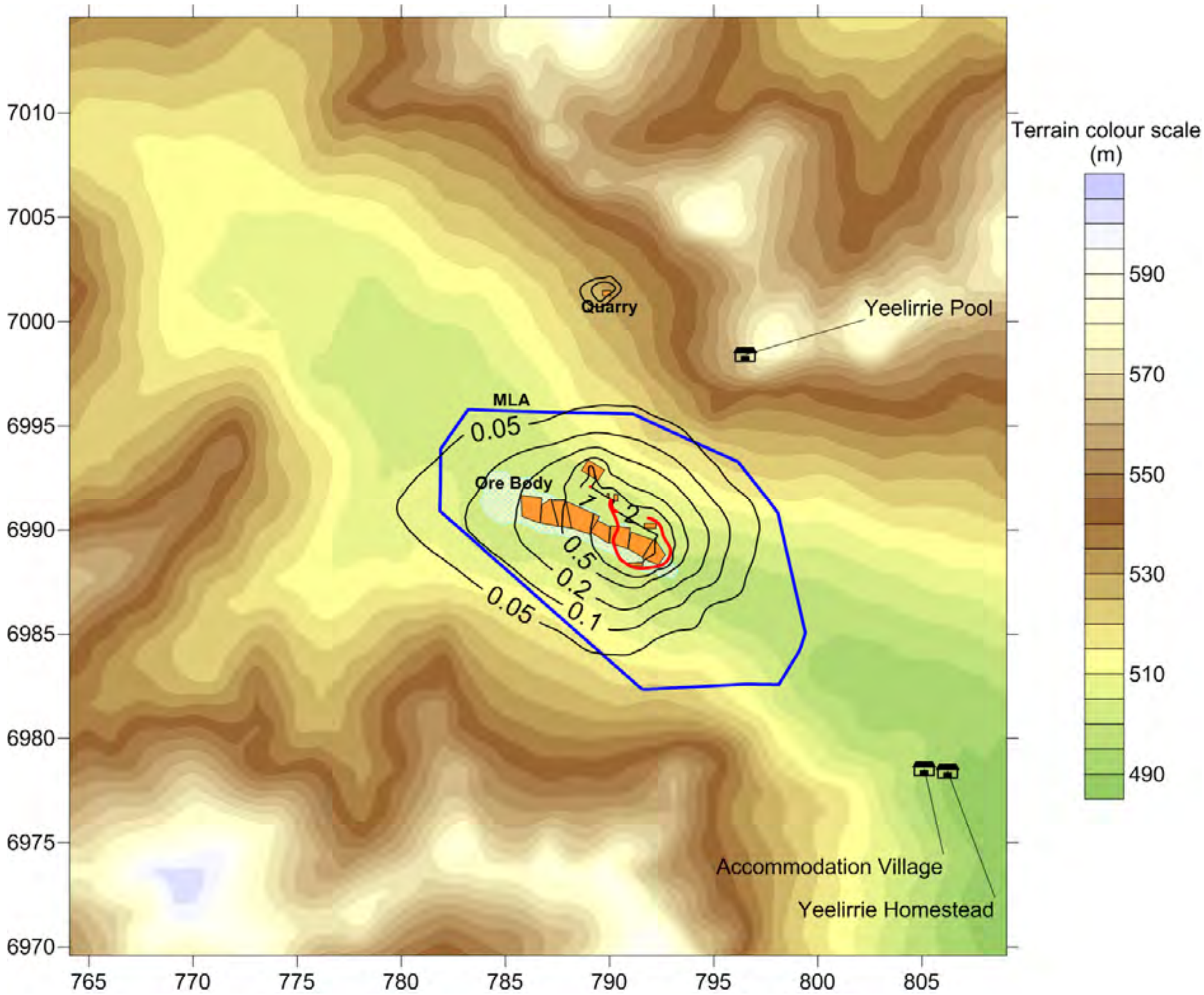


Figure 25 Predicted operationally contributed annual average dust deposition rate

Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, no background	**Standard:** 2g/m²/month (incremental)	**Prepared by:** Sarah Menzel	**Date:** January 2011

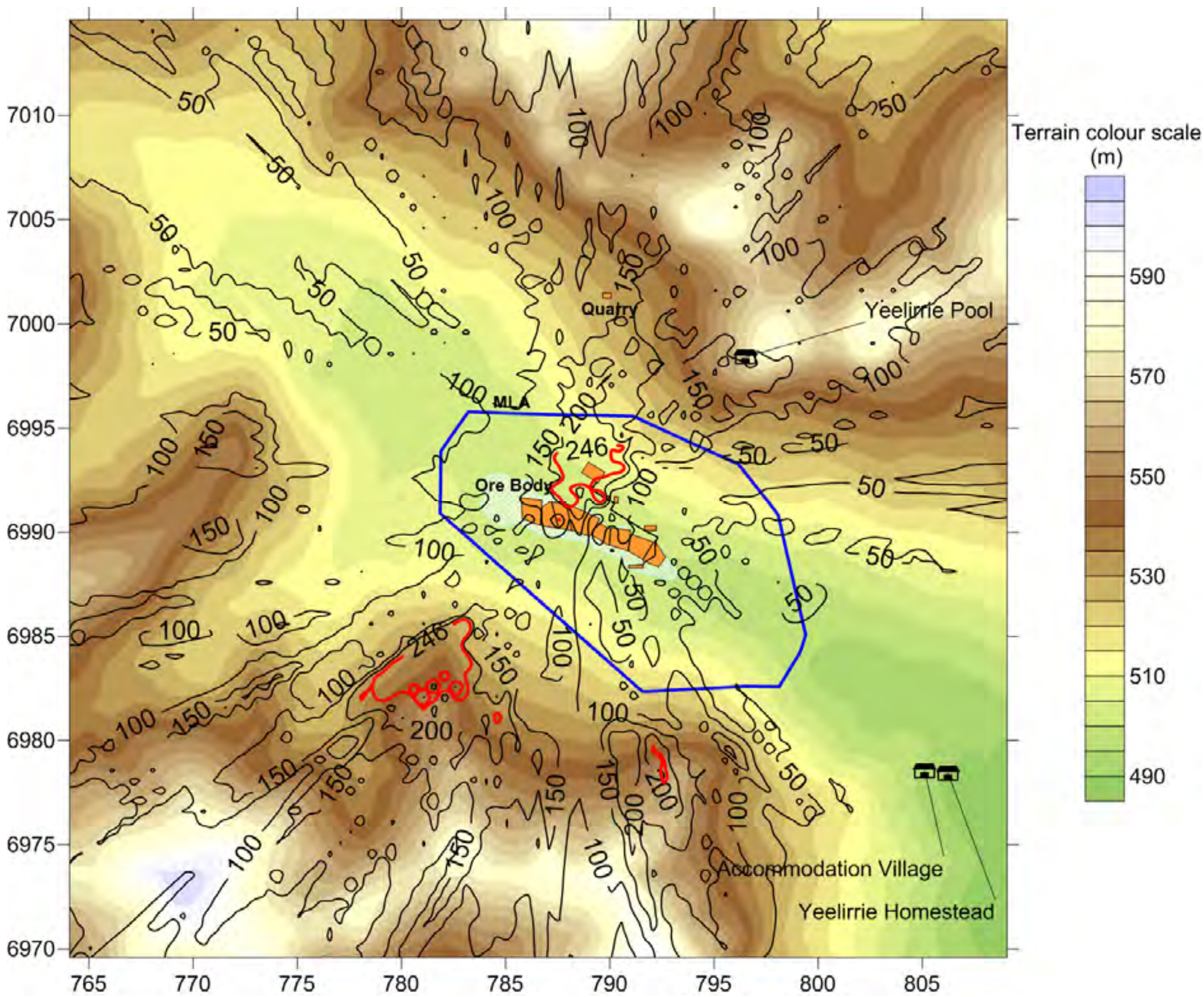


Figure 26 Predicted operationally contributed maximum 1-hour ground-level concentration of nitrogen dioxide (assume no capture of generator emissions)

Location: Yeelirrie, WA	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, no background	**Standard:** 246 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

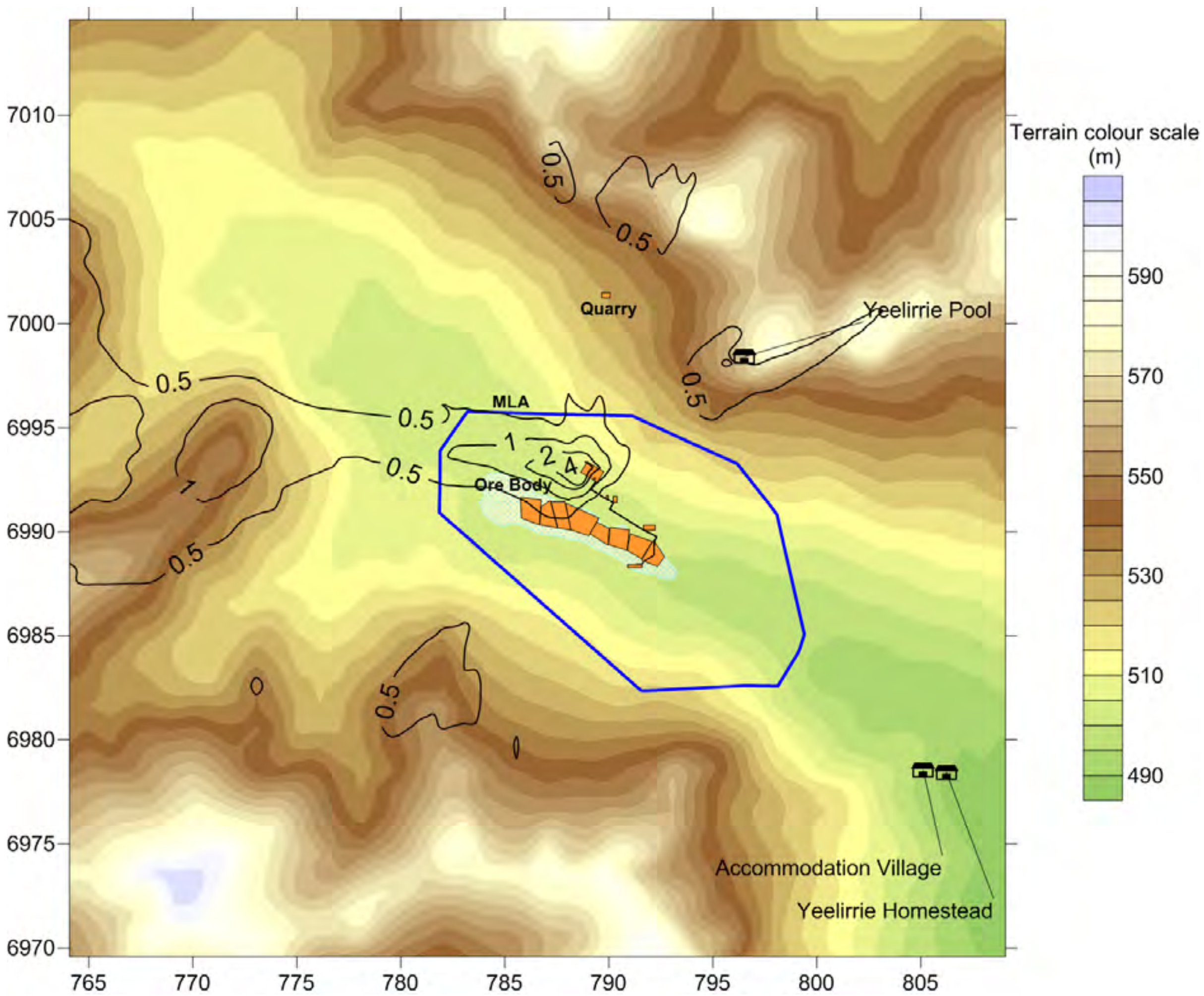


Figure 27 Predicted operationally contributed annual average ground-level concentration of nitrogen dioxide (assume no capture of generator emissions)

Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, no background	**Standard:** 62 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

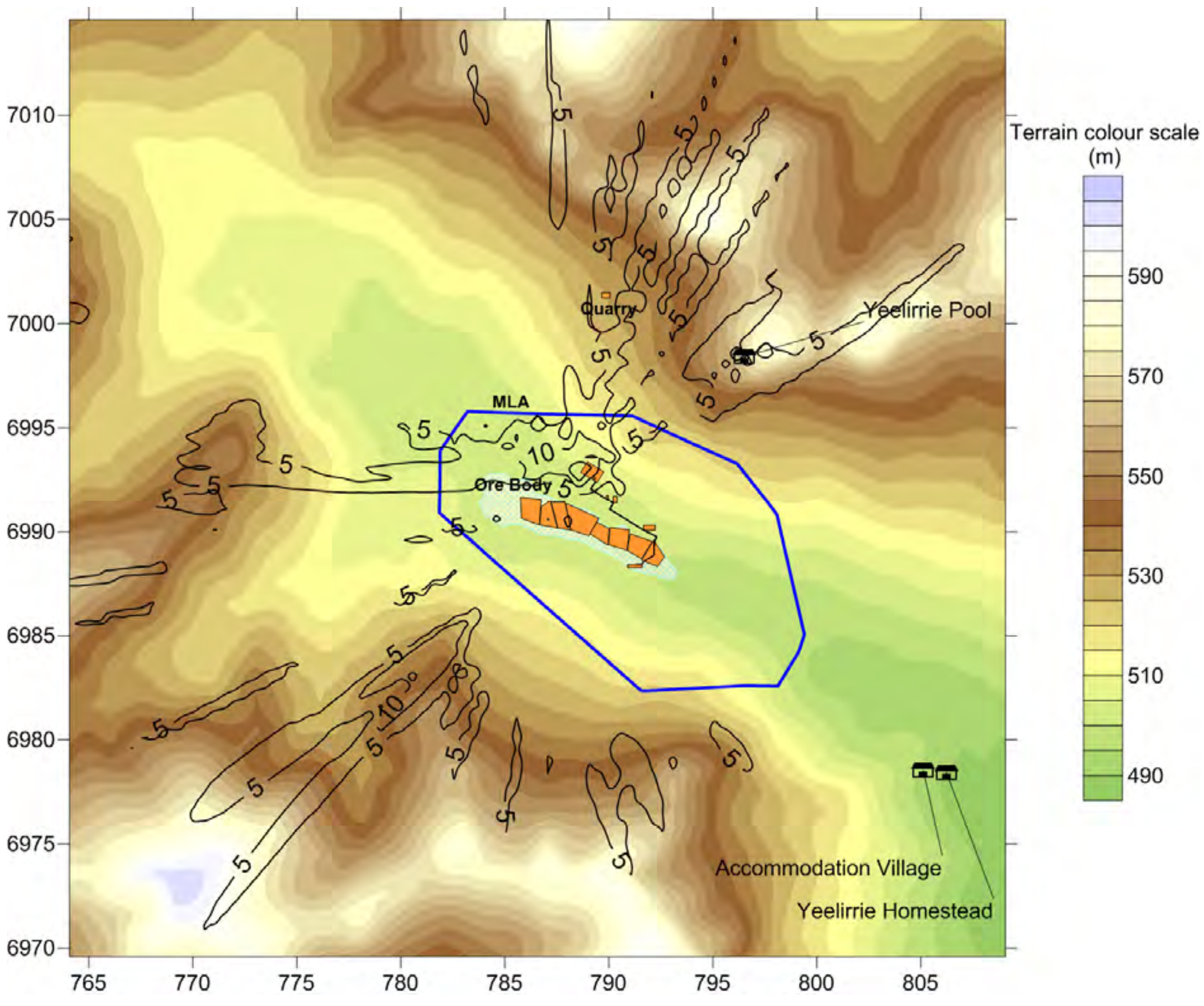


Figure 28 Predicted operationally contributed maximum 8-hour ground-level concentration of carbon monoxide (assume no capture of generator emissions)

Location: Yeelirrie, WA	**Averaging period:** 8-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, no background	**Standard:** 11,000 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

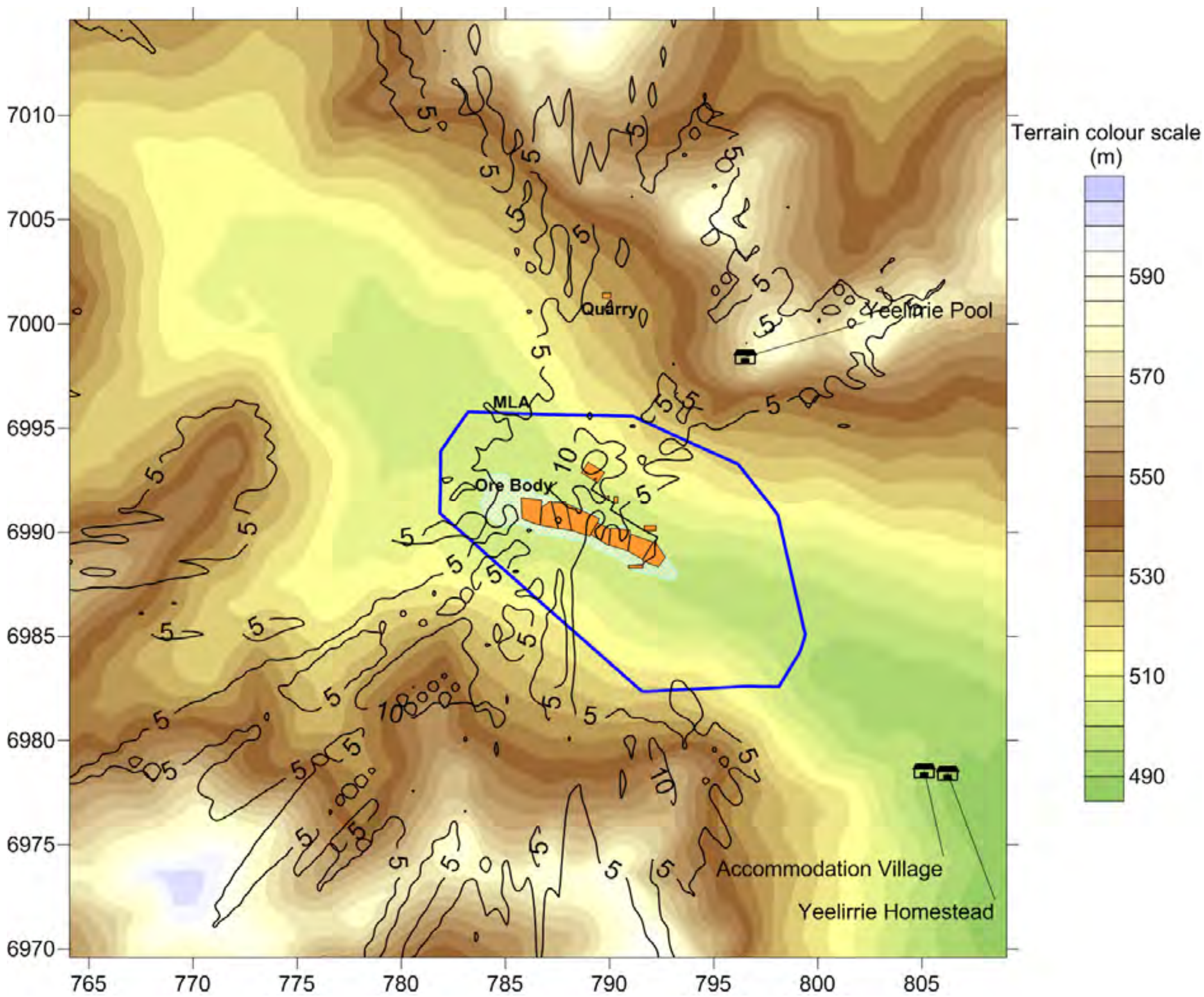


Figure 29	**Predicted operationally contributed maximum 1-hour ground-level concentration of sulfur dioxide (assume no capture of generator emissions)**

Location: Yeelirrie, WA	**Averaging period:** 1-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, no background	**Standard:** 570 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

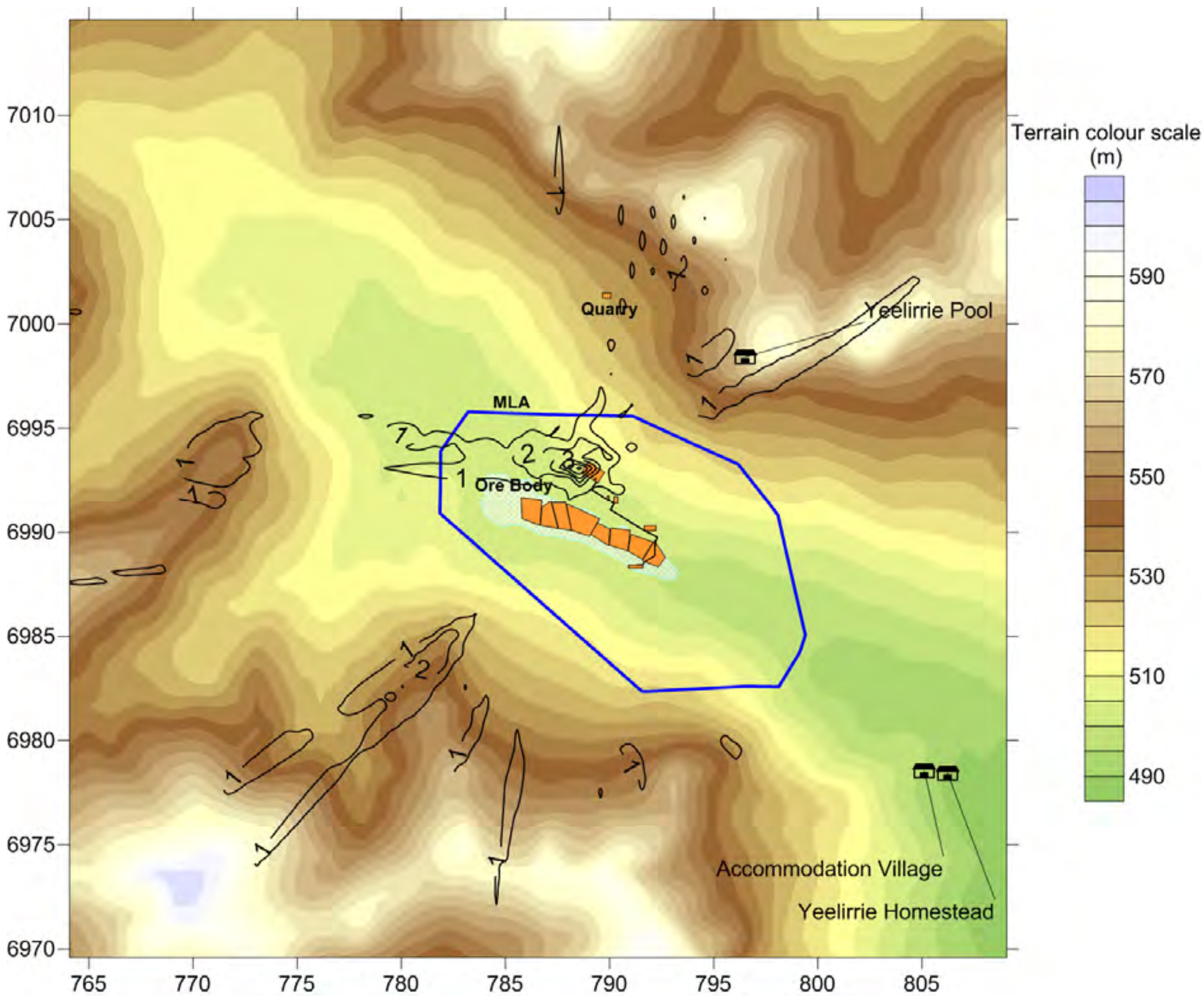


Figure 30 Predicted operationally contributed maximum 24-hour ground-level concentration of sulfur dioxide (assume no capture of generator emissions)

Location: Yeelirrie, WA	**Averaging period:** 24-hour	**Data source:** CALPUFF	**Units:** µg/m³
Type: Maximum contours, no background	**Standard:** 228 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

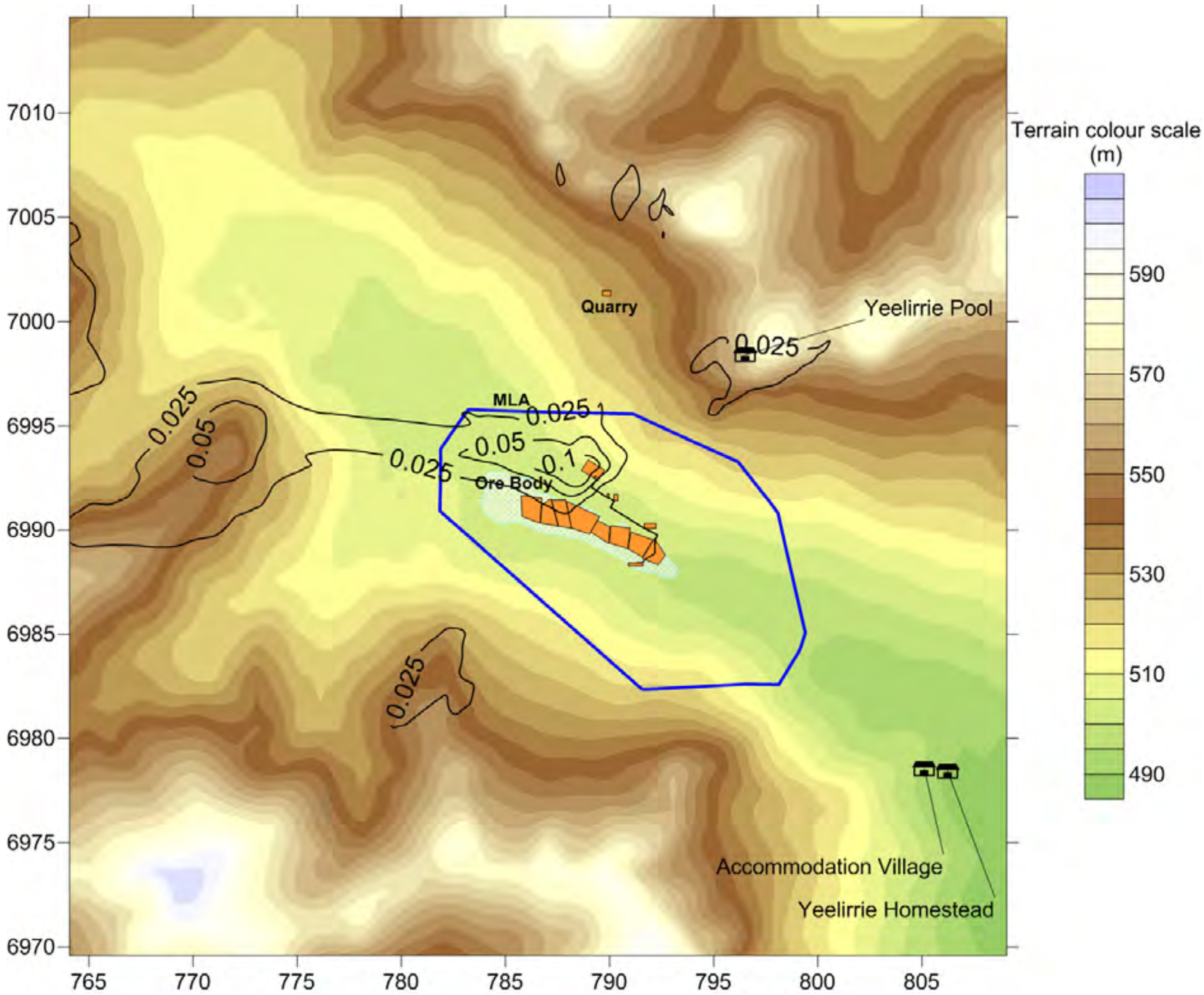


Figure 31	**Predicted operationally contributed annual average ground-level concentration of sulfur dioxide (assume no capture of generator emissions)**		
Location: Yeelirrie, WA	**Averaging period:** Annual	**Data source:** CALPUFF	**Units:** µg/m³
Type: Annual contours, no background	**Standard:** 60 µg/m³	**Prepared by:** Sarah Menzel	**Date:** January 2011

Appendix A
Emissions model

Contents

Appendix A Ore extraction and dust emission rates

This Appendix outlines the information, emission factors and emission rates that have been used in the dispersion modelling of air pollutants from the proposed Yeelirrie development during the selected mining operations scenario. The emissions calculations are for the mining scenario that has been selected to represent operations at the mine that are likely to result in the highest ground-level concentrations at the nearest sensitive receptors.

The emission factors are based on the factors developed by the United States Environment Protection Agency (US EPA AP-42) and National Pollutant Inventory (NPI) Handbooks. The emission rates are calculated using the emission factors, detailed source characteristics and operational activity data provided by BHP Billiton and assumptions made by Katestone Environmental.

The following assumptions have been made for the calculation of dust emissions from the proposed mine for the selected scenario:

- The mine and Metallurgical Plant will operate in 24/7
- Mining will occur at the maximum rate of 8 Mtpa
- Approximately 1.2 Mtpa of ore will be processed
- Ground-level dust concentrations at the nearest sensitive receptors (Yeelirrie Pool, Yeelirrie homestead and onsite accommodation village) due to the proposed Yeelirrie development will be greatest when mining activity is focussed in the eastern region of the ore pit body
- Stockpiles of topsoil, overburden and ore (all grades) will be triangular prisms with a maximum length of 50 metres, width of 10 metres and height of up to 20 metres
- Topsoil and overburden extracted from the working pit will be stockpiled in an adjacent pit void
- Low grade ore extracted from the working pit will be stockpiled along the southern boundary of the open pit
- Medium grade ore extracted from the working pit will be stockpiled along the northern boundary of the open pit
- High grade and very high grade ore extracted from the working pit will be stockpiled adjacent to the Metallurgical Plant
- All ore extracted during a one-year period will be stockpiled for processing the following year
- As the modelled scenario represents operations during the later stages of the mine, there will be no transfer of material from the quarry that is located to the north of the Metallurgical Plant

The quantities of overburden and ore extracted and the exposed areas for the mining scenario used in the assessment are presented in Table A1.

The emission factors used in the calculation of dust emissions from the mine, Metallurgical Plant and quarry are presented in Table A2, Table A3, Table A4 and Table A5.

The calculated dust emission rates (g/s) for activities at the mine, Metallurgical Plant and quarry for the mining scenario modelled presented in Table A6.

Source characteristics and emission rates for various pollutants for the onsite 2MW diesel generators are presented in Table A7 and Table A8, respectively. The air quality impact assessment has assessed the impact of the emissions from the diesel generators during prime operation, with zero percent capture of the exhaust emissions.

Table A1 Quantity of overburden and ore extracted and area sizes

Blocks mined	Active pit area (m^2)	Tonnes extracted					Total stockpile surface area (excluding RoM) (m^2)	Total Plant feed (tonnes)
		Overburden	Very-High-Grade (VHG) ore	High-Grade (HG) ore	Medium-Grade (MG) ore	Low-Grade (LG) ore		
Block 13	713,634	2,974,919	222,723	898,639	2,011,301	1,494,831	2,539,724	1,210,000

Table A2 Emission factors: Removal of overburden and topsoil

Activity	Units	Emission factors		
		TSP	PM_{10}	$PM_{2.5}$
Drilling	kg/hole	0.59	0.31	0.05
Blasting	kg/blast	146.9	76.4	11.5
Dozer ripping	kg/hr	0.78	0.14	0.08
Excavator	kg/tonne	0.025	0.012	0.002
Loading	kg/tonne	0.025	0.012	0.002
Transport	g/VKT	6,311	1,863	186
Dumping	kg/tonne	0.0010	0.0005	0.0001
Dozer operation	kg/hr	0.78	0.14	0.08

Table A3 Emission factors: Removal of ore (all grades)

Activity	Units	Emission factors		
		TSP	PM_{10}	$PM_{2.5}$
Excavator	kg/tonne	0.00009	0.00004	0.00001
Loading	kg/tonne	0.00009	0.00004	0.00001
Transport	g/VKT	6,311	1,863	186
Dumping	kg/tonne	0.00009	0.00004	0.00001
Dozer operation	kg/hr	8.16	2.59	0.18

Table A4 Emission factors: Metallurgical Plant

Activity	Units	Emission factors		
		TSP	PM_{10}	$PM_{2.5}$
FEL pick up from ROM	kg/tonne	0.00009	0.00004	0.00001
FEL drop into crusher	kg/tonne	0.00009	0.00004	0.00001
Single stage crushing unit	kg/tonne	0.010	0.004	0.001
Transfer points	kg/tonne	0.005	0.002	0.0003
Conveyor	g/m/s	0.00006	0.00003	0.000005
Semi-autogenous-grinding (SAG) mill	kg/tonne	No emissions	No emissions	No emissions

Table A5 Emission factors: Fugitive dust emissions

Activity	Units	Emission factors		
		TSP	PM_{10}	$PM_{2.5}$
Wind erosion of exposed areas	kg/ha/year	1,489	744	112

Table A6 Dust emission rate (g/s) used in the dispersion modelling assessment for mine operations

Dust emission source	TSP	PM_{10}	$PM_{2.5}$
Removal of overburden and topsoil			
Drilling	0.68	0.36	0.05
Blasting	3.40	1.77	0.27
Dozer ripping	0.22	0.04	0.02
Excavator	2.67	1.26	0.19
Loading	2.67	1.26	0.19
Transport	7.07	2.09	0.21
Dumping	0.11	0.05	0.01
Dozer activity	0.04	0.01	0.005
Removal of ore (all grades)			
Excavator	0.014	0.006	0.001
Loading	0.017	0.008	0.001
Transport	14.91	4.40	0.44
Dumping	0.017	0.008	0.001
Dozer activity	0.62	0.20	0.01
Metallurgical Plant			
FEL pick up from ROM	0.0035	0.0017	0.0003
FEL drop into crusher	0.0035	0.0017	0.0003
Single stage crushing unit	0.38	0.15	0.02
Transfer points	0.38	0.15	0.02
Conveyor	0.02	0.01	0.001
Semi-autogenous-grinding (SAG) mill	0.00	0.00	0.00

Dust emission source	TSP	PM_{10}	$PM_{2.5}$
Fugitive dust emissions			
Active stockpiles	5.99	3.00	0.45
Working pit area (active)	1.68	0.84	0.13
Previous pit used for dumping	1.42	0.71	0.11
Rehabilitated previous pits	0.86	0.43	0.06
RoM stockpile	0.03	0.02	0.002
Quarry	0.47	0.24	0.04
Total Emissions	***43.69***	***16.99***	***2.23***

Table A7 Stack characteristics of 2MW Diesel generators

Characteristic	Units	Rating		
		Standby	**Prime**	**Continuous**
Number of generators	-	6	6	6
Stack height	m	6	6	6
Stack diameter	m	0.3	0.3	0.3
Exit velocity	m/s	68.7	62.9	57.6
Temperature	°C	420	420	420
	K	693.15	693.15	693.15
Flow rate – actual	m^3/s	4.86	4.44	4.07
Flow rate – normalised	Nm^3/s	1.91	1.75	1.60

Table note:
Data source: Information provided by BHP Billiton and generator specifications sheet

Table A8 Emission rates for six 2MW Diesel generators

Pollutant	Units	Emission rate (g/s)					
		Standby rating		Prime rating		Continuous rating	
		Per generator	Total for 6 generators	Per generator	Total for 6 generators	Per generator	Total for 6 generators
Oxides of nitrogen	g/s	9.36	56.14	6.52	39.11	5.71	34.24
Carbon monoxide	g/s	0.37	2.21	0.20	1.18	0.19	1.16
Particulates (as PM_{10} and $PM_{2.5}$)	g/s	0.009	0.06	0.017	0.10	0.015	0.09
Sulfur dioxide	g/s	0.09	0.57	0.09	0.51	0.08	0.46

Appendix B
Meteorological Modelling

Contents

Appendix B Meteorological modelling

B1 Air dispersion modelling

The meteorological data for this study was generated by coupling TAPM, a prognostic mesoscale model to CALMET, a diagnostic meteorological model. The coupled TAPM/CALMET modelling system was developed by Katestone Environmental to enable high resolution modelling capabilities for regulatory and environmental assessments. The modelling system incorporates synoptic, mesoscale and local atmospheric condition, detailed topography and land use categorisation schemes to simulate synoptic and regional scale meteorology for input into pollutant dispersion models, such as CALPUFF. Details of the model configuration and evaluation are supplied in the following sections.

B1.1 TAPM

The meteorological model, TAPM (The Air Pollution Model) Version 4.0.1, was developed by the CSIRO and has been validated by the CSIRO, Katestone Environmental and others for many locations in Australia, in southeast Asia and in North America (see www.cmar.csiro.au/research/tapm for more details on the model and validation results from the CSIRO). Katestone Environmental has used TAPM throughout Australia as well as in parts of New Caledonia, Bangladesh, America and Vietnam. This model has performed well for simulating regional meteorological conditions. TAPM has proven to be a useful model for simulating meteorology in locations where monitoring data is unavailable.

TAPM is a prognostic meteorological model which predicts the flows important to regional and local scale meteorology, such as sea breezes and terrain-induced flows from the larger-scale meteorology provided by the synoptic analyses. TAPM solves the fundamental fluid dynamics equations to predict meteorology at a mesoscale (20 km to 200 km) and at a local scale (down to a few hundred metres). TAPM includes parameterisations for cloud/rain micro-physical processes, urban/vegetation canopy and soil, and radiative fluxes.

TAPM requires synoptic meteorological information for the study region. This information is generated by a global model similar to the large-scale models used to forecast the weather. The data are supplied on a grid resolution of approximately 75 km, and at elevations of 100 m to 5 km above the ground. TAPM uses this synoptic information, along with specific details of the location such as surrounding 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:

- 50 x 50 grid point domain with an outer grid of 30 km and nested grids of 10 km, 3 km and 1 km
- Grid centred near the project site (latitude -27° 7’, longitude 119° 53’)
- Geoscience Australia 9 second DEM terrain data
- Synoptic data used in simulation for the period of December 2003 to December 2008
- 25 vertical grid levels
- Hourly varying wind speed and wind direction data from the Bureau of Meteorology’s monitoring stations at Meekatharra, Leinster, Laverton, Kalgoorlie and Geraldton were assimilated into TAPM to nudge the predicted solution towards the observation
- Data assimilation were given a 40km radius of influence
- Data was assimilated over the lowest 4 vertical levels

B1.2 CALMET

CALMET is an advanced non-steady-state diagnostic three-dimensional meteorological model with micro-meteorological modules for overwater and overland boundary layers. The model is the meteorological pre-processor for the CALPUFF Modelling system. CALMET is capable of reading hourly meteorological data from multiple sites within the modelling domain; it can also be initialised with the gridded three-dimensional prognostic output from other meteorological models such as TAPM. This can improve dispersion model output, particularly over complex terrain as the near surface meteorological conditions are calculated for each grid point.

CALMET (Version 6.4) was used to simulate meteorological conditions in the study region. The CALMET simulation was initialised with the gridded TAPM three dimensional wind field data from the 1 km grid. CALMET treats the prognostic model output as the initial guess field for the CALMET diagnostic model wind fields. CALMET then adjusts the initial guess field for the kinematic effects of terrain, slope flows, blocking effects and 3-dimensional divergence minimisation.

CALMET was set up with twelve vertical levels with heights at 20 m, 60 m, 100 m, 180 m, 260 m, 360 m, 460 m, 600 m, 800 m, 1600 m, 2600 m and 4600 m at each grid point. The geophysical data (land use and terrain heights) were generated from the Shuttle Radar Topography Model v.3 (SRTM3) dataset. Land use characteristics were generated from the Australia/Pacific Land Cover Characteristics Data Base Version 2.0 and refined based on Katestone Environmental's knowledge of the site.

Key features of CALMET used to generate the wind fields are as follows:

- Domain area of 46 x 46 grid points at 1 km spacing
- 365 days (1 December 2007 to 30 November 2008)
- Prognostic wind fields generated by TAPM input as MM5/3D.dat for "initial guess" field for upper air stations only
- Gridded cloud cover from Prognostic Relative Humidity at all levels
- Layer-dependent biases modifying the weights of surface and upper air stations BIAS = -1 , -.75 , -.5 , -.25 , 0 , .25 , .5 , .75 , 1 , 1 , 1 , 1
- Varying radius of influence on
- Mixing height parameters all set as default
- Terrain radius of influence set at 2 km

B2 Model evaluation

The BoM monitoring data for Yeelirrie stations consists of the following measurement protocols :

- 10 minute spot average
- Recording at 9 am and 3 pm
- Wind speed rounded to nearest 0.5 m/s
- Wind direction rounded to nearest 15 degrees

These data are inadequate to use for a model evaluation due to it sparse resolution in time and coarse resolution of measurements.

As such the any evaluation can only be qualitative in nature, where comparisions of distributions and the simulation of site specific meteorological phenomena take precedence over statistical measures. The BOM monitoring site at Wiluna has also been included in the evaluation as this dataset is more comprehensive, covering a longer time period at a resolution of one hour, and is therefore comparible to the modelling dataset.

Figure B1 shows the modelled and observed annual wind roses for Yeellirrie. The model does a good job of simulating the prevailing north east to southeast winds which account for approximately 55% of the distribution. The overall distribution of winds is well represented in the model although the model tends to underpredict the frequency of northwesterly winds.

Figure B2 and Figure B3 show the seasonal distribution of winds from the model and the observations. The distribution of summer and autum winds are shown to be well represented in the model, while the overall variability is captured in winter and spring the northwesterly and northeasterly sectors are under represented in the model.

Figure B4 shows the distribution of wind speeds measured at Yellirrie homestead and Wiluna monitoring station compared to TAPM/CALMET. The model compares well with Wiluna's distribution of wind speeds, while Yeelirrie wind speeds appear to be skewed to the lower end of the spectrum. This may be an artifact of the recording method used at Yeelirrie as the Wiluna station recordes hourly data.

Figure B5 shows the distribution of wind directions measured at Yellirrie homestead and Wiluna monitoring station compared to TAPM/CALMET. The general distribution of winds is evident with a high frequency of easterly winds. The symmetric variability in the BoM datasets is most likely due to the measurement technique where wind direction is post processed into 15 degree (°) bins.

Figure B6 shows the distribution of temperature measured at Yellirrie homestead and Wiluna monitoring station compared to TAPM/CALMET. The model tends to over predict the frequency of temperatures less that 10°C and under predicts the frequency of temperatures below zero.

The inland areas of Western Australian region show a predominance of east to southwest winds during spring and summer, shifting to a distinct alternating westerly and easterly flow during autumn and winter. While coastal locations record a high frequency of moderate to strong winds from the north-northeast to northeast during winter, shifting to winds predominantly from the south during spring and summer (Appendix C).

The synoptic conditions responsible for these shifts in wind patterns were analysed using the K-means clustering algorithm to identify the main weather types across the region. Four weather types were identified (Table B1) as the main contributors to the weather experienced in the region.

Table B1 Weather types identified at the synoptic, regional and local scale

Weather type	Synoptic situation	General description
1	Monsoonal low off the NW coast, trough moving inland, high pressure system to the south	Hot, dry north-easterly winds
2	Ridge of high pressure pushing in behind front	Temperatures in the low 20s, 30 -40% humidity, light easterlies tending south-westerly along the coast
3	High pressure system situated over central Australia with associated fronts along the coast	Wide range of temperatures from below zero at night to above 30 °C during the day, more moderate temperatures along the coast. Humidity stable around 50 to 70%, very light winds inland from the north east to south east with more moderate winds from southeast to southwest along the coast
4	Similar to Type 3 only high pressure system is situated further south over the Great Australian Bight	Wide range of Temperature from below zero at night to above 30 °C during the day, more moderate Temperatures along the coast. High humidity 70-90 %, very light winds inland from the south east to north west with more moderate winds from south east to changing to north east along the coast

The frequency of modelled weather types is consistent with results found for Yeelirrie (Table B2), the synoptic, regional and local locations (Appendix C). The model tends to underpredict Type 1 and 2 while over predicting Type 4 conditions in winter, with a slight underprediction of Type 1 and overprediction of Type 3 in spring.

Figure B8 through to Figure B23 show the seasonal frequency distributions of wind speed, wind direction, temperature and relative humidity of the four synoptic types as measured at the Yeelirrie monitor (a) and modelled using TAPM/CALMET (b). The results show that the model does indeed capture the meteorological variability and distinct signatures of the four weather types (Appendix C).

Table B2 Seasonal frequency of weather types as measured and modelled for Yeelirrie

Site	SUMMER			
	Type1	Type2	Type3	Type4
Yeelirrie	48.7	31.9	12.1	7.3
TAPM/CALMET	33.2	38.3	17.1	11.4
	AUTUMN			
Yeelirrie	18	45	27.8	9.2
TAPM/CALMET	7.5	34.5	39.8	18.3
	WINTER			
Yeelirrie	8.3	42.3	35.7	13.6
TAPM/CALMET	0.8	17	45.5	36.7
	SPRING			
Yeelirrie	38.4	43.5	12.6	5.4
TAPM/CALMET	19.6	44.3	27.5	8.6
	All Seasons			
Yeelirrie	28.4	40.7	22.1	8.9
TAPM/CALMET	15.3	33.5	32.5	18.8

One of the most important aspects of the local meteorology around the Yeelirrie region for air dispersion is the frequency and intensity of nocturnal inversions. The model has been shown to adequately simulate the majority of atmospheric conditions and weather types in the Yeelirrie region, while also showing its limitations in similating the frequency of northwesterly winds in winter and spring. However it is the atmospheric conditions that are associated with these wind patterns that are essential to dispersion not necessarily the wind direction by itself.

The air environment around Yeellirrie is quite complex, as previous studies identified a high percentage of nocturnal inversions and an associated low-level jet which predominantly formed during winter and and early spring when the variation in daytime and nighttime temperatures are at their highest (Steadman 1978).

To determine if the model is capable of simulating this complex behaviour the vertical profile of wind speed and virtual potential temperature was extracted from TAPM for the winter months of the simulation period. Figure B7 shows the nightime vertical profiles of the atmosphere during winter. The formation of a low-level jet is apparent and coincides with the inversion layer designated by the virtual potential temperature profile.

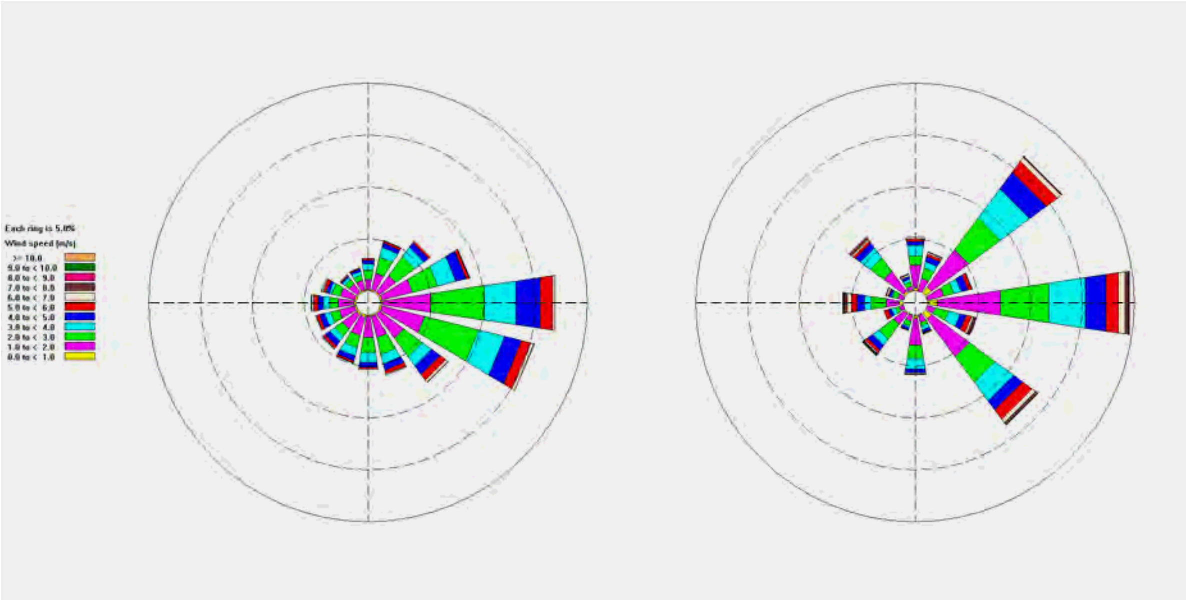
These conditions coincide with Type 3 weather conditions which are the dominant weather type during the winter months. It is these conditions that also lead to worst case dispersion conditions for pollutants suspended in the atmosphere. Table B2 shows that Type 3 conditions occur for 22% of the year, while the model predicts these conditions 32% of the year, indicating that the model is conservative.

Steedman *et al.*1978 found that stable nighttime conditions occurred on 39% of all nights in the Yeelirie region. The frequency of modelled stable nighttime conditions was 37%. Another indication of the models representativeness of the area and its conservativeness.

The frequency of a stable atmosphere coupled with the formation of a low level jet (Figure B7), shows that the model is capable of similating the extreme conditions experienced at the proposed Yeelirrie development site.

B3 References:

R.K Steedman & Associates, 1978, Yeelirrie Environmental Impact Statement: Atmospheric Studies, Report to Maunsell and Partners Pty Ltd to be incorporated in the Western Mining Corporation Limited Environmental Impact Statement on the Yeelirrie Uranium Project.



a) b)

Figure B1 Annual wind rose for a) modelled proposed Yeelirrie development site and b) observed at the Yeellirrie homestead

Location: Yeelirrie	**Period:** a)2004-2008 b)2006-2009	**Data source:** a)TAPM/CALMET b)BoM	**Units:** m/s and degrees
Type: Wind rose	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010

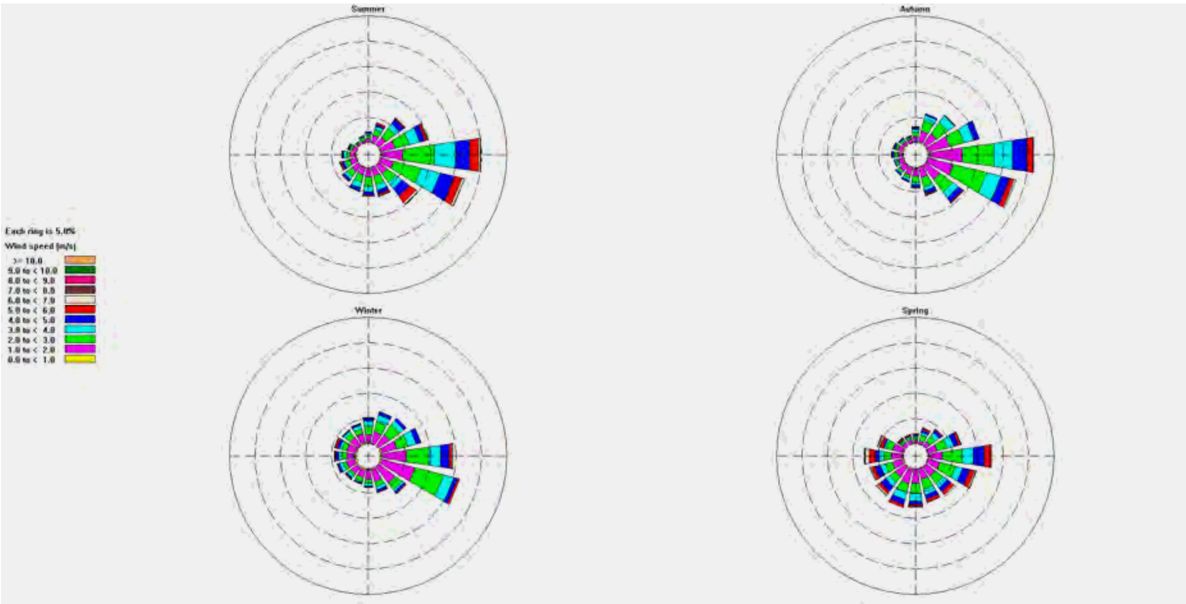


Figure B2 Modelled seasonal wind rose for the proposed Yeelirrie development site

Location: Yeelirrie	**Period:** 2004-2008	**Data source:** TAPM/CALMET	**Units:** m/s and degrees
Type: Wind rose	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010

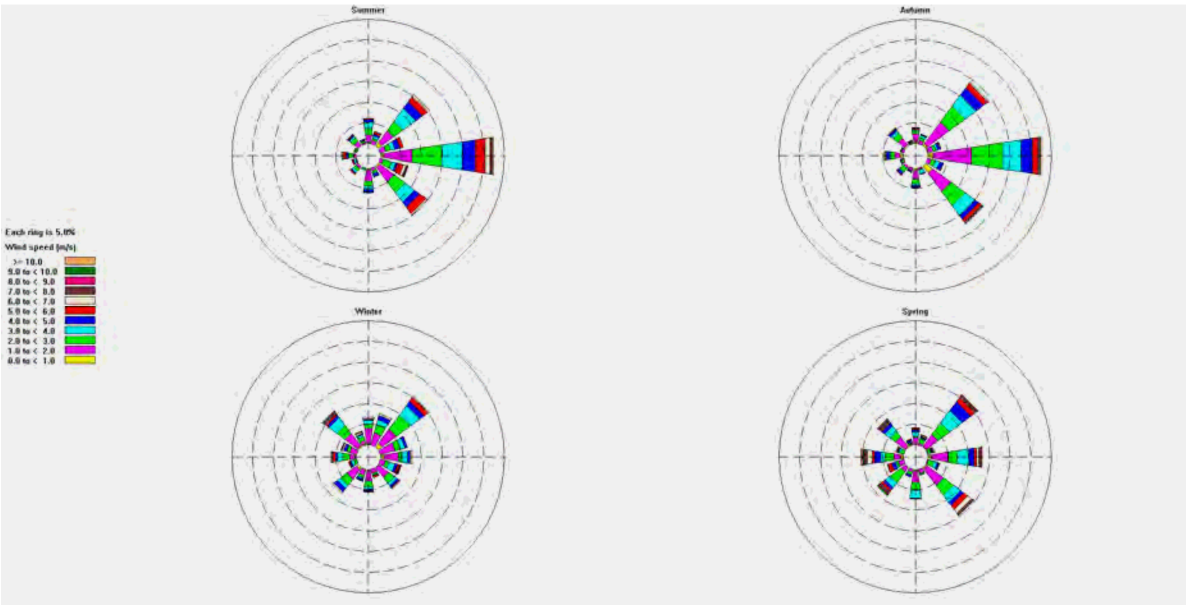


Figure B3 Observed seasonal wind rose for the Yeelirrie Homestead

Location: Yeelirrie	**Period:** 2006-2009	**Data source:** BoM	**Units:** m/s and degrees
Type: Wind rose	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010

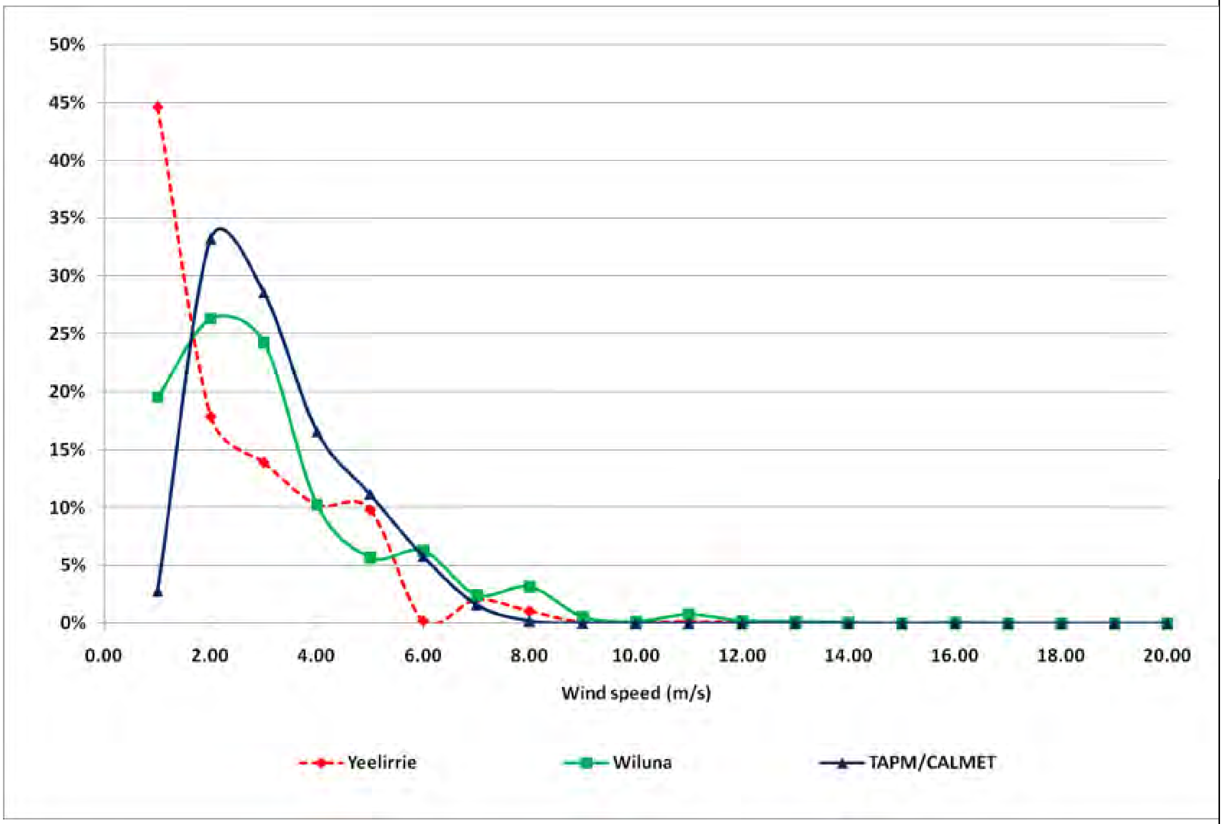


Figure B4 Distribution of wind speeds at Yeelirrie Homestead, Wiluna monitoring station and modelled for the proposed Yeelirrie development site

Location: Yeelirrie, Wiluna	**Period:** Yeelirrie and Wiluna 2006-2009 TAPM/CALMET 2004-2008	**Data source:** BoM and TAPM/CALMET	**Units:** m/s
Type: Frequency distribution	**Data frequency:** 9am and 3pm and 1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010

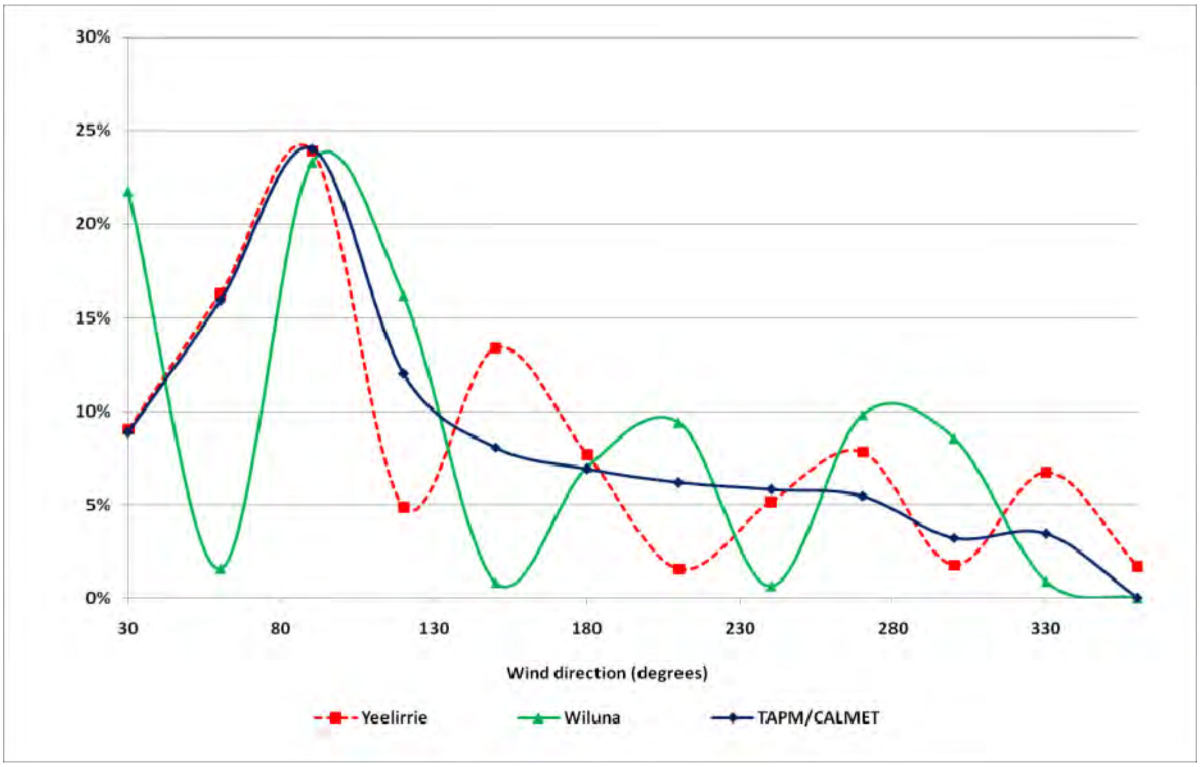


Figure B5 Distribution of wind directions at Yeelirrie Homestead, Wiluna monitoring station and modelled for the proposed Yeelirrie development site

Location: Yeelirrie, Wiluna	**Period:** Yeelirrie and Wiluna 2006-2009 TAPM/CALMET 2004-2008	**Data source:** BoM and TAPM/CALMET	**Units:** degrees
Type: Frequency distribution	**Data frequency:** 9am and 3pm and 1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010

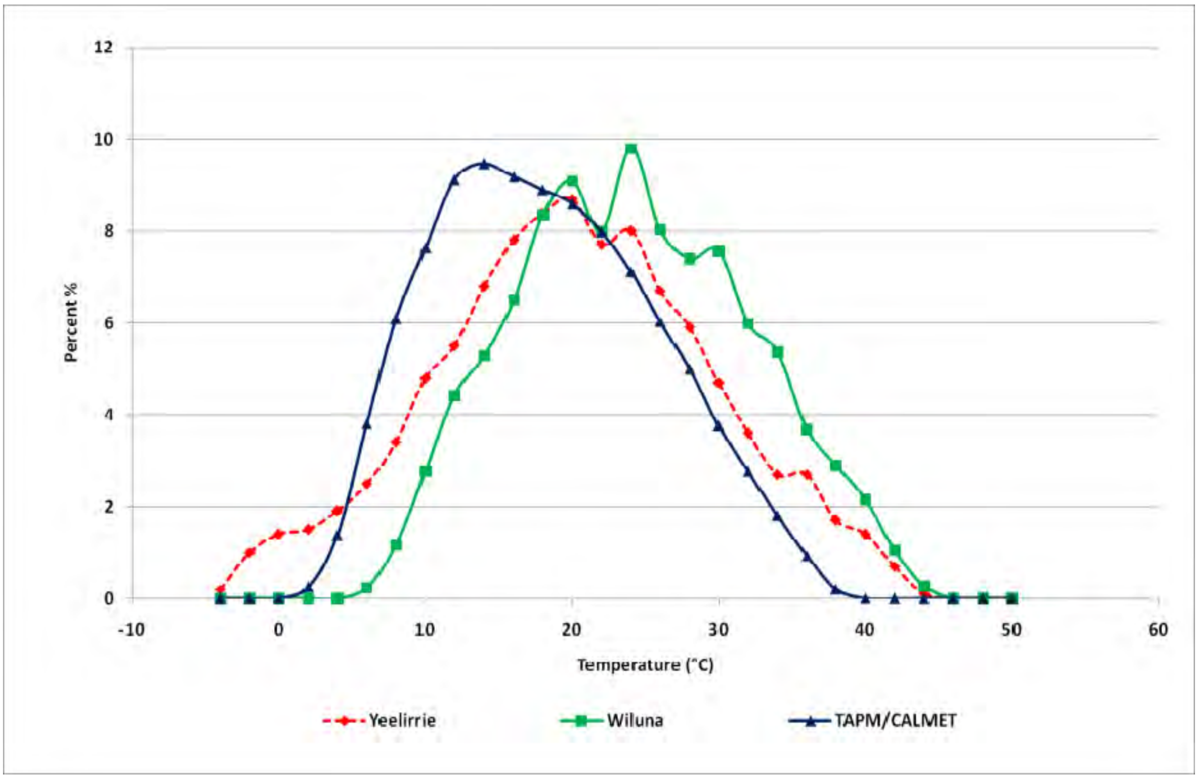


Figure B6 Distribution of temperature at Yeelirrie Homestead, Wiluna monitoring station and modelled for the proposed Yeelirrie development site

Location: Yeelirrie, Wiluna	**Period:** Yeelirrie and Wiluna 2006-2009 TAPM/CALMET 2004-2008	**Data source:** BoM and TAPM/CALMET	**Units:** degrees Celsius
Type: Frequency distribution	**Data frequency:** 9am and 3pm and 1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010

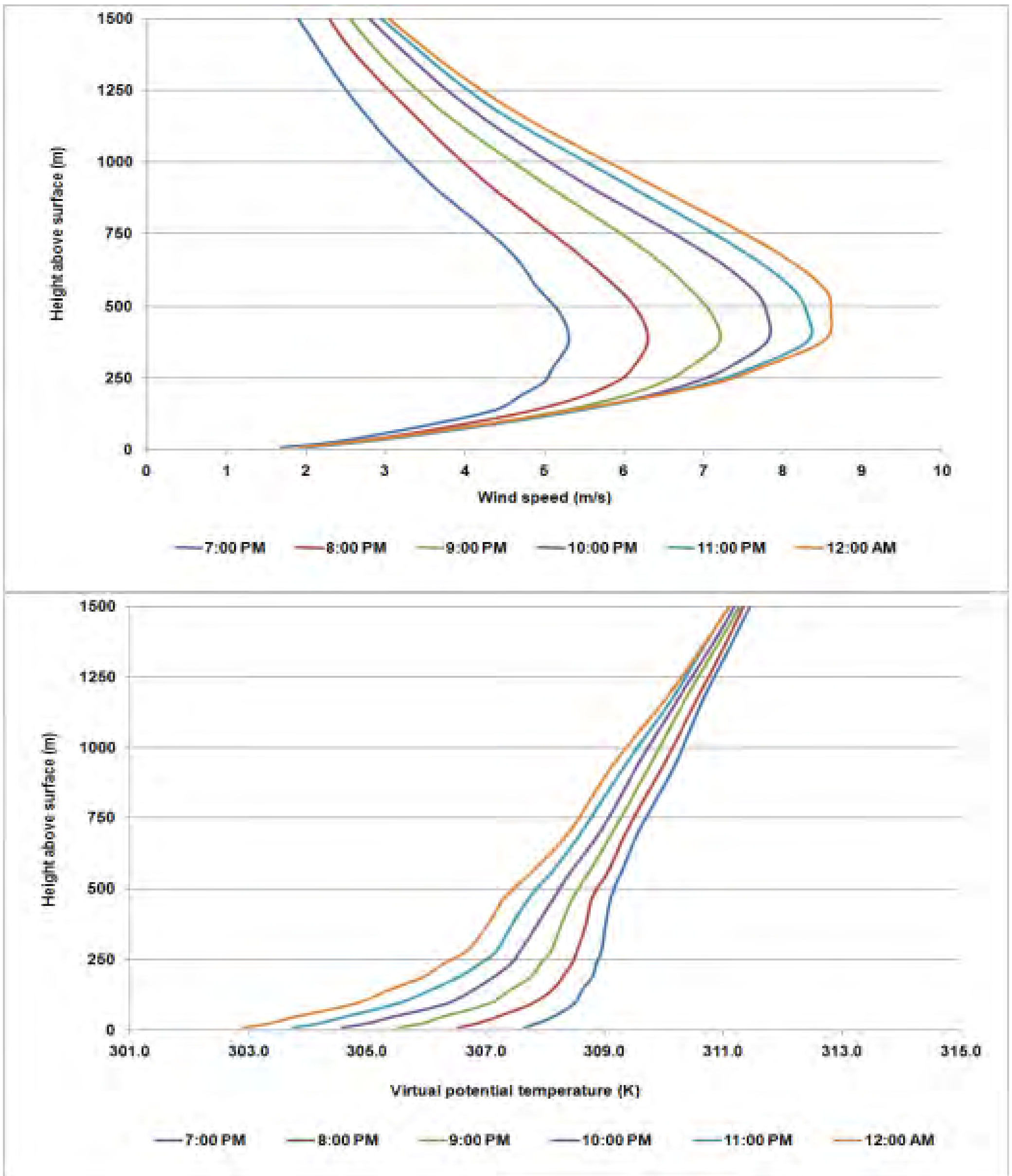
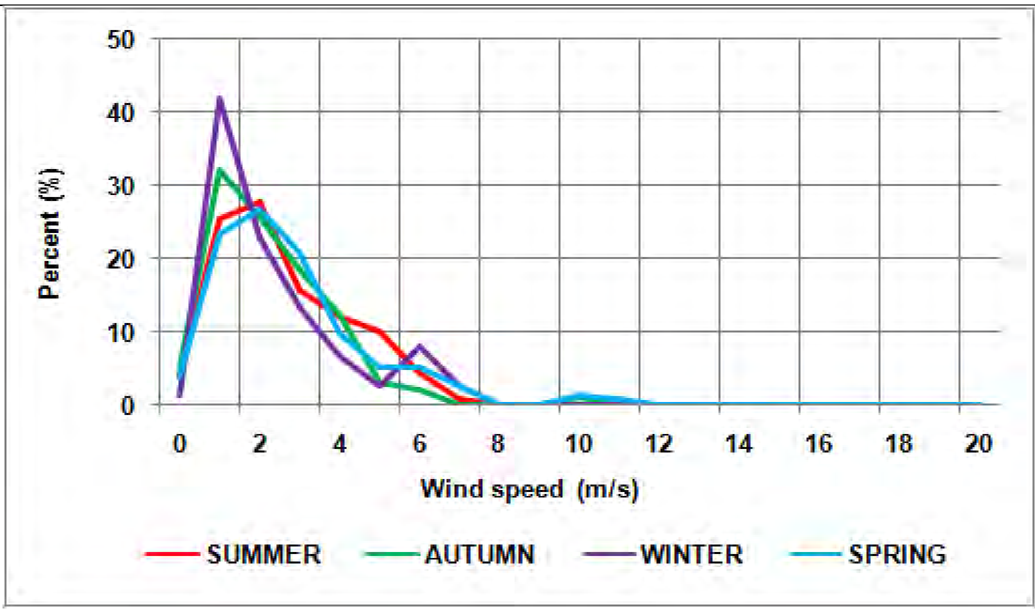


Figure B7 Winter 2008 vertical profile of wind speed and virtual potential temperature from 7 pm to 12 am showing the development of a low level jet

Location: Yeelirrie	**Period:** Winter 2008	**Data source:** TAPM	**Units:** m/s and Kelvin
Type: XY plot	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010



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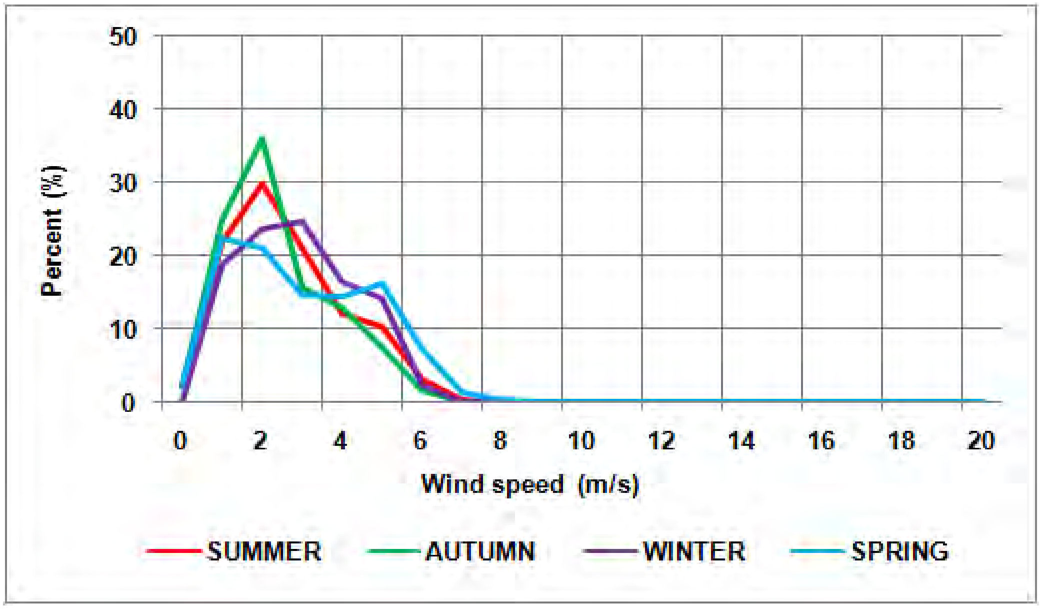
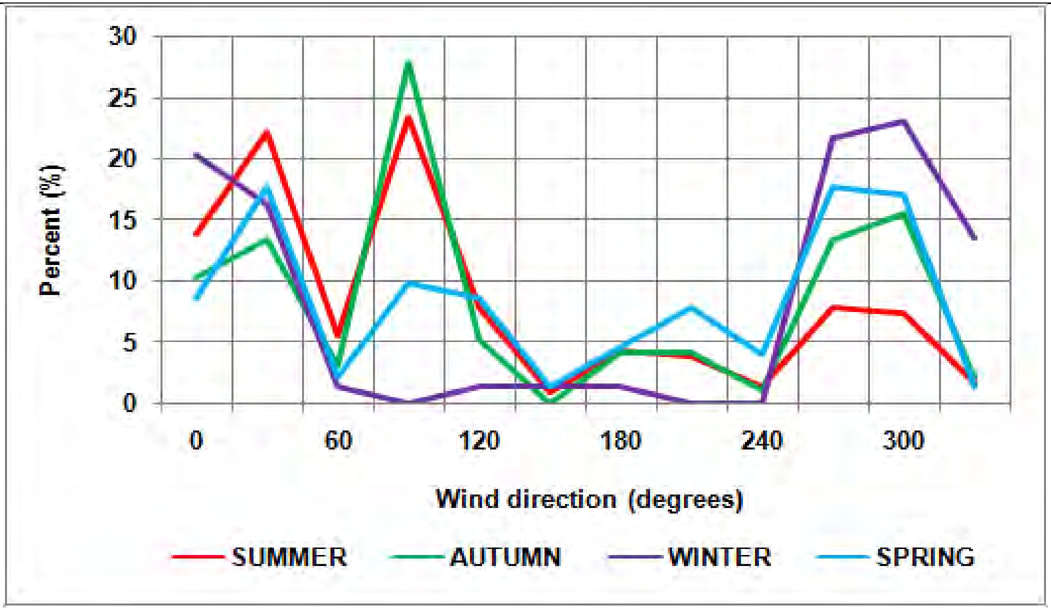


b)

Figure B8 Type 1 weather condition seasonal frequency distribution of wind speed measured (a) and modelled (b)

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** m/s
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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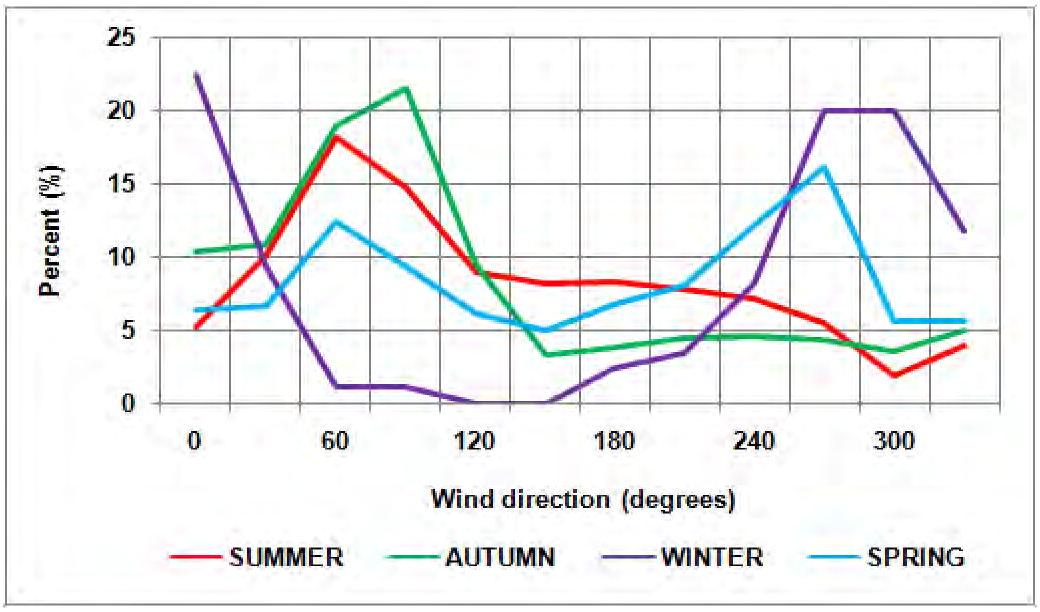
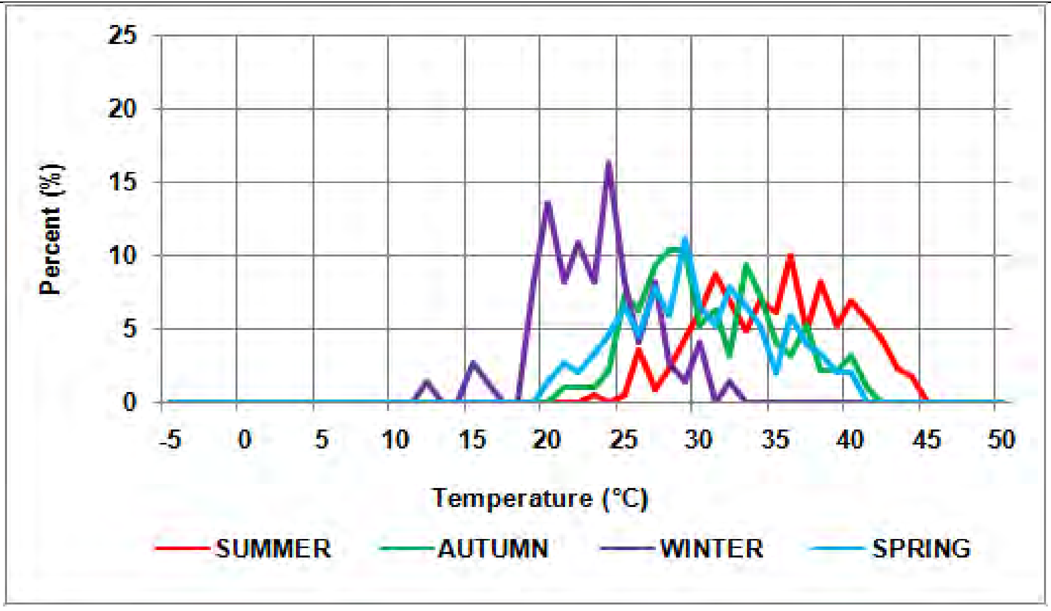


b)

Figure B9 **Type 1 weather condition seasonal frequency distribution of wind direction measured (a) and modelled (b)**			
Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** degrees
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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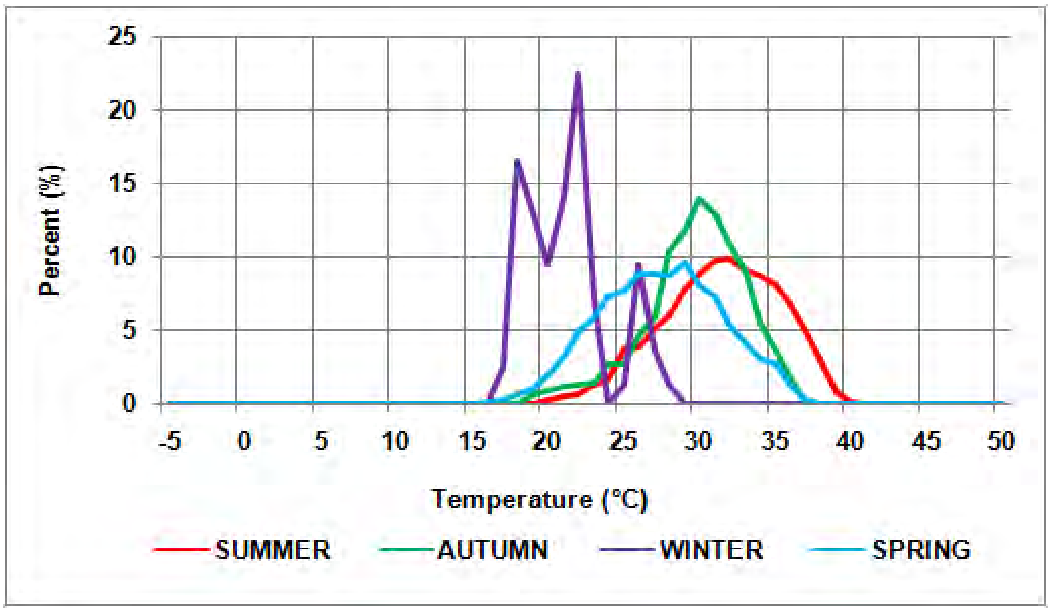
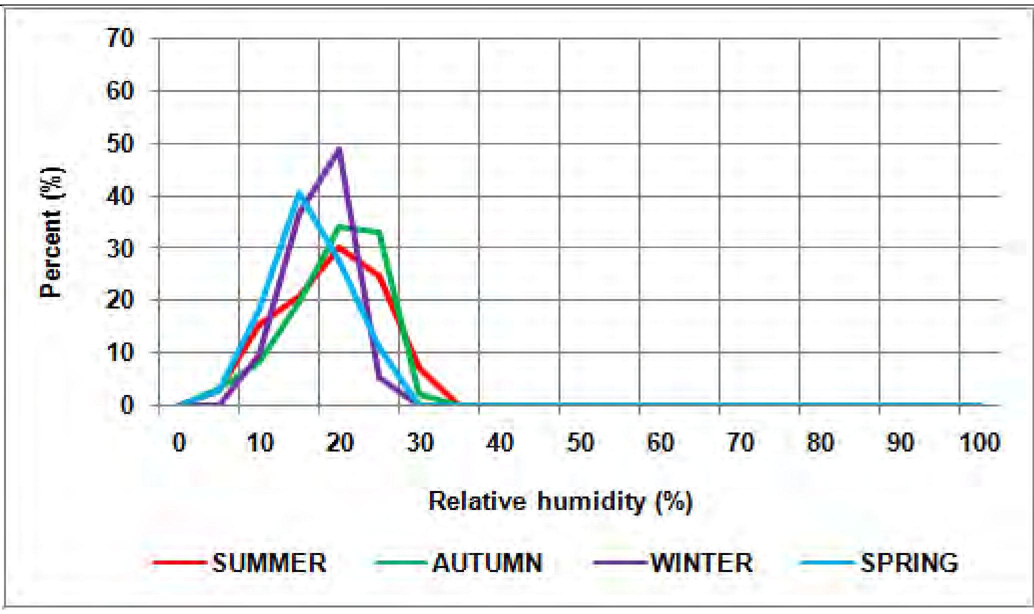


b)

Figure B10 **Type 1 weather condition seasonal frequency distribution of temperature measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** Degrees Celsius
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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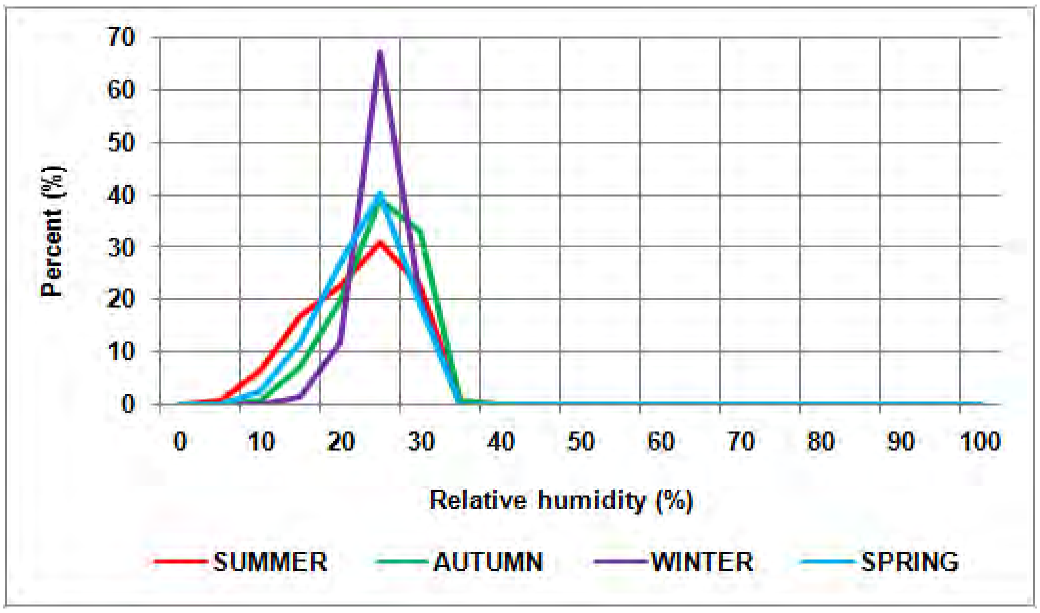
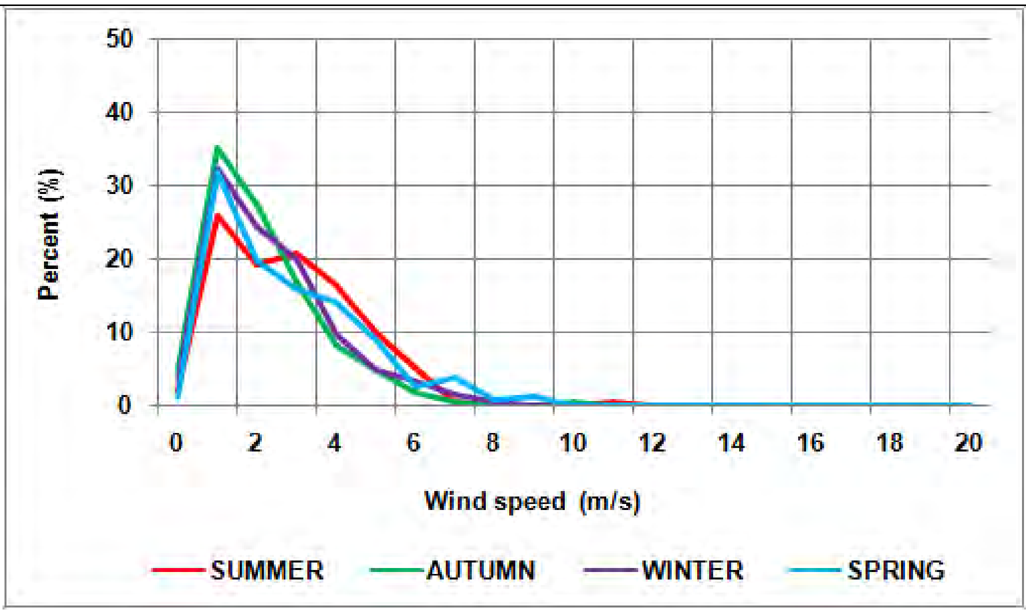


b)

Figure B11 **Type 1 weather condition seasonal frequency distribution of relative humidity measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** percent
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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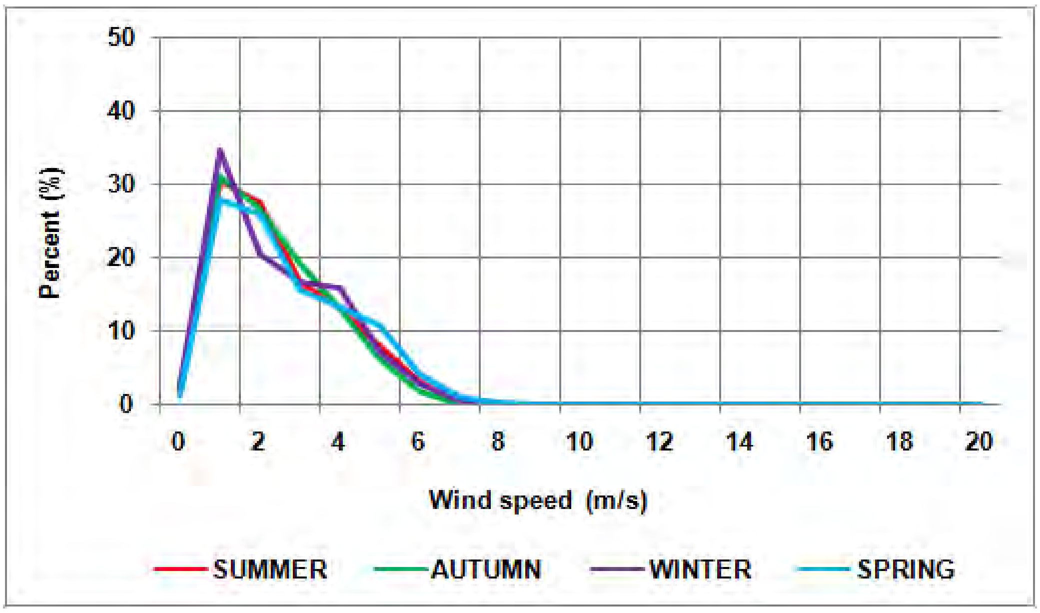
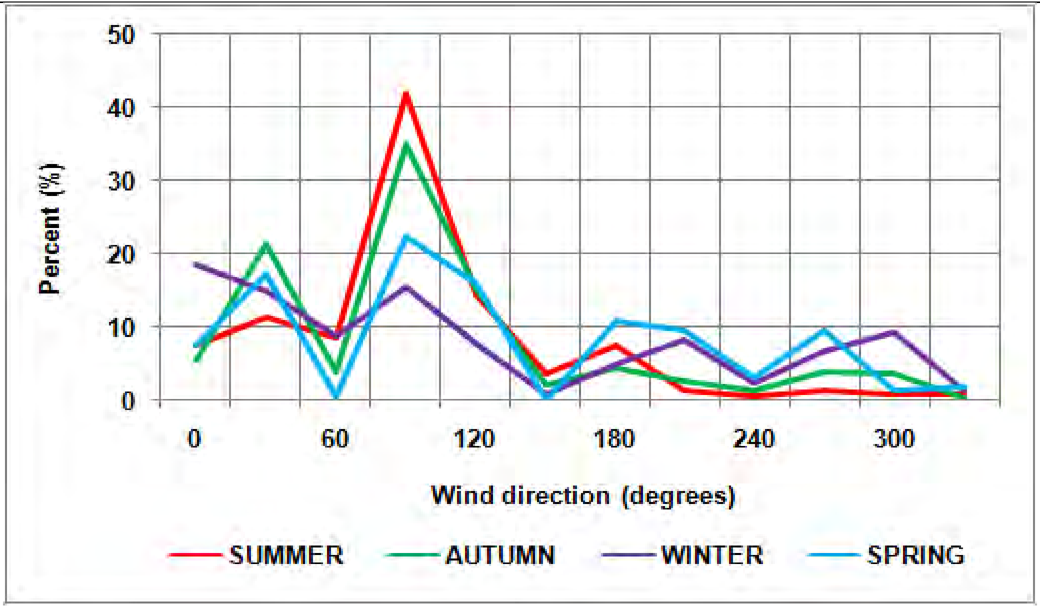


b)

Figure B12 **Type 2 weather condition seasonal frequency distribution of wind speed measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** m/s
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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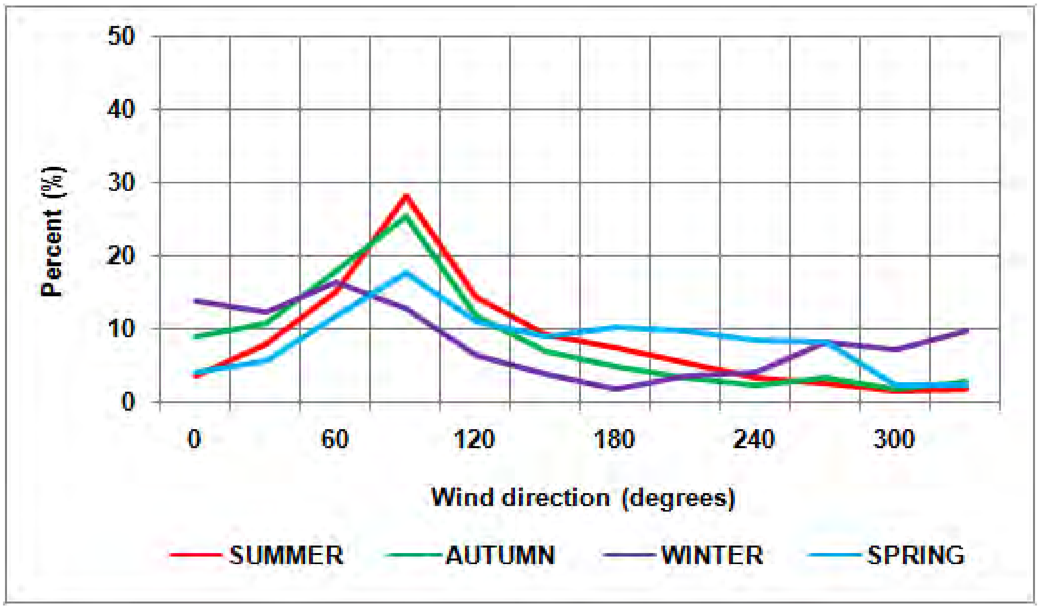
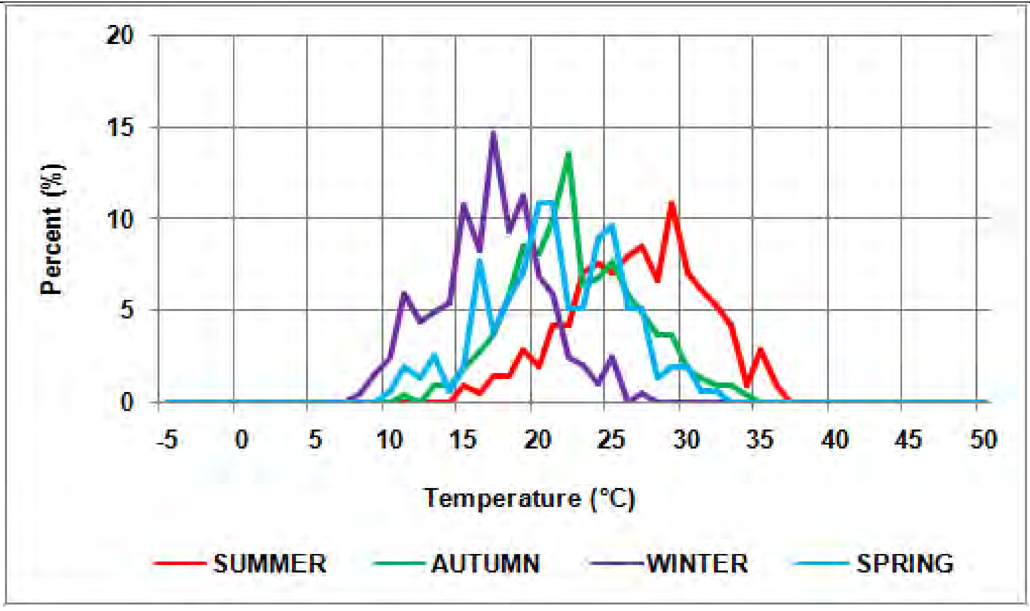


b)

Figure B13 **Type 2 weather condition seasonal frequency distribution of wind direction measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** degrees
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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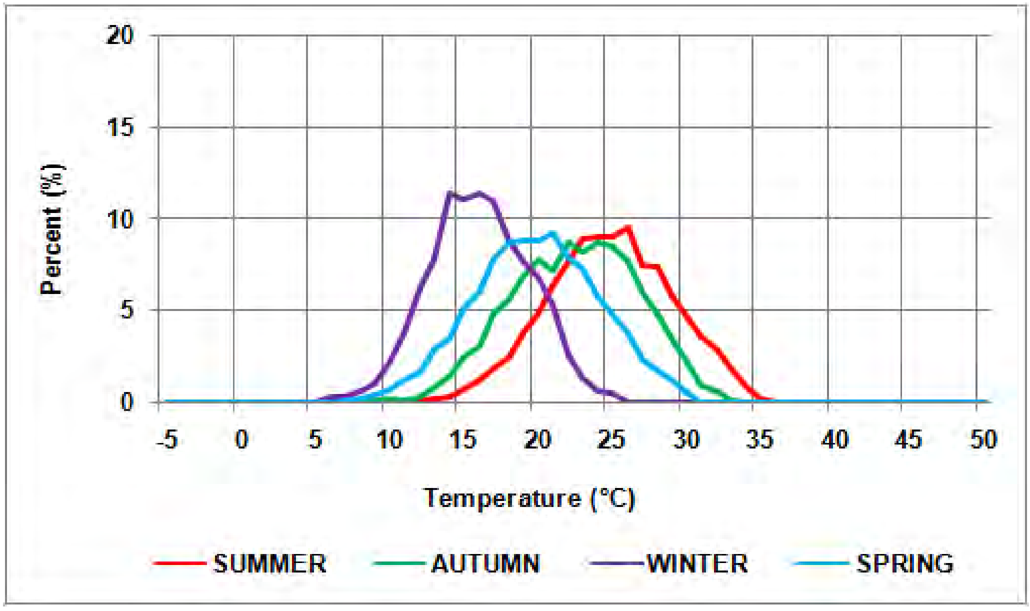
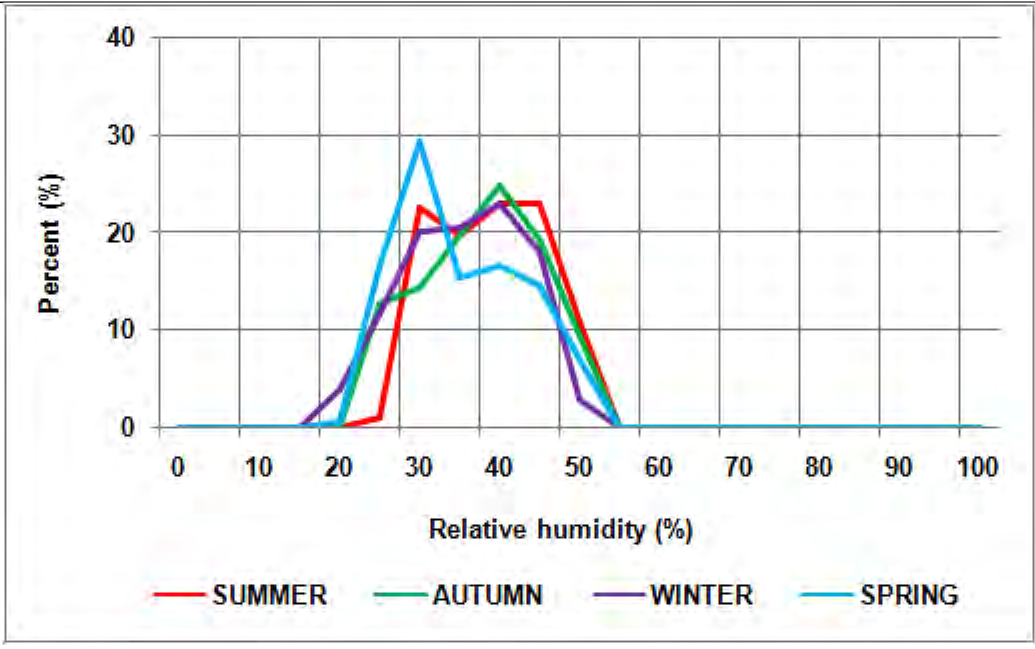


b)

Figure B14 **Type 2 weather condition seasonal frequency distribution of temperature measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** Degrees Celsius
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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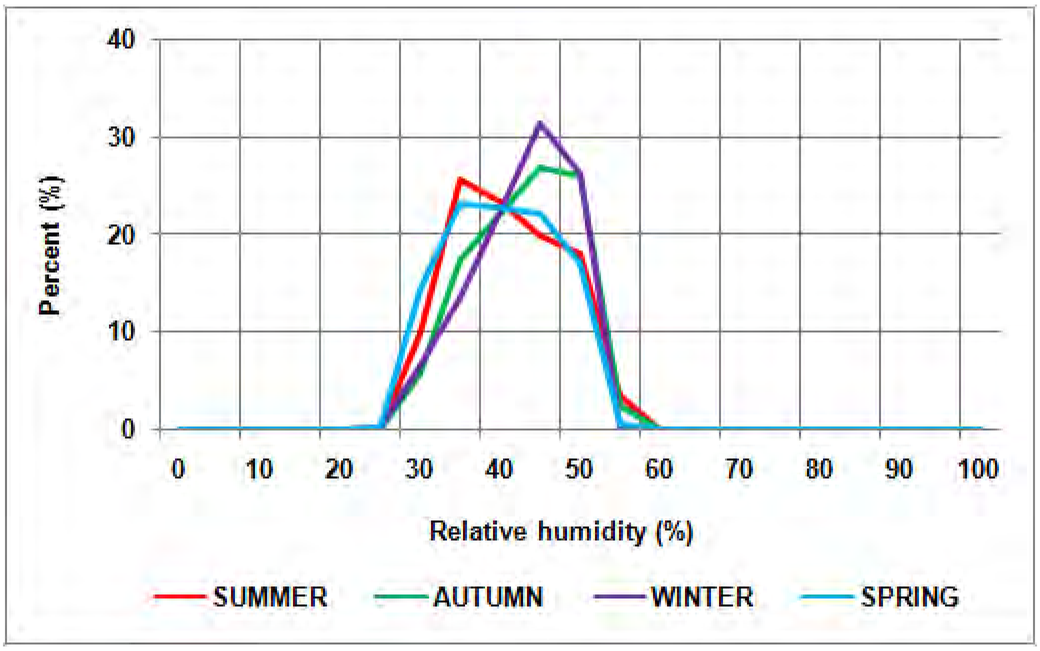
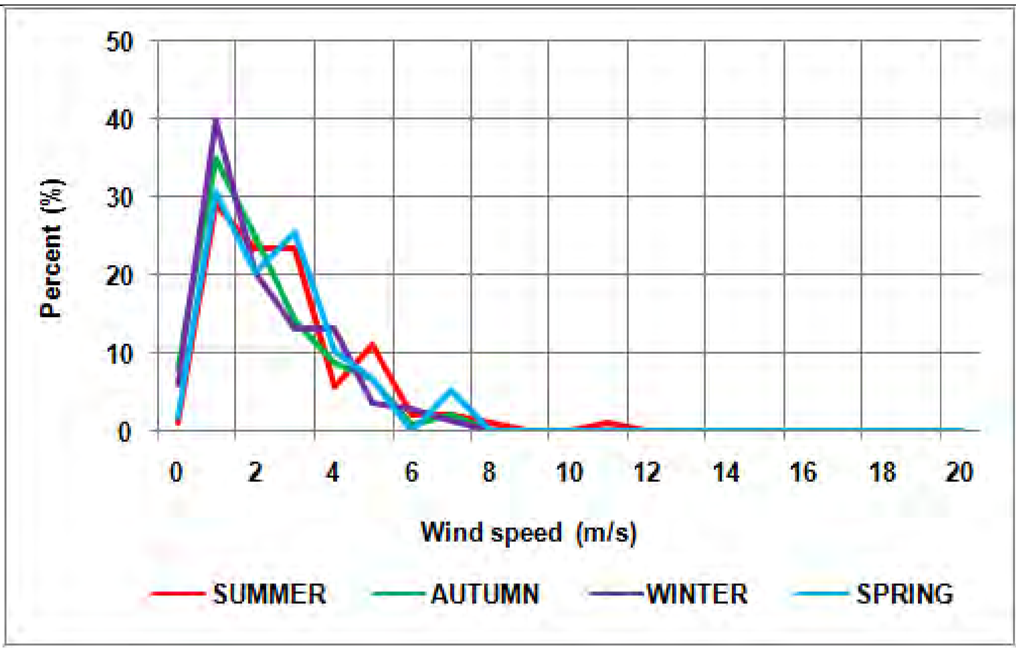


b)

Figure B15	**Type 2 weather condition seasonal frequency distribution of relative humidity measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** percent
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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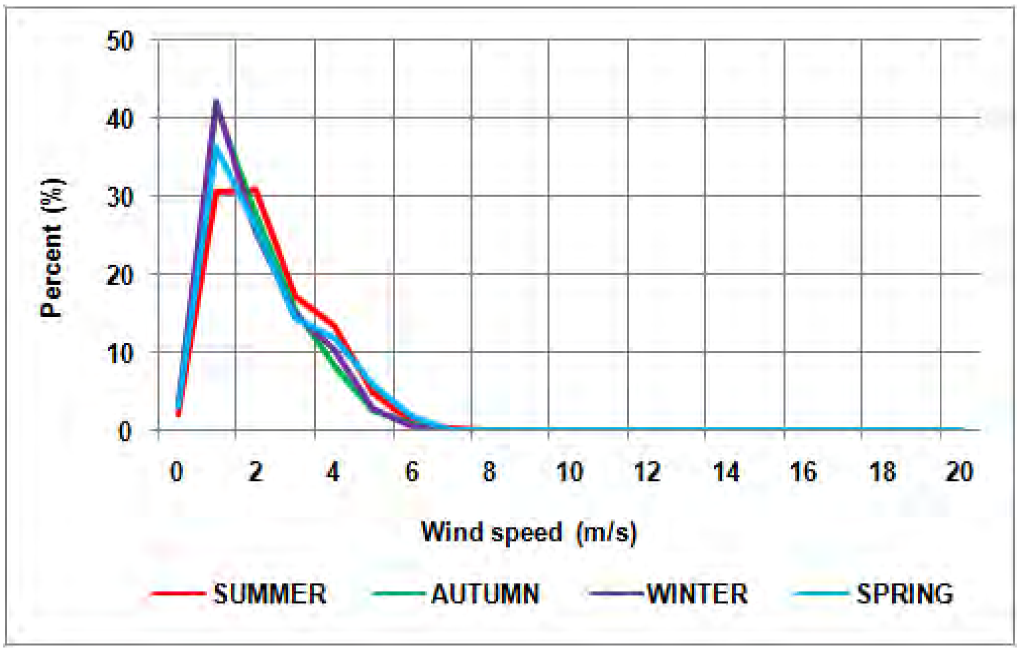
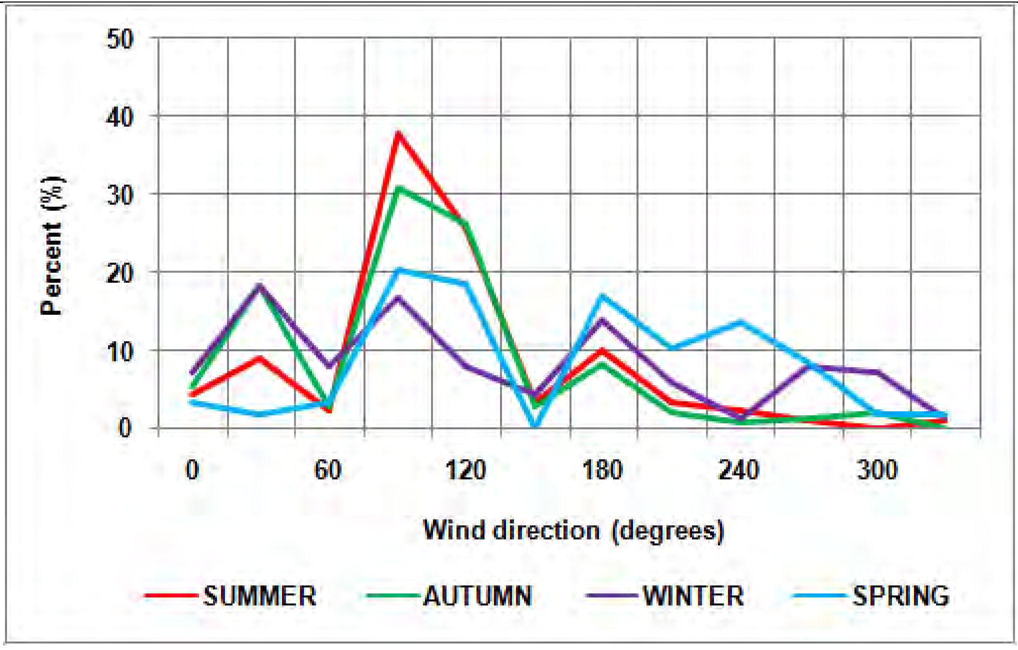


b)

Figure B16 **Type 3 weather condition seasonal frequency distribution of wind speed measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** m/s
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



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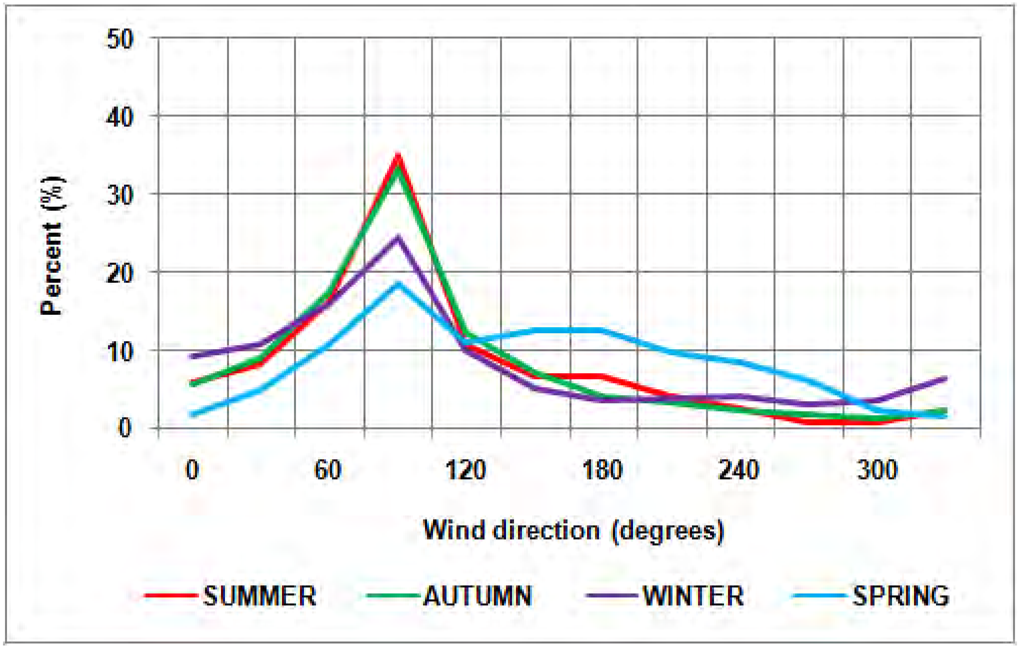
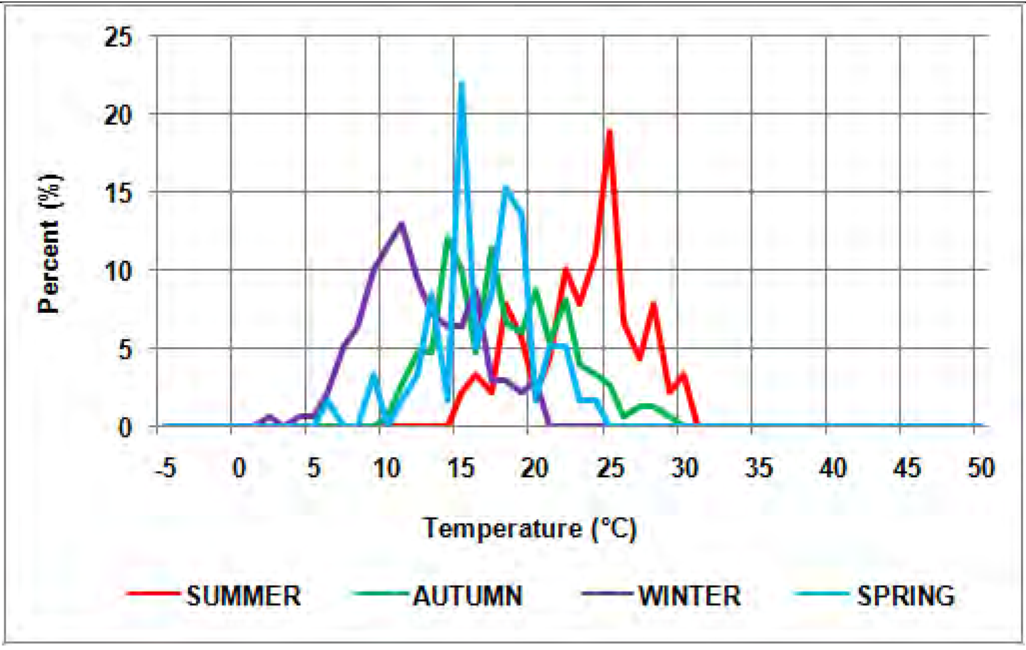
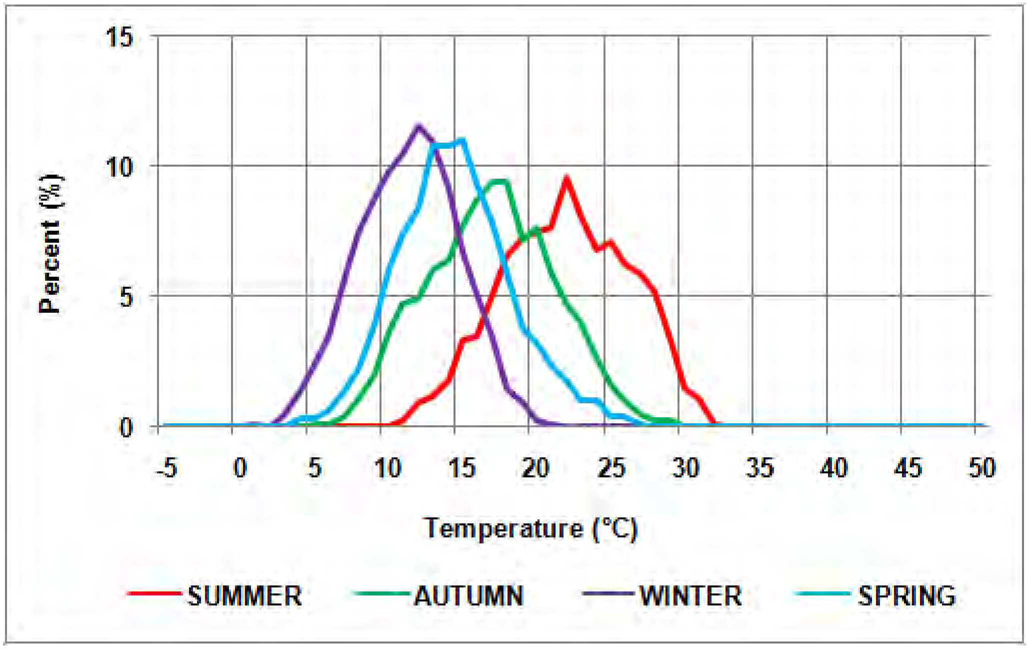


b)

Figure B17	**Type 3 weather condition seasonal frequency distribution of wind direction measured (a) and modelled (b)**		
Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** degrees
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



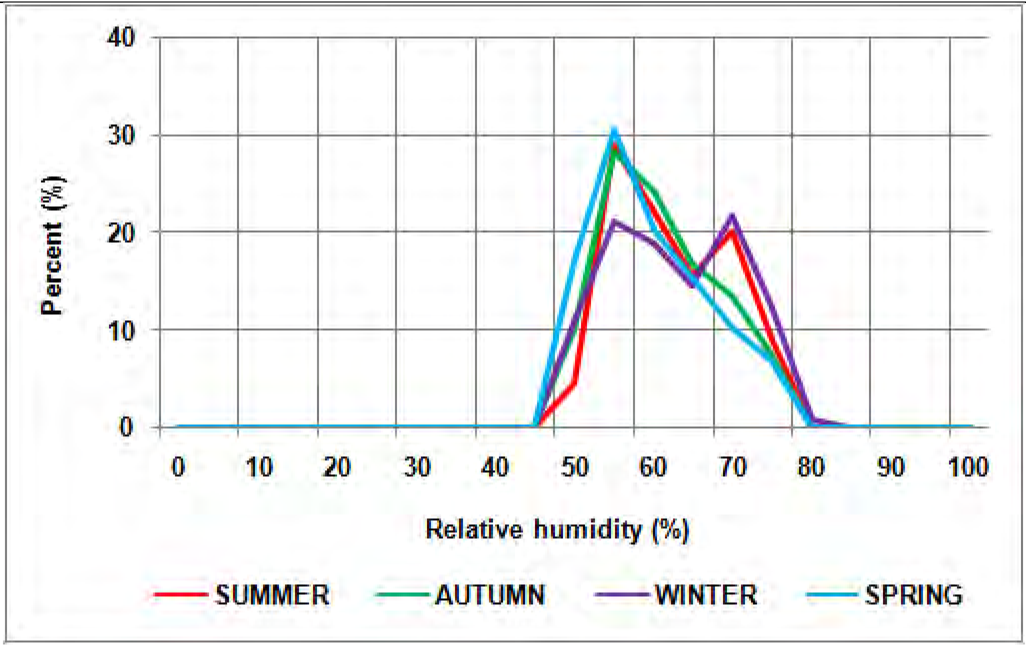
a)



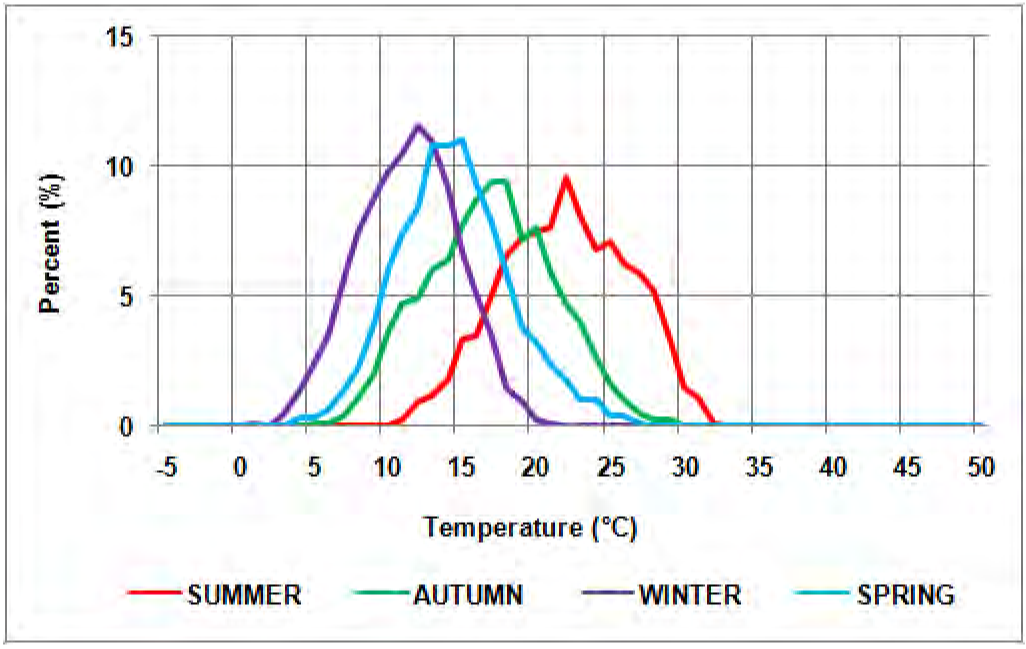
b)

Figure B18 **Type 3 weather condition seasonal frequency distribution of temperature measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** Degrees Celsius
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



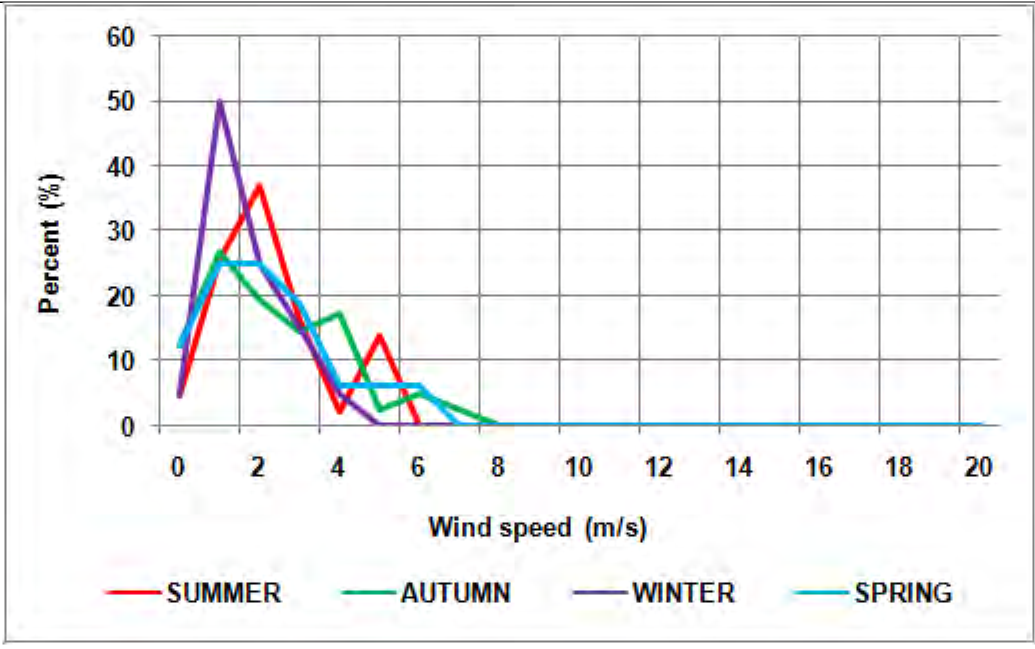
a)



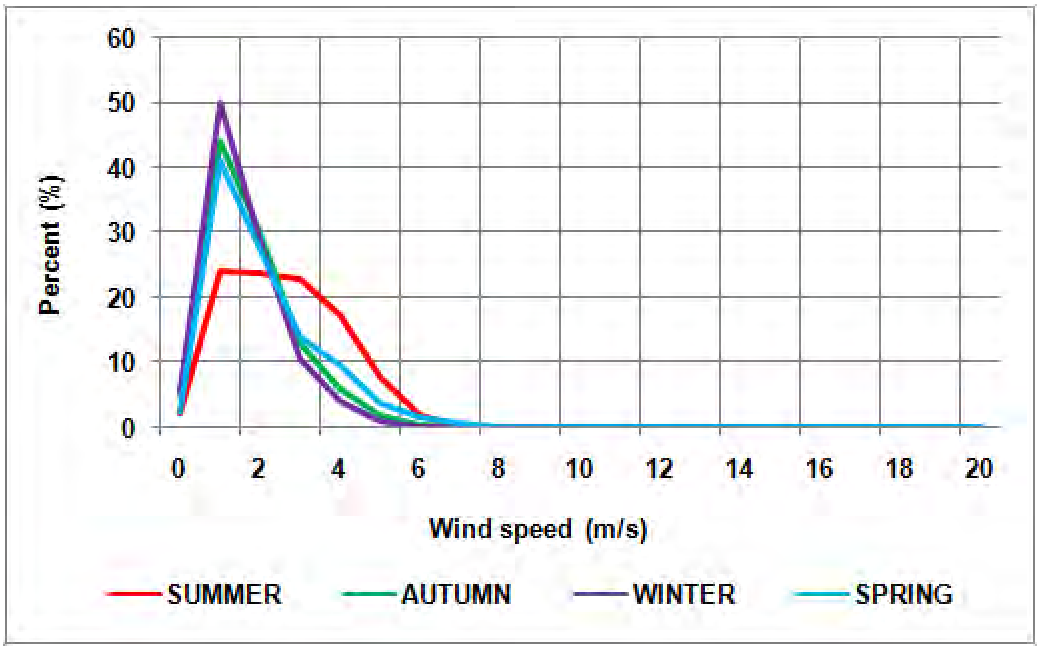
b)

Figure B19 **Type 3 weather condition seasonal frequency distribution of relative humidity measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** percent
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



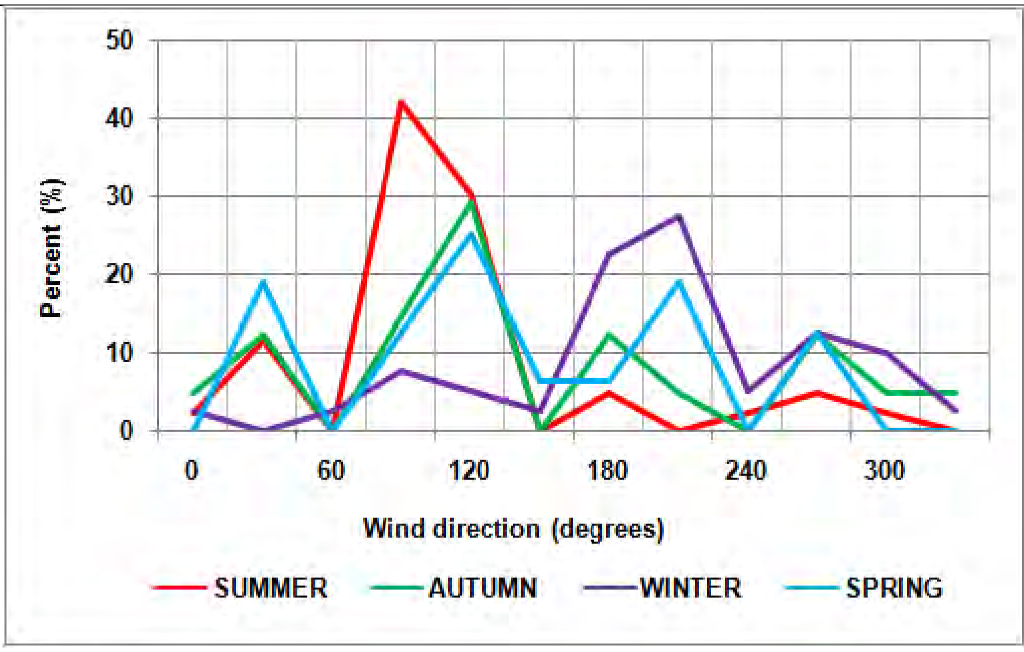
a)



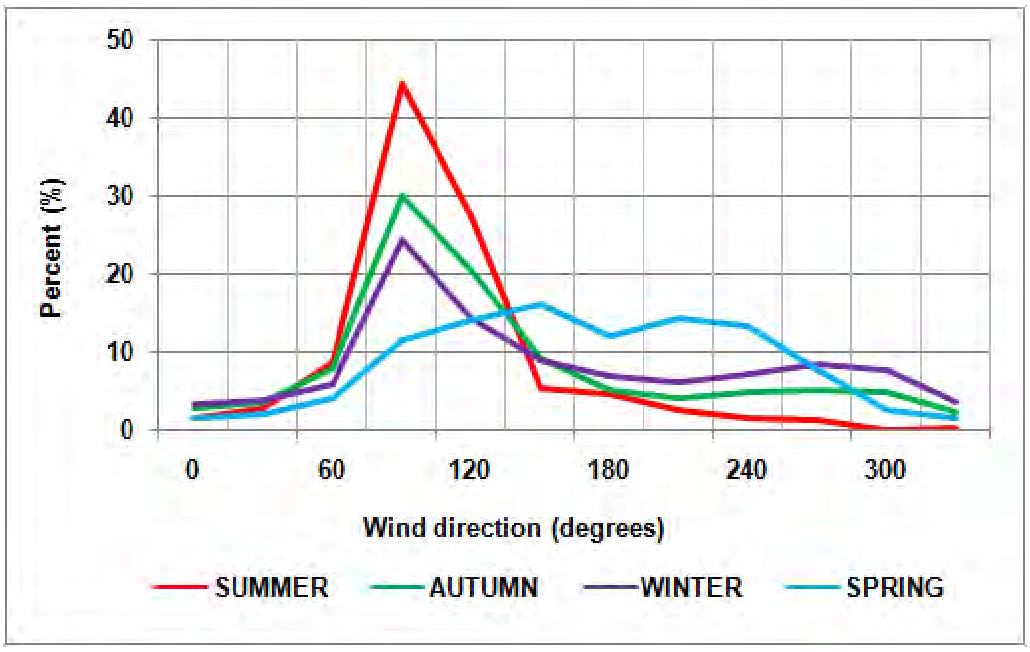
b)

Figure B20 **Type 4 weather condition seasonal frequency distribution of wind speed measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** m/s
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



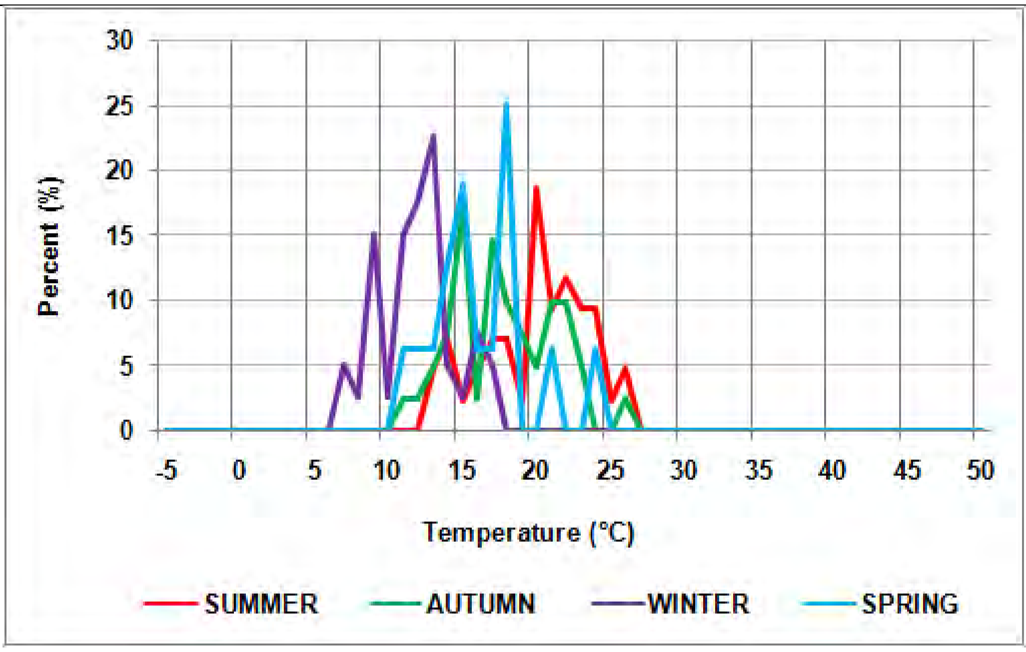
a)



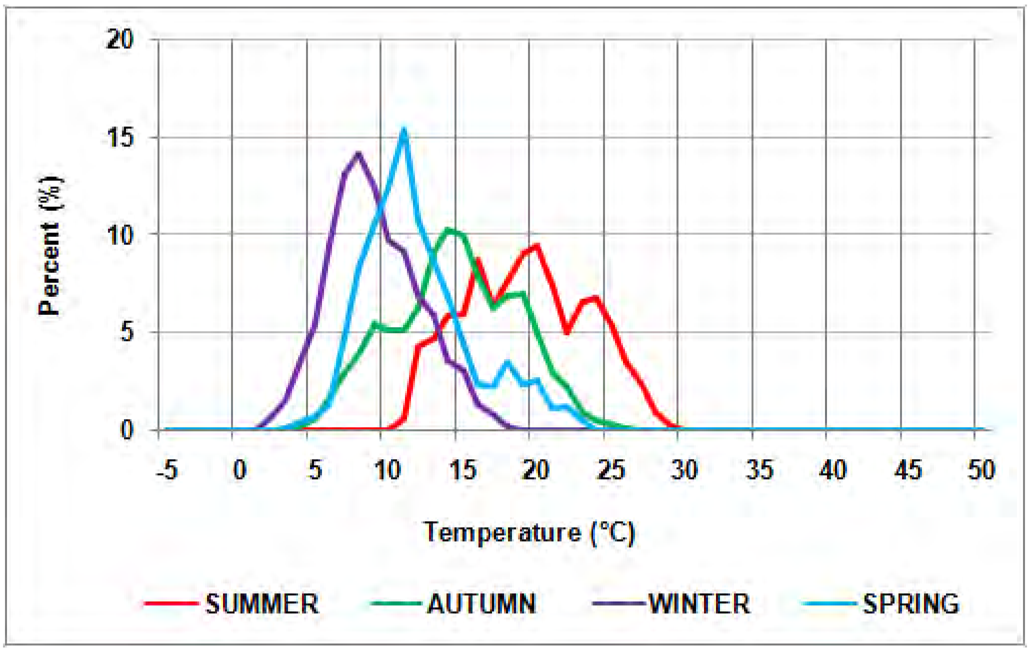
b)

Figure B21 **Type 4 weather condition seasonal frequency distribution of wind direction measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** degrees
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



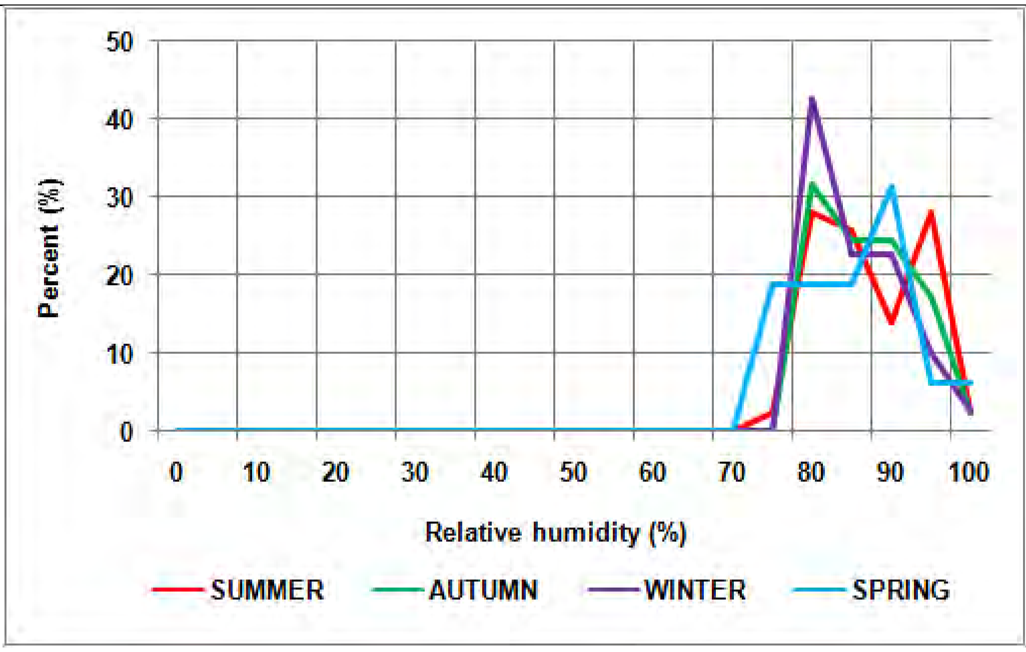
a)



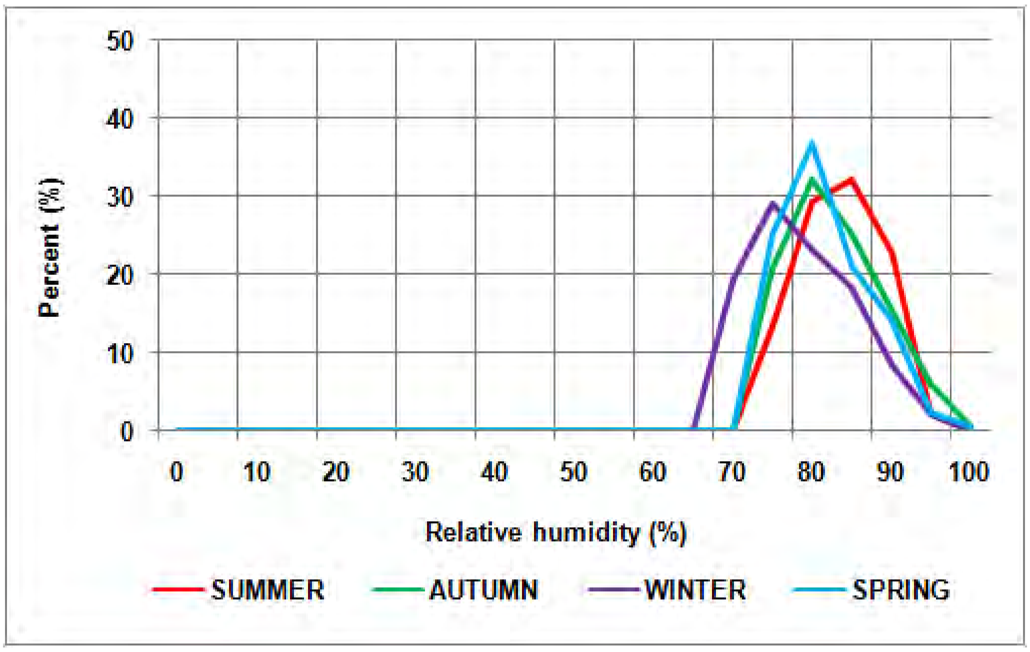
b)

Figure B22 **Type 4 weather condition seasonal frequency distribution of temperature measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** Degrees Celsius
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010



a)



b)

Figure B23 **Type 4 weather condition seasonal frequency distribution of relative humidity measured (a) and modelled (b)**

Location: Yeelirrie, WA	**Period:** a)2006-2009 b)2004-2008	**Data source:** a)BoM b)CALMET	**Units:** percent
Type: Pdf plot	**Data frequency:** a)9am & 3pm b)1 hour	**Prepared by:** Andrew Wiebe	**Date:** October 2010

Appendix C
Climate

Contents

Appendix C Climate

C1 Introduction

Climate is the average weather experienced by a location or region over a period of many years, approximately 10 and 30 years. As such, climate can be described in terms of trends in, and variability of, meteorological elements such as temperature, relative humidity, atmospheric pressure, wind speed and wind direction, or through a combination of these elements as weather types typical to a region.

The Western Australian climate varies significantly throughout the state. While the southern regions of Western Australia experience the four typical seasons (spring, summer, autumn and winter), the northern areas of the state are generally described as either wet or dry. In addition, there is a reduction in rainfall and an increase in Temperature extremes and variability with an increase in distance from the Western Australia coastline. The climate of Western Australia is strongly influenced by the size of the Australian land mass, as well as large scale synoptic processes such as warm/cold frontal systems, cut-off lows, the west coast trough, blocking highs, the southern annual mode, the Indian ocean dipole, cloud bands and tropical lows (DAFF, 2008).

Descriptions of climate are relative to the spatial and temporal scale of the assessment. The proposed Yeelirrie development site is situated near the geographic centre of Western Australia and as such is influenced by the large scale synoptic situation; which encompasses most of the Indian and Southern Ocean as well as the Australian land mass; the regional scale weather of the arid inland regions of Australia and the local scale atmospheric environment of the proposed development site itself.

Seven Bureau of Meteorology (BoM) monitoring sites have been analysed in order to assess the climate of the proposed Yeelirrie development site at the synoptic, regional and local scale (Table C1 and Figure C1). The seven sites are considered to be representative of the large scale synoptic climate, the regional arid inland environment or the local environment of the proposed development site.

Table C1 Bureau of Meteorology monitoring sites utilised in climate assessment

Site	Type	Location	Monitoring period analysed	Data frequency	Distance and direction to the proposed Yeelirrie development site (approx Km)	Distance from site to WA coastline (approx km)
Geraldton Airport	Synoptic	28.80 °S 114.70 °E	1993-2009	1-hour	540 km SW	50 km
Kalgoorlie-Boulder Airport	Synoptic	30.78 °S 121.45 °E	1994-2008	1-hour	430 km SSE	600 km
Meekatharra Airport	Synoptic	26.61 °S 118.54 °E	1993-2008	1-hour	150 km NW	470 km
Laverton Airport	Synoptic	28.61 °S 122.42 °E	1991 - present	1-hour	300 km SE	760 km
Leinster	Regional	27.84 °S 120.70 °E	1994-2009	1-hour	105 km SE	595 km
Wiluna	Regional	26.59 °S 120.23 °E	2006 - present	9 am and 3 pm	70 km NNE	630 km
Yeelirrie	Local	27.28 °S 120.09 °E	2006 - present	6 am, 9 am, and 3 pm	20 km SE	600 km

The climatic elements of Temperature, relative humidity, atmospheric pressure, wind speed and wind direction of the monitoring sites have been assessed and are presented below. Weather types, their frequency of occurrence and influence on the local climate were also identified and analysed using the K-means clustering algorithm. The analysis was performed on the four the synoptic sites, the three regional sites and the local Yeelirrie site.

C2 Synoptic analysis

C2.1 Methodology

The data from all seven of the BoM monitoring stations (Table C1) were quality assured by removing missing values. Since wind direction has a cross point at 360° the wind speed and wind direction are converted to their scalar east-west component (U m/s) and north-south component (V m/s) for the clustering process. The vector wind speed and wind direction are then reconstituted for the presentation and discussion of results. The meteorological parameters presented in Table C2 were extracted from the BoM data and analysed using the K-means clustering algorithm to determine the main weather types that occur in Western Australia.

Table C2 Meteorological parameters used to identify weather types

Parameter	Abbreviation	Unit
Mean Sea Level pressure	MSLP	hPa
Relative Humidity	RH	%
Temperature	T	°C
Wind Speed & Wind Direction		
East-West component	U	m/s
North-South component	V	m/s

The K-means algorithm requires that the number of clusters be assigned by the user. The algorithm then assigns each data point to one of the clusters based on its euclidean distance to the central value of the cluster, the process continues until convergence. The euclidean distance is calculated by:

$$distance(x, y) = \left\{ \sum_{1} (x_i - y_i)^2 \right\}^{1/2} \quad (1)$$

In order to objectively assign the number of clusters within the data a hierarchical dendogram is generated for each data set. The dendogram is simply a tree that shows how many clusters are found for a stepwise increase in euclidean distance. For this study an initial separation distance of 10 was applied with a stepwise increase of 1. The dendogram is then analysed for points of fusion (i.e. plateaus), where increasing separation distances yield the same number of clusters. The dendogram for Geraldton, Kalgoorlie, Laverton, Meekatharra, Leinster, Wiluna and Yeelirrie is presented in Figure C2 as a log normal plot.

Figure C2 indicates that there are plateau regions ranging from 0.8 to 0.4 which equates to 6 to 3 potential cluster types. In an attempt to extract peak events (i.e. single out weather types) as weather is a continuous variable and many weather types will overlap as one gives way to another, the K-means algorithm was initialised with 6 clusters. Of the initial 6 clusters only 4 were defined by K-means algorithm for all seven sites.

C2.2 Synoptic climate

The four weather types extracted from the analysis are presented in Table C3 with a brief description of the prevailing synoptic situation and associated weather. Probability density functions (pdf) of wind speed (Wspeed) and wind direction (WDir), temperature (T) and relative humidity (RH) and average sea level pressure (MSLP) for each weather type at the four synoptic monitoring sites are presented in Figure C3 to Figure C14. The weather types have been separated into seasonal components and the frequency of each weather type is shown in Table C4.

Table C3 Weather types identified for Western Australia

Weather type	Synoptic situation	General description
1	Monsoonal low of the NW coast, trough moving inland, high pressure system to the south	Hot, dry north easterly winds
2	Ridge of high pressure pushing in behind front	Temperatures in the low 20's, 30 -40% humidity, light easterlies tending south westerly along the coast
3	High pressure system situated over central Australia with associated fronts along the coast	Wide range of temperature from below zero at night to above 30 °C during the day, more moderate Temperatures along the coast. Humidity stable around 50 to 70%, very light winds inland from the north east to south east with more moderate winds from south east to south west along the coast
4	Similar to Type 3 only High pressure system is situated further south over the Australian Bight	Wide range of temperature from below zero at night to above 30 °C during the day, more moderate temperatures along the coast. High humidity 70-90 %, very light winds inland from the south east to north west with more moderate winds from south east to changing to north east along the coast

The summer months (December to February) are seen to be dominated by Type 1 and Type 2 weather at the inland sites of Kalgoorlie, Laverton and Meekatharra. This is due to the positioning of the West Coast trough which moves from its offshore position further inland with an approaching front. This explains why Geraldton sees a prevalence of Type 3 weather during these months.

Autumn sees a general reduction in Type 1 weather as the monsoon season comes to an end. Type 2 and 3 weather become more prevalent for the inland sites as more stable slow moving high pressure systems progress across the continent. The coastal site of Geraldton sees an increase in Type 4 weather mainly due to the higher frequency of high pressure systems to the south of the continent.

Type 1 weather becomes almost non-existent during the winter months with an increase in Type 2 and 3 as the heating and cooling of the Australian land mass becomes more dominant. High pressure systems tend to linger about the centre of the continent bringing relatively calm stable weather with light winds. Daytime temperatures can reach above 30°C with nigh-time temperatures dropping below 0°C.

Spring sees an increase in Type 1 weather as the monsoon begins to deepen off the north west coast. The West Coast trough begins to develop again alternating between its offshore and onshore positions.

Table C4 Seasonal frequency of weather types (%)

Site	SUMMER			
	Type 1	Type 2	Type 3	Type 4
Geraldton	7.5	25.8	49.6	17.1
Kalgoorlie	34.4	38.3	21.6	5.8
Laverton	42.1	37.3	15.4	5.2
Meekatharra	49.5	30.8	13.6	6.1
	AUTUMN			
Geraldton	6.6	28.5	39.3	25.6
Kalgoorlie	10.5	40.5	35.3	13.7
Laverton	15.3	43.6	30	11
Meekatharra	16.7	45.5	27.7	10.1
	WINTER			
Geraldton	1.4	15	41.3	42.3
Kalgoorlie	4.1	32.9	39.1	23.9
Laverton	6.9	40.7	37	15.5
Meekatharra	4.7	40.4	36.6	18.3
	SPRING			
Geraldton	4.1	21.8	42	32.1
Kalgoorlie	24.4	43.9	25.6	6
Laverton	33.1	46.5	16.9	3.6
Meekatharra	36.2	47.2	14.2	2.4

C2.3 Regional scale

Meteorological monitoring data from the Bureau of Meteorology (BoM) stations at Leinster and Wiluna have been used to characterise average wind speed, wind direction, temperature, atmospheric pressure, rainfall and relative humidity characteristic of the arid inland regions of Western Australia. The weather typing analysis conducted on the synoptic sites is presented here for the regional sites (refer to Table C3 for description of weather types).

Wiluna shows a prevalence of Type 3 weather in summer, this may be due to the timing of data recovery (9 am and 3 pm) where the daily migration of the West Coast trough may not be well resolved. Autumn and winter are dominated by Type 2 and 3 accounting for nearly 70 % of the weather. Spring sees a return to type 1 and Type 2 weather as the monsoon begins to form over the tropics. The arid inland regions of Western Australia do not show the degree of variability in weather conditions throughout the four seasons as experienced at coastal locations such as Geraldton.

Table C5 Seasonal frequency of weather types (%)

Site	SUMMER			
	Type 1	Type 2	Type 3	Type 4
Leinster	48.7	31.9	12.1	7.3
Wiluna	17	31.8	35.3	15.8
	AUTUMN			
Leinster	18	45	27.8	9.2
Wiluna	16.7	45.8	32.1	5.5
	WINTER			
Leinster	8.3	42.3	35.7	13.6
Wiluna	16.1	30.1	37.1	16.7
	SPRING			
Leinster	38.4	43.5	12.6	5.4
Wiluna	29.7	49.9	18.5	1.9

C2.4 Weather type

C2.4.1 Type 1

Type 1 weather is predominant in the summer and spring bringing hot dry air from the central desert out towards the coast. Descriptive statistics of this weather type is presented in Table C6.

This weather type generates maximum winds of 10 – 16 m/s with gusts up to 53 m/s. Average wind speeds vary between sites, Leinster averaging 4.7 m/s and Wiluna averaging 2.6, which may be due to the recording times of the Wiluna monitoring station. Winds are predominantly from the east to north east accounting for nearly 50% of the winds at both sites. Wiluna shows a distinct westerly component (24 %) under these conditions that is not seen at Leinster (Figure C15).

Relative humidity is low averaging 16% with a maximum of 34% at Leinster and 21% with a maximum of 31% at Wiluna. Temperatures are high averaging 30 °C at both locations with maximums between 44 and 50 °C (Figure C16).

Mean sea level pressure is generally low during these periods due to the heat low generated over the Pilbara and the position of the West Coast trough. This varies as the trough moves on and offshore, hence the large maximum value (1031 and 1026) and low minimums (993 and 997) (Figure C17). It rarely rains during these periods; with maximum rainfall recorded being only 4 mm at both sites (Figure C18).

Table C6 Climatic parameters measured at Leinster and Wiluna

Parameter[1]	Leinster			
	Maximum	Average	Minimum	Standard deviation
Rain	4.0	0.0	0.0	0.1
MSLP	1031	1009.4	993.2	4.9
RH	34.5	16.9	1	6.1
T	50.5	29.7	9.5	5.7
Gust	53.0	7.1	0	2.9
WSpeed	16.5	4.7	0	1.8
Parameter	**Wiluna**			
	Maximum	**Average**	**Minimum**	**Standard deviation**
Rain	4.0	0.0	0.0	0.2
MSLP	1026.0	1012.6	997.0	6.3
RH	31.0	21.3	3.0	5.5
T	44.0	30.0	9.5	6.5
WSpeed	10.3	2.6	0.6	2.0
Note: [1]Units presented in Table C2				

C2.4.2 Type 2

Type 2 weather is prevalent all year round becoming the dominant mode in autumn and winter. Descriptive statistics of this weather type is presented in Table C7.

This weather type has lower maximum wind speeds than Type 1 only reaching 13 – 14 m/s with gusts up to 23 m/s. Average wind speeds remain the same as Type 1 between sites with Leinster averaging 4.4 m/s and Wiluna averaging 2.5. Winds are predominantly from the east to north east accounting for over 50% of the winds at both sites. Leinster shows a slight increase in southeasterly winds while Wiluna shows a similar magnitude decrease in its westerly component (Figure C19).

Relative humidity is moderate averaging 38% with a maximum of 57.5% at Leinster and 40.6% with a maximum of 54% at Wiluna. Temperatures are slightly lower averaging between 20 °C and 25 °C with maximums between 37 and 44 °C (Figure C20).

Mean sea level pressure is also slightly higher under these conditions as the incoming ridge of high pressure undercuts the trough (Figure C21). This feature of Type 2 weather can generate some scattered showers (Figure C 22).

Table C7 Climatic parameters measured at Leinster and Wiluna

Parameter[1]	Leinster			
	Maximum	Average	Minimum	Standard deviation
Rain	31.4	0.0	0.0	0.5
MSLP	1034.6	1015.3	994.7	7.8
RH	57.5	38.3	19.0	8.4
T	37.2	20.1	0.5	5.7
Gust	23.2	6.4	0.0	2.8
WSpeed	13.9	4.4	0.0	1.9
Parameter	**Wiluna**			
	Maximum	**Average**	**Minimum**	**Standard deviation**
Rain	14.2	0.1	0.0	0.7
MSLP	1029.8	1014.4	997.1	6.6
RH	54.0	40.6	27.0	6.6
T	44.0	25.5	8.0	7.0
WSpeed	12.8	2.5	0.6	2.0
Note[1] Units presented in Table C2				

C2.4.3 Type 3

Type 3 weather is dominant mode in autumn and winter, although it is represented in summer and spring it generally occurs for less than 20% of the time. Descriptive statistics of this weather type is presented in Table C8.

This weather type has slightly higher maximum wind speeds than Type 2 with reaching 14 – 15 m/s with gusts up to 21 m/s. Average wind speeds are, however lower at Leinster at 3.9 m/s with Wiluna remaining steady at 2.7 m/s. Winds are predominantly from the east to north east accounting for over 50% of the winds at both sites and a small increase from the south-westerly sector (Figure C23).

Relative humidity is higher than Type 2 averaging 68% with a maximum of 87% at Leinster and 63% with a maximum of 78% at Wiluna. Temperatures are significantly lower averaging between 14.6 °C and 20.8 °C with maximums between 37 and 44 °C and minimums of -0.2 and 6.5 (Figure C24). The disparity in minimum temperatures is due to the recording period at Wiluna, by 9 am the sun as already started to heat up the surface, therefore the minimum night-time temperature is not recorded.

Mean sea level pressure is also slightly higher under these conditions as the incoming ridge of high pressure from Type 2 settles in for the winter (Figure C25). In a similar situation to Type 2 weather Type 3 can generate some significant rainfall predominantly during the summer months (Figure C26).

Table C8 Climatic parameters measured at Leinster and Wiluna

Parameter[1]	LiENSTER			
	Maximum	**Average**	**Minimum**	**Standard deviation**
Rain	47.4	0.3	0.0	1.9
MSLP	1036.0	1017.5	994.6	7.9
RH	87.0	68.0	52.0	8.7
T	39.0	14.6	-0.2	5.9
Gust	20.6	5.6	0.0	3.0
WSpeed	14.1	3.9	0.0	2.1
Parameter	**Wiluna**			
	Maximum	**Average**	**Minimum**	**Standard deviation**
Rain	35.0	0.3	0.0	1.9
MSLP	1033.6	1016.1	998.6	7.4
RH	78.0	63.1	50.0	7.3
T	42.0	20.8	6.5	7.3
WSpeed	15.3	2.7	0.6	2.0
Note[1] Units presented in Table C2				

C2.4.4 Type 4

Type 4 weather is similar to Type 3 except that the high pressure system is located over the Australian Bight not the centre of Australia. This weather is accounts for approximately 15 % of the conditions in summer and winter and less than 10 % in autumn and spring (Table C5). Descriptive statistics of this weather type is presented in Table C9.

This weather type has similar distribution of maximum wind speeds as Type3. Average wind speeds are, lower at Leinster at 3.7 m/s with Wiluna remaining steady at 2.6 m/s. Winds are predominantly from the east to north east accounting for nearly 50% of the winds at both sites with an increase in southwesterlies at Wiluna accounting for 18% of the winds and a similar increase from the west to northwest sector at Leinster (Figure C27).

Relative humidity is significantly higher than any other weather type averaging 94% with a maximum of 100% at Leinster and averaging 88% with a maximum of 100% at Wiluna. Temperatures are similar to Type 3 conditions averaging between 15.6 °C and 18.6 °C with maximums between 40 and 49 °C and minimum of -0.3 and 6.5 (Figure C28).

Mean sea level pressure is also slightly lower under these conditions compared to Type 3 (Figure C29). This is because the centre of high pressure is off the southern coast of Australia. This is also the condition that brings the most rain to the region averaging 2.6 and 2.2 mm with maximum daily rainfalls of 93.8 mm at Leinster and 70 mm at Wiluna (Figure C30).

Table C9 Climatic parameters measured at Leinster and Wiluna

Parameter	Leinster			
	Maximum	Average	Minimum	Standard deviation
Rain	93.8	2.6	0.0	7.0
MSLP	1036.0	1014.2	991.5	6.8
RH	100.0	94.0	82.0	5.2
T	40.0	15.6	-0.3	7.3
Gust	26.2	5.2	0.0	3.0
WSpeed	15.9	3.7	0.0	2.1
Parameter	**Wiluna**			
	Maximum	**Average**	**Minimum**	**Standard deviation**
Rain	70.0	2.2	0.0	7.3
MSLP	1032.2	1014.1	997.9	7.2
RH	100.0	88.2	78.0	7.0
T	39.7	18.6	6.5	6.6
WSpeed	13.9	2.6	0.6	2.1
Note[1] Units presented in Table C2				

C3 Local scale

Meteorological monitoring data from the Bureau of Meteorology (BoM) station at Yeelirrie has been assessed to characterise average wind speed, wind direction, temperature, atmospheric pressure, rainfall and relative humidity characteristic of the proposed Yeelirrie development site. The weather typing analysis conducted on the synoptic and regional sites is presented here for the local climate (refer to Table C3 for description of weather types). Data from atmospheric monitoring studies undertaken in the winter of 1977 are referenced for detailed information of the microclimate around the proposed development site.

Weather typing analysis for the Yeelirrie site is consistent with the results of the synoptic and regional scale assessment detailed above. Type 1 and Type 2 weather are dominant in summer and spring due the generation of tropical lows associated with Australian monsoon and the passage of fronts. Type 2 and 3 take precedence in autumn and winter as the monsoon dies out and the procession of low pressure systems off the southern coast of Australia shifts further south into the roaring forties.

The Yeelirrie region generally displays two modes, a summer and a winter mode or wet and dry season. Summer conditions generally see higher temperatures and lower mean sea level pressure as the climate is being driven by the Australian monsoon, hence the high proportion of rainfall during the summer months and more variable weather conditions. The winter mode consists of lower temperatures, higher mean sea level pressure and a distinct lack of rainfall, as the driving mechanism of the regional and local climate shifts from an ocean based energy exchange to a land based one.

Table C10 Seasonal frequencies of weather types

Site	SUMMER			
	Type1	Type2	Type3	Type4
Yeelirrie	48.7	31.9	12.1	7.3
	AUTUMN			
Yeelirrie	18	45	27.8	9.2
	WINTER			
Yeelirrie	8.3	42.3	35.7	13.6
	SPRING			
Yeelirrie	38.4	43.5	12.6	5.4

C3.1 Weather type

C3.1.1 Type 1

Type 1 weather is the dominant weather type in summer (48%) and spring (38%). During these seasons winds tend to be light (2 – 3 m\s) to moderate (6 – 7 m/s) from the northeast to east in summer and strong northwesterly component in spring. Autumn and winter see a marked shift towards lighter winds with nearly 40% of the winds being below 2 m/s. Despite the distinct variation in the distributions of wind speeds between seasons the average remains relatively the same, summer averaging 2.8 m/s and winter 2.6 m/s. While autumn still shows a strong easterly component winter winds are predominantly from the northeast and northwest (Figure C31).

Relative humidity has been shown to be consistently low under these conditions averaging 20% with a maximum of 30% and minimum of 5% throughout the seasons. Temperatures are also higher during these periods, summer temperatures reaching over 45 °C with minimums of only 20 °C. Winter also sees relatively higher temperatures under Type 1 conditions with minimums reaching 10 °C and maximums of 32 °C (Figure C32).

Mean sea level pressure is generally low during these periods due to the heat low generated over the Pilbara and the position of the West Coast trough. This varies as the trough moves on and offshore. It rarely rains during these periods, with maximum rainfall recorded being only 4 mm at both sites (Figure C33).

Type 1 weather is the most likely condition to generate dust storms, due to the hot dry conditions and higher frequency of moderate to strong winds throughout the seasons. However, it is important to note that Type 1 weather only occurs 8 % of the time in winter and 18 % of the time in autumn as it is linked with the development of tropical lows in the Indian Ocean and the movement of West Coast trough which is driven by the Australian monsoon.

C3.1.2 Type 2

Type 2 weather is prevalent all year round becoming the dominant mode in autumn (45%) and winter (42%). Average wind speeds tend to be higher in summer (3.1 m/s) and lower in winter (2.6 m/s). Indeed less than 20 % of winds exceed 4 m/s in autumn and winter compared to approximately 30 % in summer and spring while winds less than 2 m/s occur almost 60 % of the time. Type 2 conditions also show an increase in southeast to south westerly flow with a marked decrease in northeasterly and northwesterly winds for all seasons (Figure C34).

Relative humidity is moderate averaging 35% with a maximum of 50% and a minimum of 20% across all seasons. Temperatures are slightly lower than Type 1 with averages varying from 17 °C in winter to 26 °C in summer (Figure C35).

Mean sea level pressure is higher under these conditions as the incoming ridge of high pressure undercuts the trough. This feature of Type 2 weather can generate some scattered showers (Figure C36).

C3.1.3 Type 3

Type 3 weather is the dominant mode along with Type 2 in autumn (28%) and winter (36%), although it is present in summer and spring it occurs for less than 15% of the time.

Wind speeds are quite low under this condition with 60 % of the winds in winter and autumn being below 2 m/s. Maximum winter wind speeds do not exceed 7 m/s while summer winds can reach 11 m/s. Winds tend to be northeast to southeast throughout all seasons while spring has a distinct westerly component and winter experiences winds from all directions with a strong northeasterly component (Figure C37).

Relative humidity is higher than Type 2 averaging in the 60's to 70's with a maximums of 80% and minimums of 50% throughout the seasons. Temperatures are significantly lower especially in winter where 6 am temperatures can reach down to 2 °C. Autumn and winter also show the largest range of temperatures changing nearly 20 °C between 6 am and 9 am (Figure C38). Night-time temperatures are not recorded at this site therefore minimum temperatures are not available. However Meekatharra and Leinster are within the Murchison region and display the same prevalence of Type 3 weather during winter where temperatures drop below 0 °C.

Mean sea level pressure is also higher under these conditions as the incoming ridge of high pressure from Type 2 settles in for the winter. In a similar situation to Type 2 weather Type 3 can generate some significant rainfall predominantly during the summer months (Figure C39).

This weather type can be considered as the centre of the high pressure system that moved inland under Type 2 conditions. As the system approaches the centre of the Australian continent the daily heating and cooling of the large land mass causes the system to slow down and at times stall, becoming a blocking or stationary high. Without the procession of fronts generated by tropical depressions (Type 1) to move the system along it can last for several days, generating very calm and settled weather.

These conditions (Type 2 and 3) generally lead to the development of a stratified nocturnal atmosphere, commonly referred to as inversion layers. Where air temperatures increase with height as the atmosphere is heated by the release of radiant energy from the surface. These conditions can produce very stable conditions that hinder the effective dispersion of pollutants causing them to remain suspended in the atmosphere for long periods of time.

Studies undertaken by R.K. Steedman and Associates estimated that night-time inversions occur 44% of the time in Yeelirrie area with a higher frequency during the winter months (63%) (1978). Further studies conducted by Lyons and Steedman 1981, revealed that these nocturnal inversion conditions in winter cause a nocturnal jet to form above the inversion layer. Nocturnal jets occur when the atmosphere above the inversion layer decouples from the air below the inversion layer, this cause the upper atmosphere to lose contact with the surface thereby reducing the friction velocity (U*) to zero. Without any drag from the surface the winds are free to flow and soon reach super geostrophic velocities, thus forming a low level jet.

The frequency of Type 2 and 3 weather complement the findings in these earlier studies. Nocturnal inversions and the formation of low level jets are likely to occur on most evenings in autumn and winter with a few instances during summer and spring.

C3.1.4 Type 4

Type 4 weather is similar to Type 3 except that the high pressure system is located over the Australian Bight not the centre of Australia. This weather is accounts for approximately 14 % of the conditions in winter and less than 10 % in autumn and spring and summer.

This weather type has similar distribution of maximum wind speeds as Type 3. Average wind speeds are significantly lower in winter (1.9 m/s) and summer (2.4 m/s). Winds are predominantly from the southeast in summer (77 %) and southwest in winter (68%) (Figure C40).

Relative humidity is significantly higher than any other weather type averaging 80 - 90% across all seasons. Temperatures are similar to Type 3 conditions averaging 12 °C in winter and 20 °C in summer (Figure C41).

Mean sea level pressure is similar to Type 3 with less variability between the seasons due to the positioning of the high pressure system off the southern coast of Australia. This is also the condition that brings the most rain to Yeelirrie averaging 2.4 mm per day with a maximum of 34 mm under these conditions (Figure C42).

C4 Conclusion

The frequency of Type 2 and 3 weather conditions found in the above analysis complement the findings in the earlier studies. Nocturnal inversions and the formation of low level jets are likely to occur on most evenings in autumn and winter with a few instances during summer and spring.

The most important aspect of the Yeelirrie climate in terms of air quality is the frequency and intensity of hot, dry north-easterly winds (Type 1 weather conditions), as these are the conditions most likely to generate dust from the erosion of stockpiles and disturbed areas. Also of importance is the frequency and intensity of night-time inversions particularly in winter (Type 3 weather conditions) characterised by a stable atmosphere and the formation of a low level jet, as these conditions can cause pollutants to remain suspended in the atmosphere for long periods of time.

- Type 1 and Type 3 weather conditions are the most likely to cause increases in ambient and the proposed development generated particulate matter due to the erosion of stockpiles and disturbed areas
- Type 1 weather is characterised by hot and dry winds predominantly from the northeast with a slight northwesterly component
- Type 3 weather conditions are most likely to cause increases in ambient and the proposed development generated particulate matter due the presence of stable night-time inversions

The accommodation village and Yeelirrie homestead are situated approximately 15.6 km and 16.4 km, respectively, southeast from the proposed Yeelirrie development site. Type 1 weather conditions pose the greatest potential for dust impacts at these receptors when winds are from northwest. This condition is however most likely to occur when there is strong convection and moderate winds generating good dispersion conditions. As the receptors are a significant distance from the proposed Yeelirrie development site the potential for adverse impacts is minimal.

Type 3 weather is also of concern to the accommodation village and Yeelirrie homestead as these conditions also show a northwesterly component coupled with the very stable night-time conditions, particularly in winter. As dust emissions from exposed areas such as stockpiles are wind speed dependant, the rate of emissions from the proposed Yeelirrie development will be reduced during this period hence the light wind night-time conditions are not of significance.

C5 References

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Lyons, T.J., and Steedman, K. 1981, Stagnation and Nocturnal Temperature Jumps in a Desert Region of Low Relief, Boundary Layer Meteorology, 21:369-387.

R.K Steedman & Associates, 1978, Yeelirrie Environmental Impact Statement: Atmospheric Studies, Report to Maunsell and Partners Pty Ltd to be incorporated in the Western Mining Corporation Limited Environmental Impact Statement on the Yeelirrie Uranium Project.

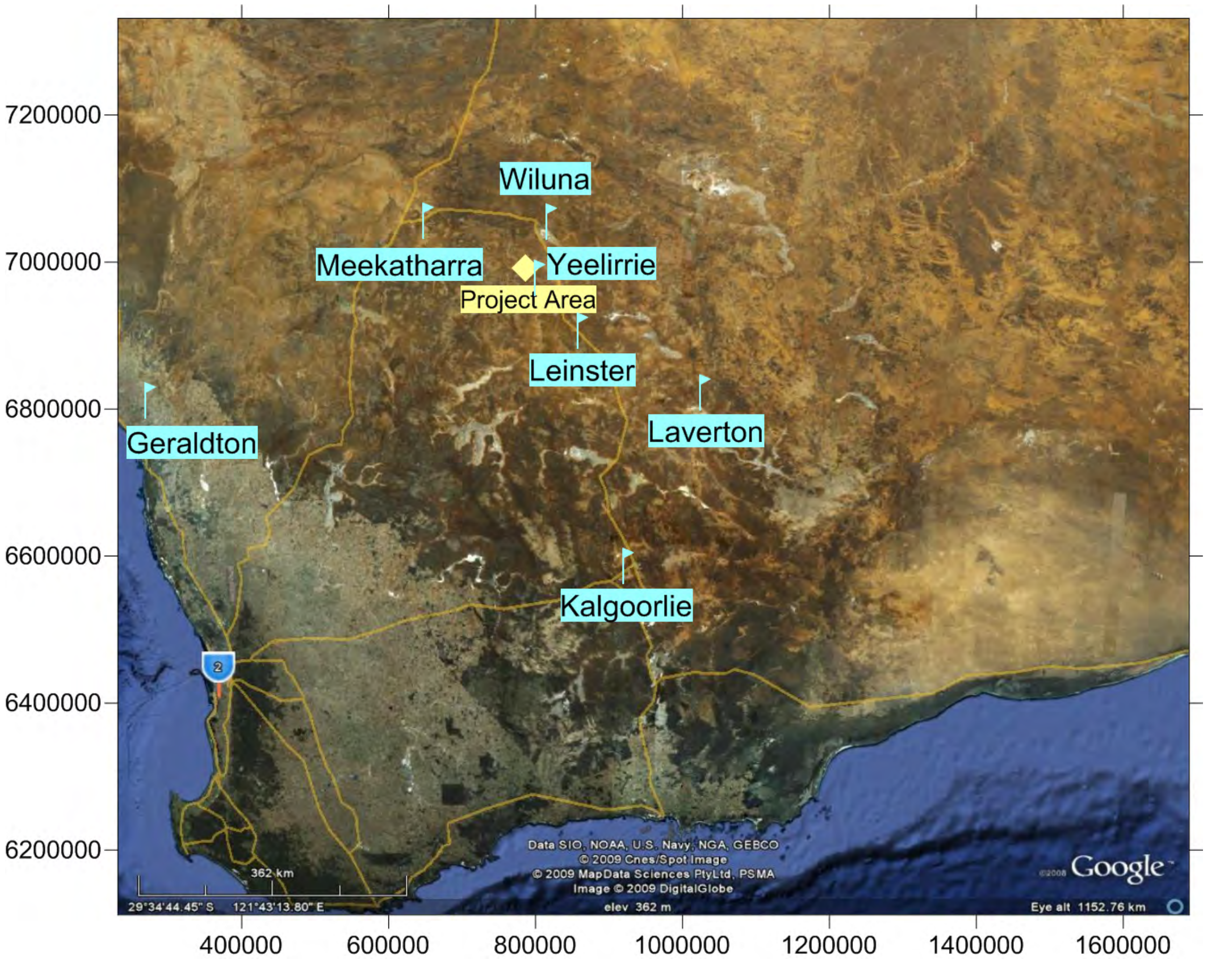


Figure C1 Bureau of Meteorology monitoring sites used for climate analysis

Location: Western Australia	**Data source:** Surfer 9 and Google-Earth	**Units:** Australian Map Grid coordinates – MGA94 1994 AMG Zone 50 and 51.
Type: Aerial map	**Prepared by:** Sarah Menzel	**Date:** January 2011

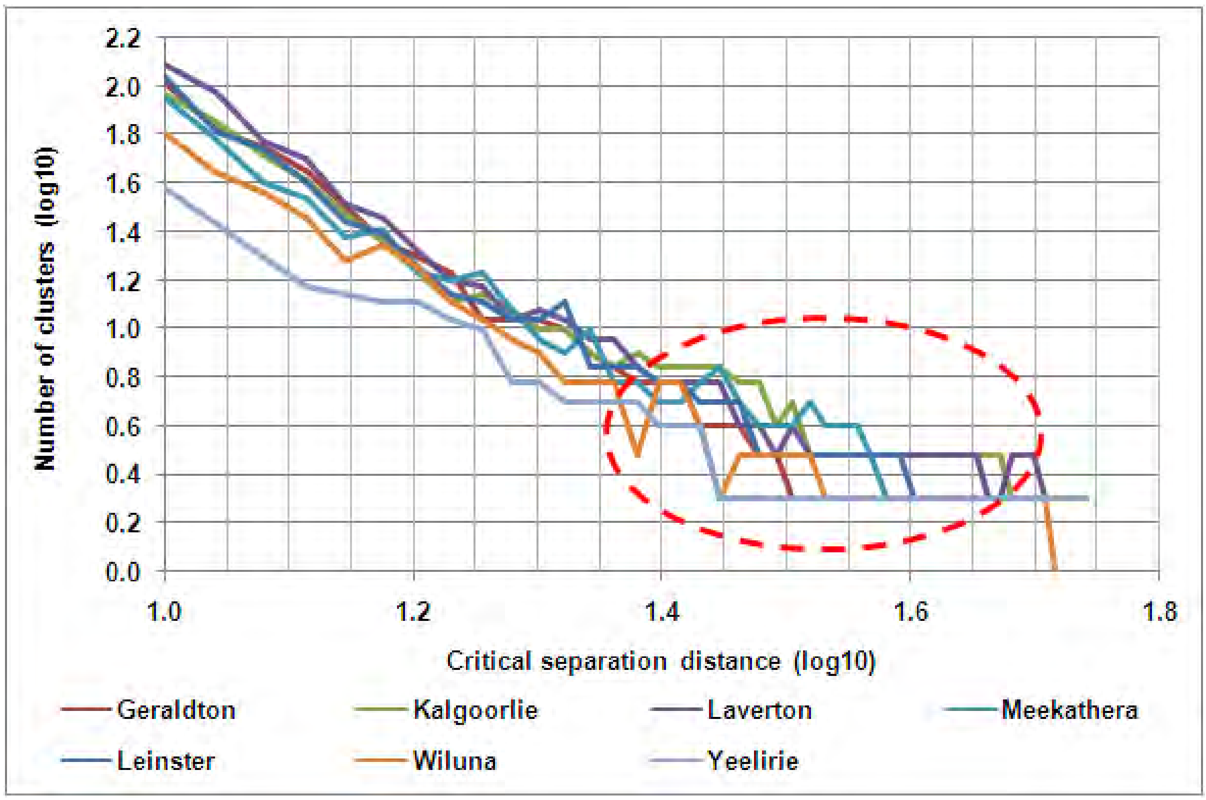


Figure C2	**Critical separation distance and number of clusters found for Western Australia**

Type:	**Period:**	**Data source:**	**Date:**
Log – log plot	1993/1994 – 2009	Bureau of Meteorology	July 2010

Prepared by:
Andrew Wiebe

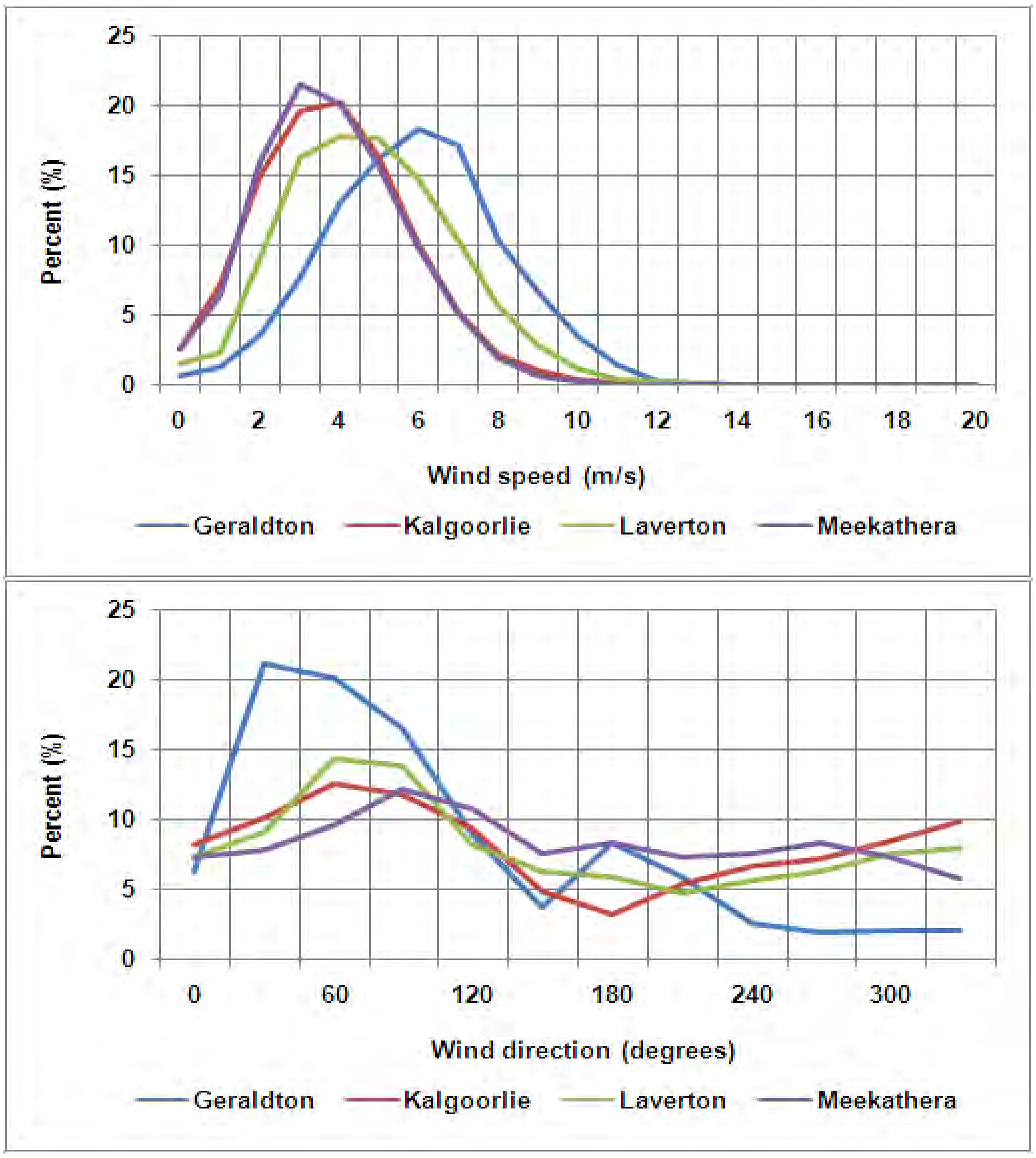


Figure C3 Type 1 synoptic weather condition distribution of wind speed and direction

Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

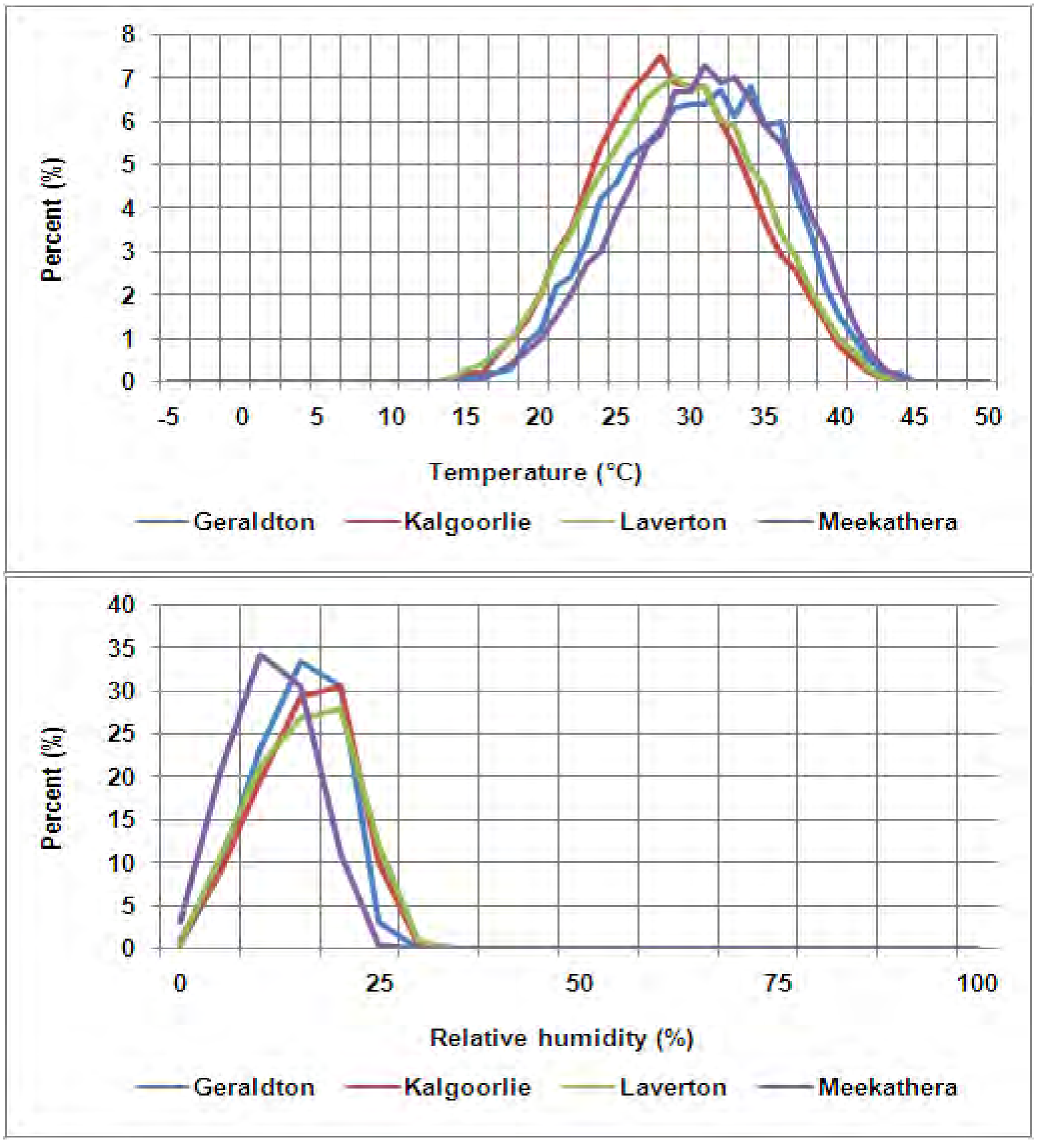


Figure C4 Type 1 synoptic weather condition distribution of temperature and relative humidity

Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

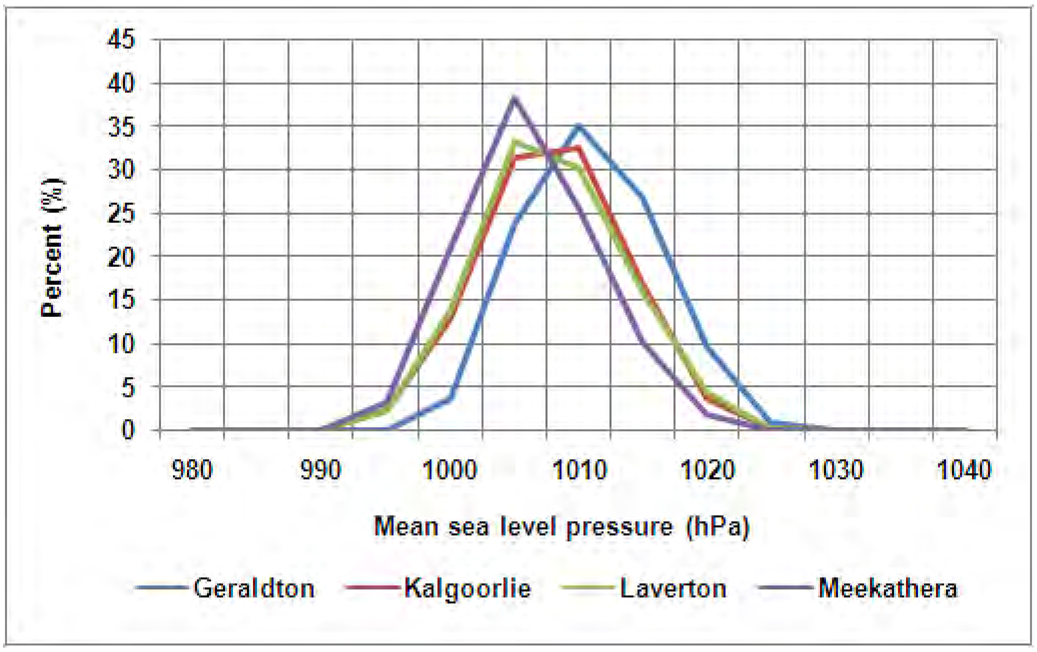


Figure C5 Type 1 synoptic weather condition distribution of average sea level pressure

Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

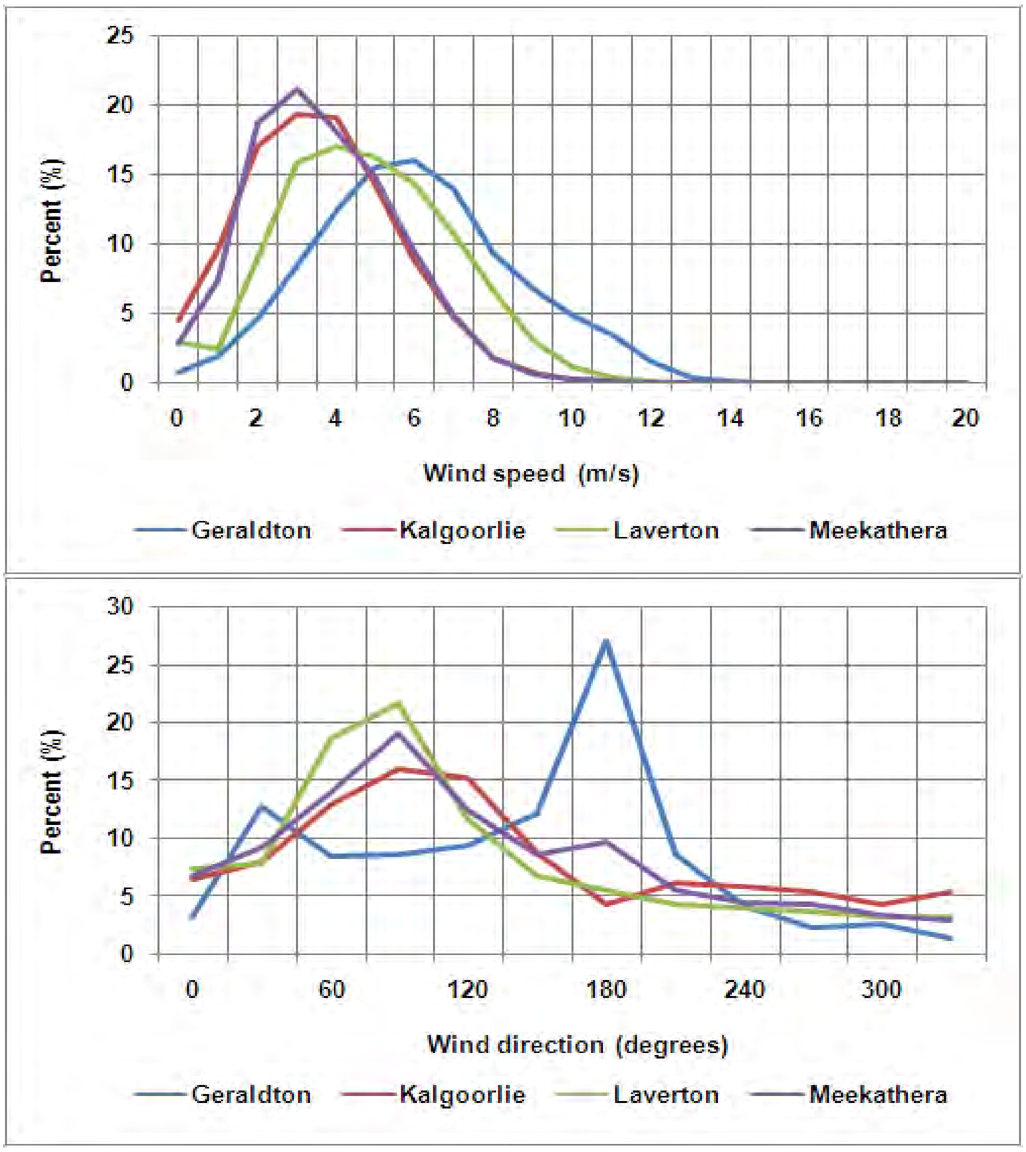


Figure C6 Type 2 synoptic weather condition distribution of wind speed and direction

Location:	**Period:**	**Data source:**	**Units:**
Western Australia	1993 - 2009	Bureau of Meteorology	m/s and degrees
Type:	**Data frequency:**	**Prepared by:**	**Date:**
Probability density function	1 hour	Andrew Wiebe	July 2010

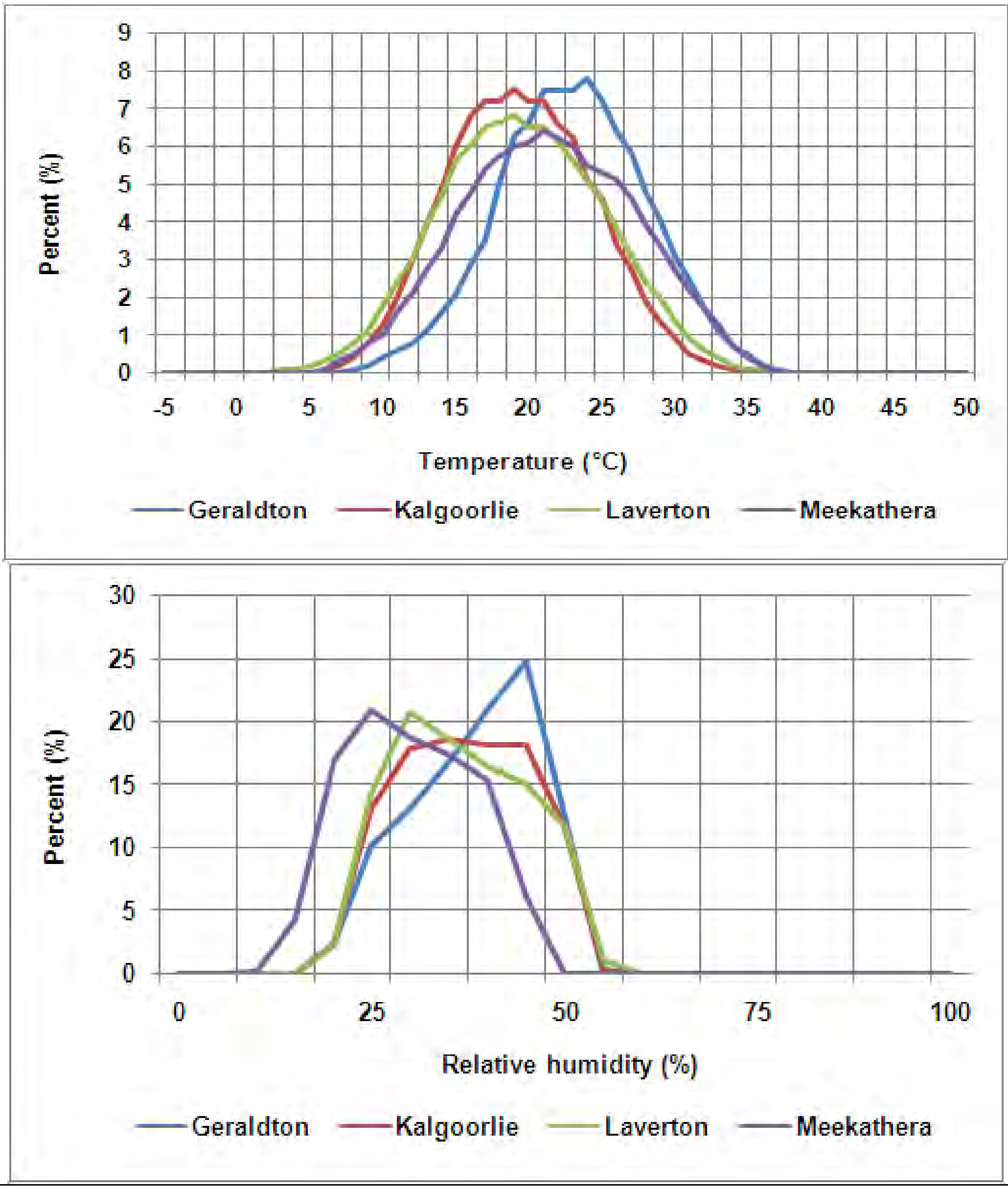


Figure C7 Type 2 synoptic weather condition distribution of temperature and relative humidity			
Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

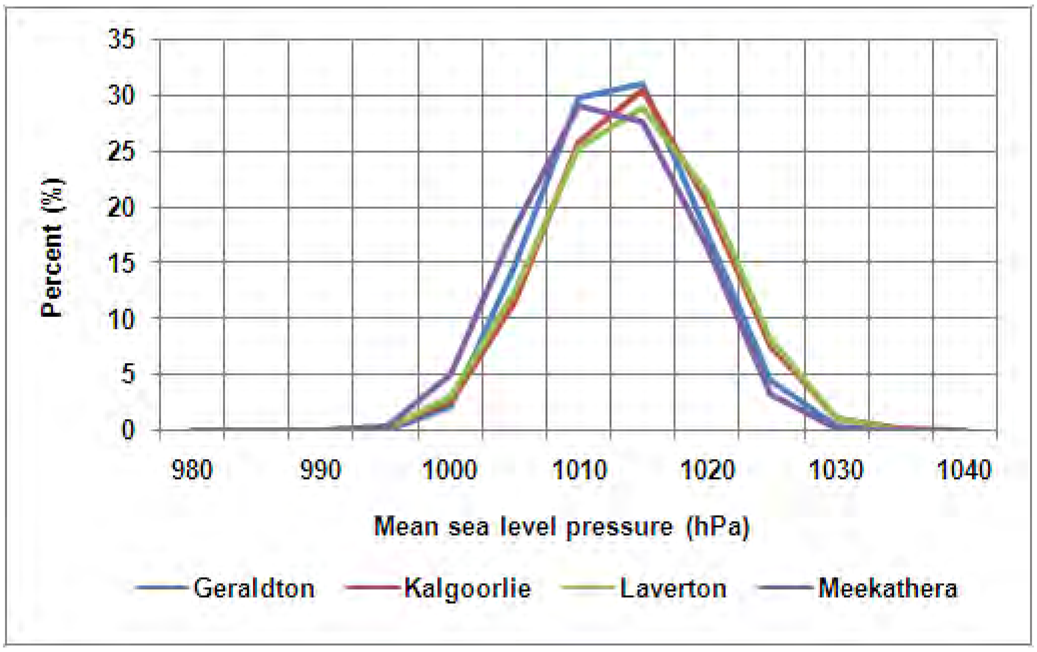
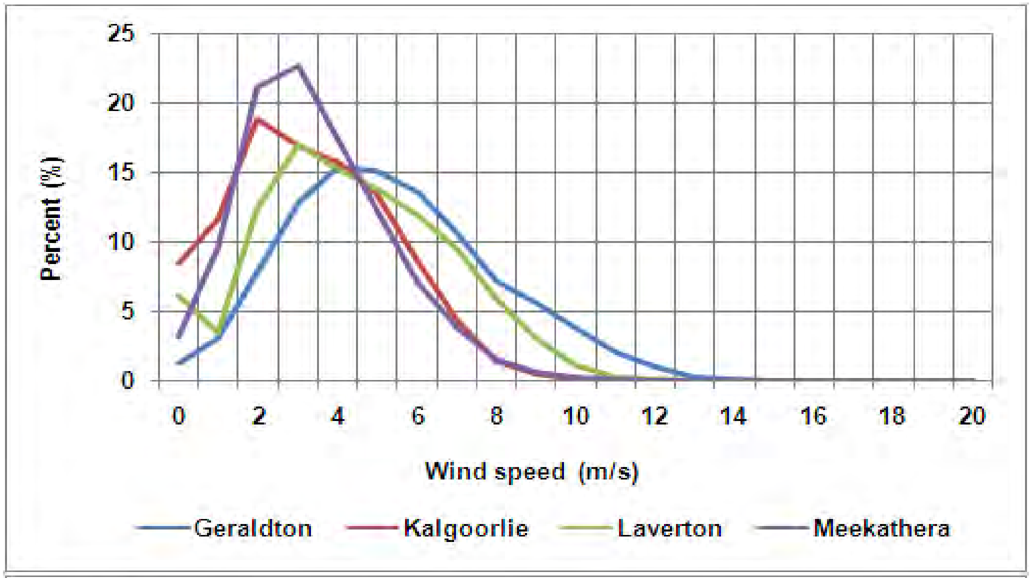


Figure C8 **Type 2 synoptic weather condition distribution of average sea level pressure**			
Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010



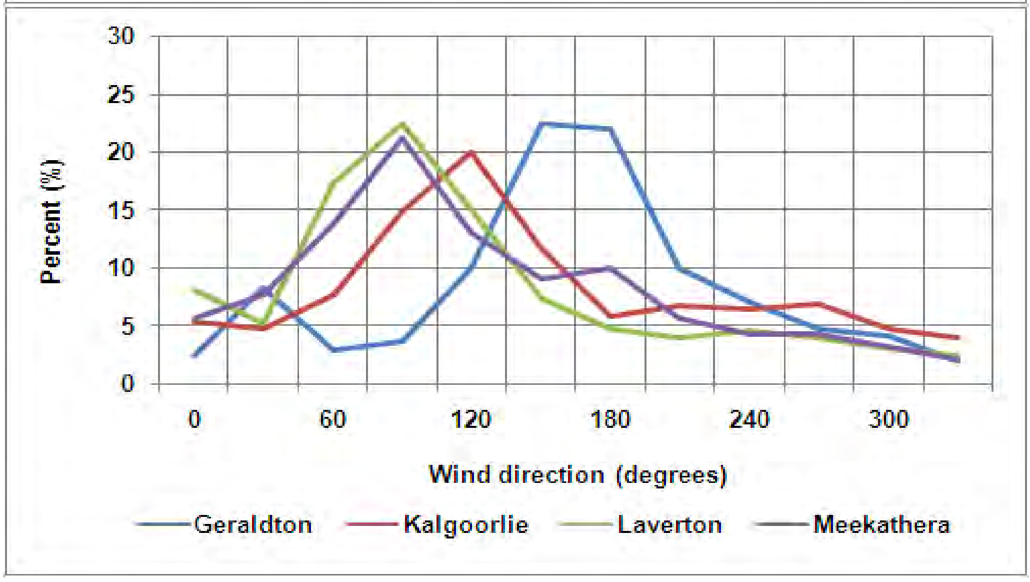
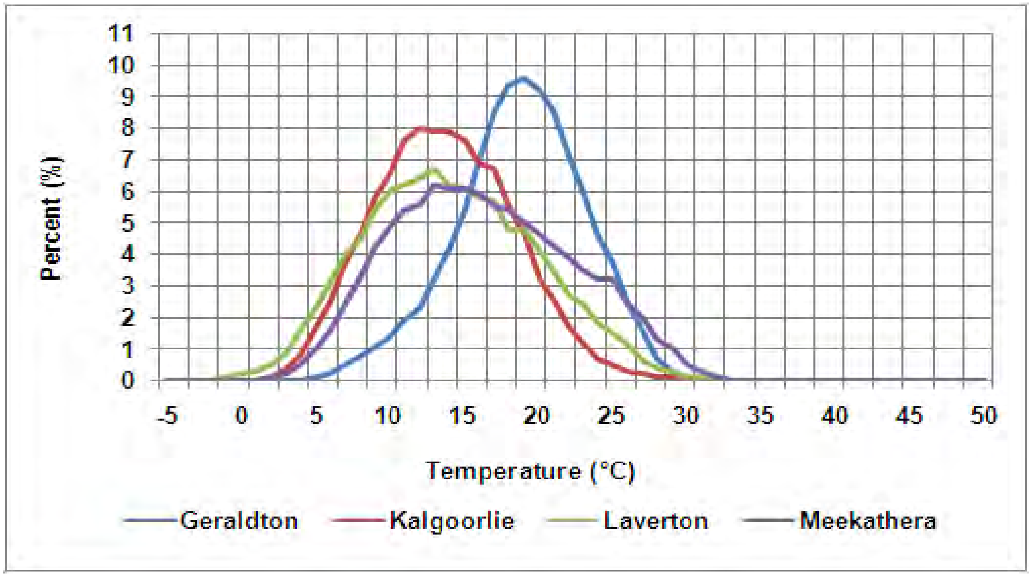


Figure C9 Type 3 synoptic weather condition distribution of wind speed and direction

Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010



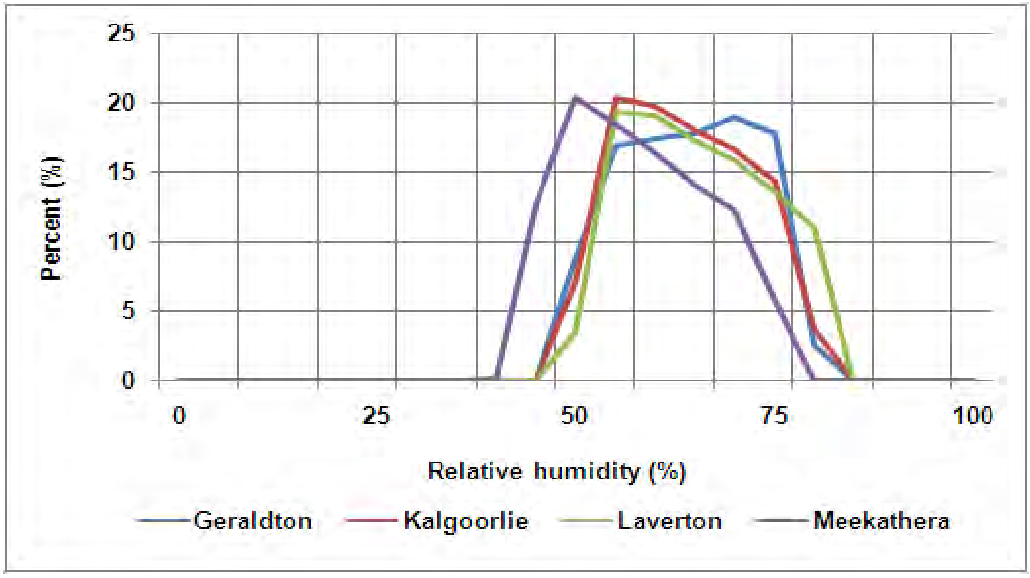


Figure C10	**Type 3 synoptic weather condition distribution of temperature and relative humidity**

Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

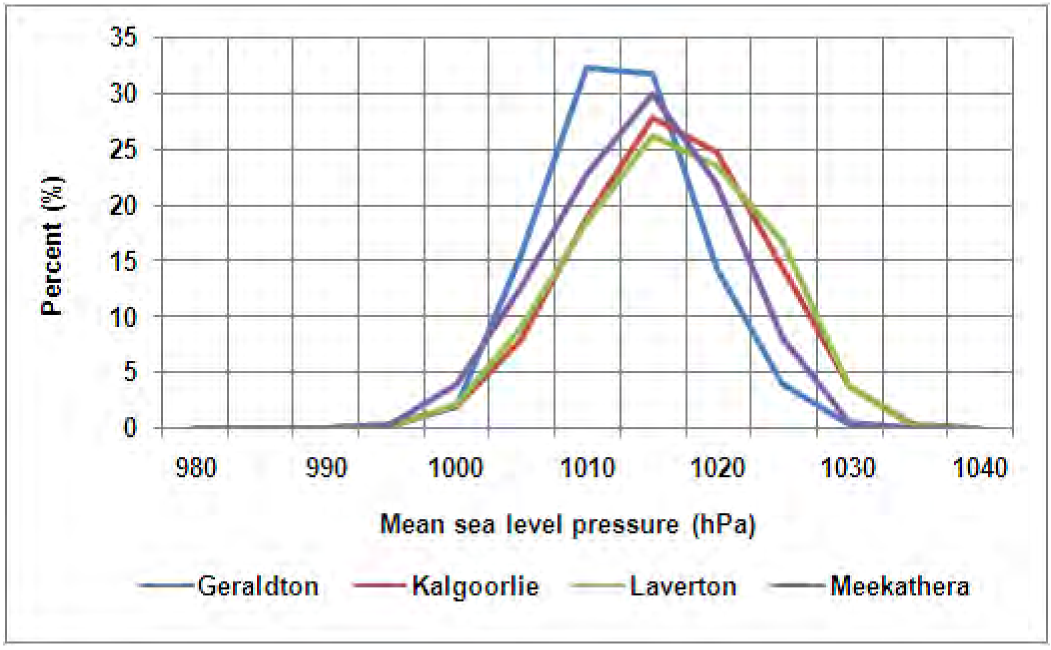


Figure C11	**Type 3 synoptic weather condition distribution of average sea level pressure**		
Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

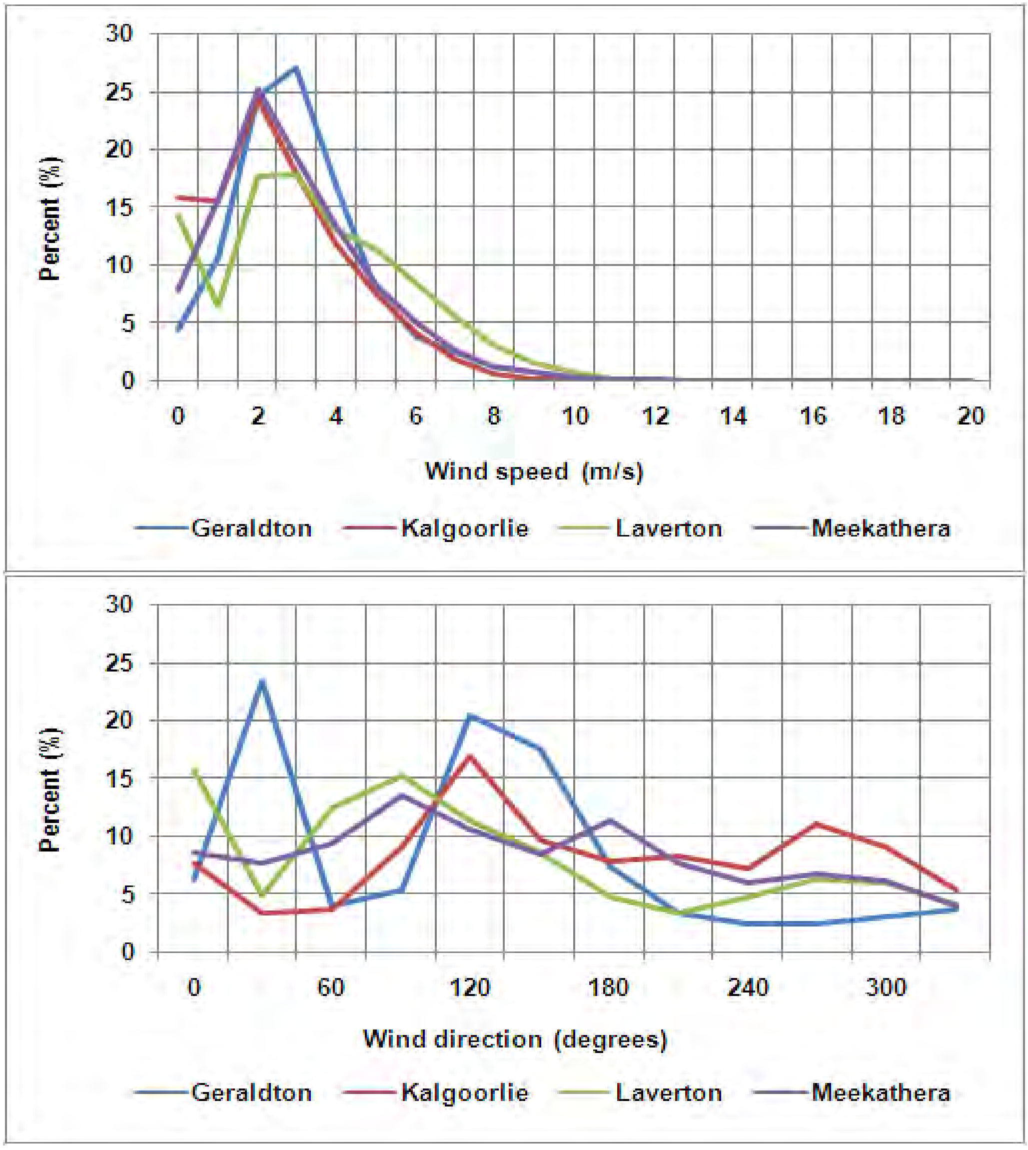


Figure C12 **Type 4 synoptic weather condition distribution of wind speed and direction**

Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

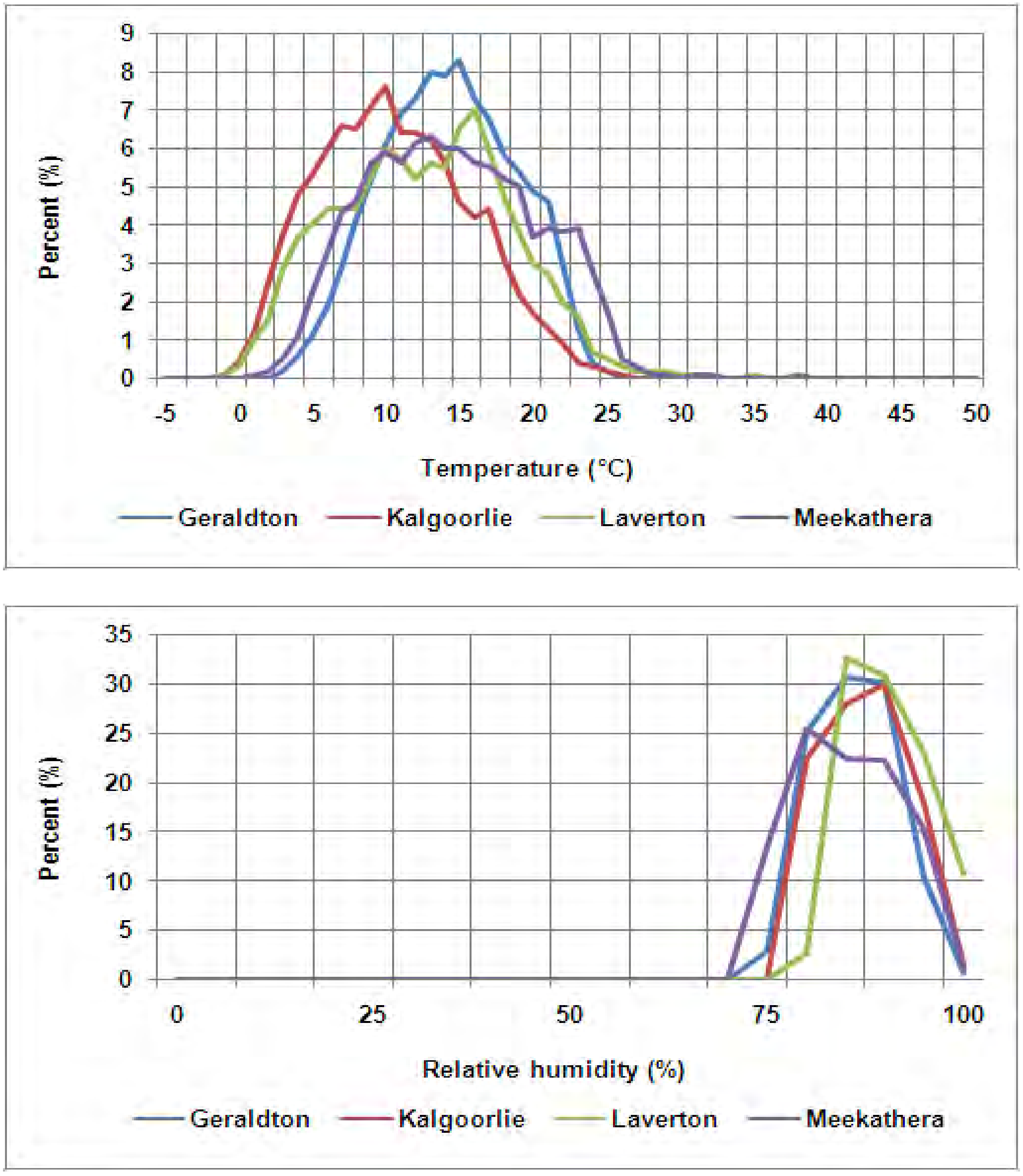


Figure C13 **Type 4 synoptic weather condition distribution of temperature and relative humidity**

Location: Western Australia	**Period:** 1993 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

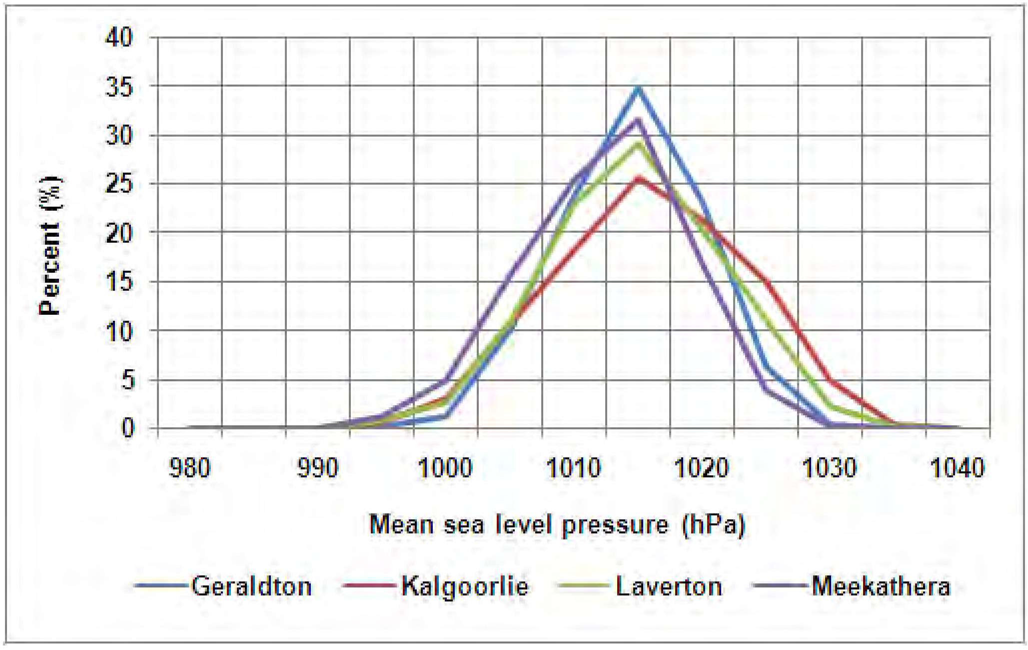


Figure C14 Type 4 synoptic weather condition distribution of average sea level pressure

Location: Western Australia	Period: 1993 - 2009	Data source: Bureau of Meteorology	Units: hectoPascal
Type: Probability density function	**Data frequency:** 1 hour	**Prepared by:** Andrew Wiebe	**Date:** July 2010

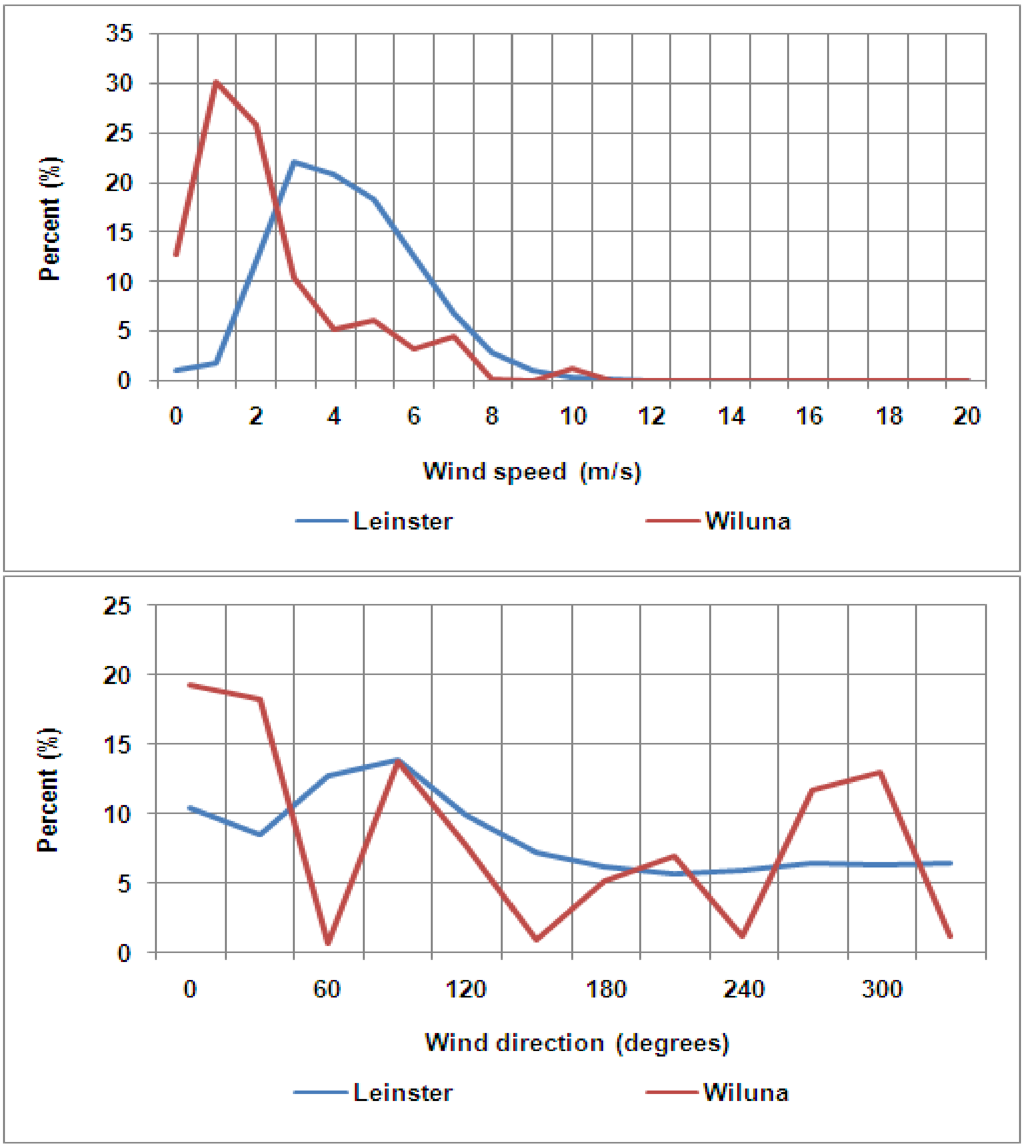
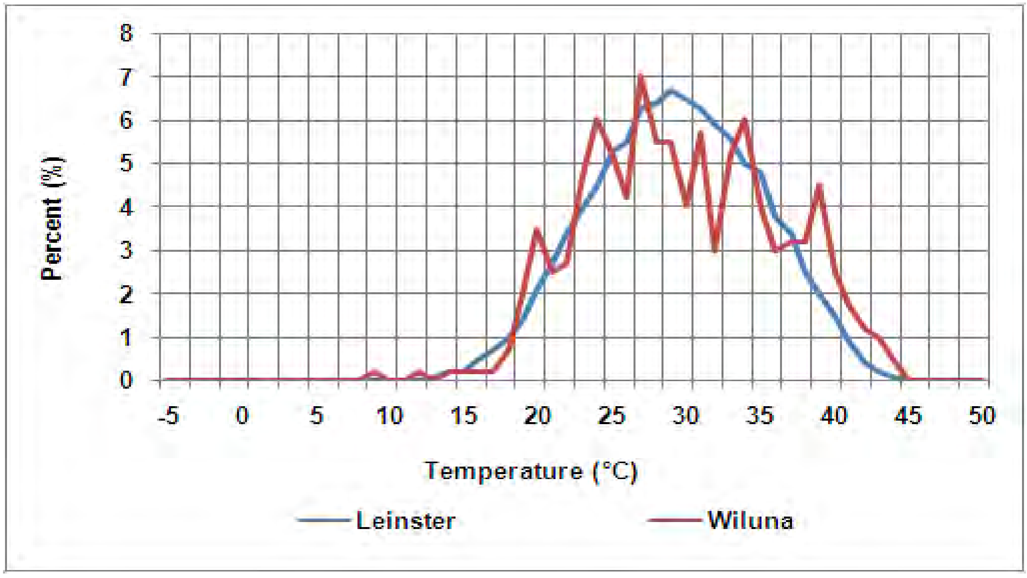


Figure C15 **Type 1 regional weather condition distribution of wind speed and direction**

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



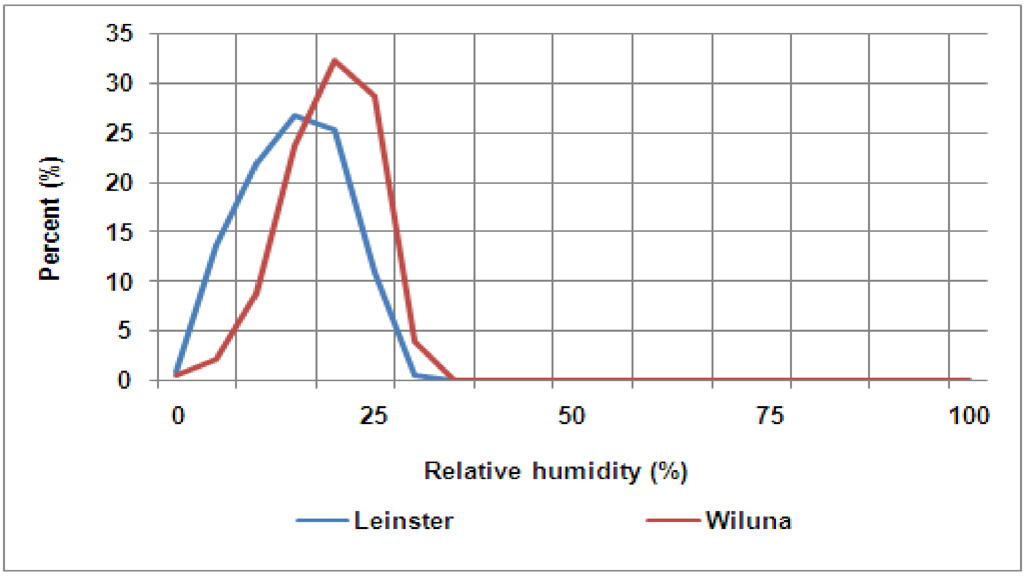


Figure C16 Type 1 regional weather condition distribution of temperature and relative humidity

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

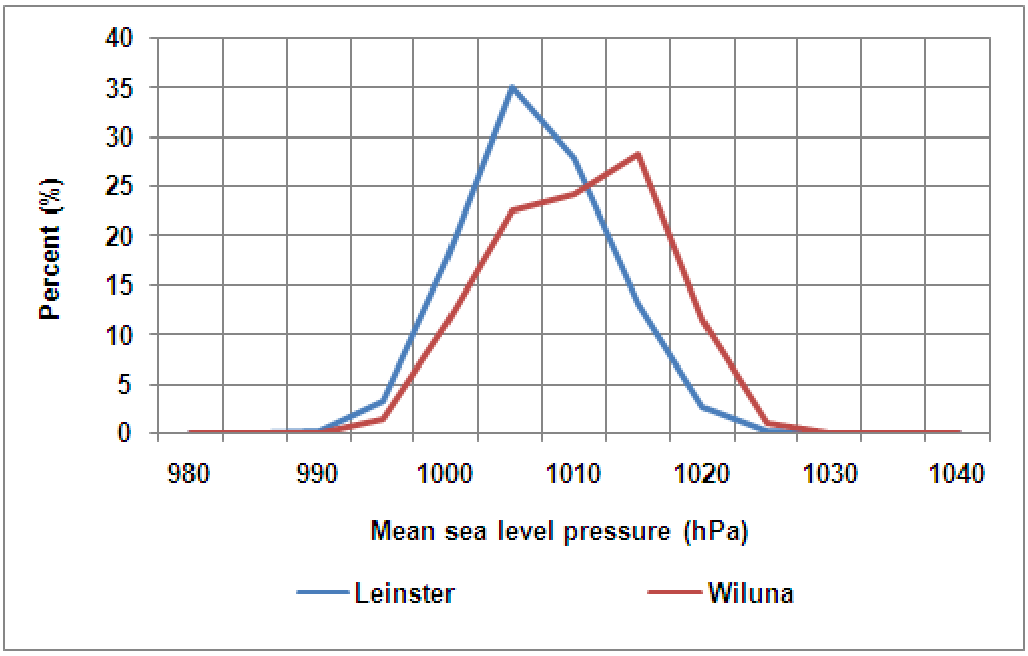
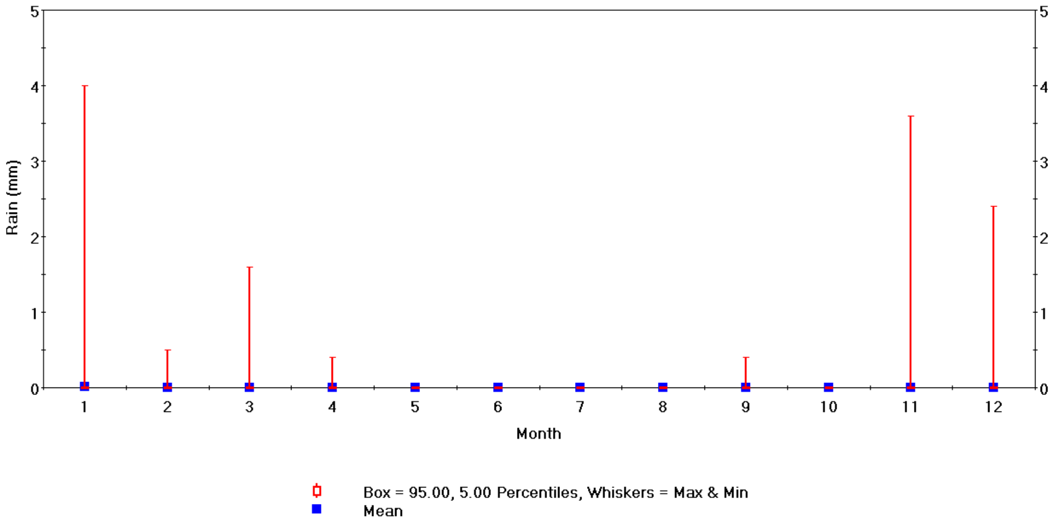
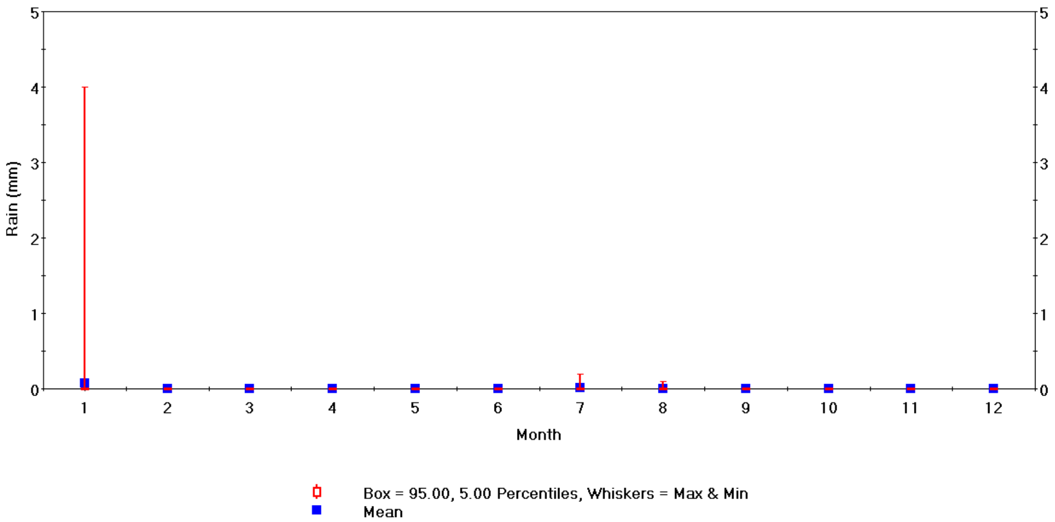


Figure C17	**Type 1 regional weather condition distribution of average sea level pressure**		
Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



a)



b)

Figure C18 Type 1 regional weather condition monthly rainfall for (a) Leinster and (b) Wiluna

Location:	**Period:**	**Data source:**	**Units:**
Murchision region Western Australia	Leinster 1994-2009 Wiluna 2006-2009	Bureau of Meteorology	Degrees Celsius and Percent
Type:	**Data frequency:**	**Prepared by:**	**Date:**
Box and whisker	Leinster 1 hour Wiluna 9 am and 3 pm	Andrew Wiebe	July 2010

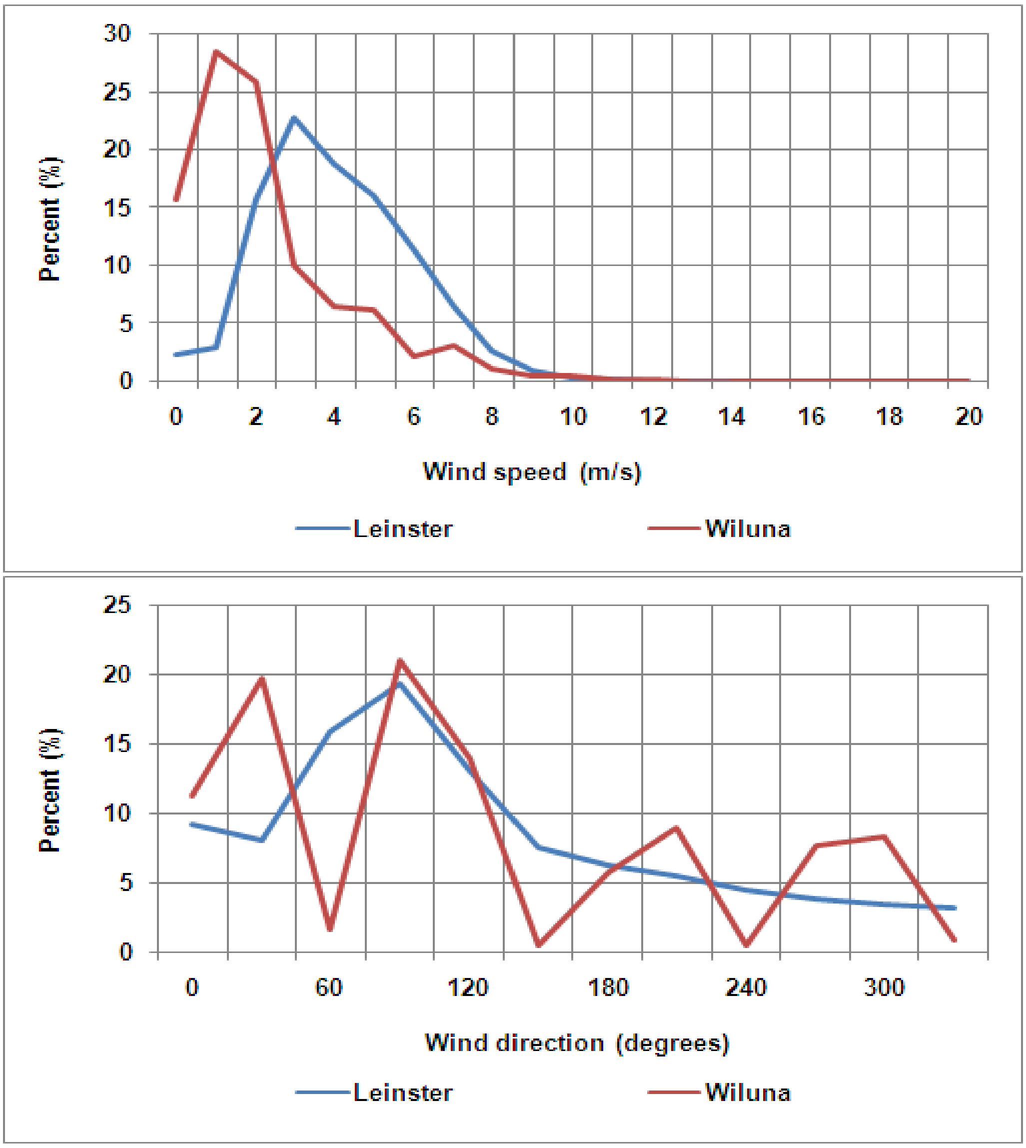


Figure C19 **Type 2 regional weather condition distribution of wind speed and direction**

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

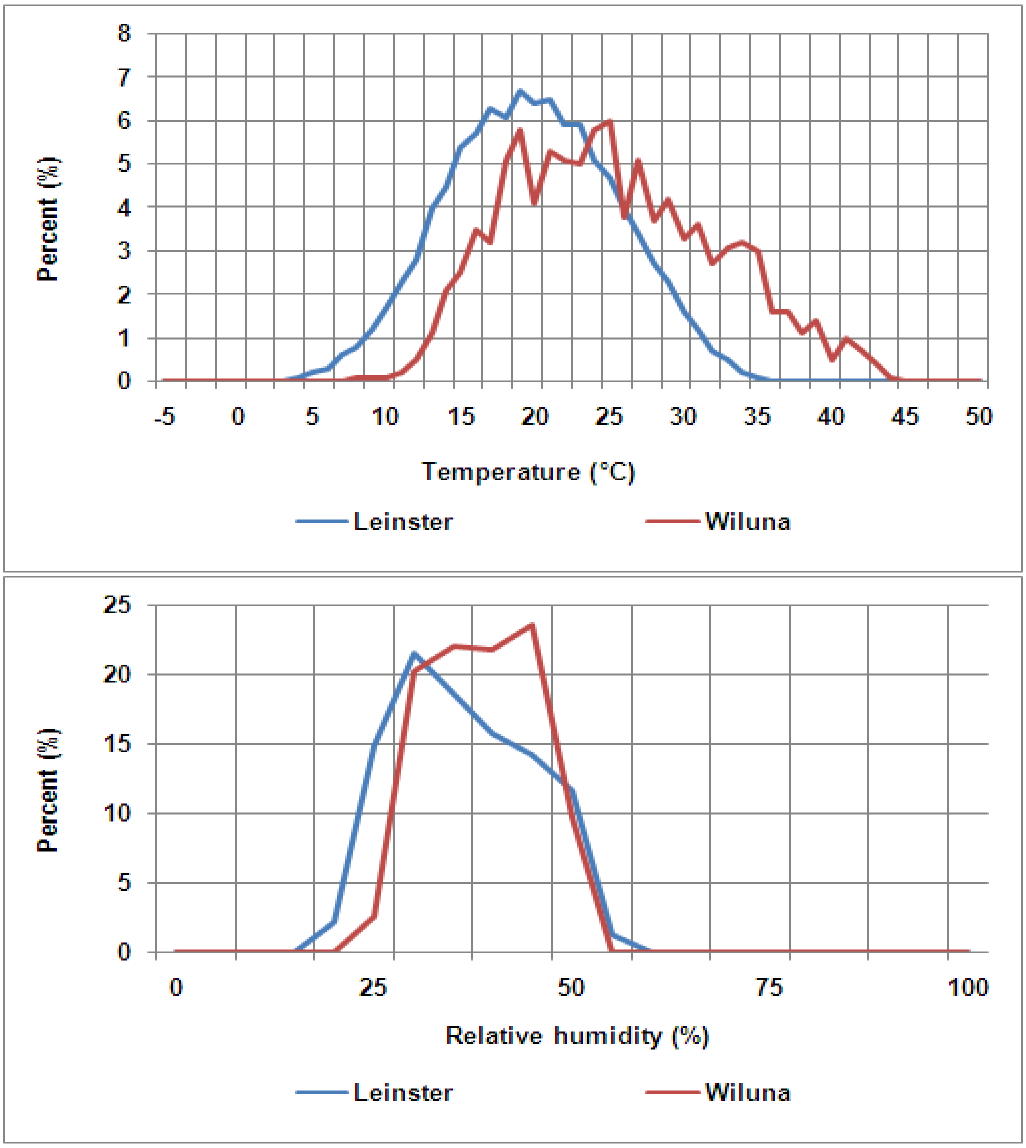


Figure C20 Type 2 regional weather condition distribution of temperature and relative humidity

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

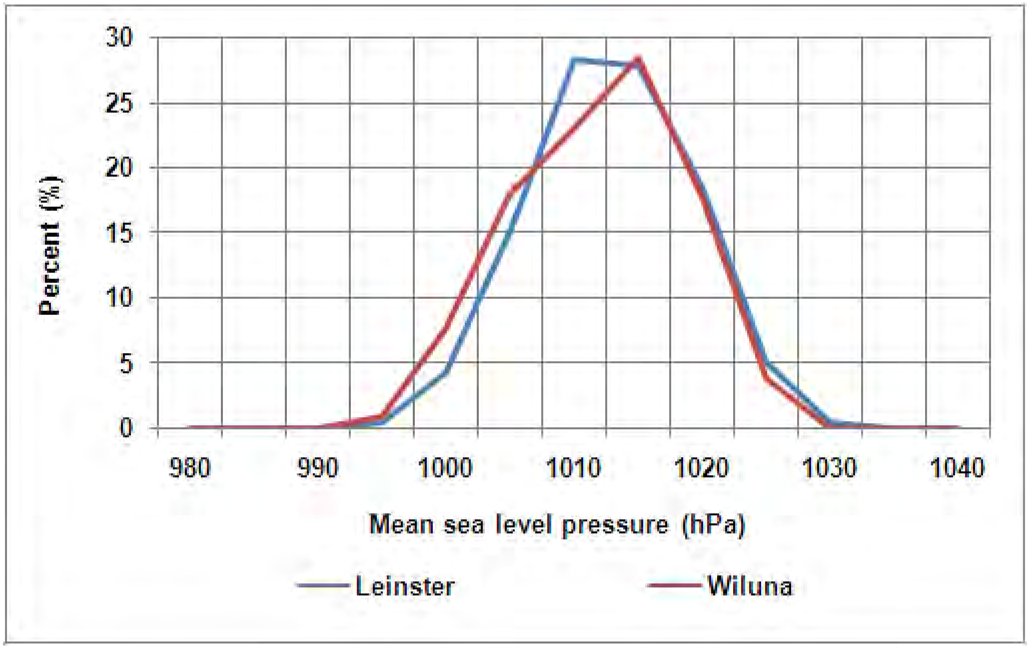
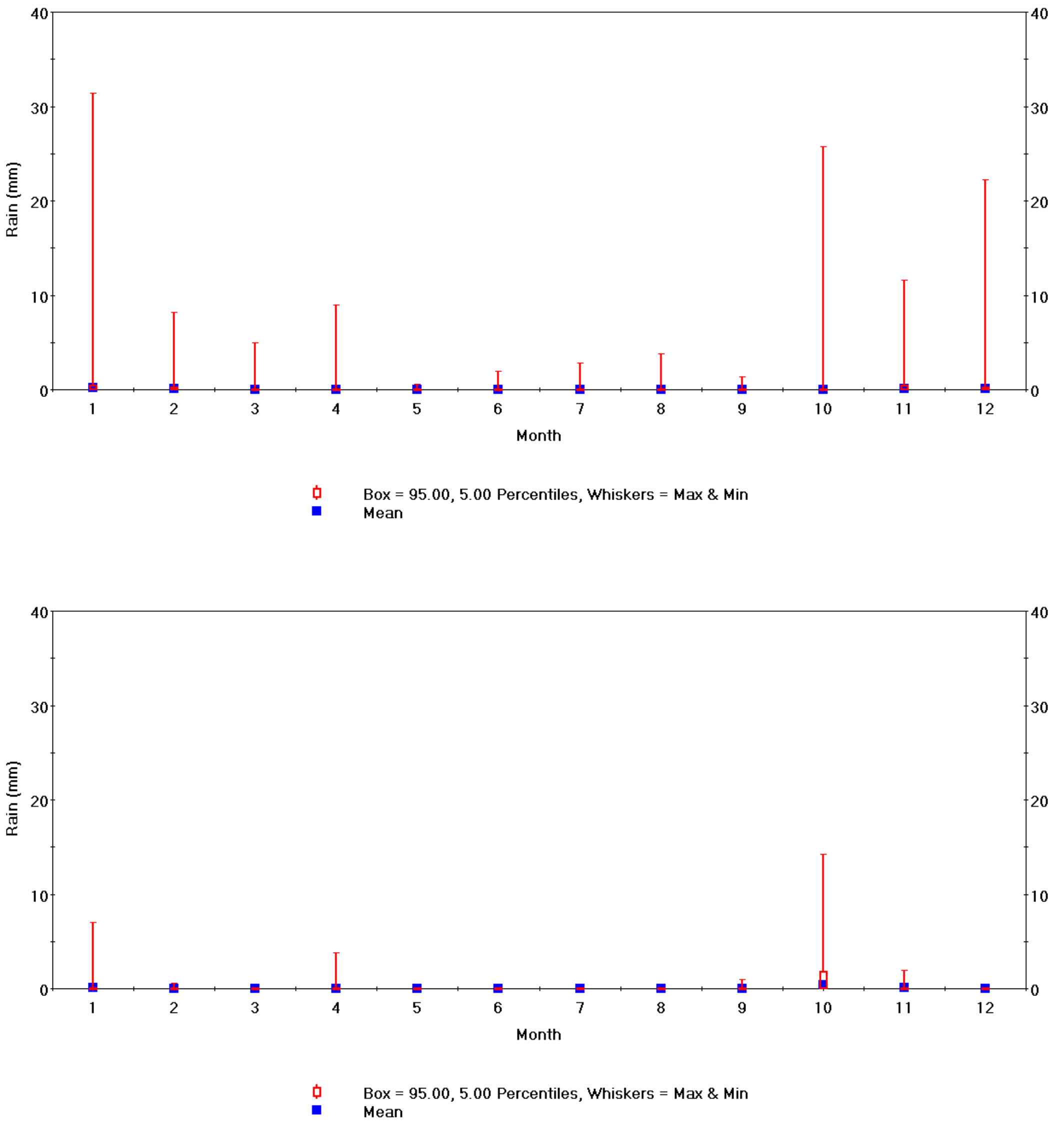


Figure C21 **Type 2 regional weather condition distribution of average sea level pressure**

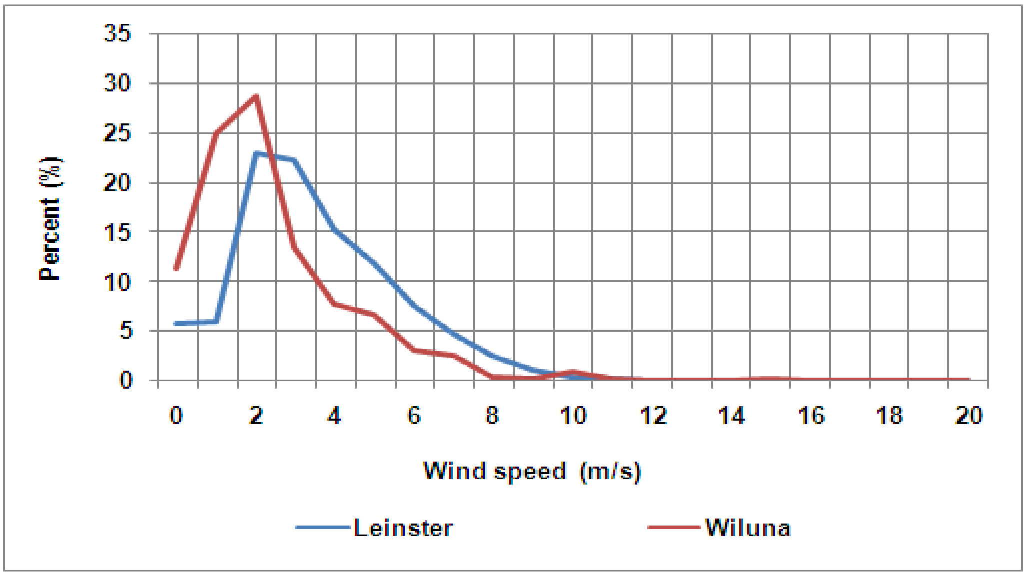
Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



b)

Figure C 22 Type 2 regional weather condition monthly rainfall for (a) Leinster and (b) Wiluna

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Box and whisker	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



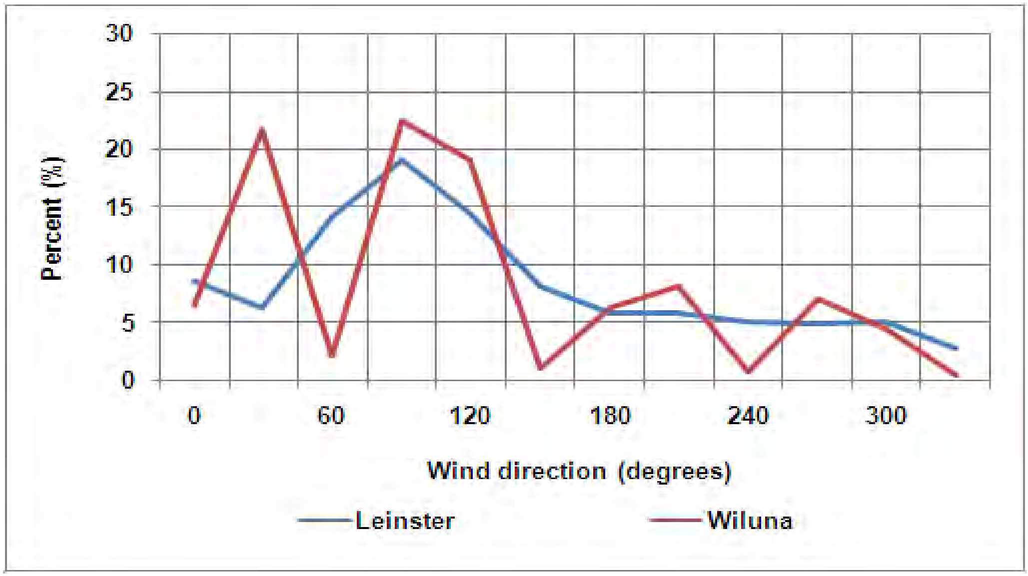
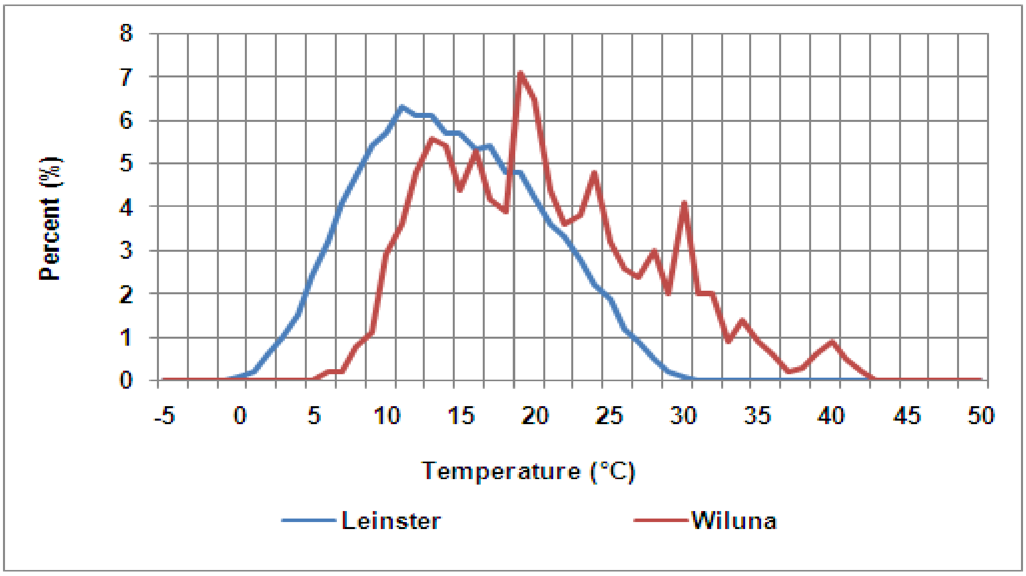


Figure C23	**Type 3 regional weather condition distribution of wind speed and direction**

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



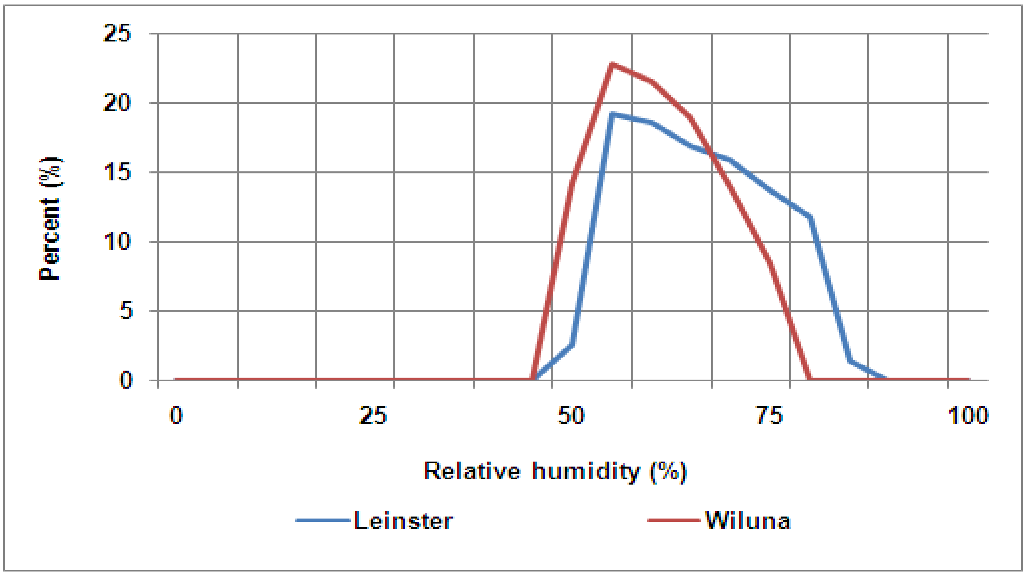


Figure C24	**Type 3 regional weather condition distribution of temperature and relative humidity**		
Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

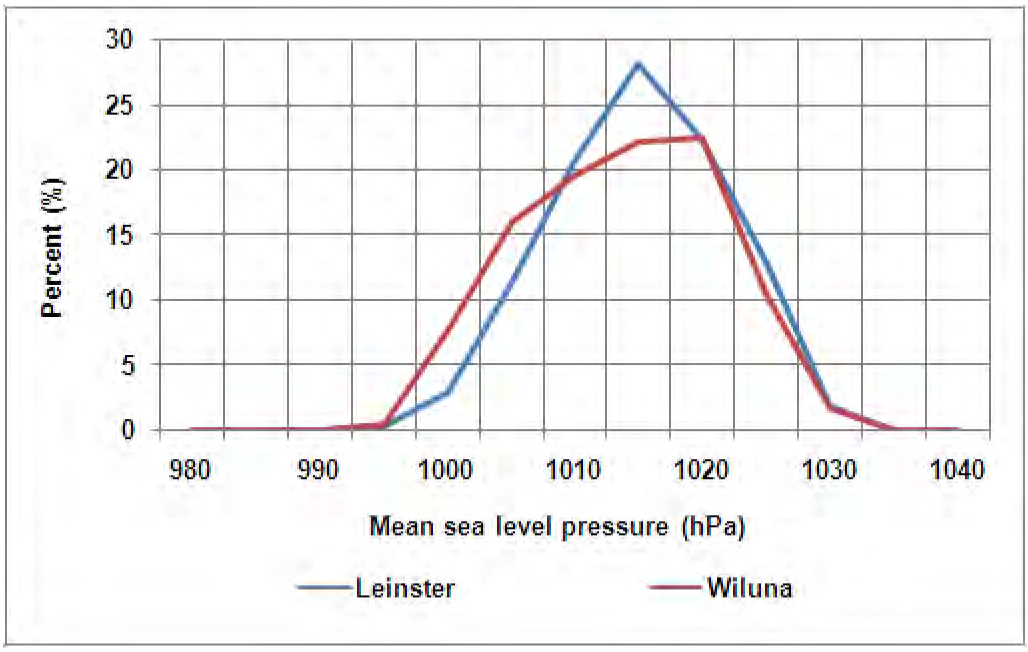
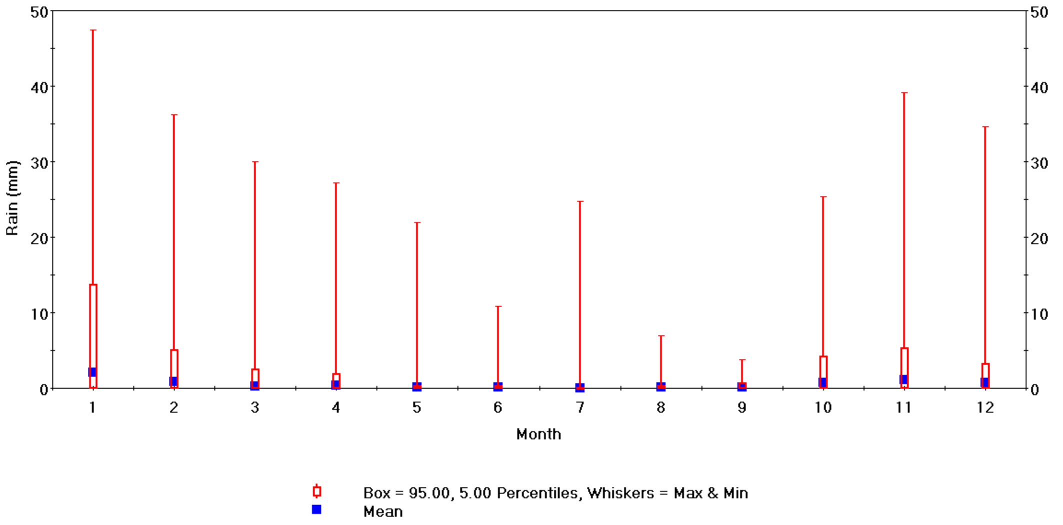
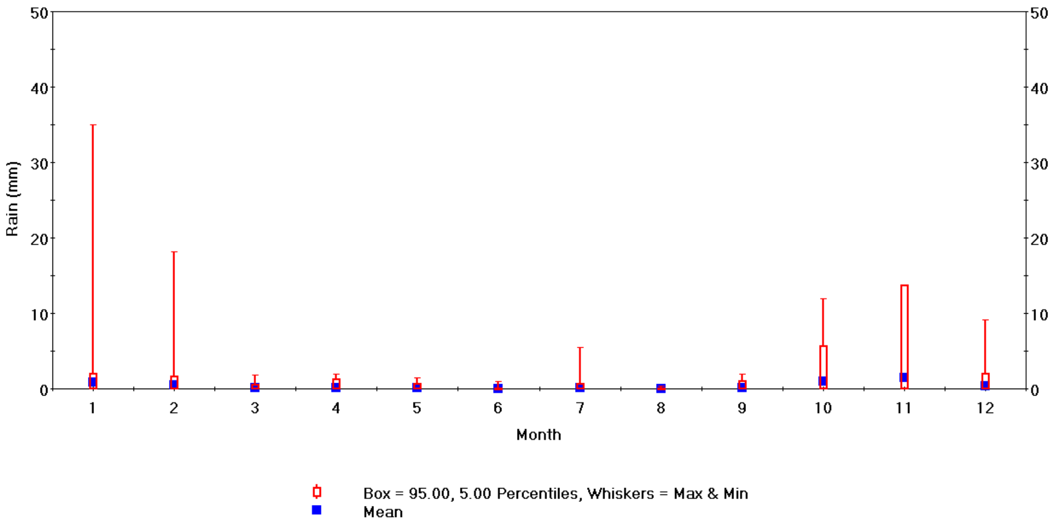


Figure C25	**Type 3 regional weather condition distribution of average sea level pressure**

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



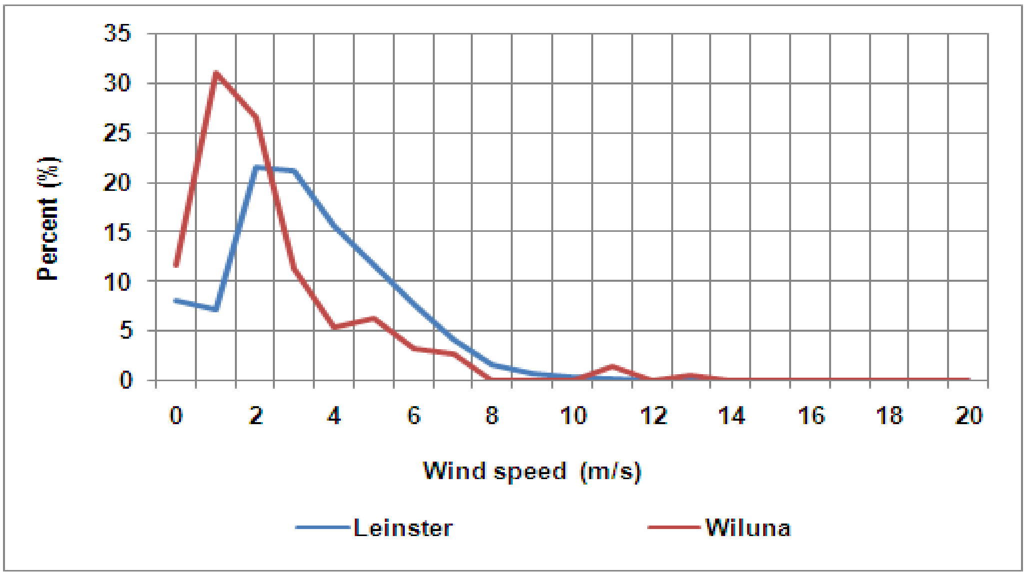
a)



b)

Figure C26 Type 3 regional weather condition monthly rainfall for (a) Leinster and (b) Wiluna

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Box and whisker	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



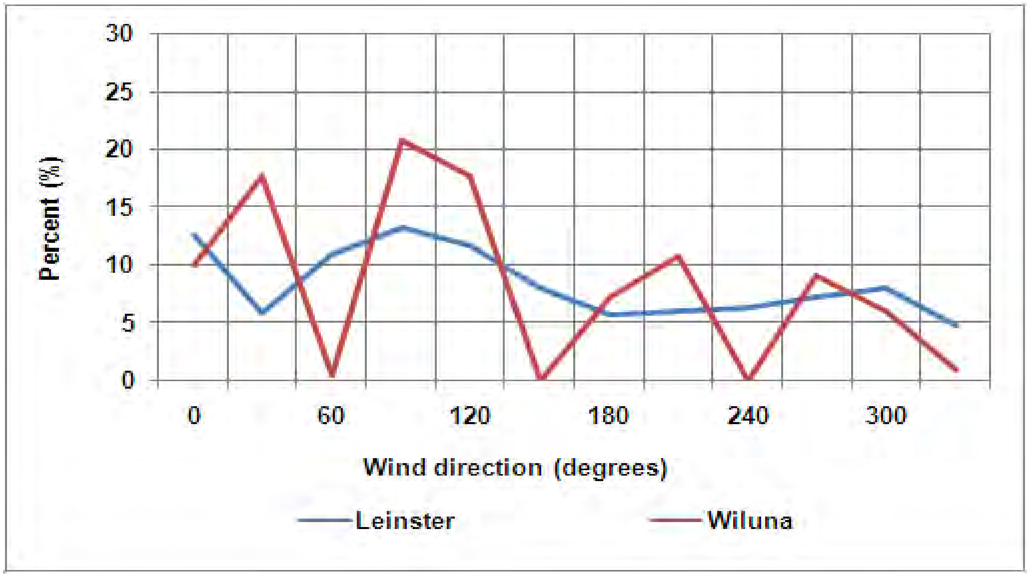
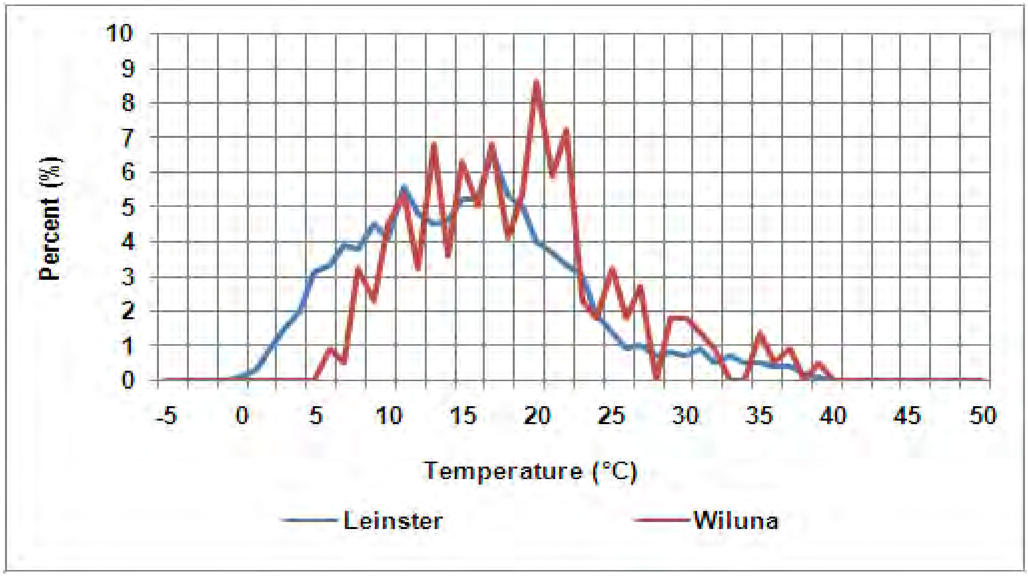


Figure C27 **Type 4 regional weather condition distribution of wind speed and direction**

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



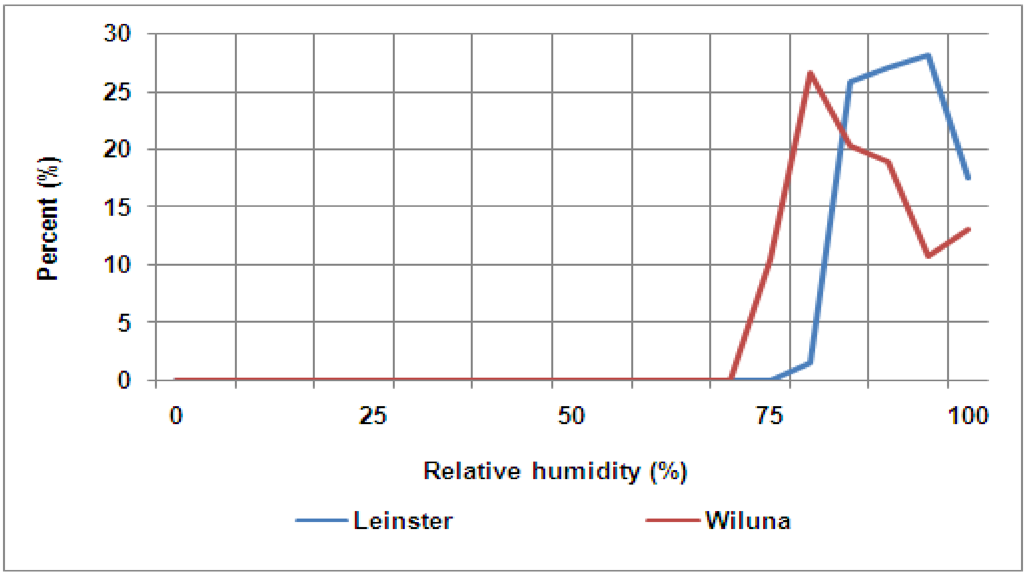


Figure C28 **Type 4 regional weather condition distribution of temperature and relative humidity**

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

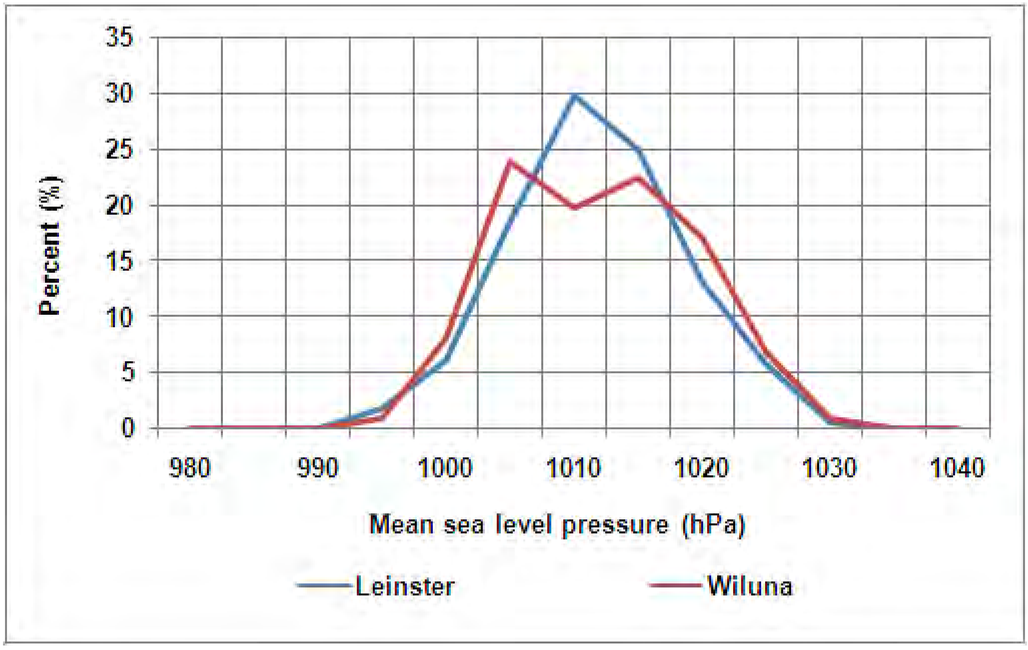
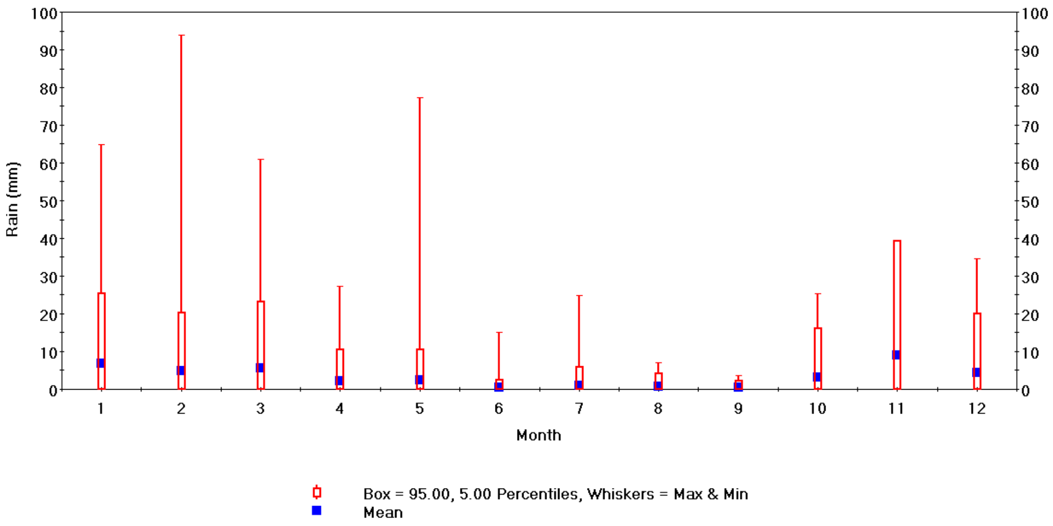
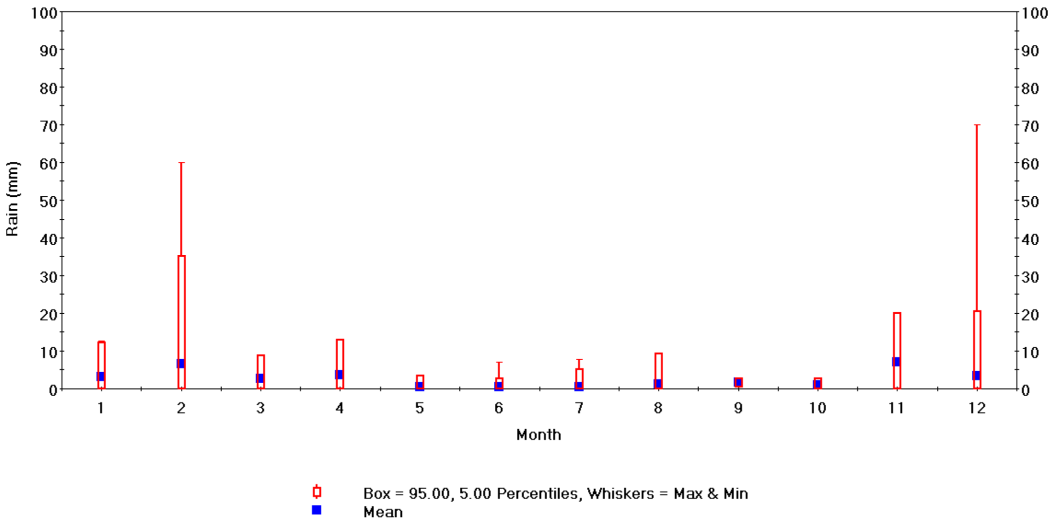


Figure C29 Type 4 regional weather condition distribution of average sea level pressure

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal
Type: Probability density function	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



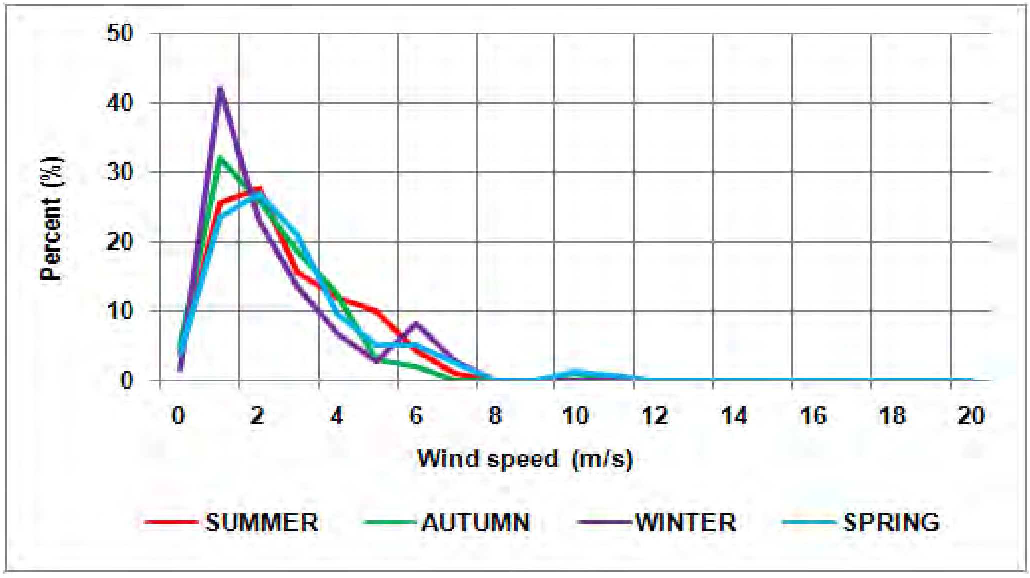
a)



b)

Figure C30 Type 4 regional weather condition monthly rainfall for (a) Leinster and (b) Wiluna

Location: Murchision region Western Australia	**Period:** Leinster 1994-2009 Wiluna 2006-2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Box and whisker	**Data frequency:** Leinster 1 hour Wiluna 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



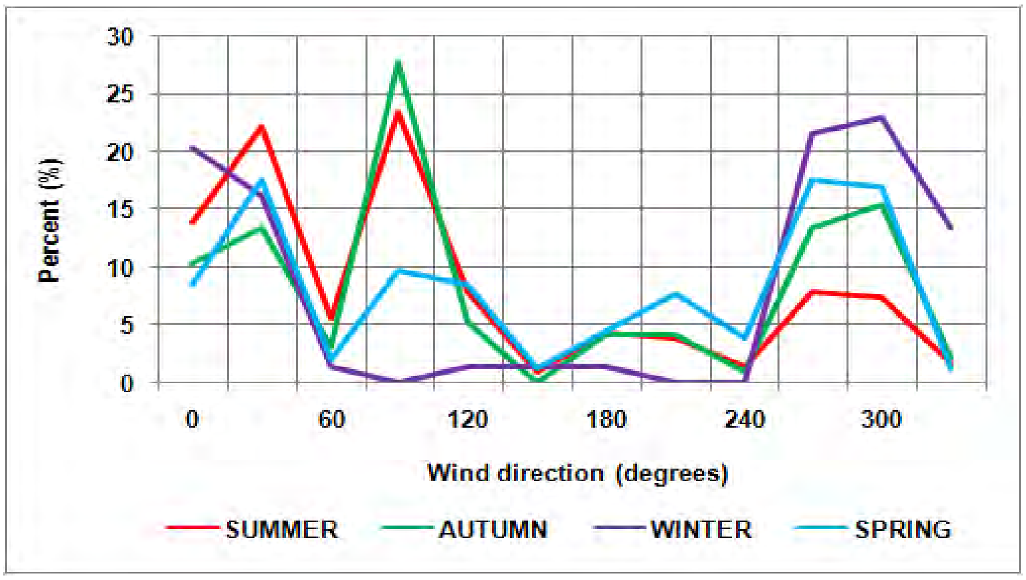
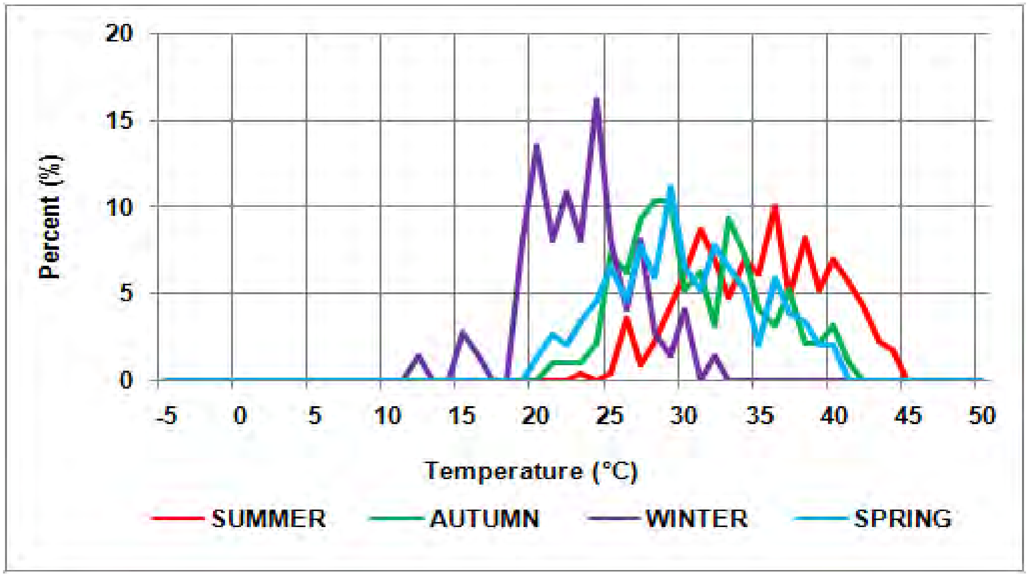


Figure C31 Type 1 local weather condition distribution of wind speed and direction

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



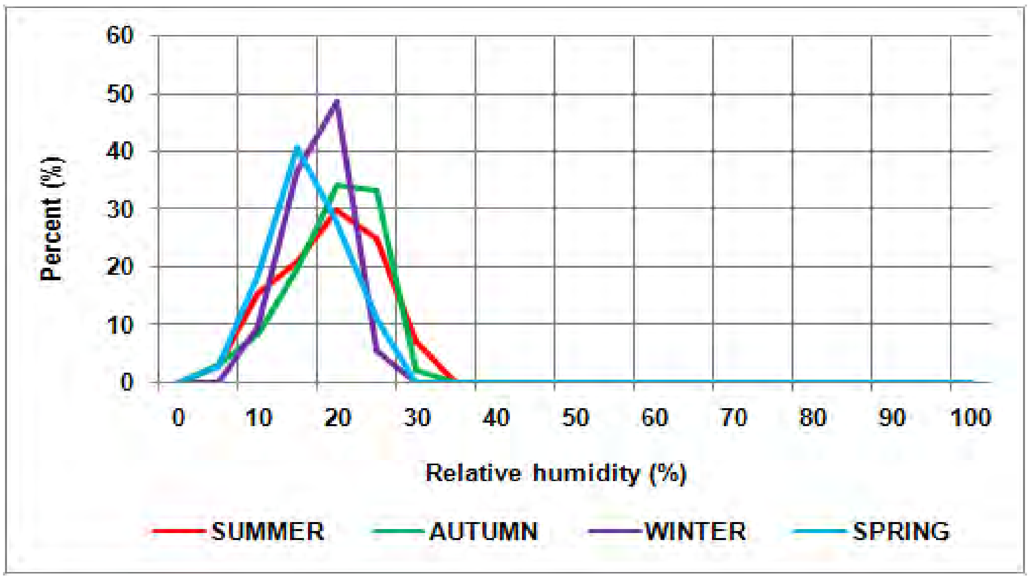
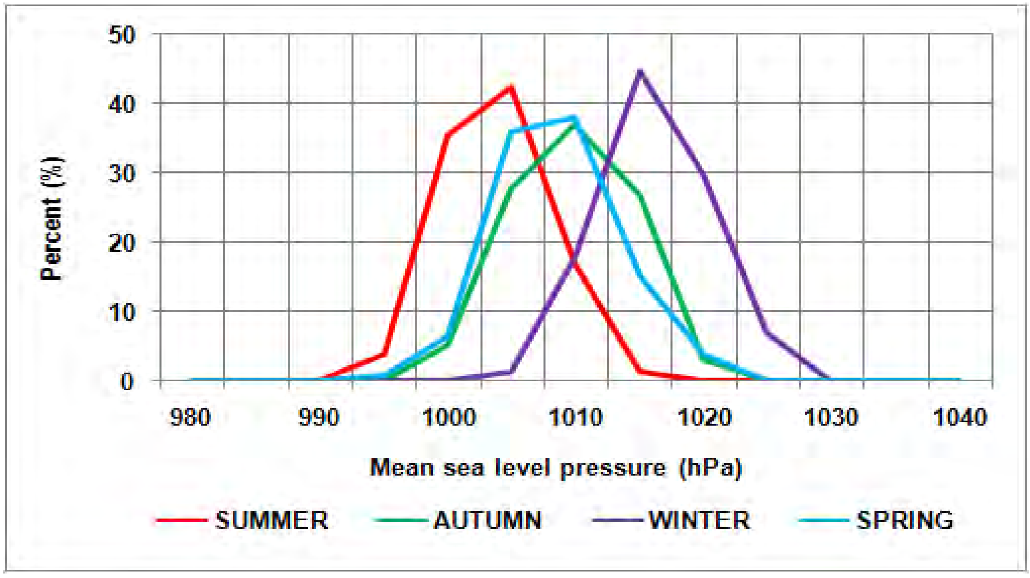


Figure C32 **Type 1 local weather condition distribution of temperature and relative humidity**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



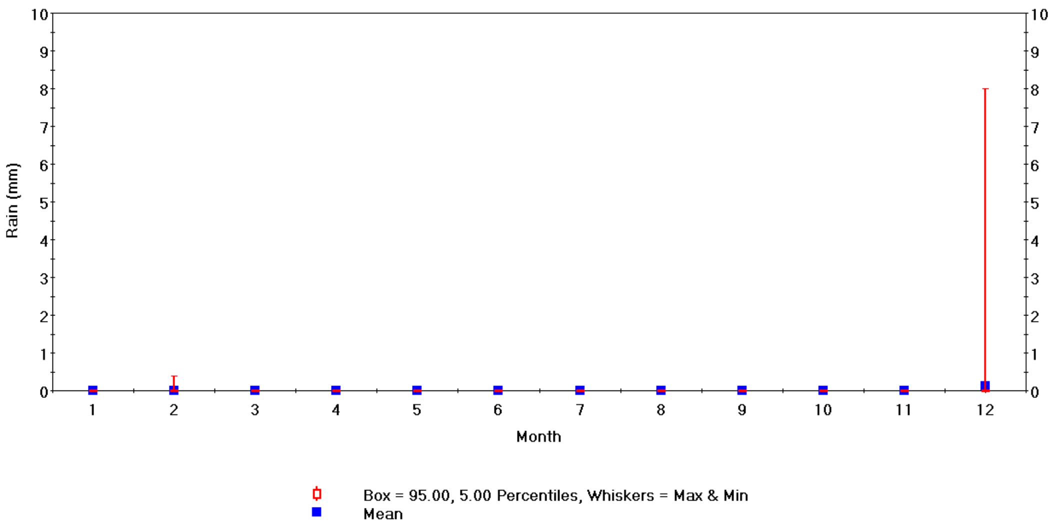


Figure C33 **Type 1 local weather condition distribution of average sea level pressure and monthly rainfall**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal and millimetre
Type: Probability density function and box and whisker	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

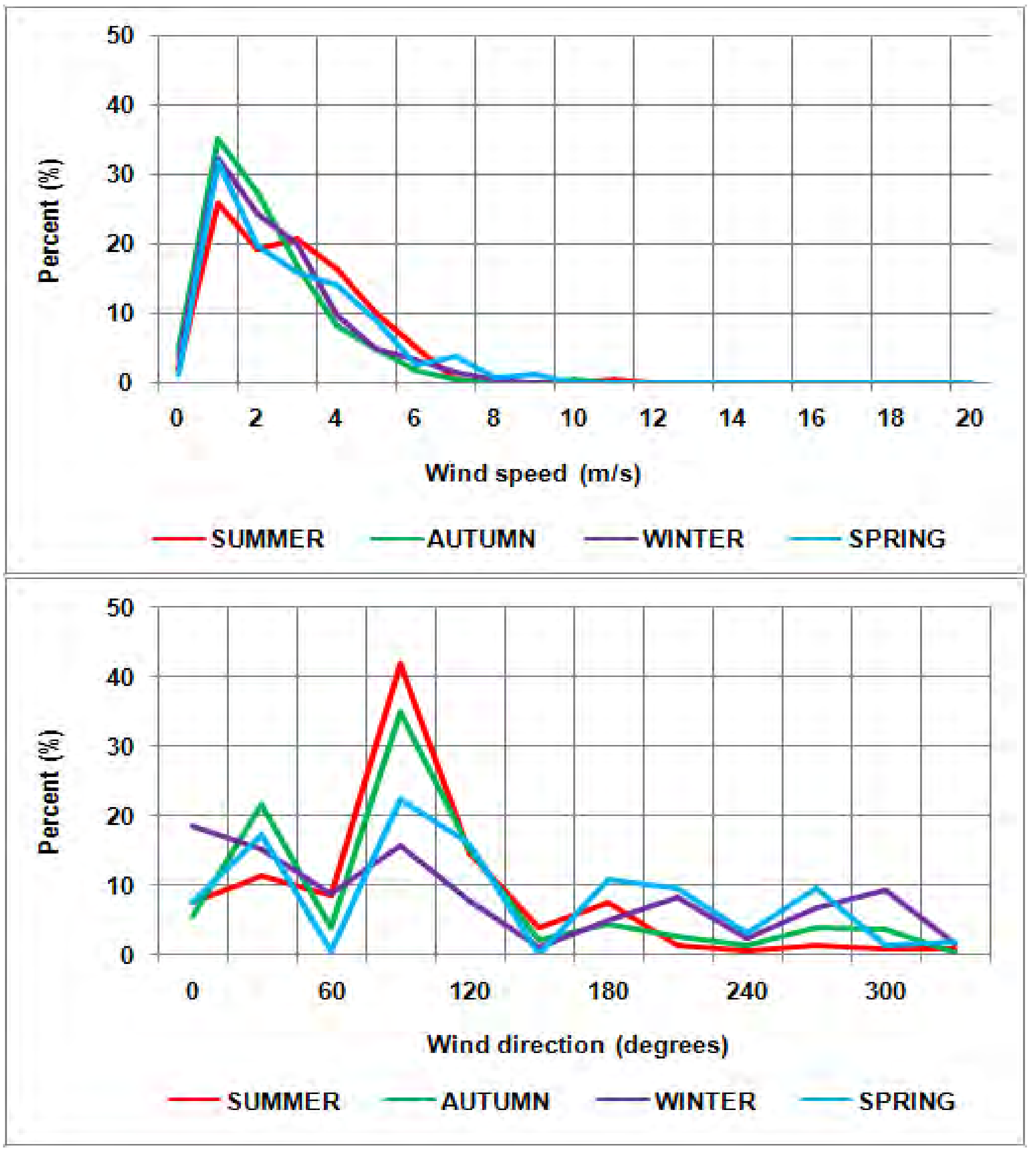
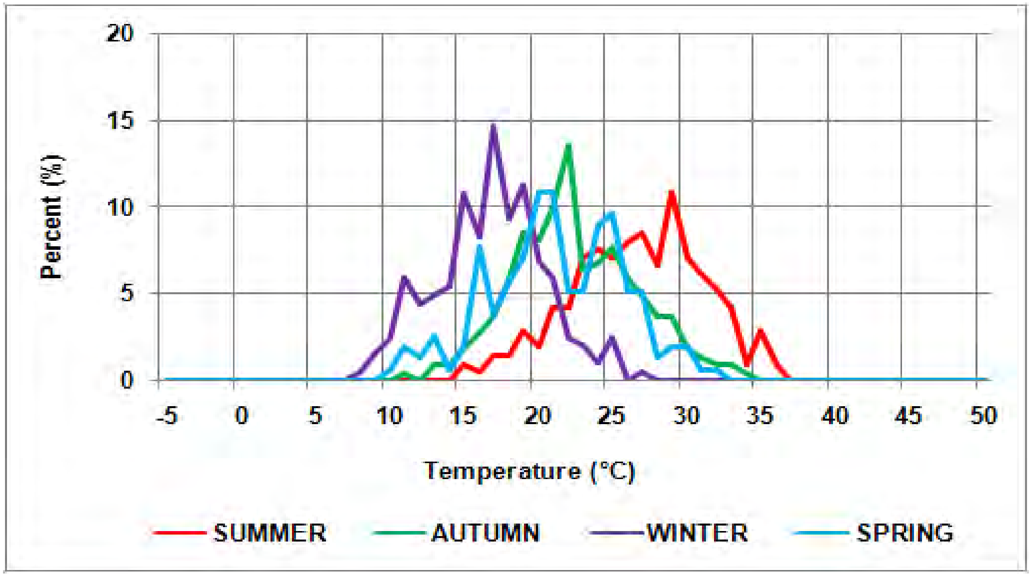


Figure C34 Type 2 local weather condition distribution of wind speed and direction

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



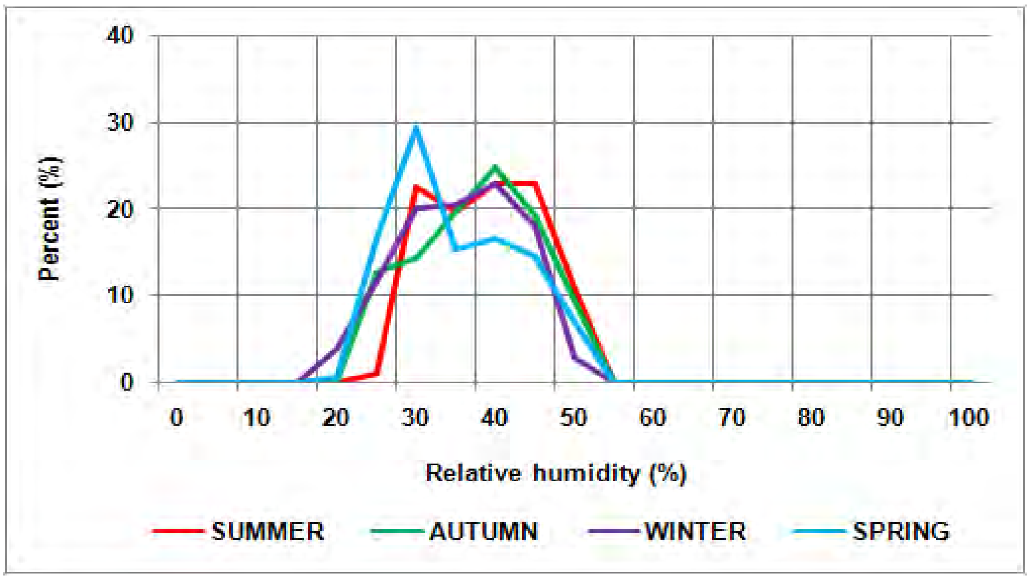
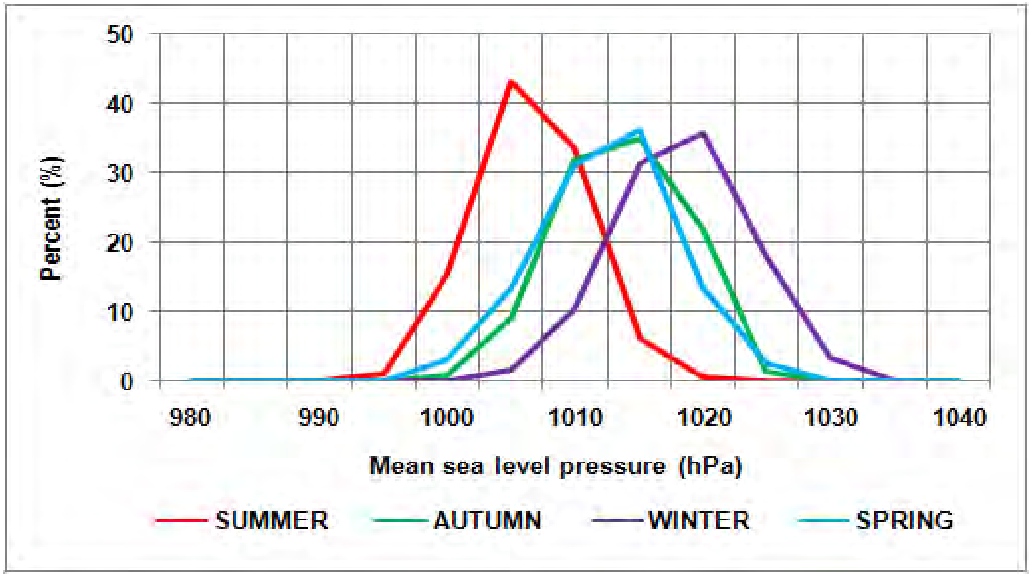


Figure C35 **Type 2 local weather condition distribution of temperature and relative humidity**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



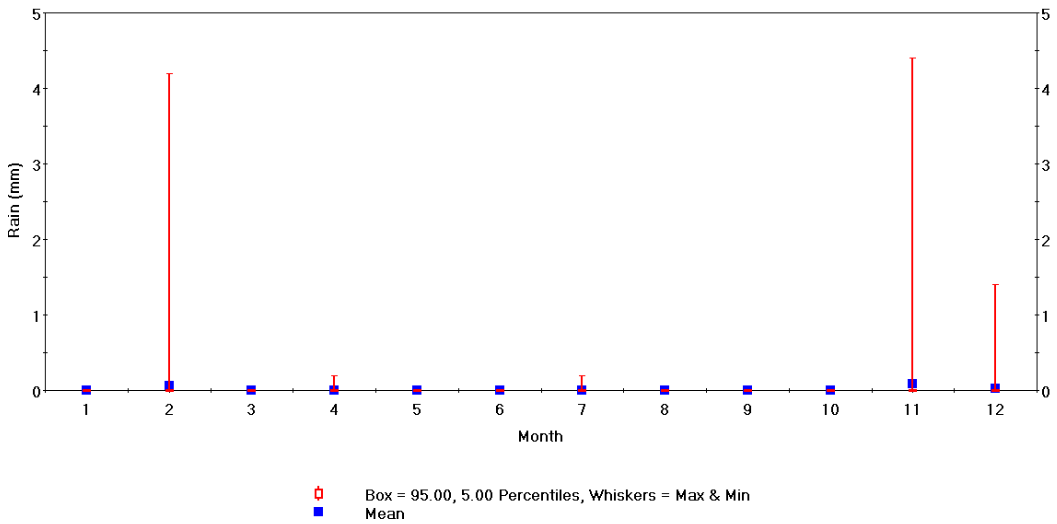


Figure C36 **Type 2 local weather condition distribution of average sea level pressure and monthly rainfall**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal and millimetre
Type: Probability density function and box and whisker	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

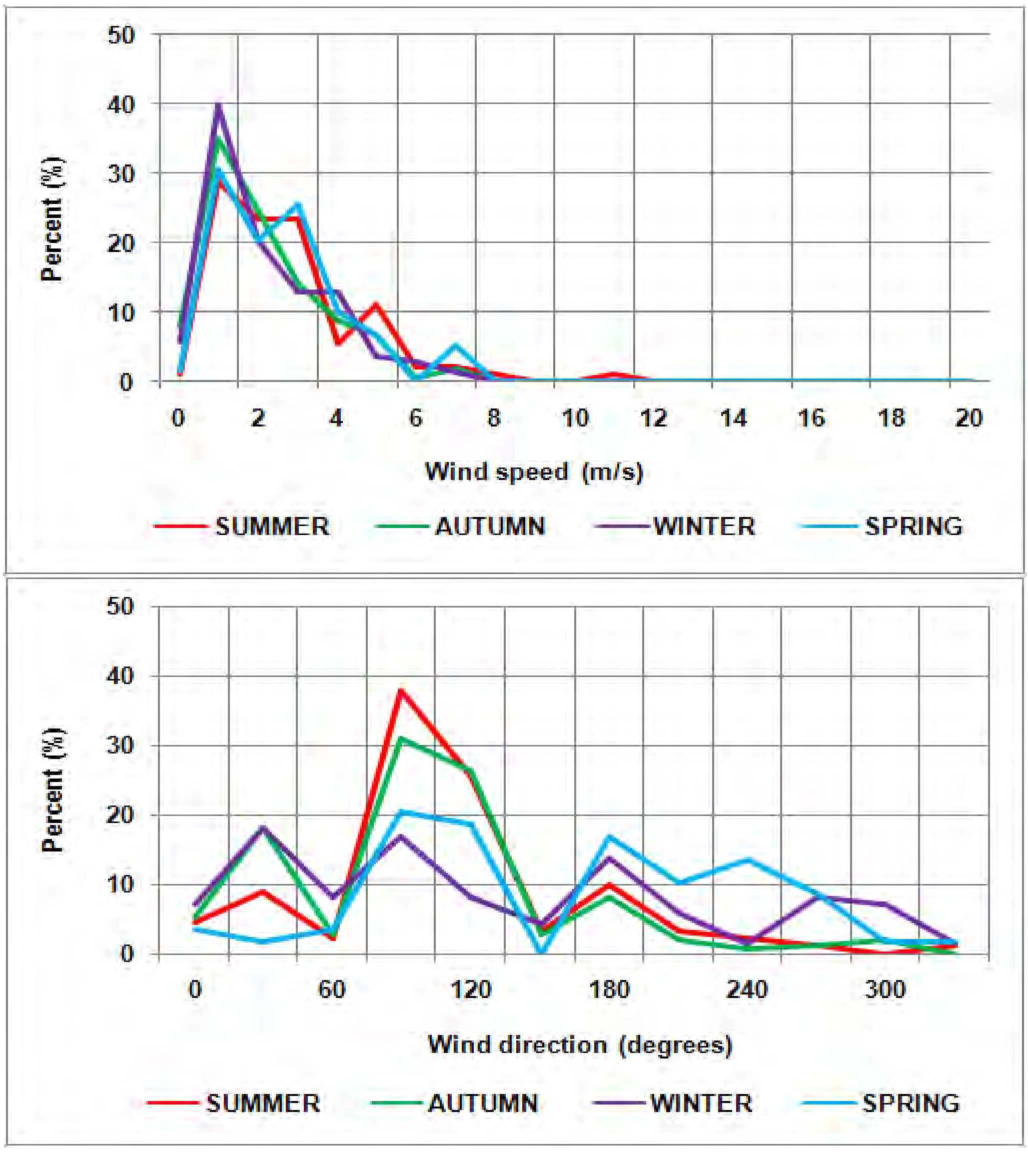
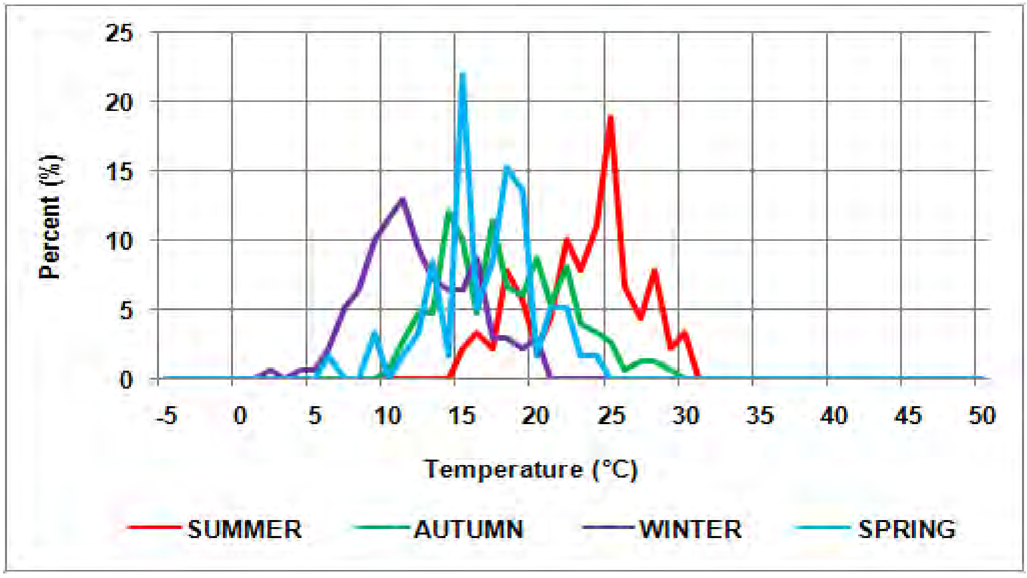


Figure C37 Type 3 local weather condition distribution of wind speed and direction

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** m/s and degrees
Type: Probability density function	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



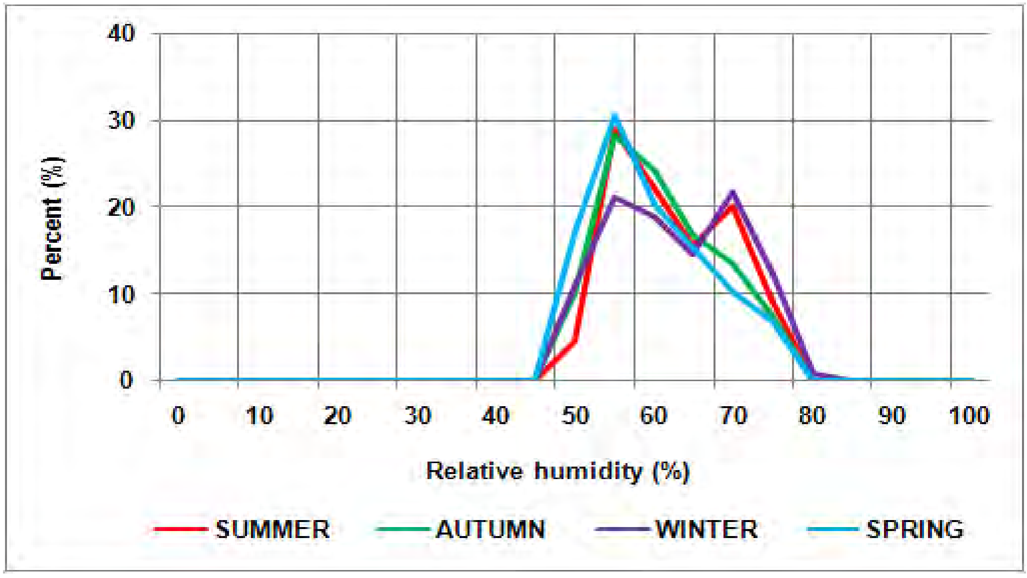
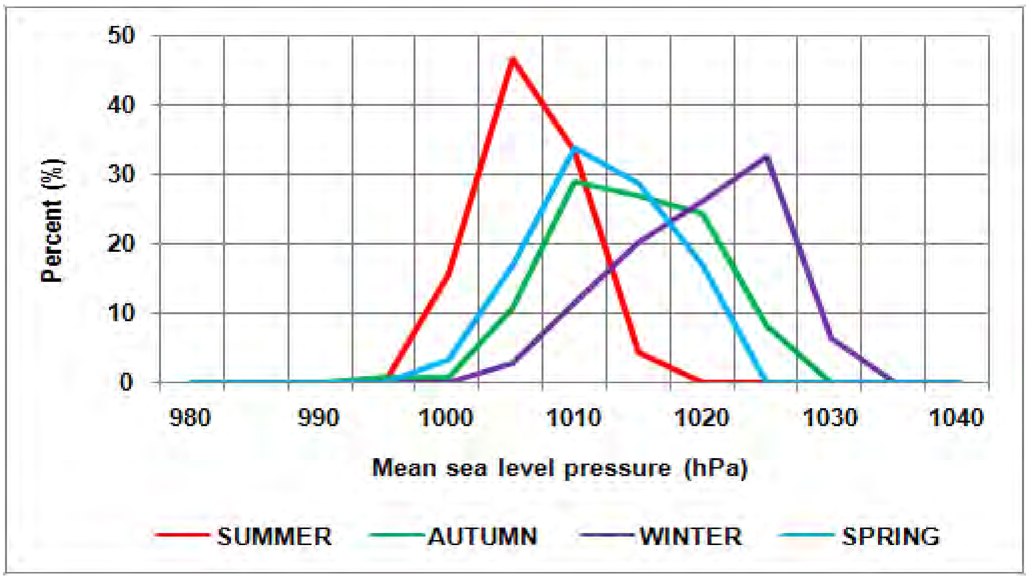


Figure C38 **Type 3 local weather condition distribution of temperature and relative humidity**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



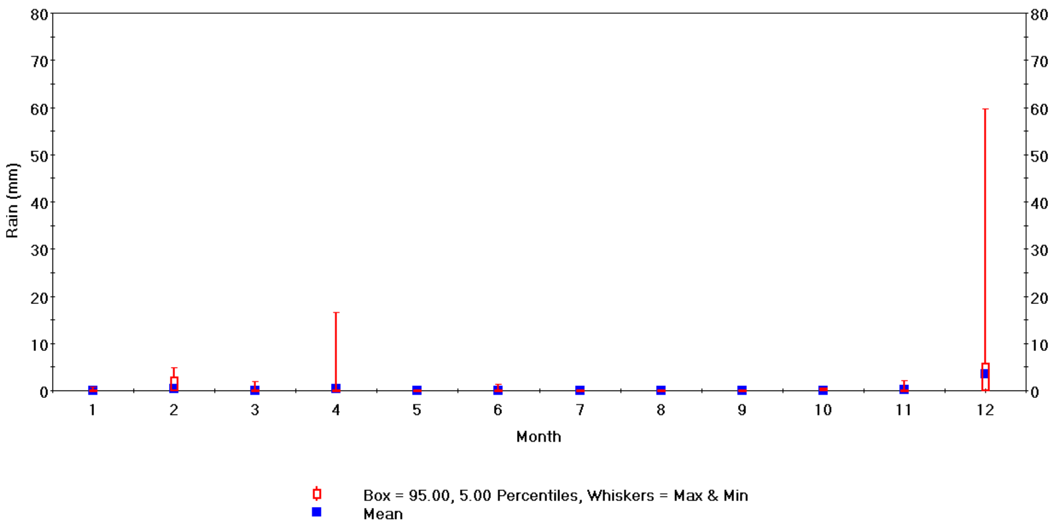


Figure C39 **Type 3 local weather condition distribution of average sea level pressure and monthly rainfall**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal and millimetre
Type: Probability density function and box and whisker	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010

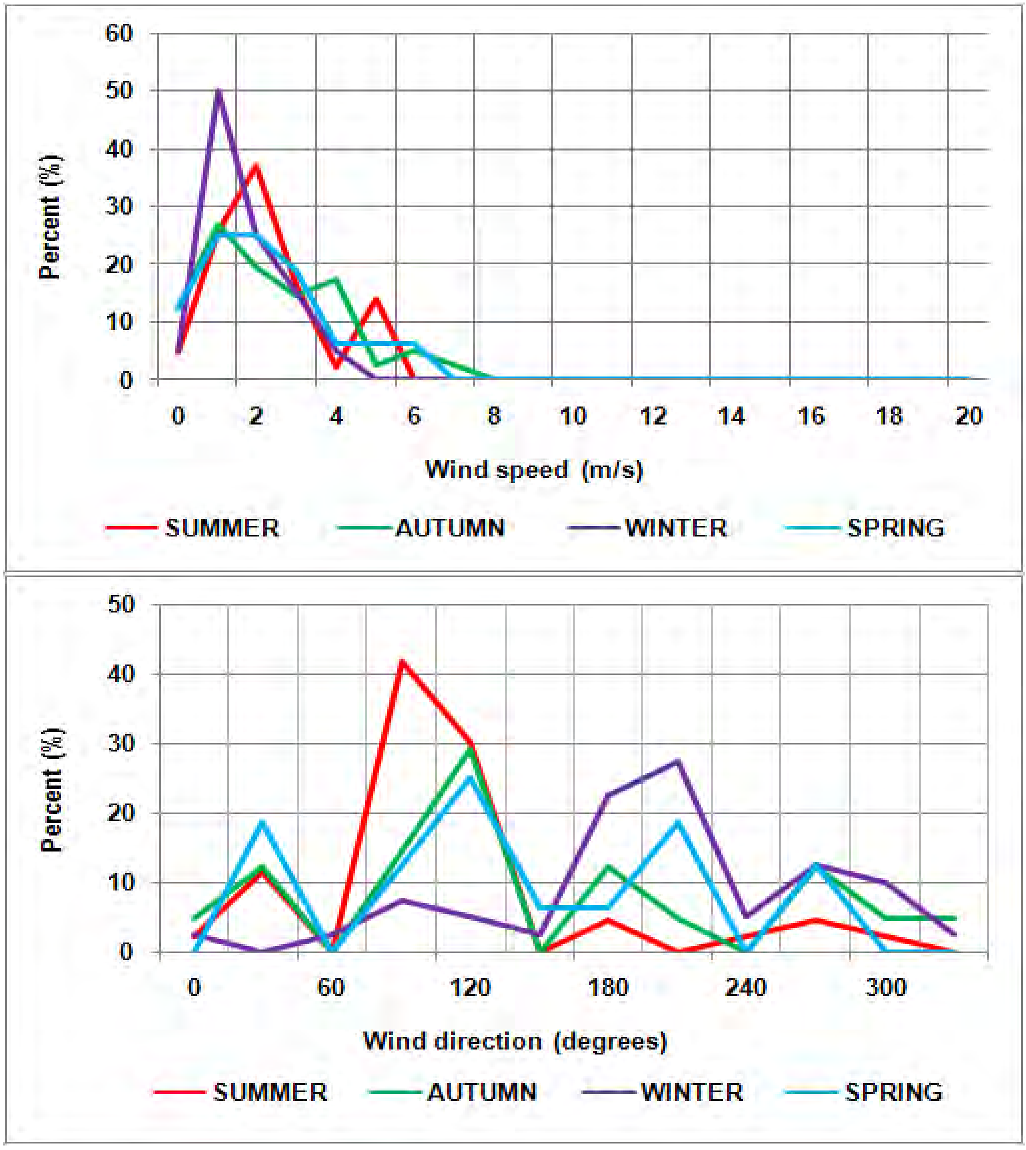
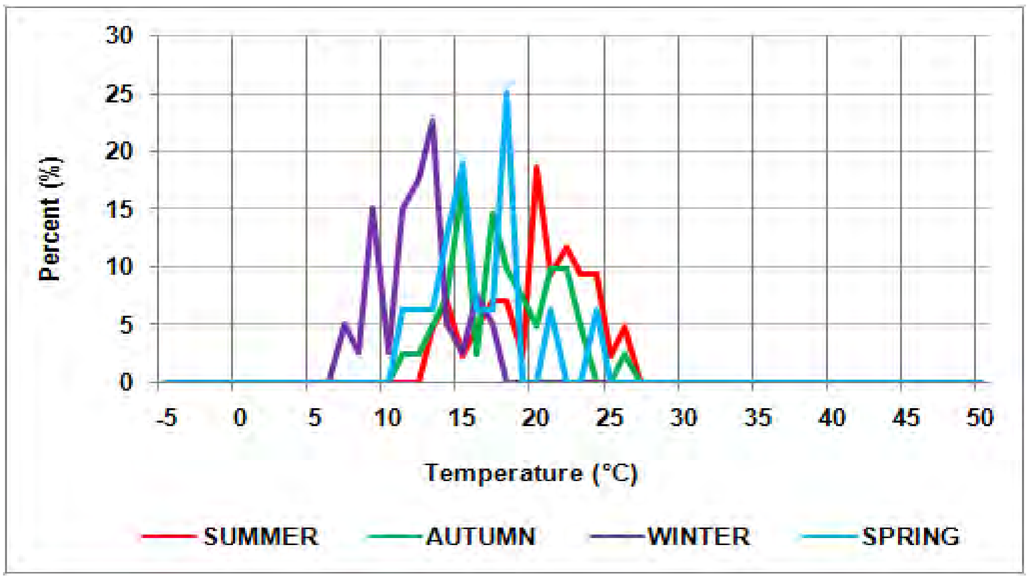


Figure C40 **Type 4 local weather condition distribution of wind speed and direction**

Location:	**Period:**	**Data source:**	**Units:**
Yeelirrie Western Australia	2006 - 2009	Bureau of Meteorology	m/s and degrees
Type:	**Data frequency:**	**Prepared by:**	**Date:**
Probability density function	6 am, 9 am and 3 pm	Andrew Wiebe	July 2010



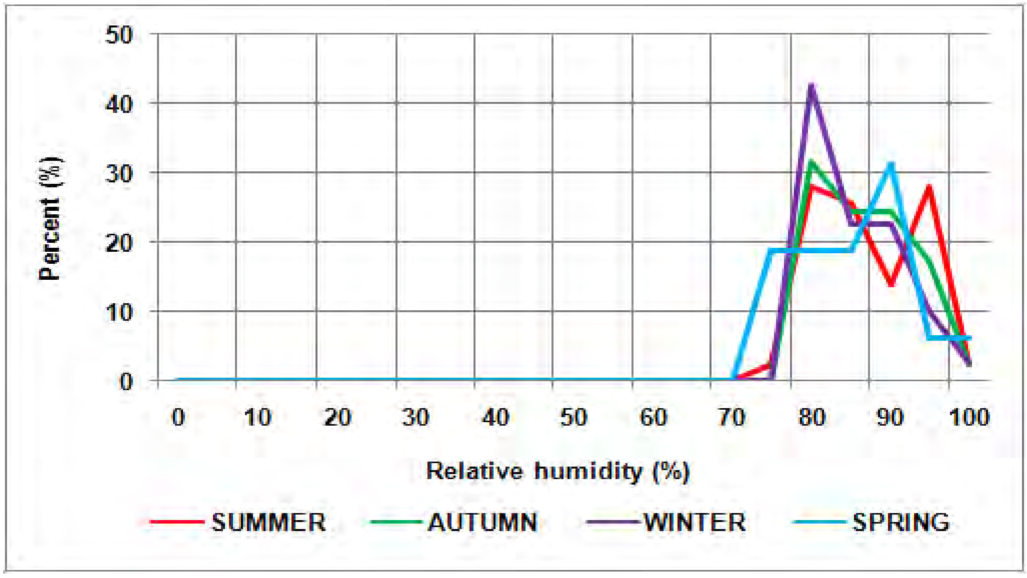
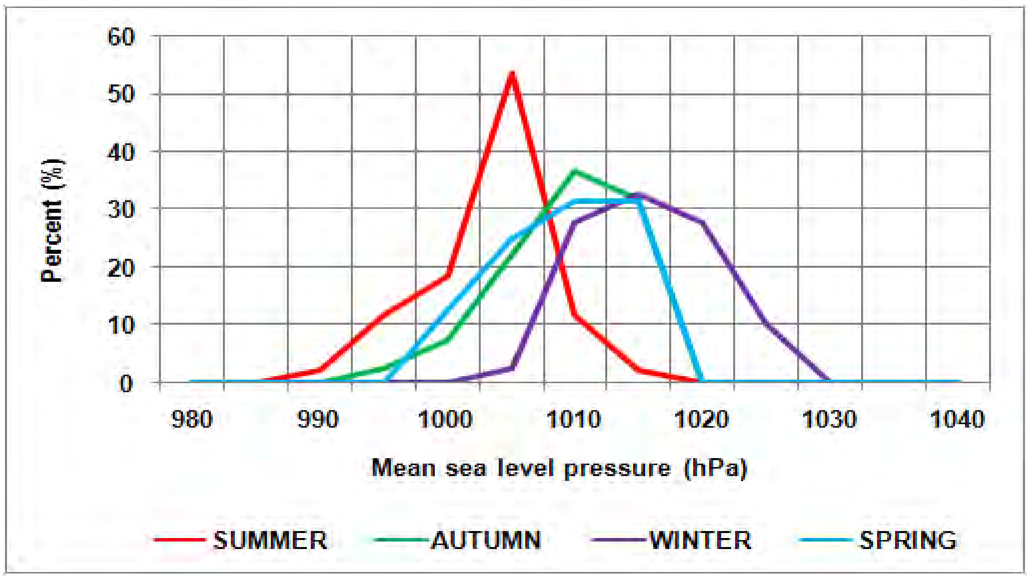


Figure C41	**Type 4 local weather condition distribution of temperature and relative humidity**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** Degrees Celsius and Percent
Type: Probability density function	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010



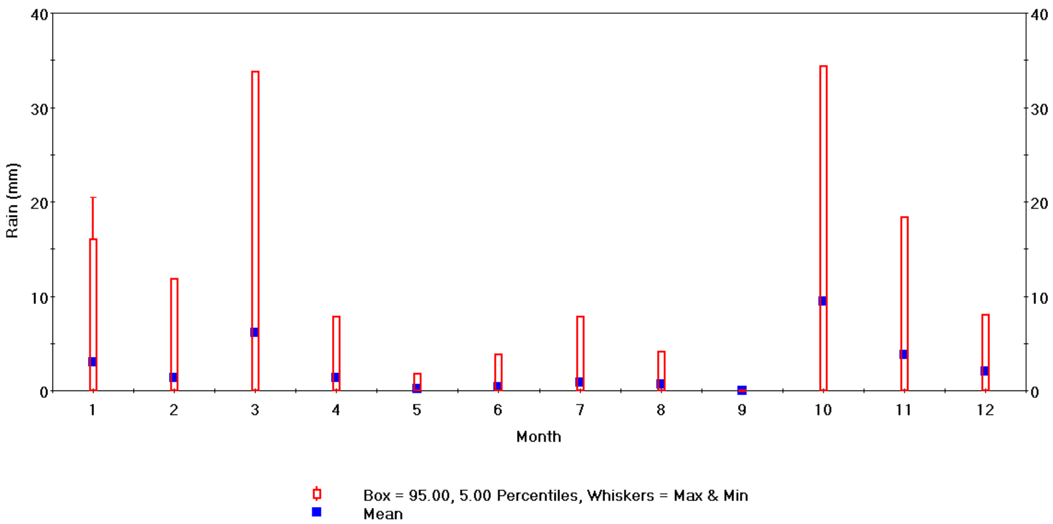


Figure C42 **Type 4 local weather condition distribution of average sea level pressure and monthly rainfall**

Location: Yeelirrie Western Australia	**Period:** 2006 - 2009	**Data source:** Bureau of Meteorology	**Units:** hectoPascal and millimetre
Type: Probability density function and box and whisker	**Data frequency:** 6 am, 9 am and 3 pm	**Prepared by:** Andrew Wiebe	**Date:** July 2010