TOTAL E&P PNG LIMITED

PAPUA LNG

Upstream Environmental Impact Statement

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Part 19
Upstream Air Quality Baseline Report

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global environmental solutions

Papua LNG Project

Upstream Air Quality Baseline Report

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Papua LNG Project

Upstream Air Quality Baseline Report

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EXECUTIVE SUMMARY

Joint venture partners are currently planning the development of the Elk-Antelope gas field, which is located within Petroleum Retention License 15 (PRL-15) in the Gulf Province, Papua New Guinea. Total E&P PNG Limited (hereafter referred to as TEP PNG), a wholly owned subsidiary of TOTAL, has the largest interest in the Elk-Antelope gas field and is the operator of the Papua LNG Project (the Project) on behalf of the other joint venture partners.

The Project will comprise upstream production well development and associated infrastructure at the gas field within PRL-15, construction of an upstream central processing facility (CPF) and delivery of gas and condensate via onshore and offshore export pipelines to a Liquefied Natural Gas (LNG) Plant at Caution Bay, Central Province, 20 km northwest of Port Moresby.

This report characterizes the baseline air environment in the upstream Project area. The objectives of this air quality baseline study are as follows:

- Identify/summarize the key values of the air quality environment in the study area.
- Define the study area for the air quality baseline characterization that would also support an impact assessment.
- Identify existing potentially sensitive receptors within the study area, such as local villages and ecosystems.
- Characterize the meteorological patterns in the study area with the potential to impact on the generation and dispersion of air emissions from the Project.
- Characterize the existing ambient air quality to enable an estimation of background concentrations of relevant air pollutants (i.e. those anticipated to be emitted by the Project) anticipated to be emitted by the Project to allow an assessment of potential cumulative impacts.

The air quality baseline study has included a review of the regulatory framework relevant to characterizing baseline air quality conditions for the Project. While there is a requirement to ensure that the baseline air quality is characterized at an appropriate level of detail, through either qualitative or quantitative assessments, there are no specific requirements relevant to the Project regarding the scope and methodology to be used for the air quality baseline assessment.

The key environmental values relating to air quality have been identified as:

- Health of humans.
- Health of other forms of life, including the protection of ecosystems, crops and biodiversity.
- Amenity and aesthetic enjoyment.
- Visibility.
- The useful life and aesthetic appearance of buildings, structures, property and materials.

Potential risks to the above environmental values will be assessed in the Project impact assessment which will be documented separately.

A review of available meteorological data has shown that the study area is characterized by high rainfall, high humidity and consistently warm temperatures year round. Average monthly wind speeds are consistently low at around 2 m/s, with a low frequency of stronger winds (up to 11 m/s as a 10-minute average) recorded. Wind speeds are highest during October to January, which is the start of the northwest monsoon season.

EXECUTIVE SUMMARY

A detailed meteorological modeling study has been performed using the WRF (Weather Research and Forecasting Model) and CALMET models to compile site representative 3-dimensional meteorological files (2014 and 2015 calendar years) suitable for use in an atmospheric dispersion model for the CPF site. A review of the resulting dataset and validation against observational data from Wabo has shown that it satisfactorily resolves the complex topographical influences on wind channeling and downslope flows within the study area around the CPF site and will be suitable for use in the atmospheric dispersion modeling study to be performed as part of the air quality impact assessment.

The results of the modeling indicate that during the modeled years (2014 and 2015), the CPF site experienced mainly light to moderate winds (less than 5 m/s), with winds from the northeastern quadrant predominating. Calm wind conditions (wind speeds less than 0.5 m/s) were predicted to occur 4% to 5% of the time. A relatively high frequency of stability class F conditions was predicted at the CPF site, which is associated with very stable night-time conditions (i.e. low winds) and a low level of mechanical mixing (i.e., poorly dispersive conditions). There were no significant differences in the meteorological parameters most relevant to pollutant dispersion (wind speed, wind direction, stability class and mixing height) in the 2014 and 2015 datasets, even though 2015 was associated with a drought period.

Wind patterns and other variables such as temperature and rainfall will vary along the export pipeline corridor due to changes in topography and elevation. Wind data predicted by the modeling at the mid-point along the onshore pipeline corridor indicates that this area experiences more varied wind directions compared to the CPF site and the winds are slightly stronger.

The study area is remote from existing industrial pollution sources, hence the ambient air quality across the entire study area and at sensitive receptor locations can be assumed to be generally good and would be regarded as a ‘non-degraded’ airshed in relation to International Finance Corporation (IFC) assessment requirements. Concentrations of gaseous pollutants would be negligible compared to relevant international guidelines for ambient air quality and baseline monitoring of gaseous pollutant concentrations is not warranted.

Despite some natural (e.g. pollens) and anthropogenic (e.g. cooking fires, generators (if used) and agricultural activities) sources of particulate matter, background levels of particulate matter are also expected to be low, given the high rainfall, low wind speeds and dense vegetation in the area.

During the operational phase, particulate emissions from the CPF would be low, as particulate emissions from gas combustion are minimal. Significant emissions of particulate matter from the Project will therefore be limited to the construction period only. These emissions will be generated at ground level, and would only have potential for very localized impacts in the immediate vicinity of the construction work areas. Given that the risk of fugitive dust emissions from construction activities impacting on particulate levels at sensitive receptor locations is very low, baseline monitoring of particulate concentrations was not performed. Existing concentrations of particulate matter were instead estimated based on information presented in other air quality impact assessments and baseline studies performed for other projects in Papua New Guinea and other remote and undeveloped areas. This approach is consistent with Guidance Note 1 for Performance Standard 1. The background concentrations estimated are shown in **Table E-1** and are below relevant air quality guidelines.

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Table E-1 Estimated Baseline Particulate Concentrations

Pollutant	Averaging Period	Range of Background Particulate Concentrations Expected to Occur in the Study Area ($\mu g/m^3$)	Background Concentration Assumed ($\mu g/m^3$)
TSP	24-hours	10 – 70	50
	Annual	20 – 40	40
PM_{10}	24-hours	5 – 35	25
	Annual	10 – 15	15
$PM_{2.5}$	24-hours	2 – 20	15
	Annual	5 – 8	8

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1 INTRODUCTION

1.1 Project Overview

Joint venture partners are currently planning the development of the Elk-Antelope gas field, which is located within Petroleum Retention License 15 (PRL-15) in the Gulf Province, Papua New Guinea. Total E&P PNG Limited (hereafter referred to as TEP PNG), a wholly owned subsidiary of TOTAL, has the largest interest in the Elk-Antelope gas field and is the operator of the Papua LNG Project (the Project) on behalf of the other joint venture partners.

The Elk-Antelope gas field is a significant gas discovery in Papua New Guinea consisting of a gas reservoir with an estimated several trillion cubic feet of gas reserves located approximately 120 km inland from the township of Kerema, and 360 km northwest of Port Moresby (refer **Figure 1**).

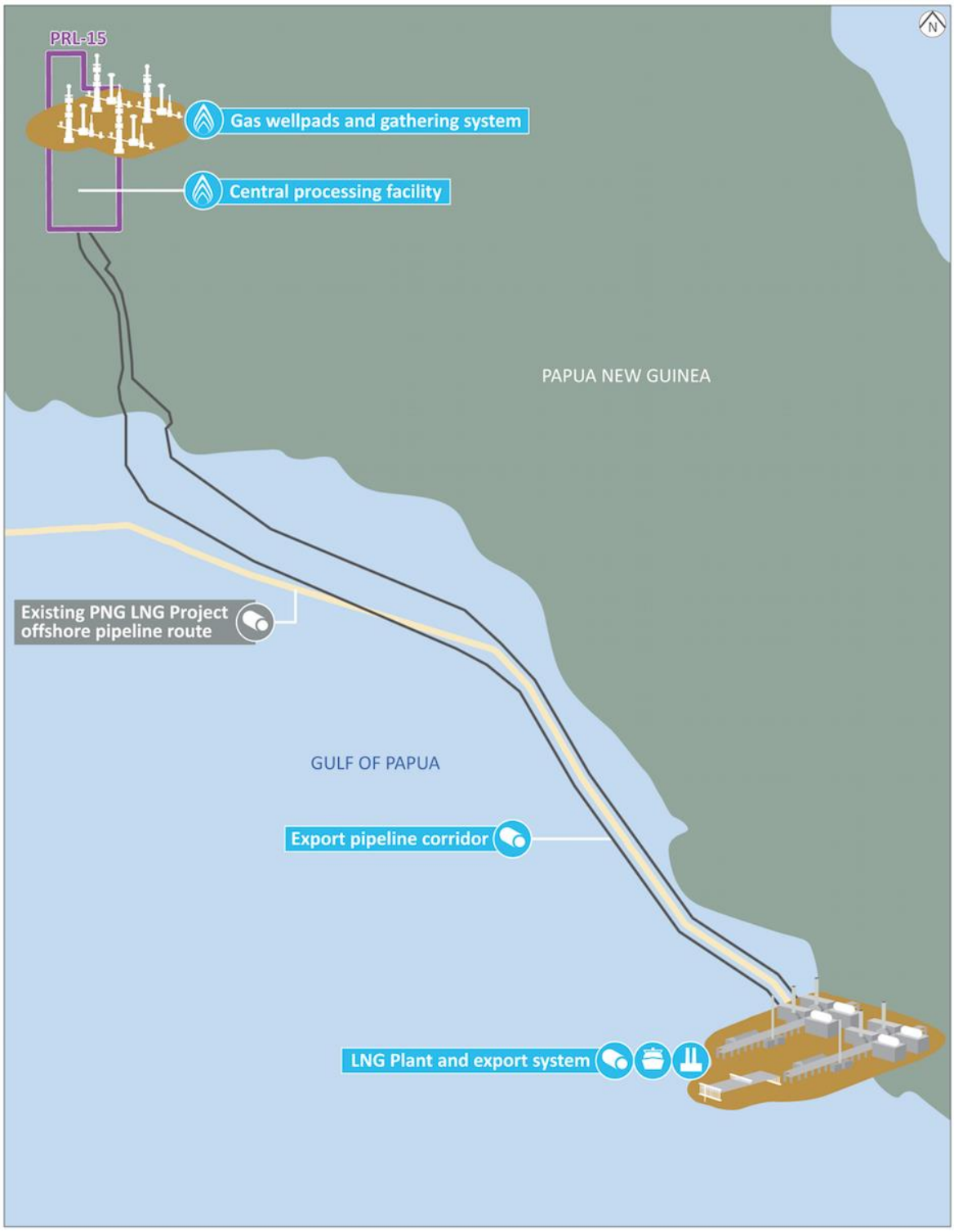
The Project will comprise upstream production well development and associated infrastructure at the gas field within PRL-15, construction of an upstream central processing facility (CPF) and delivery of gas and condensate via onshore and offshore export pipelines to a LNG Plant site at Caution Bay, Central Province, 20 km northwest of Port Moresby. The design life for the Project will be 25 years.

The Project area comprises the physical footprint of the various Project components and associated infrastructure as detailed below.

- Production, processing and related facilities (within PRL-15):
  - Wellpads and the associated gathering system (including flowlines and trunkline);
  - CPF;
  - Logistics base and river offloading facilities, accommodation camps, airstrip, roads and bridges;
  - Quarries, communications infrastructure;
  - Initial section of the onshore export pipeline.
- Onshore pipeline (outside PRL-15):
  - Remainder of the onshore export pipeline to landfall on the Gulf coast including valve stations;
  - Temporary laydown areas and camps;
  - Quarries, communications infrastructure.
- Transport (river) corridors:
  - River transport routes— the Purari, Ivo-Urika and Wame-Varoi rivers.
- Offshore pipeline:
  - Offshore section of the export pipeline to a LNG Plant site, Caution Bay.

This report characterizes the baseline air environment in the upstream Project area.

Figure 1 Project Schematic



1.2 Study Objectives

SLR Consulting Pty Ltd (SLR) has been commissioned by ERIAS Group on behalf of TEP PNG to undertake an air quality baseline study for the upstream Project area.

The objectives of the air quality baseline study are as follows:

- Define the study area for the air quality baseline characterization that would also support an impact assessment.
- Characterize the meteorological patterns in the study area with the potential to impact on the generation and dispersion of air emissions from the Project.
- Characterize the existing ambient air quality to enable an estimation of background concentrations of relevant air pollutants (i.e. those anticipated to be emitted by the Project) to allow an assessment of potential cumulative impacts.
- Identify existing potentially sensitive receptors within the study area, such as local villages and ecosystems.
- Identify/summarize the key values of the air quality environment in the study area.

The results of the air quality baseline study will provide inputs to the formal air quality assessment required as part of the Papua LNG Environmental Impact Statement (EIS) / Environmental, Social and Health Impact Assessment (ESHIA).

1.3 Environmental Values

This baseline air quality assessment has been prepared to inform the assessment of the Project's potential impacts on biophysical environmental values. A biophysical environmental value is generally defined as a quality or physical characteristic of the environment that is important to ecological health or public amenity.

The key environmental values relating to air quality are those relating to public health and amenity and include:

- Health of humans.
- Health of other forms of life, including the protection of ecosystems, crops and biodiversity.
- Amenity and aesthetic enjoyment.
- Visibility.
- The useful life and aesthetic appearance of buildings, structures, property and materials.

Potential risks to the above environmental values will be assessed in the Project impact assessment which will be documented separately.

2 REGULATORY FRAMEWORK AND STANDARDS

2.1 Papua New Guinean Authorities and Legislation

In February 2014, the Papua New Guinea (PNG) Parliament passed an Act to set up a new Conservation and Environment Protection Authority (CEPA). CEPA has replaced the Department of Environment and Conservation (DEC) as the government agency responsible for administering the *Environment Act 2000*.

The *Environment Act 2000* (Environment Act) is the primary legislation in PNG that regulates the environmental impact of development activities and how adverse effects of such activities should be avoided, remedied or mitigated. The Environment Act caters for the sustainable management of the biological and physical components of the land, air and water resources of the country.

Several guidelines have also been published by the then DEC relevant to the assessment of air emissions from proposed developments, including:

- *Guideline for submission of an application for an environmental permit to discharge waste* (DEC, 2004a).
- *Technical Guideline (Additional Information) Air discharges* (DEC, 2004b)

The *Guideline for submission of an application for an environmental permit to discharge waste* requires that baseline information be provided on the bio-physical environment as follows:

- *geomorphological, topographical and geological characteristics,*
- *natural or induced hazard in the area (e.g. flood, earthquake, volcanic zone, etc.),*
- *climatic regime (e.g. rainfall, temperature, etc.),*
- *air quality and meteorological data set for air dispersion modeling,*
- *seasonal surface water quality and hydrological data,*
- *seasonal ground water quality data and flow regime,*
- *noise levels,*
- *details of other pollution sources available within the locality and the additive effects of their emissions on the baseline environmental quality.*

This report presents information on the climate of the Study Area (**Section 3.2**), the baseline air quality (**Sections 6.1.2**, **6.2.2** and **6.3.2**) and the meteorological dataset to be used in the air dispersion modeling in the impact assessment (**Section 6.1.1**).

The *Technical Guideline (Additional Information) Air Discharges* sets out the information that should be provided as part of an application for an Environment (Waste Discharge) Permit where air emissions may be generated. This includes:

- Details of the source, nature, composition and rate of air emissions.
- Information on emissions control equipment and proposed methods to minimize air discharges (specific information for fabric filters, afterburners and wet scrubbers is requested).
- Maintenance procedures and contingency procedures to avoid air discharges from process failure and shut down.
- Stack emission details.
- Calculated ground level concentrations of pollutants proposed to be discharged to air under normal and maximum operating conditions and start up and shutdown conditions.
- An assessment of the impact of the proposal on the environment.

The above information will be provided in the air quality impact assessment to be prepared for the Project. The *Technical Guideline (Additional Information) Air Discharges* also requires that in assessing the potential impacts on air quality the *'effects of existing on-site discharges and existing loadings from neighboring industries' must be considered*, however no specific requirements regarding the scope or methodology to be applied in defining the baseline air quality are provided.

2.2 International Standards and Guidelines

As PNG does not currently have any statutory air quality standards, a review of relevant air quality criteria and guidelines set by other agencies has been performed in the following sections, including:

- International Finance Corporation (IFC) Performance Standards.
- IFC Environmental, Health and Safety Guidelines.
- World Health Organization (WHO) Air Quality Guidelines.
- European Commission Air Quality Standards.
- United States Environmental Protection Agency (US EPA) standards.
- Australian guidelines.

The objective of this review was to identify:

- Any specific requirements for performing air quality baseline studies that would be applicable to this Project; and
- Relevant ambient air quality criteria to use in the air quality baseline study in the absence of PNG-specific guidelines.

In performing this review it is noted that regulatory authorities manage air quality through a range of mechanisms, including ambient air quality guidelines and source emission limits.

Ambient air quality guidelines or standards relate to the maximum downwind, ground level concentrations that may occur as a result of the emissions and are the maximum concentrations to which the public may be exposed. These criteria are normally based on the results of epidemiological or other health-based studies and are generally designed to protect sensitive populations from adverse health effects, or to prevent damage to sensitive vegetation and crops. When assessing compliance with ambient air quality criteria it is necessary to account for other sources in the area (i.e. the baseline or background air quality) so that the total cumulative impact of all sources is considered.

Source emission limits are maximum allowable emission concentrations or emission rates which relate to in-stack concentrations at the point of discharge. Emission limits are normally specified for particular source types, such as sulfur dioxide (SO_2) emission rates for sulfuric acid plants or in-stack concentrations of oxides of nitrogen (NO_X) for gas-fired combustion sources, and are generally based on the current best available technology for the relevant equipment type. A review of source emission limits, or emission limit values (ELVs), has not been performed as part of the air quality baseline study. Compliance with ELVs will be assessed as part of the air quality impact assessment for the Project.

2.2.1 IFC Performance Standard 1: Assessment and Management of Environmental and Social Risks and Impacts

IFC Performance Standard 1 (IFC, 2012a) was developed by the IFC to establish the importance of integrated assessment to identify the environmental and social impacts, risks, and opportunities of projects. In reference to baseline studies, Performance Standard 1 states that the identification of risks and impacts is to be based on recent environmental and social baseline data '*at an appropriate level of detail'*.

In addition, when assessing the potential environmental impacts from a project, the cumulative impacts that may result from the incremental impact of the project in addition to other '*existing, planned or reasonably defined developments*' at the time the assessment is conducted are to be considered.

In Guidance Note 1 (IFC, 2012b) for Performance Standard 1 it is noted that '*reference to secondary information on the project's area of influence is acceptable, but it may still be necessary to gather primary information from field surveys to establish baselines appropriate to the proposed project's potential impacts and risks. Relevant data may be available from various host governmental agencies, nongovernmental organizations and academic studies*'.

2.2.2 IFC Performance Standard 3: Resource Efficiency and Pollution Prevention

IFC Performance Standard 3 (IFC, 2012c) outlines a project-level approach to resource efficiency and pollution prevention and control in line with internationally disseminated technologies and practices. This Performance Standard promotes the ability of private sector companies to adopt such technologies and practices as far as their use is feasible in the context of a project that relies on commercially available skills and resources. Technical feasibility is based on whether the proposed measures and actions can be implemented with commercially available skills, equipment, and materials, taking into consideration prevailing local factors such as climate, geography, infrastructure, security, governance, capacity and operational reliability.

In regard to the consideration and assessment of baseline conditions, IFC Performance Standard 3 states:

> *To address potential adverse project impacts on existing ambient conditions, the client will consider relevant factors, including, for example:*
>
> *(i) existing ambient conditions;*
>
> *(ii) the finite assimilative capacity of the environment (i.e., the capacity of the environment for absorbing an incremental load of pollutants while remaining below a threshold of unacceptable risk to human health and the environment);*
>
> *(iii) existing and future land use;*
>
> *(iv) the project's proximity to areas of importance to biodiversity; and*
>
> *(v) the potential for cumulative impacts with uncertain and/or irreversible consequences.*
>
> *In addition to applying resource efficiency and pollution control measures as required in this Performance Standard, when the project has the potential to constitute a significant source of emissions in an already degraded area, the client will consider additional strategies and adopt measures that avoid or reduce negative effects. These strategies include, but are not limited to, evaluation of project location alternatives and emissions offsets.*

Guidance Note 3 (IFC, 2012d) for Performance Standard 3 states that when developing a new project '*Considerations should include background ambient conditions (that may occur due to natural and/or anthropogenic causes not related to the project), the presence of local communities, environmentally sensitive receptors (such as potable water supplies or protected areas), the expected project demand for water, and the availability of waste disposal facilities*. *Potential for cumulative impacts should also be reviewed'.*

2.2.3 IFC General EHS Guidelines: Environmental – Air Emissions and Ambient Air Quality

The International Finance Corporation (IFC) *Environmental, Health and Safety Guidelines: Environmental – Air Emissions and Ambient Air Quality* (IFC, 2007a) provides an approach to the management of significant sources of air emissions, including specific guidance for assessment and monitoring of impacts. This guideline states that:

> *'Where possible, facilities and projects should avoid, minimize, and control adverse impacts to human health, safety, and the environment from emissions to air. Where this is not possible, the generation and release of emissions of any type should be managed through a combination of:*
>
> - *Energy use efficiency*
> - *Process modification*
> - *Selection of fuels or other materials, the processing of which may result in less polluting emissions*
> - *Application of emissions control techniques.'*

Projects with significant sources of air emissions, and potential for significant impacts to ambient air quality, should prevent or minimize impacts by ensuring that:

- Emissions do not result in pollutant concentrations that reach or exceed relevant ambient quality guidelines and standards by applying national legislated standards or, in their absence, the current WHO Air Quality Guidelines (refer **Section 2.2.5**), or other internationally recognized sources.
- Emissions do not contribute a significant portion to the attainment of relevant ambient air quality guidelines or standards (as a general rule, the guideline suggests 25% of the applicable air quality standards to allow additional, future sustainable development in the same airshed).

The IFC general air quality guidelines require that impacts on air quality of a proposed development be estimated through qualitative or quantitative assessments by the use of baseline air quality assessments and atmospheric dispersion models to assess potential ground level concentrations. Local atmospheric, climatic, and air quality data should be applied when modeling plume dispersion, taking into account atmospheric downwash, wakes, or eddy effects of the source, nearby structures and terrain features. The dispersion model applied should be internationally recognized, or comparable.

In relation to baseline air quality studies, the IFC general air quality guidelines state that '*before a project is developed, baseline air quality monitoring at and in the vicinity of the site should be undertaken to assess background levels of key pollutants, in order to differentiate between existing ambient conditions and project-related impacts*'. No other overarching or specific requirements are provided in regards to the methodology or scope of baseline monitoring programs.

2.2.4 IFC Environmental, Health and Safety Guidelines for Onshore Oil and Gas Development

The IFC industry sector environmental, health and safety (EHS) guideline document for onshore oil and gas development (IFC 2007b) designed to be used together with the General EHS Guidelines document and provides general and industry-specific examples of Good International Industry Practice (GIIP). This document applies to exploration and production drilling; development and production activities; transportation activities including pipelines; other facilities including pump stations, metering stations, pigging stations, compressor stations and storage facilities; ancillary and support operations; and decommissioning.

The EHS guideline document for onshore oil and gas development notes that principal air emission sources from onshore oil and gas developments include:

- Combustion sources associated with power and heat generation, and the use of compressors, pumps, and reciprocating engines (boilers, turbines, and other engines);
- Emissions resulting from flaring and venting of hydrocarbons; and
- Fugitive emissions.

Principal pollutants from these sources are identified as:

- Oxides of nitrogen (NO_X).
- Sulfur oxides (SO_X).
- Carbon monoxide (CO).
- Particulates.

Additional pollutants can include:

- Hydrogen sulfide (H_2S).
- Volatile organic compounds (VOCs) such as benzene, ethylbenzene, toluene, and xylenes (BTEX), methane and ethane.
- Glycols.
- Polycyclic aromatic hydrocarbons (PAHs).

The EHS guideline document for onshore oil and gas development provides guidance on recommended air emissions mitigation strategies for combustion units, venting and flaring operations, fugitive emissions and well testing operations. It states that air quality impacts should be estimated by the use of baseline air quality assessments and atmospheric dispersion models to establish potential ground level ambient air concentrations during facility design and operations planning, however no specific requirements are provided in regards to the methodology or scope of the baseline assessment.

2.2.5 World Health Organization Air Quality Guidelines

The first edition of the WHO air quality guidelines was issued in 1987 and was intended for European countries. By 2000, research concerning health effects of air pollution had significantly advanced to enable the WHO to update its guideline resulting in the publication of *Air Quality Guidelines for Europe, Second Edition* (WHO, 2000). In this edition the guidelines were no longer presented as European-specific, but applied to all countries.

In 2005, WHO issued the *Air Quality Guideline - Global Update – Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide* (WHO, 2005) which updated their recommended ambient air quality guidelines for PM_{10} (particulate matter less than 10 microns in aerodynamic diameter), $PM_{2.5}$ (particulate matter less than 2.5 microns in aerodynamic diameter), nitrogen dioxide (NO_2) and SO_2 based on current research. Interim targets were also provided by the WHO in recognition of the need for a staged approach to achieving the new recommended guidelines. The updated guidelines and interim targets are presented in **Table 1**. The CO and H_2S guidelines shown in **Table 1** are from the WHO Air Quality Guidelines for Europe, 2nd Edition, 2000.

Table 1 Relevant WHO Air Quality Guidelines

Pollutant	Averaging Time	Interim Target 1	Interim Target 2	Interim Target 3	Guideline Value	Source
		(µg/Nm^3)	(µg/Nm^3)	(µg/Nm^3)	(µg/Nm^3)	
Carbon monoxide (CO)	15-Minutes	-	-	-	100,000	WHO, 2000
	30-Minutes	-	-	-	60,000	WHO, 2000
	1-Hour	-	-	-	30,000	WHO, 2000
	8-Hours	-	-	-	10,000	WHO, 2000
Hydrogen sulfide (H_2S)	30-Minutes	-	-	-	7	WHO, 2000
	24-hours	-	-	-	150	WHO, 2000
Nitrogen dioxide (NO_2)	1-Hour	-	-	-	200	WHO, 2005
	Annual	-	-	-	40	WHO, 2005
PM_{10}	24-Hours	150	100	75	50	WHO, 2005
	Annual	70	50	30	20	WHO, 2005
$PM_{2.5}$	24-Hours	75	50	37.5	25	WHO, 2005
	Annual	35	25	15	10	WHO, 2005
Sulfur dioxide (SO_2)	10-minutes	-	-	-	500	WHO, 2005
	24-Hours	125	50	-	20	WHO, 2005

2.2.6 European Commission Air Quality Limit Values

The European Union has established health based standards and objectives for a number of pollutants in air. Directive 2008/50/EC of the European Parliament and of the Council adopted on 21 May 2008 (EC, 2008), merged four prior directives and one Council decision into a single directive on air quality that sets out ambient air quality limit values for Europe. Those air quality limit values relevant to the Project are summarized in **Table 2**.

Table 2 Relevant European Commission Ambient Air Quality Limit Values

Pollutant	Averaging Period	Air Quality Limit Values (µg/m^3)	Permitted Exceedances Each Year
Carbon monoxide (CO)	8-Hours	10,000	none
Nitrogen dioxide (NO_2)	1 hour	200	18
	Annual	40	-
PM_{10}	24-Hours	50	35
	Annual	40	-
$PM_{2.5}$	Annual	25	-
Sulfur dioxide (SO_2)	1-Hour	350	24
	24-Hours	125	3 days per year

Source: EC, 2017

2.2.7 US Environmental Protection Agency National Ambient Air Quality Standards

The USEPA Office of Air Quality Planning and Standards (OAQPS) have set National Ambient Air Quality Standards for seven criteria pollutants: PM_{10}, $PM_{2.5}$, ground level ozone (O_3), CO, SO_2, NO_2 and lead (Pb) (USEPA, 2017a). These standards are applicable throughout the USA, and while individual states may have stronger air pollution laws or regulate additional pollutants, they cannot have less stringent pollution limits than those set by the USEPA. USEPA standards are often referred to in the absence of local guidelines as they are designed to apply for a variety of populations and industry types through a well-regulated process of formulation and review.

The current USEPA primary and secondary standards relevant to the Project are presented in **Table 3**. The primary standards are set to protect public health, including the health of 'sensitive' populations such as asthmatics, children, and the elderly. Secondary standards are also set for some pollutants, which were developed to protect public welfare, including protection against decreased visibility, damage to animals, crops, vegetation and buildings. In all cases, the secondary standards are either equal to or higher, i.e. less stringent, than the primary standards shown in **Table 3**.

A guideline value for Total Suspended Particulate (TSP) is no longer published, but since TSP concentrations can be used to assess nuisance effects, it is useful to refer to the USEPA's 1987 guideline values and these are also listed in **Table 3** (USEPA, 2017b). In addition, in June 2010, the USEPA set a new 1-hour average primary standard for SO_2 of 75 ppb and revoked the two existing primary standards of 140 ppb as a 24-hour average, and 30 ppb as an annual average (USEPA, 2012). Only the new 1-hour average standard is presented in **Table 3**.

Table 3 USEPA National Ambient Air Quality Standards

Pollutant	Averaging Time	Primary Standard		Secondary Standard	
		ppb	µg/m^3	ppb	µg/m^3
Carbon monoxide (CO)	8-Hour s [1]	9,000	10,000	-	-
	1-Hour [1]	35,000	40,000	-	-
Lead	3-Month Average	-	0.15	-	0.15
Nitrogen dioxide (NO_2)	Annual	53	100	53	100
	1-Hour [2]	100	190	-	-
Ozone (O_3)	8-Hours [3]	70	137	70	137
PM_{10}	24-Hours [4]	-	150	-	150
$PM_{2.5}$	Annual [5]	-	12	-	15
	24-Hours [6]	-	35	-	35
Sulfur dioxide (SO_2)	1-Hour [7]	75	200	-	-
	3-Hours [8]	-	-	500	1,330
TSP	Annual [9]	-	75	-	60
	24-Hours [9]	-	260	-	150

Source: https://www.epa.gov/criteria-air-pollutants/naaqs-table

1 Not to be exceeded more than once per year
2 3-year average of the 98th percentile of the daily maximum 1-hour average
3 3-year average of the fourth-highest daily maximum 8-hour average
4 Not to be exceeded more than once per year on average over 3 years
5 Annual mean, averaged over 3 years.
6 3-year average of the 98th percentile of 24-hour concentrations
7 3-year average of the 99th percentile of the daily maximum 1-hour average
8 Not to be exceeded more than once per year
9 Replaced by PM_{10} standards in 1987 – included here to assess nuisance effects

2.2.8 Australian Regulatory Requirements for Deposited Dust

Dust deposition guidelines are relatively uncommon and are not available for any of the jurisdictions reviewed above. New South Wales (Australia) provides the following guidelines for the potential nuisance impacts from dust deposition (NSW OEH, 2005):

- 2 g/m^2/month for incremental impacts (annual average).
- 4 g/m^2/month for cumulative impacts (annual average).

These criteria are also adopted by other States and Territories in Australia for the assessment of nuisance dust impacts.

2.3 TOTAL Company Standards and Commitments

Relevant baseline assessment requirements set out in TOTAL policy documents and General Specification documents have also been reviewed. The findings of this review are outlined below.

2.3.1 Environmental Baseline and Monitoring Studies: Onshore Sites

TOTAL General Specification, GS EP ENV 111, *Environmental Baseline and Monitoring Studies: Onshore Sites* (TOTAL, 2012a) sets out technical instructions for the establishment of the baseline environmental status and for carrying out environmental monitoring of an onshore site. Appendix 9 of GS EP ENV 111 lists concerns and recommendations for various environmental issues depending upon the receiving environment for a given project. For '*tropical forest environments*' and '*sensitive humid environments (mangroves, etc.)*', no issues or specific requirements regarding air quality are listed.

2.3.2 Environmental Baseline and Monitoring Studies: Offshore and Nearshore Sites

TOTAL General Specification, GS EP ENV 112, *Environmental Baseline and Monitoring Studies: Offshore and Nearshore Sites* (TOTAL, 2012b) sets out technical instructions for the establishment of the baseline environmental status and for carrying out environmental monitoring of an offshore or a nearshore site. GS EP ENV 112 does not identify any issues or any specific requirements regarding air quality for offshore or a nearshore sites.

2.4 Air Quality Assessment Criteria

The air quality assessment criteria against which the Project will be assessed will be defined and described in the relevant air quality impact assessment report based on the review of international air quality guidelines and standards identified above.

3 STUDY AREA

3.1 Study Area

The upstream terrestrial part of the Project is located largely in the Gulf Province of Papua New Guinea, with the southern offshore pipeline section straddling into Central Province. The Project comprises four main components:

- Production, processing and related facilities.
- Onshore export pipeline.
- Transport river corridors.
- Offshore export pipeline.

The study area for the air quality baseline assessment is defined as any area where air quality may be directly impacted as a result of Project activities, including construction and operation of facilities and infrastructure for the Project.

The most significant source of air emissions associated with the production, processing and related facilities is the proposed CPF site. The potential area of impact of construction and operational phase emissions from this site will be assessed as part of the air quality impact assessment using dispersion modeling. As discussed in **Section 5.6** and shown in **Figure 6**, the modeling domain that will be used for the air quality impact assessment covers a 15 km by 12 km area, which includes the CPF site and the nearest sensitive receptors, Poroi 1and Mapaio Fish Camp, as well as Herd Base.

Other emissions to air that will occur as a result of the Project include:

- Venting of gas during construction and operation of wellpads, the gas gathering system and the trunkline.
- Fugitive dust emissions from construction of the infield production facilities and infrastructure (e.g. wellpads, trunkline, and access road), the onshore export pipeline and other related infrastructure (camps, laydowns).
- Engine exhaust emissions and wheel-generated dust from vehicles travelling on access roads during construction and operation.
- Engine exhaust emissions from vessel traffic travelling along the Purari River.
- Engine exhaust emissions from vessels during construction of the offshore export pipeline.
- Products of combustion from generators and waste incinerators.
- Products of fuel combustion from aircraft transporting employees and equipment during construction.

Given the above, the study area for the air quality baseline assessment also includes the entire PRL-15, the onshore and offshore export pipeline corridor and locations along the Purari, Ivo-Urika and Wame-Varoi Rivers within which sensitive receptors are located. However as noted above, the greatest risk of air quality impacts for the Project relates to potential air emissions from the CPF, hence the baseline air quality assessment has focused on the CPF site.

3.2 Climate

Papua New Guinea has a tropical, monsoonal climate. The coastal and islands regions tend to be hot and humid, with temperature averages ranging between 20°C to 32°C, relative humidity levels ranging from 70% to 90% and high rainfall year-round.

Seasonal climate changes in the study area are controlled by two mass air movements. Typically the easterly trade wind season occurs from April/May to October/November and the northwest monsoon occurs from November/December to March/April. There are transitions at the cross over of each season.

Papua New Guinea's climate varies considerably from year to year due to the El Niño-Southern Oscillation (ENSO). This is a natural climate pattern that affects weather across the world. El Niño is a warming of the Pacific Ocean resulting in longer and cooler dry seasons (i.e. periods of drought), and a delay to the start of monsoon season. La Niña, the cold phase of ENSO, typically results in higher than average rainfall and warmer temperatures during the wet season, often leading to flooding events and landslides (PACCSAPP, 2015). Papua New Guinea also experiences neutral phases.

A dominant climatic factor in the upland areas is cloud and fog; and for most of the year, they are important sources of moisture. Western and northern parts of Papua New Guinea experience the most precipitation, since the north- and westward-moving monsoon clouds are heavy with moisture by the time they reach these more distant regions. However, on rare occasions, vegetation of the uplands can become dry enough to burn, as happened during a severe drought in 2015 when fires spread from the Highlands to West New Britain across to Milne Bay province in the latter half of the year. Towards the coast, rainfall is lower and more evenly spread throughout the year (averaging around 300 mm/month) (Evesson, 1983).

Temperatures in the study area are mild and remain relatively consistent throughout the year. Temperature is altitude dependent, with hot and humid conditions associated with lower altitudes and cooler conditions at higher altitudes.

Tropical cyclones affect southern Papua New Guinea between November and April. In the 41-year period between 1969 and 2010, 23 tropical cyclones passed within 400 km of Port Moresby, an average of less than one cyclone per season. From 1969–2010, cyclones occurred more frequently in neutral phases of the El Niño-Southern Oscillation (PACCSAPP, 2015).

3.3 Topography and Land Use

The topography and land use of the study area have the potential to impact on the baseline air quality as well as the dispersion of air emissions from the Project. Local wind patterns will be influenced by hills and valleys which will act to channel winds. Night-time drainage flows will create downslope winds which will also influence the direction in which emissions from the Project will be dispersed. The natural vegetation in the study area also has the potential to affect wind speeds and atmospheric turbulence through changes in surface roughness associated with changes in canopy heights. Ambient particulate levels are also affected by vegetation, which reduces wind erosion but also has the potential to contribute to increased pollen levels.

Mountains, hills and levee plains characterize PRL-15. The northern two-thirds of PRL-15 comprises southeast to northwest trending ridges and folded terrain of the lower Eastern Highlands, up to approximately 450 m above sea level (asl) in places, and with Crater Mountain located to the north. The existing wellpads from previous appraisal drilling are primarily located on steep ridges, some up to 250 m asl. Terrain in the southwestern portion of PRL-15 lowers to the plains of the Purari River basin that are typically subject to frequent inundation from overbank river flows during the wet season.

The proposed CPF site is located on the flood plain of the Purari River bounded to the south by the Purari River main tributary and to the east by the tributary Kuku Creek. Oyomo Creek lies to the west and southwest, with its minor tributaries running through the CPF site itself. The generally flat swampy terrain of the site has a maximum elevation of about 50 m asl, but is more generally below this elevation. The site is prone to inundation from the Purari River. The topographical data used in the meteorological modeling study for the CPF site and surrounds is discussed in **Section 5.6.4**.

From the north, the export pipeline corridor traverses extensive ranges of asymmetrical mountains and hills, which descend into alluvial plains and composite levee plains, coastal mangroves and finally beach ridges and beach plains.

PRL-15 and the surrounding areas are densely forested by tropical forest. Limited clearing has been performed by the local population for subsistence farming and construction of dwellings and small villages. Sago cultivation is the principal staple in the lowland areas, with production restricted to the river zones (e.g. Purari River and its tributaries). Sago is supplemented by other garden crops such as banana, kaukau and greens. There is extensive commercial logging in parts of the Purari River catchment and growing oil and gas exploration activity: both industries provide employment for local people.

Along the export pipeline corridor, remote inland communities rely almost entirely on native flora and fauna for their livelihoods and wellbeing. Coconuts and sago are the most important food staples. These are supplemented by hunting and trapping of wild animals and birds, and fishing in rivers and creeks. Transport is limited to waterways and established tracks.

In coastal villages, the main staple food is sago harvested from sago palms that have mostly been planted along the banks of creeks or in swampy areas or alluvial plains. Coconuts are also an important staple and nypa palm nuts are harvested as a food resource on a seasonal basis. Extensive fishing occurs in the sago swamps, creeks, mangroves and the sea.

3.4 Anthropogenic Setting

PRL-15 is largely unsettled but owned and used by the Pawaian people, who reside in villages along the Purari River. Most of these villages are outside of but near to PRL-15 except for two small villages (Poroi 1 and Mapaio Fish Camp) that are located on the Purari River within the southern part of the licence area. Aside from subsistence livelihood activities from the Pawaian people, the main anthropogenic activities in PRL-15 relate to the recent and ongoing gas exploration activities, including the main operations camp at Herd Base, temporary camps at Antelope-3 Operations Camp and Hou Creek Base (both now demobilized), and activities and disturbances relating to wellpads, access roads, and helipads.

The inland section of the export pipeline corridor is largely unpopulated however has been modified by large-scale industrial logging. Near to and along the coast, the number and size of villages, and hence population density, increases. Anthropogenic activities include clearing of forest for settlements, subsistence agriculture (food gardens, sago planting, hunting and fishing) and historical clearing for coconut plantations.

Along the Purari riverways, villages are predominately located on or in the vicinity of the upper reaches of the tidal influence where there is likely to be a greater availability of resources. In addition to subsistence agriculture activities, logging and Project-commissioned barges transporting supplies and equipment to the base, regularly travel along the Purari channels.

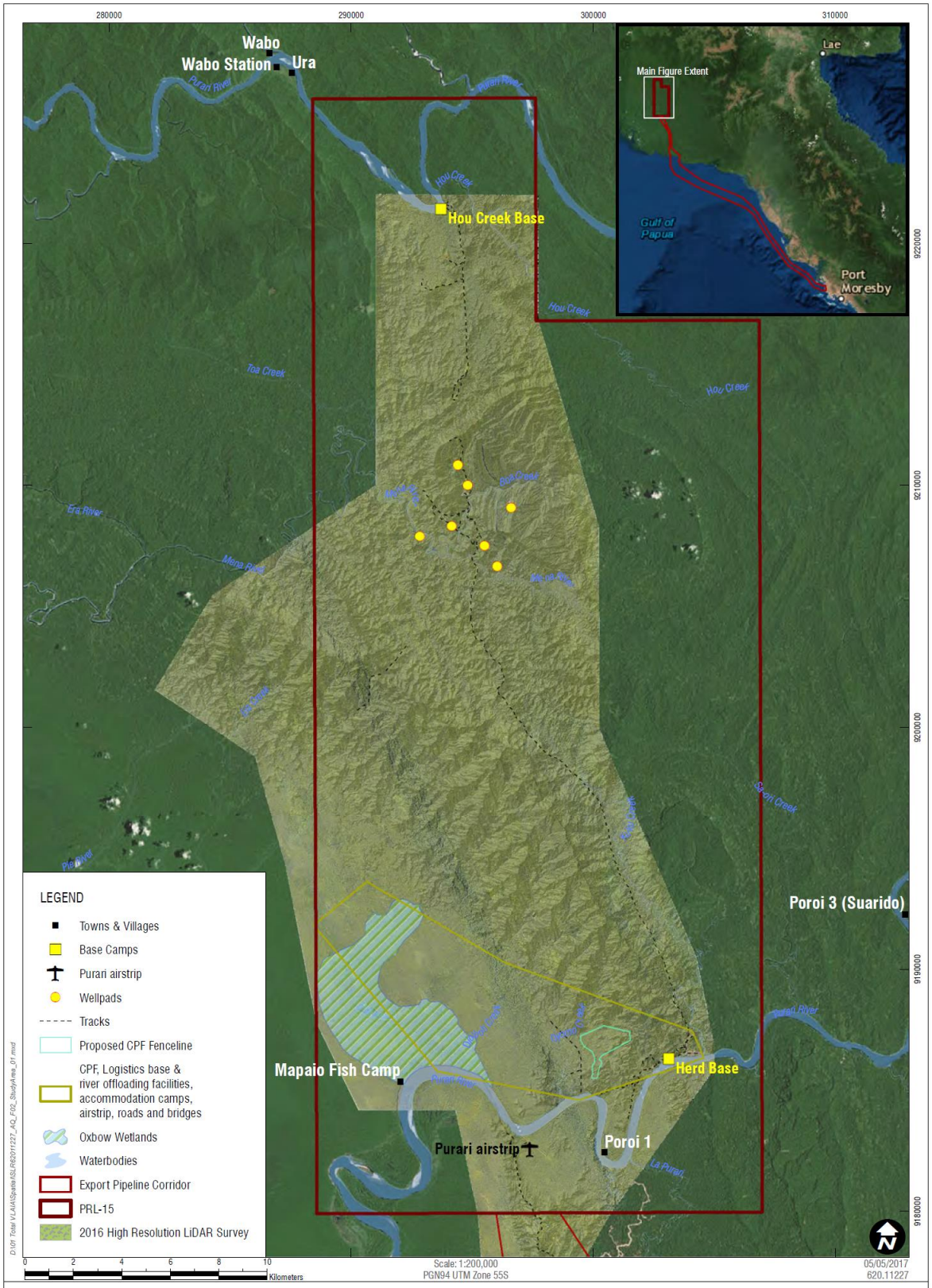
3.5 Sensitive Receptors

As indicated above, the ecosystem within the study area is characterized by largely intact tropical forest with disturbance related to petroleum exploration within PRL-15, logging along the export pipeline corridor and the pressures of human settlement including clearances for gardens, plantations and housing closer to the coast. The riverways are generally banked by intact forest, with the exception of clearing associated with villages and their gardens.

As shown in **Figure 2**, the nearest existing human receptors to the CPF are located at Poroi 1 village, approximately 3 km to the south of the CPF. The next closest existing sensitive receptor is Mapaio Fish Camp, located approximately 9 km to the west.

Villages are generally not common along much of the export pipeline corridor until close to the coastline.

It is noted that this air quality baseline study was prepared focusing on existing sensitive receptors. Potential future sensitive receptors associated with in-migration will be addressed in the air quality impact assessment report.



CPF Site Sensitive Receptors

FIGURE 2

4 EXISTING INFORMATION

4.1 Prior Studies within the Study Area

4.1.1 Available Meteorological Data

PNGClimate commissioned a meteorological station in Wabo in May 2013, which is located 38 km north-northwest of the proposed CPF site. Details of the station are as follows:

- Latitude: 7.00666, longitude: 145.073°.
- Elevation: 433 m above mean sea level.
- Parameters: wind speed and direction, temperature, rainfall, relative humidity, barometric pressure.

All available data from this station were obtained from PNGClimate, which covered the following periods:

- 1 June – 31 December 2013.
- 1 January – 21 February 2014.
- 14 February – 19 December 2015.

As indicated above, limited data are available for this station during 2014 due to a lightning strike damaging the station in February of that year, which was not fixed until February 2015. Plots of the data are included in Error! Reference source not found..

In addition to the Wabo meteorological station, rainfall data is recorded by TEP PNG at Herd Base and Hou Creek. Rainfall data collected during 2013 to 2015 by these rainfall stations have also been reviewed.

Meteorological modeling was performed by BMT ARGOSS for the study area using the Weather Research and Forecasting (WRF) model (BMT ARGOSS, 2014, 2015a and 2015b). The model configuration used in the WRF model was initially validated for a 1-year model run for 2012 based on observational data from Jackson Airport and Horn Island, prior to performing a 10-year model run (2004-2013) for the wider Project area including PRL-15. A review of the validation (BMT ARGOSS, 2014) showed that the model configuration used by BMT AGROSS resulted in statistically acceptable predictions of temperature and atmospheric pressure at both Port Moresby and Horn Island. Predicted wind speeds at Horn Island were also in agreement with observational data, however WRF over-predicted wind speeds at Port Moresby. No wind roses or wind direction data were presented to demonstrate whether WRF had accurately characterized the predominant wind directions.

A full WRF modeling analysis has been performed for the study area as part of this baseline assessment (see Section 5.6.2) using model options that have resulted in a more accurate prediction of wind speeds at other locations within PNG performed by SLR in the recent past. The results of the meteorological modeling study performed by SLR have been validated using the available observational data from Wabo and by an analysis of the model's ability to resolve topographical features within the predicted wind fields. Further details of this modeling are provided in **Section 5.6**.

4.1.1.1 Temperature

A summary of the Wabo temperature data is presented in **Table 4**. As shown in **Table 4**, the average daily maximum temperatures range between 24.7°C and 30.3°C and the average daily minimum temperatures range between 19.2°C and 22.2°C. The highest temperatures are generally recorded from November to February, and the lowest during August. In general, however, there is little seasonal variation in ambient temperatures.

Table 4 Summary of Available Temperature Data – Wabo Meteorological Station

Year	Month	Average Daily Minimum Temperature (°C)	Average Daily Maximum Temperature (°C)	Average Temperature (°C)
2013	June	22.1	27.3	23.8
	July	21.5	26.1	22.9
	August	20.9	25.3	22.2
	September	21.0	26.7	23.0
	October	21.4	28.2	23.8
	November	21.9	29.7	24.7
	December	22.2	29.9	25.0
2014	January	21.9	29.5	25.0
	February *	22.0	30.3	25.4
2015	February *	21.3	28.7	24.5
	March	21.7	28.6	24.5
	April	21.7	28.2	24.0
	May	21.1	27.0	23.2
	June	21.0	26.5	22.8
	July	20.2	25.4	21.9
	August	19.2	24.7	21.2
	September	20.0	26.1	22.0
	October	20.6	27.8	22.9
	November	22.0	30.2	24.9
	December *	21.9	30.3	25.1

* Incomplete month

4.1.1.2 Wind Speed and Direction

Wind data recorded from June 2013 to February 2014 by the Wabo meteorological station are presented as a wind rose in **Figure 3**. Each branch of the rose represents winds coming from that direction, with north at the top of the diagram. The branches are divided into segments of different thickness and color, which represent wind speed ranges from that direction. The length of each segment within a branch is proportional to the frequency of winds blowing within the corresponding range of speeds from that direction.

Figure 3 shows that at the Wabo meteorological station winds blow predominantly from the west-northwest and the south. Calm conditions (wind speeds less than 0.5 m/s) were recorded 11.9% of the time.

Figure 3 Annual Wind Rose - Wabo Meteorological Station

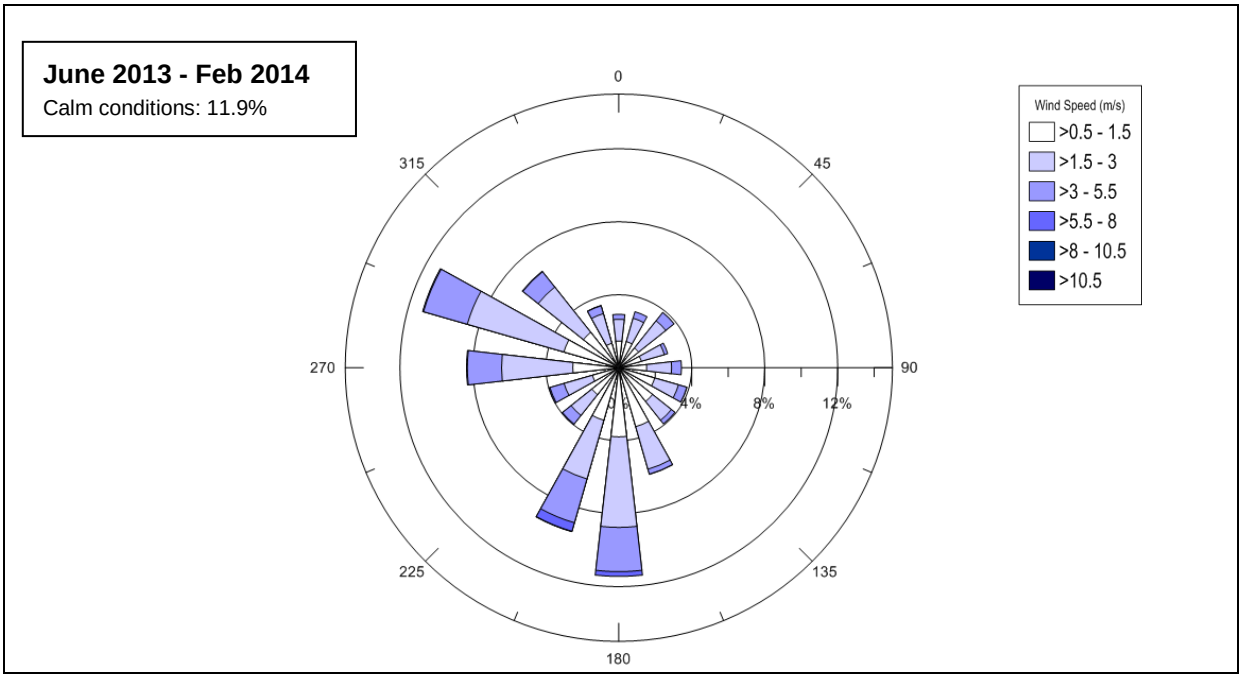


Table 5 shows the minimum, maximum and average wind speeds recorded at Wabo during each month based on the raw 10-minute average data. This table shows that the average monthly wind speeds are consistently low at 1.6 to 2.2 m/s. Stronger winds up to 11 m/s (as a 10-minute average) were recorded, the wind speeds highest during October to January, which is the start of the northwest monsoon season.

Table 5 Summary of Available Wind Speed Data – Wabo Meteorological Station

Year	Month	Average Wind Speed (m/s)	Maximum Wind Speed (m/s)
2013	June	1.7	8.2
	July	1.6	7.2
	August	1.7	7.3
	September	1.8	7.6
	October	1.8	9.9
	November	2.1	11.0
	December	1.9	7.5
2014	January	2.0	10.6
	February	2.2	8.5
2015	February	2.0	7.8
	March	1.8	7.7
	April	1.7	6.9
	May	1.7	6.4
	June	1.6	6.5
	July	1.7	7.1
	August	1.6	6.9
	September	1.6	7.4
	October	1.7	7.1
	November	1.6	8.7
	December	1.7	6.8

Based on 10-minute average observations

4.1.1.3 Rainfall

Available rainfall data collected during 2013 - 2016 at Wabo, Herd Base and Hou Creek are presented in **Table 6**. The recorded rainfall data indicate that annual average rainfall varies significantly from year to year and across the study area. The available data indicates that rainfall at Hou Creek is slightly higher than at Wabo, while rainfall at Herd Base is normally much lower than at Wabo and Hou Creek.

4.1.1.4 Relative Humidity

The plot of relative humidity data from Wabo in Error! Reference source not found. demonstrates the high humidity levels that are characteristic of the study area. The daily average humidity levels remain above 80% year-round and are normally above 90%.

Table 6 Summary of Recorded Rainfall Data – Wabo, Herd Base and Hou Creek

Month	2013			2014			2015		
	Wabo (mm)	Hou Creek (mm)	Herd Base (mm)	Wabo (mm)	Hou Creek (mm)	Herd Base (mm)	Wabo (mm)	Hou Creek (mm)	Herd Base (mm)
January	-	1,035	586	694	839	447	-	-	1,190
February	-	400	307	483	469	384	-	-	1,302
March	-	899	560	-	519	354	302	-	461
April	-	1,652	456	-	660	168	811	-	263
May	-	989	206	-	779	320	721	-	181
June	806	1,263	487	-	1,084	354	747	-	242
July	859	676	278	-	857	742	430	-	261
August	880	1,012	181	-	1,138	1,499	284	-	89
September	697	818	231	-	-	2,638	303	-	9
October	1,313	1,521	304	-	-	402	391	-	49
November	801	1,014	382	-	-	282	513	-	86
December	782	841	332	-	-	713	-	-	126
TOTAL	**-***	**12,120**	**4,310**	**-***	**-***	**8,303**	**-***	**-***	**4,259**

* Incomplete dataset

4.1.2 Available Air Quality Data

No ambient air quality monitoring data is available for the study area from previous studies.

A number of Environmental Impact Assessment and Environmental Management Plans were prepared for the drilling program within PRL-15 (GHD 2015a, 2015b, 2015c, 2015d), however none of these documents presented air quality baseline information.

In 2008, an environmental impact statement (EIS) was prepared by Douglas Environmental Services (DES) for the Elk Antelope Gas Field Project (DES, 2008). This EIS was prepared for the installation of production wells connected by a network of pipelines in the Elk Antelope Gas Field, construction of a delivery pipeline to take the raw gas to a gas processing facility on the bank of the Purari River, and transport of the dehydrated gas stream via a pipeline to a LNG plant located at Napa Napa near Port Moresby for further processing and export.

No baseline air quality data is presented in the DES EIS.

4.2 Studies in Neighboring Regions

4.2.1 Available Meteorological Data

The complex topography of the study area means that there is limited value in incorporating any observational meteorological data from outside the study area, e.g. Kerema and Mt Hagen. The intervening terrain and changes in elevation between such monitoring stations and the study area means that the observational data would not be representative of the study area.

4.2.2 Available Air Quality Data

No ambient air quality monitoring data is publicly available for neighboring regions from previous studies.

The air quality impact assessment prepared by Holmes Air Sciences (HAS) in 2009 for the upstream components of the Papua New Guinea Liquefied Natural Gas Project (PNG LNG Project) has been reviewed (HAS, 2009). The upstream development components of this Project included the construction and recompletion of wells, and construction of a gas gathering system and gas conditioning plant in the Hides Gas Field, some 300 km northwest of the proposed CPF site.

The HAS air quality impact assessment states:

> *'There are no ambient air quality monitoring data to establish existing levels of air pollutants. The project areas are remote from existing industrial pollution sources except those that are part of the existing facilities or those very closely related to these, for example the existing power station at the Hides Gas Plant that supplies power to the Porgera Project. The approach used in the current assessment uses a computer-based dispersion model to estimate the ground-level concentrations of emissions including those from the existing sources as well as the new sources. These are collectively assumed to be released into a pristine environment where the existing concentrations of gaseous pollutants are taken to be negligible.'*

For the assessment of potential cumulative impacts on ambient particulate concentrations during the construction period, the HAS air quality impact assessment noted the following:

> *'Background PM_{10} levels have not been measured in this area, but based on local land use are estimated to be less than 20 µg/m^3 (annual average) and less than 30 to 40 µg/m^3 (24-hour average) except when affected by smoke from fires.'*

The air quality impact assessment prepared for the Hidden Valley Gold Mine in 2004, which is located approximately 160 km east of the proposed CPF site, was also reviewed (RHA, 2004). This study also did not include a baseline air quality monitoring program. Instead the background concentrations of particulate levels were noted as being conservatively estimated based on ambient monitoring data from rural areas in Western Australia. As rainfall and vegetative coverage is much lower in Western Australia compared to PNG, these assumed background concentrations would be expected to overestimate background particulate levels. The values used were a 24-hour average PM_{10} concentration of 20 µg/m^3 and an annual average TSP concentration of 40 µg/m^3. Background concentrations of NO_2 and SO_2 were assumed to be negligible due to the absence of any industry or other anthropogenic sources in the area.

4.3 Summary

The review of existing information outlined above shows that there is no detailed meteorological data for the study area suitable as input into an atmospheric dispersion modeling study. As a result, this baseline study has focused on the compilation of a detailed, site-representative meteorological dataset using current best-practice meteorological modeling techniques, as described in **Section 5.6**.

As outlined in **Section 5.6** limited data are available from the Wabo meteorological station due to a lightning strike in February 2014, which was not fixed until February 2015. Due to this limitation on the data availability and considering the distance between the Wabo meteorological station and the CPF site, and the complexity of the intervening terrain, observational data from Wabo have not been input into the meteorological model. Instead, available data from this station was used to evaluate the performance of the meteorological model, by comparing the model predictions at the site of the Wabo station to the observational data.There is also no ambient air quality data currently available for the study area.

5 METHODS

5.1 General Approach

5.1.1 Meteorology

The characterization of the meteorology of the study area has focused on the proposed location of the CPF as this component of the Project has the greatest potential for off-site air quality impacts. A detailed meteorological modeling study has therefore been performed for the area surrounding the CPF site in order to compile a site-representative 3-dimensional meteorological data file suitable for use in a dispersion modeling study. Further details on the modeling methodology are provided in **Section 5.6**.

The pipeline corridor and transport river corridors cover large distances and include a range of topographical features. Wind patterns, rainfall, ambient temperatures and humidity levels can therefore be expected to vary along the corridors depending on topography and elevation. However the types of activities proposed within these corridors will only have potential for much localized impacts on air quality. For example, fugitive dust emissions from construction activities within the onshore export pipeline corridor will be emitted at ground level, with little or no upward momentum or plume buoyancy. Their dispersion will therefore be limited to a very localized area surrounding the active work area, and the long-range transport of dust emissions will not be a significant consideration. A detailed analysis of meteorological conditions along each corridor has therefore not been performed. Instead, wind speed and wind direction data have been extracted from the meteorological modeling performed for the CPF at a location approximately halfway along the pipeline corridor. These data are indicative of the wind conditions that may be anticipated along the pipeline and transport river corridors, and will be used in the air quality impact assessment to qualitatively assess the potential for local air quality impacts from these activities and the level of air emissions control that will be required.

No modeling or detailed analysis of the meteorology experienced along the offshore export pipeline corridor has been performed as there will be no emissions to air associated with this component of the Project during the operational phase. During the construction of the offshore export pipeline there will be emissions associated with fuel combustion in vessels and machinery used to construct the underwater pipeline. However, there will be no sensitive receptors in close vicinity to the emissions and no significant potential for air quality impacts.

5.1.2 Baseline Air Quality

As identified in **Section 2.2.4**, air pollutants that have the potential to be generated by the Project are:

- Fugitive dust emissions from construction of the infield production facilities and infrastructure.
- Combustion-related NO_X, SO_X, CO and particulate.
- H_2S.
- VOCs and methane.
- Glycols.
- PAHs.

As discussed in **Section 3.4**, the study area is undeveloped and there are no significant existing sources of combustion products (i.e., NO_X, SO_X, CO and PAHs), H_2S or glycols located within the airshed. As a result, ambient concentrations of these pollutants can reasonably be expected to be negligible under normal conditions. While there is the potential for elevated concentrations of combustion-related pollutants to occur during agricultural burn-offs and in the event of forest fires, such events are intermittent, highly variable and relatively short term. Given that ambient concentrations will be negligible except for these intermittent abnormal events, baseline monitoring of these pollutants is not warranted.

Background levels of particulate matter are also expected to be low, given the high rainfall, low wind speeds and dense vegetation in the area. The main sources of background particulate matter include both natural sources (e.g. pollens) and anthropogenic activities (e.g. cooking fires, generators (if used) and agricultural activities). The study area is surrounded by thick forest and during peak flowering times (twice per year) pollen levels may be high. The use of biomass for cooking fires is a potentially significant source of exposure to air pollutants for the local population. There is also potential for significant events, such as a volcanic eruption, to affect air quality across large areas of the Asia-Pacific region, including the study area, however this would be infrequent. Wildfires have occurred in the past during dry El Niño years, caused by agricultural fires for land clearing burning out of control (NASA, 2009).

Significant levels of particulate emissions would only occur during the construction phase of the Project. During the operational phase, particulate emissions from the CPF would be low, as particulate emissions from gas combustion are minimal. The most significant source of dust emissions during the operational phase is likely to be wheel-generated dust from Project vehicles travelling on unpaved roads.

Baseline monitoring of existing particulate concentrations in the study area is not warranted given that significant emissions of particulate matter from the Project will be limited to the construction period only. These emissions will be generated at ground level, and would only have potential for very localized impacts in the immediate vicinity of the construction work areas. As noted in **Section 3.5**, the nearest human receptors to the CPF (which will have the greatest potential for off-site dust impacts during construction) are located at Poroi 1 village, approximately 3 km to the south of the CPF. The risk of fugitive dust emissions from the CPF construction impacting on particulate levels at this distance is negligible. Other construction activities that have the potential to generate fugitive dust emissions, such as wellpad, pipeline and road construction, will be much smaller in scale, and the case of the pipeline and roads, will be transient in nature, moving along the corridor as works progress. The risk of fugitive dust emissions from these construction activities impacting on particulate levels at sensitive receptor locations is therefore very low.

Existing concentrations of particulate matter were instead estimated based on information presented in other air quality impact assessments and baseline studies performed for other projects in Papua New Guinea, and SLR's experience in the collection and review of ambient particulate monitoring data in other areas of Papua New Guinea and other remote and undeveloped areas in countries such as the Philippines. This approach is consistent with Guidance Note 1 (IFC, 2012b) for Performance Standard 1 (see Section 2.2.1).

5.2 Data Sources

The data sources used in the meteorological modeling performed as part of the air quality baseline study included:

- Topographical data was sourced from the Shuttle Radar Topography Mission (SRTM3).
- 2016 AAM LIDAR & Imagery Survey Data, Rev01.
- Land use data based on aerial imagery from Google Earth.
- NCEP FNL Operational Global Analysis data (meteorological input data required by the WRF model).

- Meteorological modeling was performed for two years based on a review of observational data from Port Moresby sourced from PNGClimate for 2013 to 2016.
- The results of the meteorological modeling were compared against the Wabo observational data sourced from PNGClimate for 2013 and 2014 presented in **Section 4.1.1**.

5.3 Field Surveys

No field studies were performed as part of the air quality baseline study (see **Section 5.1**).

5.4 Protocols Used

No field studies were performed as part of the air quality baseline study, hence no protocols were developed.

5.5 Permits Obtained

No field studies were performed as part of the air quality baseline study, hence no permits were required or obtained.

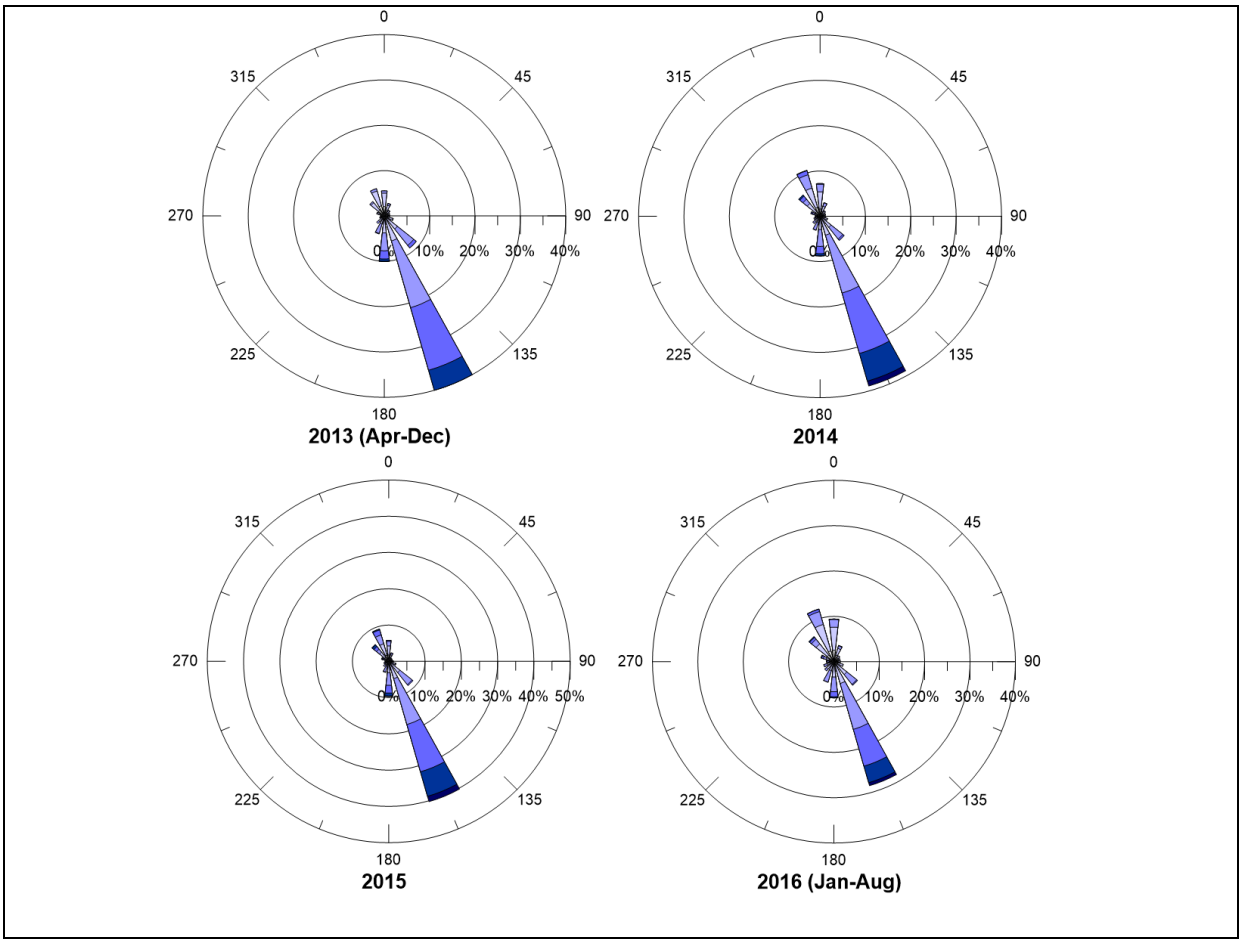
5.6 Meteorological Modeling Methodology

5.6.1 Selection of Representative Year

As noted in **Section 4.1.1** the data available from the Wabo meteorological station is limited, with only two months of data in 2014 and six months of data in 2013. While there is a year of data (almost) for 2015 this is not sufficient to be able to do an inter-annual comparison to assess whether any particular year would be more appropriate for use in the modeling.

SLR therefore reviewed meteorological data sourced from PNGClimate for Jacksons International Airport at Port Moresby (approximately 320 km southeast of the CPF site) for the period of April 2013 to August 2016. Annual wind roses for each year are presented in **Figure 4**. The data show a relatively similar pattern for each year.

Figure 4 Annual Wind Roses Compiled from Jacksons International Airport Data



Based on the above, SLR performed meteorological modeling for both the 2014 and 2015 calendar years using a combination of the WRF and CALMET models.

5.6.2 Weather Research and Forecasting (WRF) Model

The WRF model is a next generation mesoscale numerical weather prediction system designed for both atmospheric research and operational forecasting needs. It features two dynamical cores; a data assimilation system and a software architecture facilitating parallel computation and system extensibility. The model serves a wide range of meteorological applications across scales from tens of meters to thousands of kilometers.

For this assessment, the WRF modeling system was used to produce the meteorological data required as an input to the CALMET meteorological model. **Figure 5** shows the WRF modeling domains used. Domain 1 was run initially to compile a coarse (30 km grid resolution) 3- dimensional data file. The output from the Domain 1 model run was then used as input into the finer (10 km grid resolution) run covering Domain 2. The geographical extents of the domains was chosen to best cover the area of interest including the effects of large-scale weather events, while keeping the computational requirements for the atmosphere model as low as possible.

The WRF model uses data derived from the GFS (Global Forecast System) model. This is a global spectral atmosphere model, operated by the National Centers for Environmental Prediction, USA (NCEP). GFS is a global spectral model (GSM), composed of four separate models (an atmosphere model, an ocean model, a land/soil model, and a sea ice model), that work together to provide an accurate picture of weather conditions. The GFS data provides initial and/or boundary conditions for NCEP's other models for regional, ocean and wave prediction systems. The Global Data Assimilation System (GDAS) uses maximum amounts of satellite and conventional observations from global sources and generates initial conditions for the global forecasts. The GFS model has a spatial resolution of 0.5° x 0.5° and produces 10-day forecasts, four times per day. The final analysis (FNL) data - a historical collection of all 'best estimate' analysis results from the GFS - is used in WRF, which has a time resolution of 6 hours and a spatial resolution of 1° x 1°. Further details of the WRF model settings are presented in **Table 7**.

Modeling was performed for the 2014 and 2015 calendar years.

Table 7 WRF Model Configuration

Parameter	Domain 1	Domain 2
Modeling domain	2,100 km × 2,100 km	490 km × 490 km
Grid resolution	30 km	10 km
Number of vertical levels	30	30
Topographical data	SRTM3 ^	SRTM3 ^
Microphysics	WSM6 ⅄	WSM6 ⅄
Cumulus parameterization	Kain-Fritsch	Kain-Fritsch
Shortwave radiation physics	Dudhia	Dudhia
Longwave radiation physics	RRTM #	RRTM #
Planetary boundary layer	YSU *	YSU *

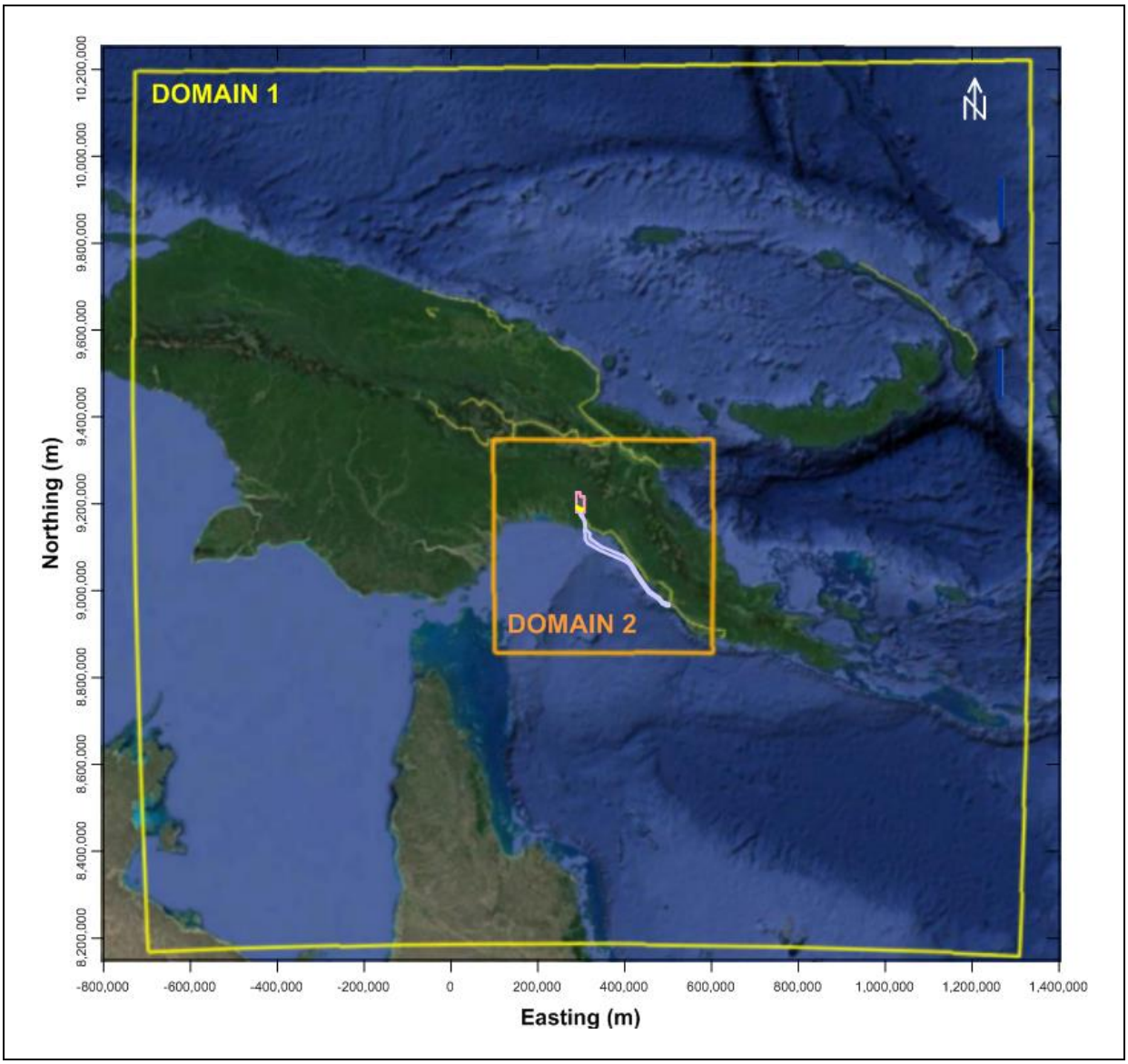
^ Shuttle Radar Topography Mission

⅄ WSM6: WRF Single-Moment 6-Class Microphysics Scheme

RRTM: Rapid Radiative Transfer Model

* YSU: Yonsei University

Figure 5 WRF Modeling Domains



Note: Coordinate datum PNG94/PNGMG 94 Zone 55

5.6.3 CALMET

In the simplest terms, CALMET is a meteorological model that develops hourly wind and other meteorological fields on a 3-dimensional gridded modeling domain that are required as inputs to the CALPUFF dispersion model. Associated 2-dimensional fields such as mixing height, surface characteristics and dispersion properties are also included in the file produced by CALMET. The interpolated wind field is then modified within the model to account for the influences of topography, sea breeze (where relevant), as well as differential heating and surface roughness associated with different land uses across the modeling domain. These modifications are applied to the winds at each grid point to develop a final wind field. The final hourly varying wind field thus reflects the influences of local topography and land uses.

CALMET modeling was conducted using the nested CALMET approach, where the final results from a coarse-grid run were used as the initial guess of a fine-grid run. This has the advantage that off-domain terrain features including slope flows, blocking effect can be allowed to take effect and the larger-scale wind flow provides a better start in the fine-grid run.

The outer domain was modeled with a resolution of 3 km. WRF-generated 3-dimensional meteorological data were used as the initial-guess wind field and local topography and land use information were used to refine the wind field predetermined by the WRF data.

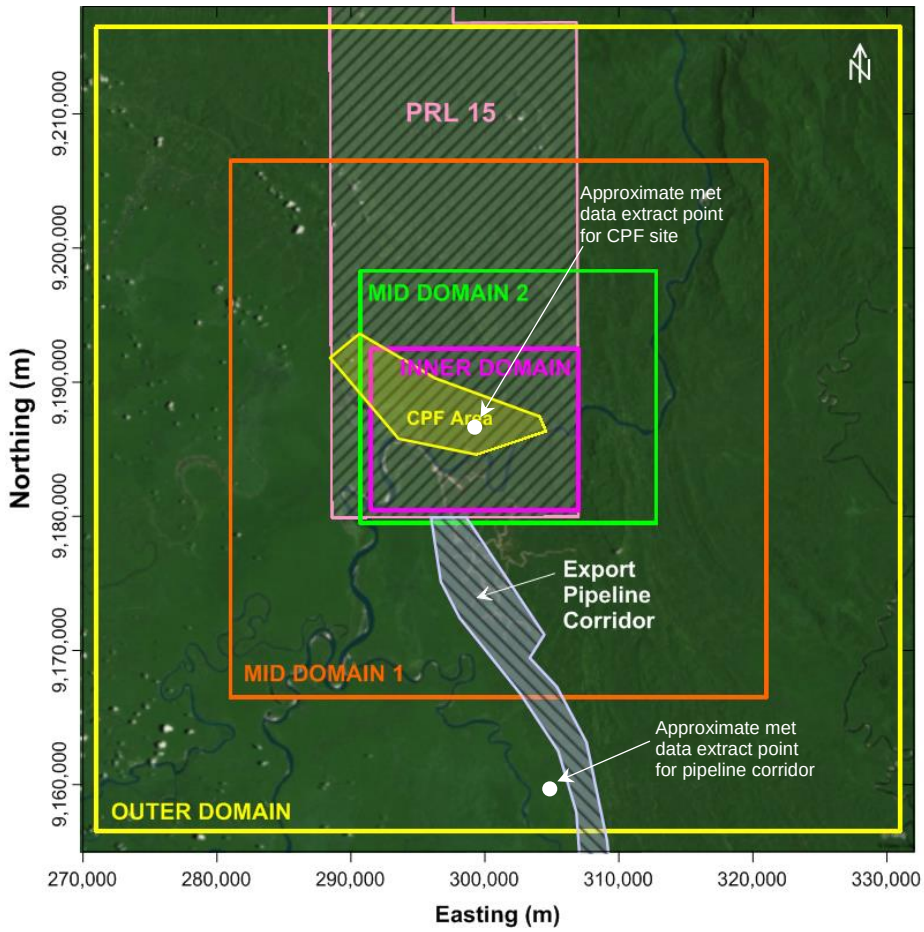
The output from the outer domain CALMET modeling was then used as the initial-guess field for the mid and inner domain CALMET modeling. A horizontal grid spacing of 1 km, 0.3 km and 0.1 km were used in the two mid and inner domains to adequately represent the important local terrain features and land use. Fine scale local topography and land use information were used in the inner domain run to refine the wind field parameters predetermined by the coarse CALMET runs.

Table 8 details the configuration used in the meteorological modeling to drive the CALMET model, while the extents of the model domains used for each Project area modeled are illustrated in **Figure 6**.

Table 8 Meteorological Parameters Used - CALMET

Meteorological Modeling Parameters	Project Site
Outer Domain	
Meteorological grid	60 km × 60 km
Meteorological grid resolution	3 km
Initial guess field	3D output from WRF model
Mid Domain 1	
Meteorological grid	40 km × 40 km
Meteorological grid resolution	1 km
Initial guess field	3D output from outer domain modeling
Mid Domain 2	
Meteorological grid	18.8 km × 18.8 km
Meteorological grid resolution	0.4 km
Initial guess field	3D output from mid domain 1 modeling
Inner Domain	
Meteorological grid	15 km × 12 km
Meteorological grid resolution	0.1 km
Initial guess field	3D output from mid domain 2 modeling

Figure 6 CALMET Modeling Domains



Note: Coordinate datum PNG94/PNGMG 94 Zone 55

5.6.4 Topographical and Land use Data

Topographical data was sourced from the Shuttle Radar Topography Mission (SRTM3) for input into both WRF and CALMET. This data is 3 second arc (90 m) resolution data. The LIDAR data provided to SLR (2016 AAM LIDAR & Imagery Survey Data, Rev01) have been integrated into the GEO file to replace the SRTM3 data in areas where LIDAR data is available. The CPF site was then leveled to a pad height of 25 m above mean sea level to reflect the final pad height post-construction. This refined topographical dataset was used in the inner CALMET model run.

WRF references a built-in database of land use categories (which include roughness height) based on the model domain.

Appropriate land use categories were selected for input into CALMET based on aerial imagery. The domain was mostly designated as land use category 40 (‘forest land’) with grid cells along the river identified as land use category 50 (‘waterbody’).

5.6.5 Model Validation

The wind direction, wind speed and temperature data recorded by the Wabo meteorological station during 2015 are compared against the predictions given by the WRF/CALMET modeling study at this location for the same time period in **Table 9**, **Figure 7** and **Figure 8**.

Table 9 shows that the predicted wind speed distribution at Wabo is very similar to that recorded by the meteorological station. The wind roses presented in **Figure 7** also show that the modeling has captured the predominant northwesterly and southerly wind directions. There are some variations between the observational wind rose and the predicted wind rose, with a slight shift in the predicted data from the west-northwest towards the northwest for example. Some variations between the predicted and observed datasets are inevitable given the highly complex terrain in the region, as the wind speed and wind direction data will be very sensitive to any slight variations or inaccuracies in the coordinates of the station or the topography/canopy heights in the immediate area.

Figure 8 shows that neither the observational nor predicted dataset has any observable seasonal trends in the hourly wind speed records.

A review of the hourly 2-dimensional surface wind fields (see **Figure 11** as an example) was also performed to assess the models' performance in accounting for the impacts of local features on the meteorology within the local area. This review showed that downslope flows, wind channeling and the blocking of winds by elevated terrain were all evident in the database, as would be expected.

Table 9 shows that peak ambient air temperatures (e.g. 90th percentile and above) tend to be slightly over-predicted by the modeling and the lowest temperatures tend to be under-predicted by the modeling. The 50th percentile and annual average predictions are within 10% - 13% of the measured values. It is noted that the results of the dispersion modeling will be significantly less sensitive to ambient temperature than the wind speed and wind direction data.

Based on the findings of the data analysis presented above, the methodology and model configurations used in the meteorological modeling study are concluded to have provided a synthetic 3-dimensional meteorological dataset that is representative of the key meteorological features of the study area relevant to pollutant dispersion, and which is suitable for use in the atmospheric dispersion modeling study to be performed as part of the air quality impact assessment.

Table 9 Comparison of Measured and Predicted Wind and Temperature Statistics at Wabo (2015)

Statistic	Wind Speed (m/s)		Temperature (°C)	
	Predicted	Measured	Predicted	Measured
99th Percentile	4.8	4.9	35.3	29.8
95th Percentile	3.7	3.6	32.3	28.1
90th Percentile	3.3	3.0	30.0	26.9
80th Percentile	2.7	2.5	27.0	25.2
70th Percentile	2.3	2.1	24.5	24.0
60th Percentile	2.0	1.8	22.2	23.3
50th Percentile	1.7	1.5	20.3	22.8
25th Percentile	1.0	0.9	15.2	21.5
10th Percentile	0.6	0.5	10.9	20.4
Average	**1.9**	**1.7**	**20.4**	**23.2**

Figure 7 Wind Roses Compiled from Measured and Predicted Wind Data at Wabo (2015)

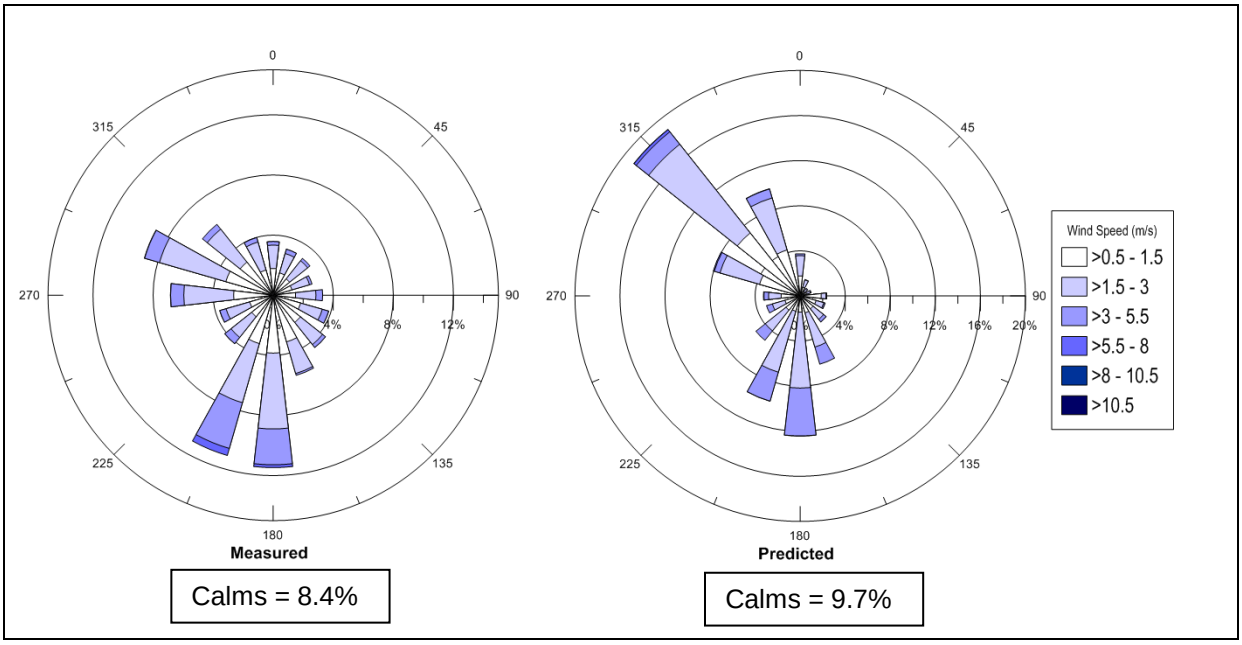
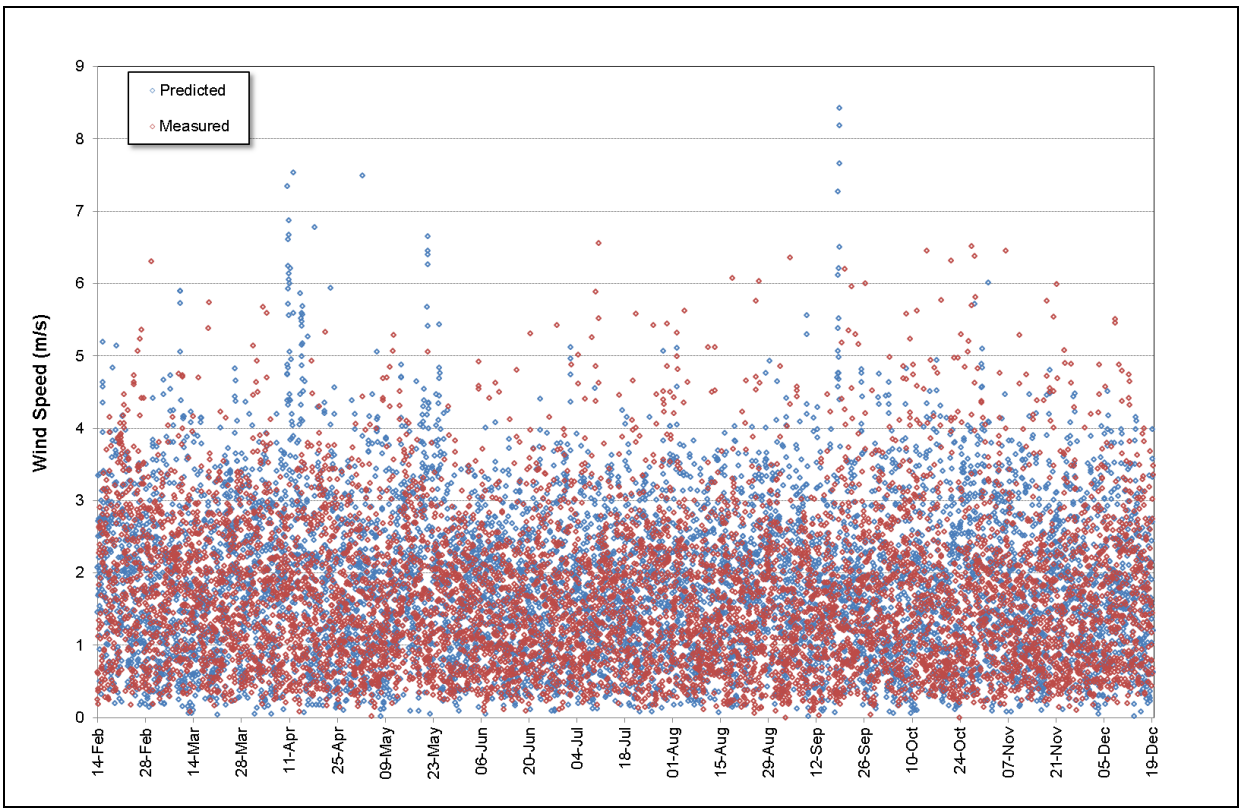


Figure 8 Comparison of Measured and Predicted Wind Speeds at Wabo (2015)



5.7 Limitations

The complex topography of the site means that validation of the model's performance is limited to a relatively small area of influence around the location where the observational data was collected. As the Wabo observational data relates to a location some 38 km north-northwest of the proposed CPF site, with very different surrounding topography, there is potential for the accuracy of the model to vary at the two sites. However, the use of 3-dimensional meteorological data which has been shown (as seen in **Figure 11**) to resolve the topographical influences on wind channeling and downslope flows gives confidence in the data being input into the model. The methodology used represents current best practice for air quality impact assessments and meteorological modeling studies. In addition, SLR has used a similar methodology for other air quality impact assessments in PNG and the predicted meteorological datasets have been demonstrated to represent actual conditions with a high level of reliability.

6 BASELINE CHARACTERIZATION

The following sections describe the local meteorological patterns relevant to the generation and dispersion of air pollutants in the key Project areas considered in the air quality baseline study, based on the results of the meteorological modeling described in **Section 5.6**. The locations at which the meteorological data were extracted for this analysis are presented in Table 10 and are also shown in **Figure 6**.

As shown in **Table 10**, the discussion of meteorological patterns along the onshore export pipeline corridor and transport river corridors is based on a single extract point, located roughly halfway along the onshore export pipeline corridor, approximately 9.5 km southeast of Evara, 9.8 km north of Aivai and 3 km east of the Wame and Varoi rivers. The meteorological data predicted by the modeling at this location will be only indicative of the types of conditions experienced along the onshore export pipeline and transport river corridors. Both of these study areas cover large distances and include a range of topographical features. Wind patterns, rainfall, ambient temperatures and humidity levels can therefore be expected to vary along the corridors. However the types of activities proposed within these corridors will only have potential for very localized impacts on air quality. A detailed analysis of meteorological conditions along each corridor has therefore not been performed, as an overview of indicative conditions provides the information that will be required to assess the potential for air quality impacts from these activities and the level of air emissions control that will be required.

The baseline air quality in each of the three key Project areas considered in the air quality baseline study has been characterized based on a qualitative review as described in **Section 5.1**.

Table 10 Locations of Predicted Meteorological Data Extractions

Project Area	Extract Point	Easting (m)	Northing (m)
Production, processing and related facilities	Centre of CPF site	300,550	9,186,950
Onshore export pipeline and transport river corridors	Halfway along export pipeline route	305,500	9,161,000

Note: Coordinate datum PNG94/PNGMG 94 Zone 55

6.1 Production, Processing and Related Facilities

6.1.1 Meteorology

6.1.1.1 Wind Speed and Direction

Wind roses showing the wind data predicted by the modeling at the CPF site for 2014 and 2015 are shown in **Figure 9**. Presented in a circular format, wind roses show the frequency of winds blowing from particular directions over a specified period. The length of each ‘spoke’ around the circle is related to the frequency that the wind blows from a particular direction per unit time. Each spoke is also broken down into color-coded bands to show the frequency of specific wind speed ranges.

Figure 9 indicates that during the modeled years, 2014 and 2015, the CPF site experienced mainly light to moderate winds (less than 5.5 m/s), with winds from the north-northeast and northeast predominating. Calm wind conditions (wind speeds less than 0.5 m/s) were predicted to occur 4-5% of the time.

The plot of predicted wind speed frequencies presented in **Figure 10** further illustrates that the site predominantly experiences low to moderate wind speeds, with a very low frequency of wind speeds above 5 m/s predicted during either 2014 or 2015.

An example of the temporal variation in wind speed and wind direction predicted by the modeling across the computational domain is shown in **Figure 11**. In this plot, the length of the vector indicates the wind speed predicted for each grid point, and the direction of the vector indicates the direction the wind is blowing. This plot represents a single hour of the 1-year data file and shows the effect of topography in channeling the winds.

Figure 9 Wind Roses for the CPF Site (CALMET)

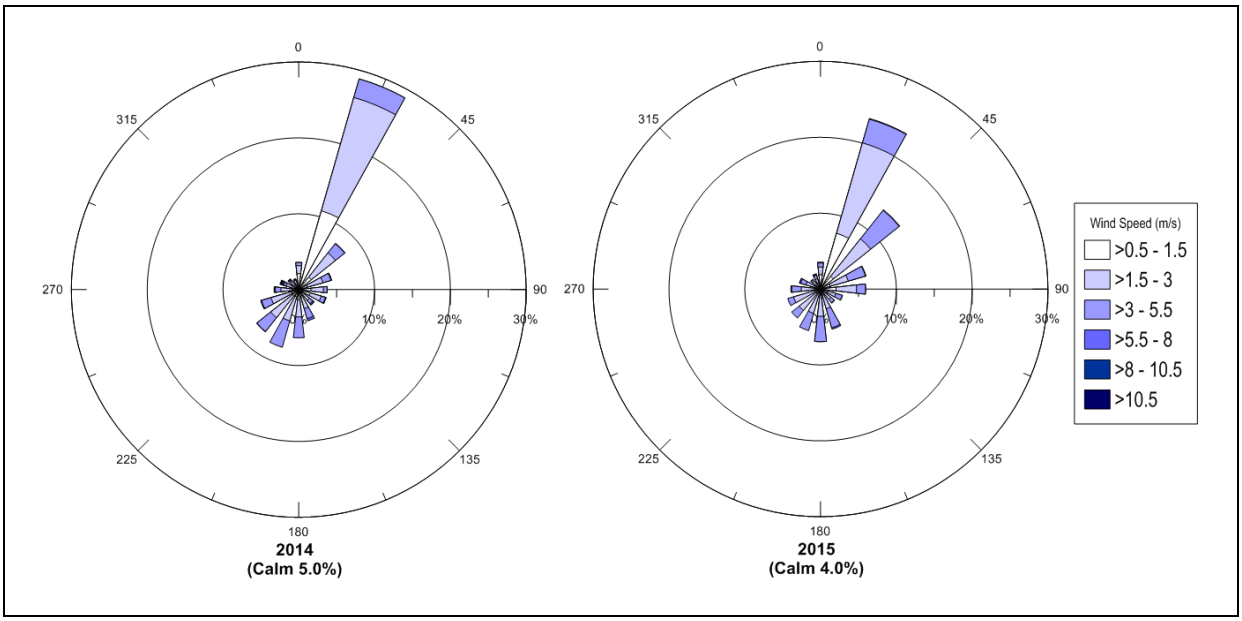


Figure 10 Predicted Wind Speed Frequency Distributions for the CPF Site (CALMET)

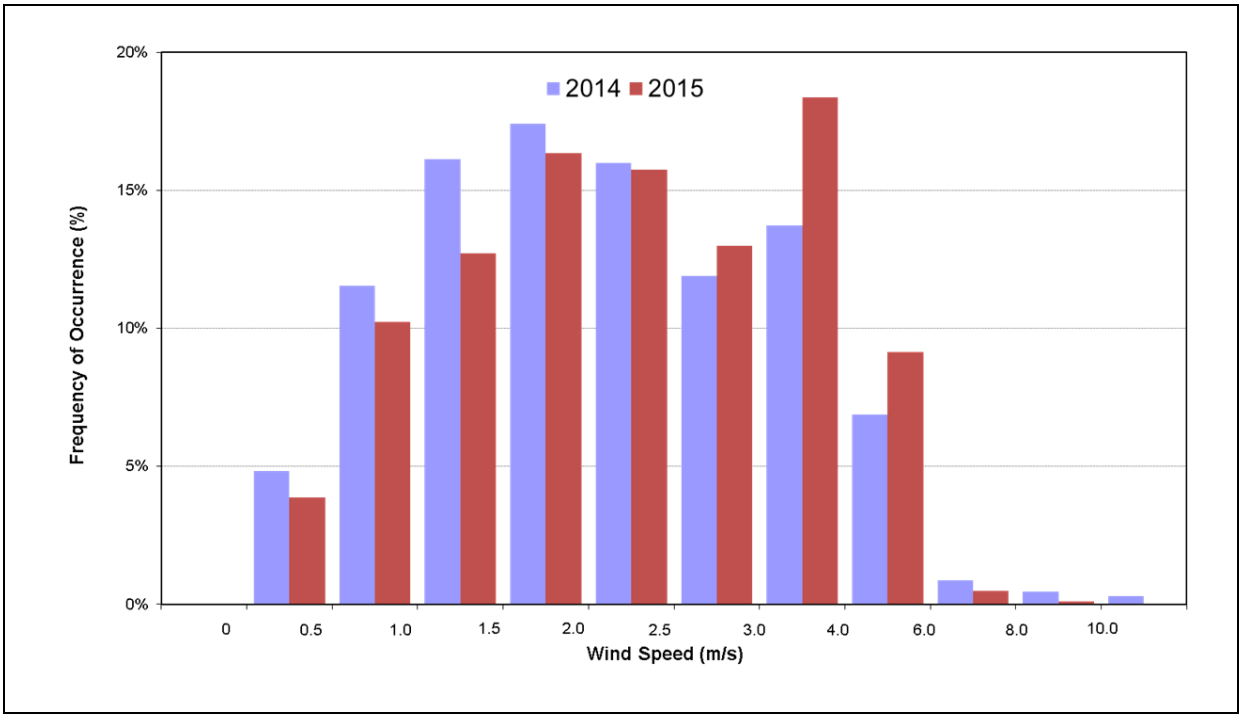
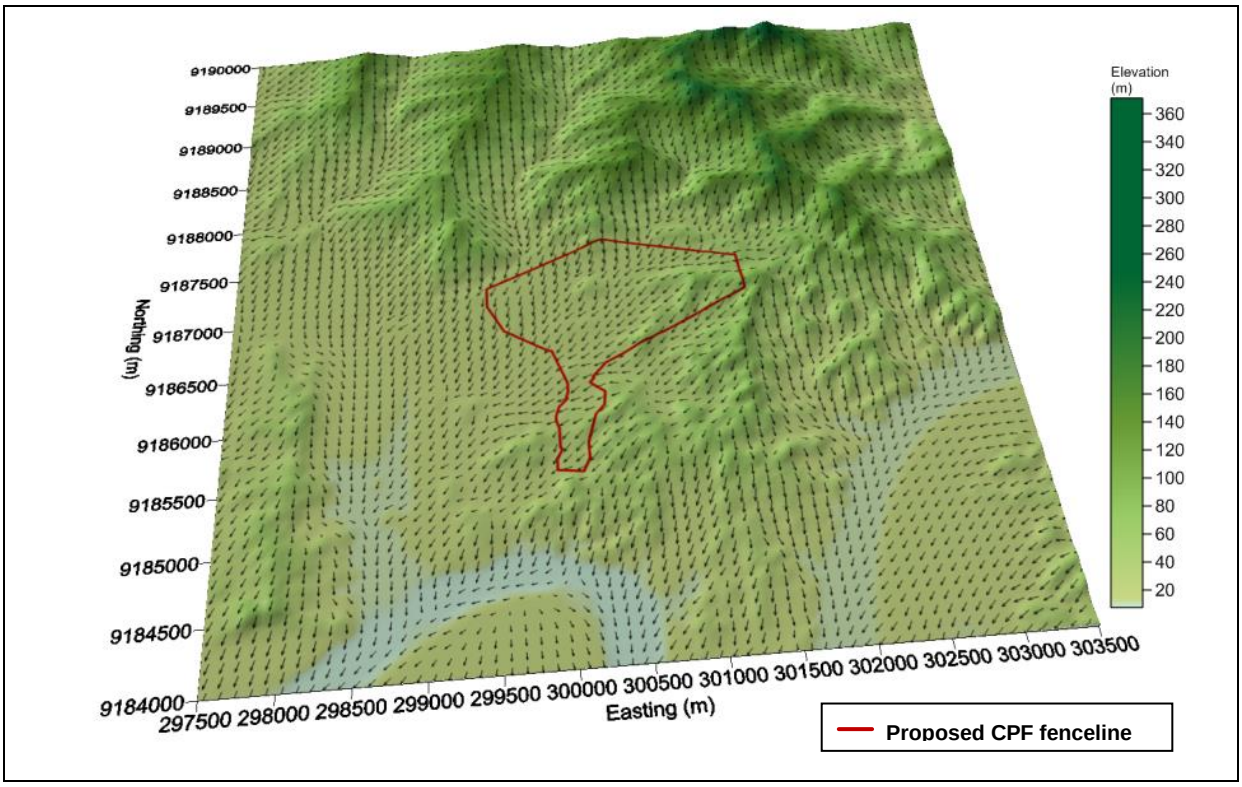


Figure 11 Example of the Predicted Wind Field Surrounding the CPF Site (CALMET)



Notes: Coordinate datum PNG94/PNGMG 94 Zone 55
The length of each vector (arrow) indicates the wind speed predicted for each grid cell, and the direction of the vector indicates the direction the wind is blowing

6.1.1.2 Atmospheric Stability

Atmospheric stability refers to the tendency of the atmosphere to resist or enhance vertical motion. The Pasquill assignment scheme identifies six Stability Classes, A to F, to categorize the degree of atmospheric stability as follows:

- A = Extremely unstable conditions.
- B = Moderately unstable conditions.
- C = Slightly unstable conditions.
- D = Neutral conditions.
- E = Slightly stable conditions.
- F = Moderately stable conditions.

The meteorological conditions defining each Pasquill stability class are shown in **Table 11**.

Table 11 Meteorological Conditions Defining Pasquill Stability Classes

Surface wind speed (m/s)	Daytime insolation [3]			Night-time conditions [2]	
	Strong [1]	Moderate	Slight [1]	Thin overcast or > 4/8 low cloud [4]	≤ 4/8 cloudiness
< 2	A	A - B	B	E	F
2 - 3	A - B	B	C	E	F
3 - 5	B	B - C	C	D	E
5 - 6	C	C - D	D	D	D
> 6	C	D	D	D	D

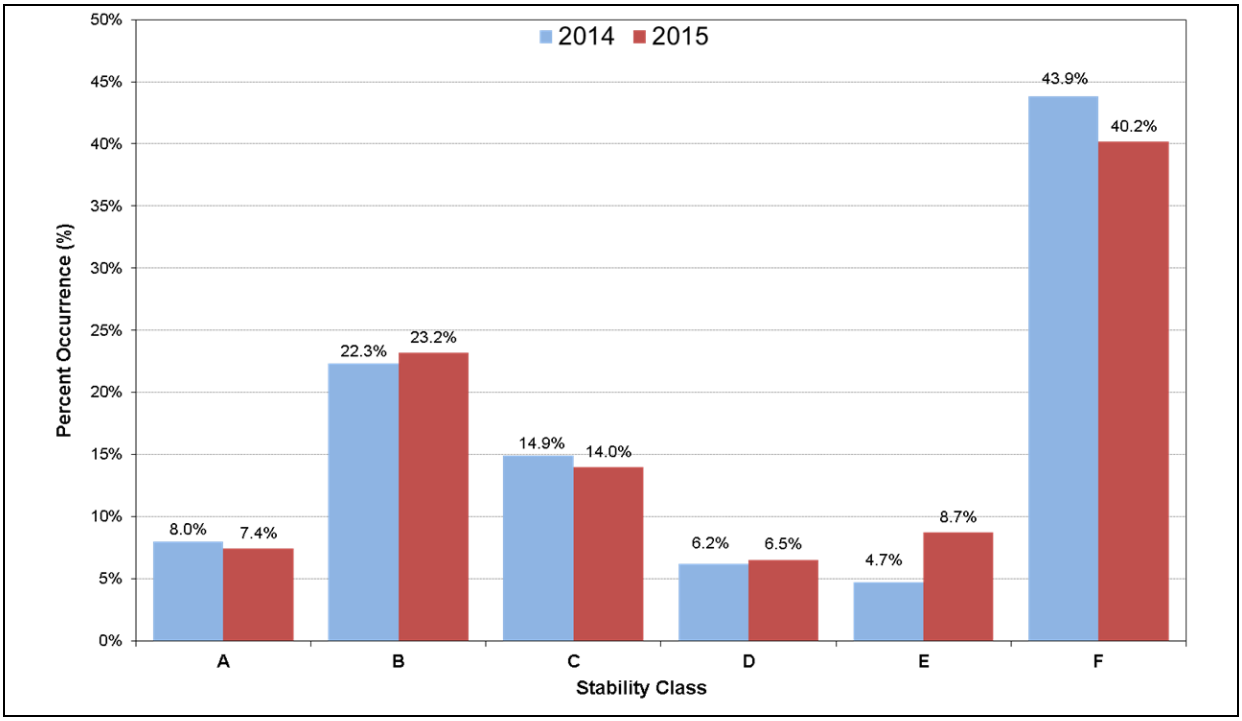
(Source: Pasquill, 1961)

Notes:

1. Strong insolation corresponds to midday on a sunny midsummer day; slight insolation corresponds to similar conditions in midwinter
2. Night refers to the period from 1 hour before sunset to 1 hour after sunrise
3. The neutral category D should also be used, regardless of wind speed, for overcast conditions during day or night and for any sky conditions during the hour preceding or following night as defined above
4. An 'okta' is a unit of measurement used to describe the amount of cloud cover at any given location. Sky conditions are estimated in terms of how many eighths of the sky are covered in cloud, ranging from 0 oktas (completely clear sky) through to 8 oktas (completely overcast). In addition, an extra cloud cover indicator of '9' can be used which indicates that the sky is totally obscured (i.e. hidden from view), usually due to dense fog or heavy snow

The frequencies of each stability class predicted by CALMET to occur in the 2014 and 2015 hourly datasets for the proposed CPF site are presented in **Figure 12**. The results indicate a relatively high frequency of stability class F conditions for both years. Stability class F is indicative of very stable night-time conditions (i.e. low winds), leading to a low level of mechanical mixing and poor dispersion. Stability class B (moderately unstable) conditions are predicted to occur 22% to 23% of the year. Stability class B is associated with low to moderate wind speeds and strong to moderate solar insolation, giving rise to a moderate level of atmospheric turbulence and mixing.

Figure 12 Predicted Stability Class Frequency Distributions for the CPF Site (CALMET)



6.1.1.3 Mixing Heights

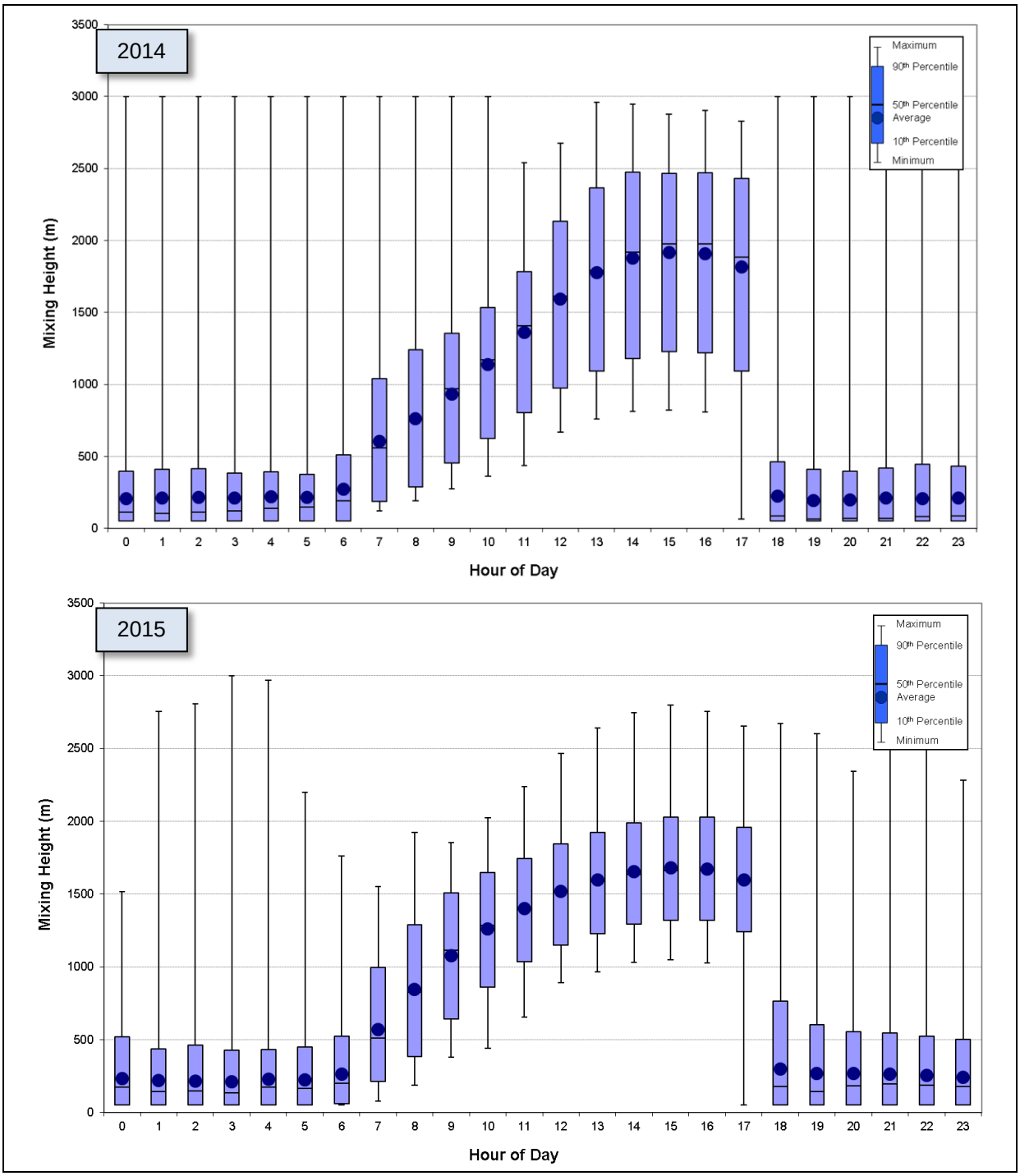
The term mixing height refers to the height of the turbulent layer of air near the earth's surface into which ground-level emissions will be rapidly mixed. A plume emitted above the mixed-layer will remain isolated from the ground until such time as the mixed-layer reaches the height of the plume. The height of the mixed-layer is controlled mainly by convection (resulting from solar heating of the ground) and by mechanically generated turbulence as the wind blows over the rough ground.

An analysis of the diurnal pattern in the mixing heights predicted at the proposed CPF site was performed and is presented in **Figure 13**. As would be expected, an increase in the mixing depth during the morning is apparent, arising due to the onset of vertical mixing following sunrise. Maximum mixing heights occur in the mid to late afternoon (approximately 3:00 PM at a height of around 1,700 - 1,900 m), due to the dissipation of ground-based temperature inversions and the growth of the convective mixing layer. In the early evening, the mixing height rapidly drops back to night-time levels. The data shown in **Figure 13** indicate that the model is adequately simulating the expected diurnal variation in mixing heights and is suitable for use in modelling the dispersion of emissions from the CPF site.

6.1.1.4 Rainfall, Relative Humidity and Temperature

The key parameters relating to the dispersion of air pollutants, wind direction, wind speed, stability class and mixing height are discussed in detail above. As discussed in **Section 3.2** and **Section 4.3**, the study area is characterized by high rainfall, high humidity and consistently warm temperatures year round. It is noted that rainfall is not included in the CALMET modeling file compiled for use in the air quality impact assessment.

Figure 13 Predicted Diurnal Variation in Mixing Height for the CPF Site (CALMET)



6.1.2 Existing Air Quality

As the background air quality will reflect the virtually ubiquitous absence of industrial sources, a baseline ambient air quality monitoring program has not been conducted. Highly localized exceptions, with very small zones of impact, would be limited to the area immediately surrounding Herd Base (where diesel-powered generators are currently operating), and locations immediately adjacent to unsealed roads currently used for logging operations, gas exploration activities and other local traffic, including river traffic (e.g. barges).

As the study area is remote from existing industrial pollution sources, the ambient air quality can be assumed to be generally good. Concentrations of gaseous pollutants (i.e., NO_2, SO_2, CO and VOCs) would be negligible compared to relevant international guidelines for ambient air quality and the study area would be regarded as a 'non-degraded' airshed in relation to IFC assessment requirements.

Similar to other air quality impact assessments performed for projects in PNG, background concentrations of particulate matter have been estimated by SLR as shown in **Table 12** based on our experience in the collection and review of TSP, PM_{10} and $PM_{2.5}$ monitoring data for other projects and with consideration given to the local land use and high rainfall in the study area. These values are similar to the levels assumed in the PNG LNG air quality impact assessment for upstream activities and the Hidden Valley Gold Mine air quality impact assessment (refer **Section 4.2.2**), and are below the air quality guidelines identified in **Section 2.2**. Long term (annual) average concentrations have been conservatively assumed to be at the maximum of the expected range. The 24-hour average concentrations have been assumed to be at the upper end of the range but not at the maximum, to avoid overestimating the cumulative impacts. This is because the probability of the worst case background levels occurring on the same day as the worst case impacts from the Project is low.

As noted above, baseline concentrations of gaseous pollutants (i.e., NO_2, SO_2, CO and VOCs) are assumed to be negligible (i.e., 0 µg/m^3) compared to international ambient air quality criteria presented and discussed in **Section 2.2**.

Table 12 Estimated Baseline Particulate Concentrations

Pollutant	Averaging Period	Range of Background Particulate Concentrations Expected to Occur in the Study Area (µg/m^3)	Background Concentration Assumed (µg/m^3)
TSP	24-hours	10 – 70	50
	Annual	20 – 40	40
PM_{10}	24-hours	5 – 35	25
	Annual	10 – 15	15
$PM_{2.5}$	24-hours	2 – 20	15
	Annual	5 – 8	8

6.2 Onshore Pipeline Corridor

6.2.1 Meteorology

The topography, elevation and vegetation vary significantly along the 70 km long upstream export pipeline corridor. This will result in changes in local wind patterns and other meteorological features relevant to pollutant dispersion.

Potential air quality impacts related to the onshore export pipeline corridor will be associated with dust emissions during construction and air emissions during the operational phase will be negligible. Fugitive dust emissions from construction activities will be emitted at ground level, with little or no upward momentum or plume buoyancy. Their dispersion will therefore be limited to a localized area surrounding the active work area and the long range transport of dust emissions will not be a significant consideration. The key meteorological parameters that will influence the dispersion of pollutants during the construction works will therefore be wind speed and wind direction.

Wind speed and wind direction data have been extracted from the outer CALMET model domain (see **Figure 6**) at a location 9.5 km southeast of Evara, 9.8 km north of Aivai and 3 km east of the Wame and Varoi rivers. These data are presented below as an indication of the conditions that may be anticipated along the corridor.

A wind rose showing the wind data predicted by the modeling along the onshore export pipeline corridor is presented in **Figure 14**. **Figure 14** indicates that during the modeled years, 2014 and 2015, the area experienced mainly light to moderate winds (less than 5 m/s), with predominant winds from the northern and southeastern quadrants. Calm wind conditions (wind speeds less than 0.5 m/s) were predicted to occur 2.6% to 3% of the time. The predominant wind directions predicted at this location are more varied than at the CPF site and the winds are slightly stronger.

The predicted wind speed frequency plot presented in **Figure 15** further illustrates that the area predominantly experienced low to moderate wind speeds during 2014 and 2015, with a very low frequency of high wind speeds (>8 m/s).

Figure 14 Wind Roses for the Onshore Pipeline Midpoint (CALMET)

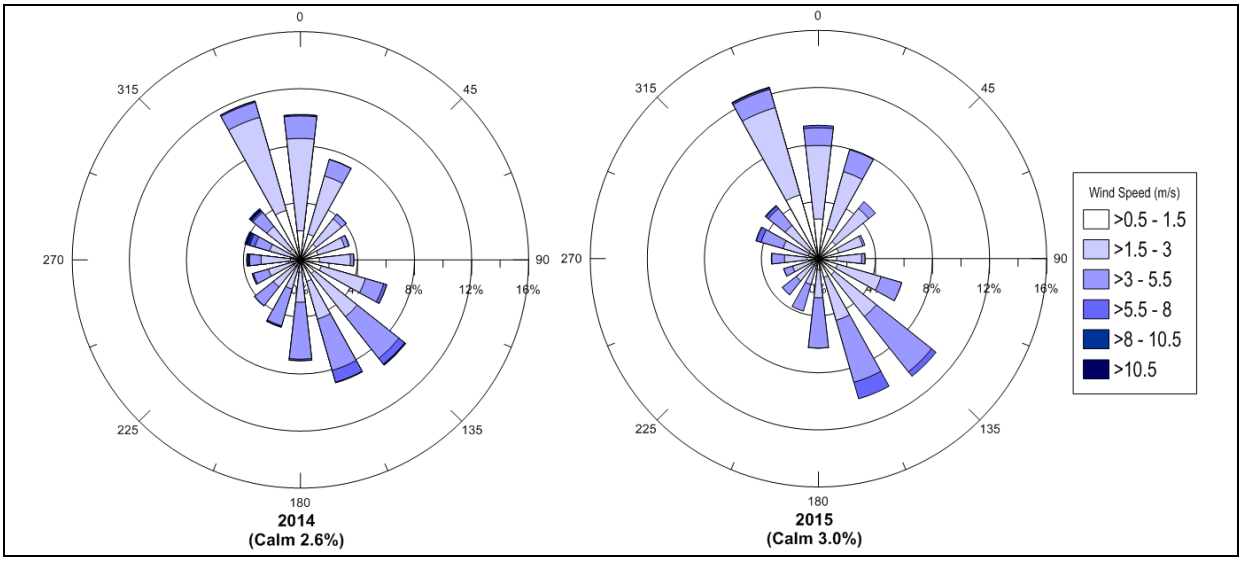
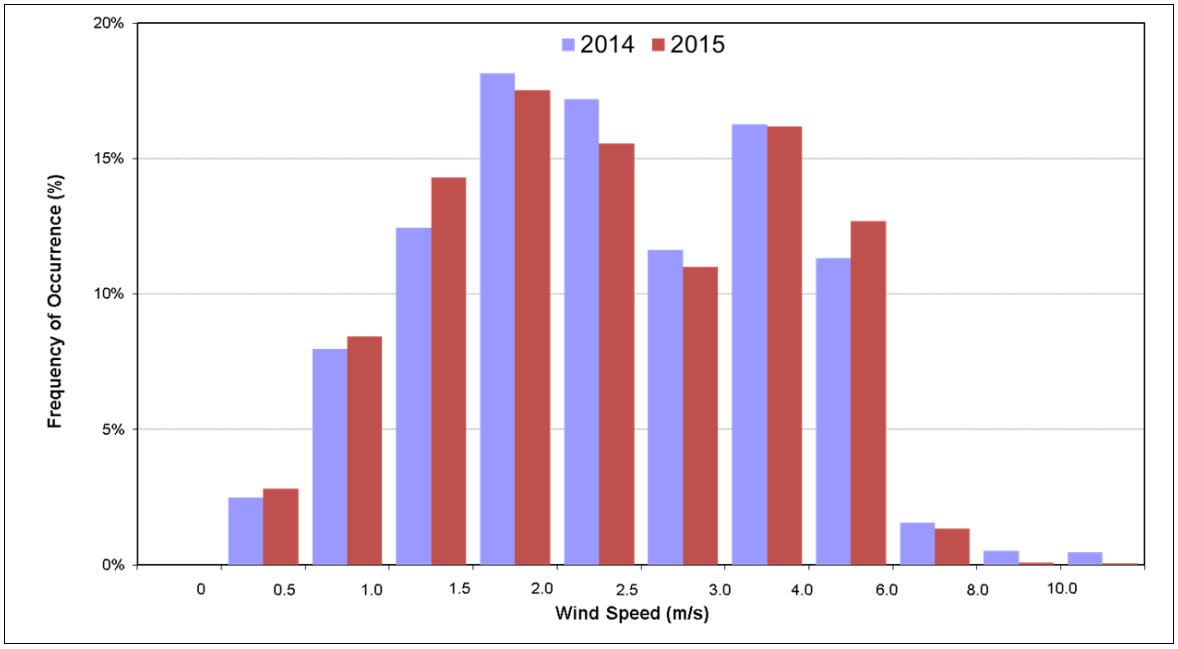


Figure 15 Predicted Wind Speed Frequency Distributions – Onshore Pipeline Midpoint (CALMET)



6.2.2 Existing Air Quality

As per the production, processing and related facilities, the onshore export pipeline corridor is remote from existing industrial pollution sources and the ambient air quality can be assumed to be generally good with concentrations of gaseous pollutants (i.e. NO_2, SO_2, CO and VOCs) negligible and below the air quality guidelines identified in **Section 2.2**.

Background levels of particulate matter are also expected to be low; however they would not be negligible. It is expected that baseline particulate levels might be higher near the coast where there is a greater concentration of villages, than inland along the more remote sections of the corridor. The same background TSP, PM_{10} and $PM_{2.5}$ concentrations assumed for the production, processing and related facilities are considered appropriate for the onshore export pipeline corridor, which are below the air quality guidelines identified in **Section 2.2**.

6.3 Transport River Corridor

6.3.1 Meteorology

The discussion presented in **Section 6.2.1** is also relevant for the transport river corridor.

6.3.2 Existing Air Quality

The discussion presented in **Section 6.2.2** is also relevant for the transport river corridor. Air emissions from existing boat transport activities along the rivers would not be anticipated to significantly impact on air quality at sensitive receptor locations along the transport river corridor and as a result baseline concentrations of gaseous pollutants can be assumed to be negligible and below the air quality guidelines identified in **Section 2.2**. The same background TSP, PM_{10} and $PM_{2.5}$ concentrations assumed for the production, processing and related facilities are considered appropriate for the transport river corridor, which are below the air quality guidelines identified in **Section 2.2**.

6.4 Offshore Export Pipeline

6.4.1 Meteorology

As discussed in **Section 5.1.1**, there is no significant potential for air quality impacts associated with the construction or operational phases of this component of the Project. No modeling or detailed analysis of the meteorology experienced along the offshore export pipeline corridor has therefore been performed.

6.4.2 Existing Air Quality

The existing air quality along the offshore export pipeline corridor can be expected to be very good, with potential for low levels of particulate concentrations associated with the transport of dust from the mainland by offshore winds and salt spray. All other baseline pollutant concentrations can be expected to be negligible.

7 CONCLUSIONS

The air quality baseline study has:

- Identified/summarized the key values of the air quality environment in the study area, with the potential risks to these values to be assessed in the Project impact assessment.
- Defined the study area for the air quality baseline characterization that would also support an impact assessment.
- Identified existing potentially sensitive receptors within the study area.
- Characterized the meteorological patterns in the study area with the potential to impact on the generation and dispersion of air emissions from the Project.
- Characterized the existing ambient air quality to enable an estimation of background concentrations of relevant air pollutants anticipated to be emitted by the Project to allow an assessment of potential cumulative impacts.

A review of available meteorological data has shown that the study area is characterized by high rainfall, high humidity and consistently warm temperatures year round. Average monthly wind speeds are consistently low at around 2 m/s, with a low frequency of stronger winds (up to 11 m/s as a 10-minute average) recorded. Wind speeds are highest during October to January, which is the start of the northwest monsoon season.

A detailed meteorological modeling study has been performed using the WRF and CALMET models to compile site representative 3-dimensional meteorological files (2014 and 2015 calendar years) suitable for use in an atmospheric dispersion model for the CPF site. A review of the resulting dataset and validation against observational data from Wabo has shown that it satisfactorily resolves the complex topographical influences on wind channeling and downslope flows within the study area around the CPF site and will be suitable for use in the atmospheric dispersion modeling study to be performed as part of the air quality impact assessment.

The results of the modeling indicate that during the modeled years (2014 and 2015), the CPF site experienced mainly light to moderate winds (less than 5 m/s), with winds from the northeastern quadrant predominating. Calm wind conditions (wind speeds less than 0.5 m/s) were predicted to occur 4% to 5% of the time. A relatively high frequency of stability class F conditions was predicted at the CPF site, which is associated with very stable night-time conditions (i.e. low winds) and a low level of mechanical mixing (poor dispersion). There were no significant differences in the meteorological parameters most relevant to pollutant dispersion (wind speed, wind direction, stability class and mixing height) in the 2014 and 2015 datasets, even though 2015 was associated with a drought period.

Wind patterns and other variables such as temperature and rainfall will vary along the onshore export pipeline corridor due to changes in topography and elevation. Wind data predicted by the modeling at the mid-point along the onshore pipeline corridor indicates that this area experiences more varied wind directions compared to the CPF site and the winds are slightly stronger.

As the study area and identified sensitive receptors are remote from existing industrial pollution sources, the ambient air quality across the entire study area can be assumed to be generally good and would be regarded as a ‘non-degraded’ airshed in relation to IFC assessment requirements. Concentrations of gaseous pollutants would be negligible compared to relevant international guidelines for ambient air quality. Background levels of particulate matter are also expected to be low given the high rainfall, low wind speeds and dense vegetation in the area; however they would not be negligible. Similar to other air quality impact assessments performed in the region, background concentrations of particulate matter (TSP, PM_{10} and $PM_{2.5}$) have been estimated by SLR based on our experience in the collection and review of monitoring data and with consideration given to the local land use and high rainfall in the study area. These levels are below the relevant international guidelines for particulate matter.

8 STUDY TEAM

Kirsten Lawrence	Kirsten was Project Manager for this study, providing technical oversight, contributing to report preparation, and performing internal peer review.
Fardausur Rahaman	Fardaus was responsible for the meteorological modeling study (WRF and CALMET), model validation and related data analysis. He also prepared the report sections relevant to these aspects of the study.

9 GLOSSARY AND ABBREVIATIONS

9.1 Glossary

air dispersion model	A computer-based software program which provides a mathematical prediction of how pollutants from a source will be distributed in the surrounding area under specific conditions of wind, temperature, humidity and other environmental factors
airshed	The geographical area associated with a given air supply
algorithms	A step-by-step problem-solving procedure, especially an established, recursive computational procedure for solving a problem in a finite number of steps
ambient	Pertaining to the surrounding environment or prevailing conditions
atmosphere	A gaseous mass surrounding the planet Earth that is retained by Earth's gravity. It is divided into five layers. Most of the weather and clouds are found in the first layer
atmospheric stability	The tendency of the atmosphere to resist or enhance vertical motion
background	The existing air quality in the study area excluding the impacts from the proposed development
baseline monitoring program	A monitoring program designed to measure the ambient concentration levels which currently exist prior to the proposed development
CALMET	A meteorological model that develops wind and temperature fields on a 3-dimensional gridded modeling domain
CALPUFF	A transport and dispersion model that advects ‘puffs’ of material emitted from modeled sources, simulating dispersion and transformation processes
combustion	The process of burning. A chemical change, especially oxidation, accompanied by the production of heat and light
commissioning	A systematic process of ensuring that a new facility performs according to the documented design intent and the owner’s operational needs, and that specified system documentation and training are provided to the facility staff
decommissioning	Planned shut-down or removal of a building, equipment, plant, etc., from operation or usage
dust deposition	Settling of particulate matter out of the air through gravitational effects (dry deposition) and scavenging by rain (wet deposition)
dispersion	The spreading and dilution of substances emitted in a medium (e.g. air or water) through turbulence and mixing effects
diurnal	Relating to or occurring in a 24-hour period; daily

downwind	The direction in which the wind is blowing
fugitive emissions	Pollutants which escape from an industrial process due to leakage, materials handling, transfer, or storage
guideline	A general rule, principle, or piece of advice. A statement or other indication of policy or procedure by which to determine a course of action.
insolation	The amount of solar radiation reaching a given area
mechanical mixing	Atmospheric turbulence due to wind shear and obstacles, which predominates at night-time
meteorological	The science that deals with the phenomena of the atmosphere, especially weather and weather conditions
mixing height	The height to which the lower atmosphere will undergo mechanical or turbulent mixing, producing a nearly homogeneous air mass
modeling domain	The area over which the model is making predictions
particulate	Of, relating to, or formed of minute separate particles. A minute separate particle, as of a granular substance or powder
Pasquill stability class	Scheme for categorizing atmospheric stability which is the tendency of the atmosphere to resist or enhance vertical motion
plume	A space in air, water, or soil containing pollutants released from a point source
point source	A pollution source that is fixed and/or uniquely identifiable, such as a stack, chimney, outlet pipe or vent
pollutant	A substance or energy introduced into the environment that has undesired effects, or adversely affects the usefulness of a resource
sensitive receptor	Locations such as residential dwellings, hospitals, churches, schools, recreation areas etc. where people (particularly the young and elderly) may often be present, or locations with sensitive vegetation and crops
solar radiation	The total electromagnetic radiation emitted by the Sun
standard	The prescribed level of a pollutant in the outside air that should not be exceeded during a specific time period to protect public health
topography	Detailed mapping or charting of the features of a relatively small area, district, or locality
volatile organic compounds	All organic compounds (substances made up of predominantly carbon and hydrogen) with boiling temperatures in the range of 50-260°C, excluding pesticides. This means that they are likely to be present as a vapor or gas in normal ambient temperatures.

wind direction	The direction from which the wind is blowing
wind erosion	Detachment and transportation of loose topsoil or sand due to action by the wind
wind rose	A meteorological diagram depicting the distribution of wind direction and speed at a location over a period of time

9.2 Abbreviations

%	percent
°C	degrees Celsius
µg	microgram
$\mu g/m^3$	microgram per cubic meter
asl	above sea level
BTEX	benzene, toluene, ethylbenzene, xylene
CEPA	Conservation and Environment Protection Authority (PNG)
CO	carbon monoxide
CPF	central processing facility
EC	European Commission
EIS	Environmental Impact Statement
EHS	Environmental Health and Safety
ELV	emission limit value
ENSO	El Niño-Southern Oscillation
FNL	GFS final analysis data
GDAS	Global Data Assimilation System
GIIP	good international industry practice
g	gram
GFS	Global Forecast System
g/m^2/month	grams per square meter per month
GSM	global spectral model
H_2S	hydrogen sulfide
IFC	International Finance Corporation
km	kilometer
LNG	liquefied natural gas
m^2	square meter
m^3	cubic meter
mm	millimeter
m/s	meters per second
NCEP	National Centers for Environmental Prediction (USA)
NO_2	nitrogen dioxide
NO_X	oxides of nitrogen
NSW OEH	New South Wales Office of the Environment and Heritage (Australia)
OAQPS	Office of Air Quality Planning and Standards (USA)
O_3	ozone
PAHs	polyaromatic hydrocarbons

PM_{10}	particular matter with an equivalent aerodynamic diameter of 10 microns or less
$PM_{2.5}$	particular matter with an equivalent aerodynamic diameter of 2.5 microns or less
PNG	Papua New Guinea
ppb	parts per billion (10^9)
PRL-15	Petroleum Retention License 15
SO_2	sulfur dioxide
SRTM3	Shuttle Radar Topography Mission 3
TSP	total suspended particulate matter
USA	United States of America
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
WHO	World Health Organization
WRF	Weather Research and Forecasting Model

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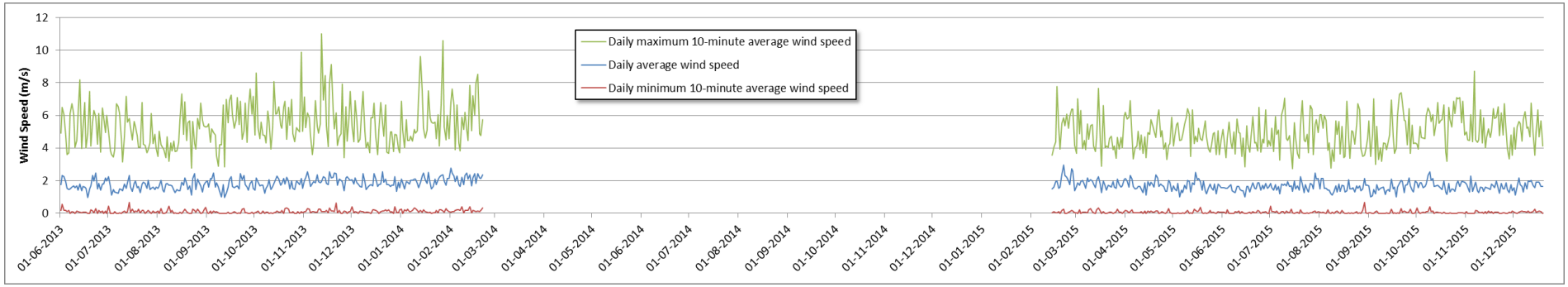
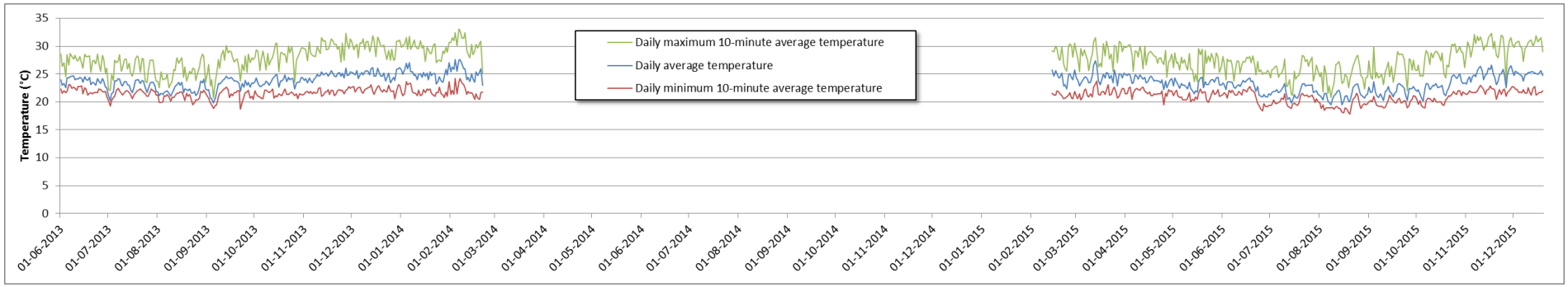
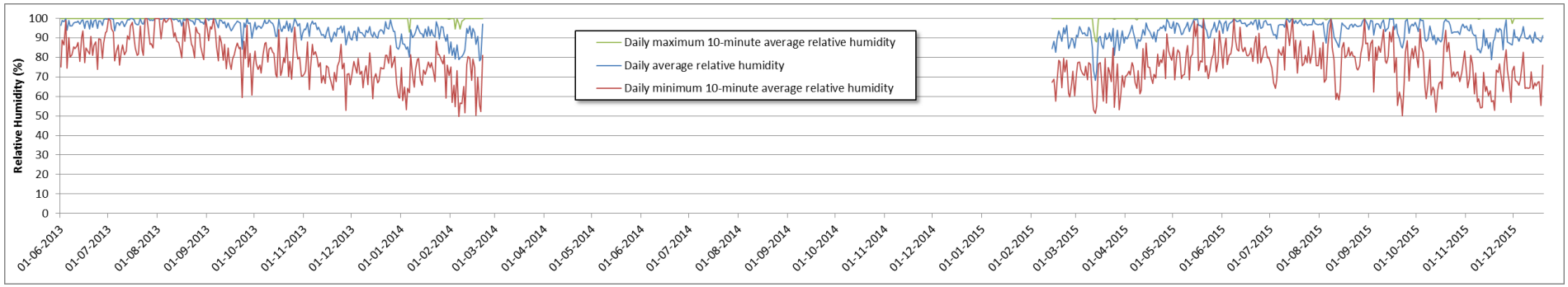
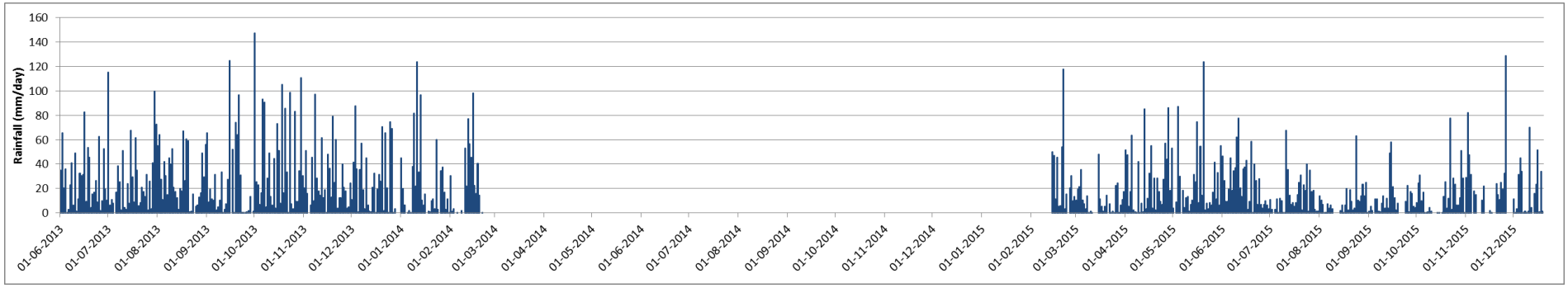
Appendix A – WABO METEOROLOGICAL DATA

Wabo Meteorological Data








Rainfall (mm/day)
160
140
120
100
80
60
40
20
0
01-06-2013
01-07-2013
01-08-2013
01-09-2013
01-10-2013
01-11-2013
01-12-2013
01-01-2014
01-02-2014
01-03-2014
01-04-2014
01-05-2014
01-06-2014
01-07-2014
01-08-2014
01-09-2014
01-10-2014
01-11-2014
01-12-2014
01-01-2015
01-02-2015
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