Report

Port of Brisbane PM2.5 Air Quality Modelling

Document Control Number: AQU-QD-004-21193

Date: 23 January 2017

Pacific Environment Limited

Technologies Consulting Monitoring

www.pacific-environment.com

Project Name: Port of Brisbane PM2.5 Air Quality M

Document Control Number: AQU-QD-004-21193

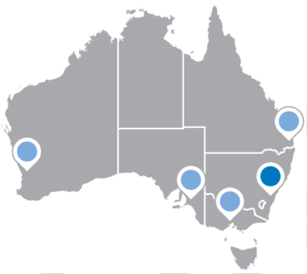
Prepared For: Port of Brisbane

Approved For Release By: Bethany Warren

Disclaimer & Copyright:

Document Control

Version	Date	Comment	Prepared by	Reviewed by
0	15.11.2016		Rebecca Chalmer Bethany Warren	Johan Meline
1	12.12.2016		Bethany Warren	
2	23.01.2017		Bethany Warren	



Adelaide

35 Edward Street,
Norwood SA 5067
PO Box 3187, Norwood SA 5067
Ph: +61 8 8332 0960
Fax: +61 7 3844 5858

Brisbane

Level 19, 240 Queen Street
Brisbane Qld 4000
Ph: +61 7 3004 6400
Fax: +61 7 3844 5858

Melbourne

Level 10, 220 Queen Street
Melbourne Vic 3000
Ph: +61 3 9036 2637
Fax: +61 2 9870 0999

Perth

Level 1, Suite 3
34 Queen Street, Perth WA 6000
Ph: +61 8 9481 4961
Fax: +61 2 9870 0999

Sydney Head Office

Suite 1, Level 1, 146 Arthur Street
North Sydney, NSW 2060
Ph: +61 2 9870 0900
Fax: +61 2 9870 0999

Disclaimer

Pacific Environment acts in all professional matters as a faithful advisor to the Client and exercises all reasonable skill and care in the provision of its professional services.

Reports are commissioned by and prepared for the exclusive use of the Client. They are subject to and issued in accordance with the agreement between the Client and Pacific Environment. Pacific Environment is not responsible for any liability and accepts no responsibility whatsoever arising from the misapplication or misinterpretation by third parties of the contents of its reports.

Except where expressly stated, Pacific Environment does not attempt to verify the accuracy, validity or comprehensiveness of any information supplied to Pacific Environment for its reports.

Reports cannot be copied or reproduced in whole or part for any purpose without the prior written agreement of Pacific Environment.

Where site inspections, testing or fieldwork have taken place, the report is based on the information made available by the client or their nominees during the visit, visual observations and any subsequent discussions with regulatory authorities. The validity and comprehensiveness of supplied information has not been independently verified and, for the purposes of this report, it is assumed that the information provided to Pacific Environment is both complete and accurate. It is further assumed that normal activities were being undertaken at the site on the day of the site visit(s), unless explicitly stated otherwise.

Executive Summary

Port of Brisbane Pty Ltd engaged Pacific Environment to perform an air quality assessment of Port of Brisbane's $PM_{2.5}$ emission sources and predict how $PM_{2.5}$ ground level concentrations may change in the future. Four emission scenarios considered were:

- Base Case
- Year 2025
- Year 2035
- Year 2035 – High Technology

Previously determined emissions were used for this assessment and updated, if required, with current understanding of activities and emissions factors. For sources not included in the previous assessment, emissions were estimated using generalised activity data and industry emission factors. Background sources were determined using available monitoring data.

The TAPM/CALMET/CALPUFF atmospheric dispersion modelling system was used to predict ground level particulate matter concentrations. This methodology is consistent with other modelling studies of international ports. Model validation was performed using the PM_{10} model results and monitoring data.

The modelling predicted no exceedances of the $PM_{2.5}$ assessment criteria at any residential receptors for any of the scenarios. The $PM_{2.5}$ maximum 24-hour average and annual average concentration contours show an area exceeding the assessment criteria near the port ship loading areas and major heavy duty truck thoroughfares. The area exceeding the criteria is predicted to increase in size for the Year 2025 and again for the Year 2035 scenario. The exceedance contour is significantly decreased for the Year 2035 – High Technology scenario. This result indicates that $PM_{2.5}$ emission reduction programs implemented at the port should result in decreased concentrations in the future.

The model source apportionment results show that the largest contributing source for the five days with highest predicted $PM_{2.5}$ concentrations is background concentrations. This result is similar to the results from the source contribution measurement study from 2013, which showed that mass contribution from sources other than shipping exhaust and landside diesel emissions could be as high as 99% on days with elevated concentrations.

It is recommended to use the recently installed $PM_{2.5}$ monitoring network to confirm the models overall predictions. After a year of valid monitoring data, that the statistics be reviewed and compared to modelling results. If the monitoring results differ significantly from the model, then the model assumption should be reviewed and updated to ensure the most accurate predictions. It is also noted that the Queensland Department of Science, Information Technology and Innovation (DSITI) is currently developing a port emissions inventory. If this inventory results in different emission estimates than considered in the modelling, we recommend updating the model results accordingly.

Once the $PM_{2.5}$ model has been validated with both the DSITI emissions inventory and the $PM_{2.5}$ monitoring data, it is recommended that a $PM_{2.5}$ emissions reduction program be developed and implemented across the port.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Background

Port of Brisbane Pty Ltd (PBPL) engaged Pacific Environment to perform an air quality assessment of the ports fine particulate matter[a] emission sources. PBPL has commissioned several studies to understand the air quality impacts from their port operators, shipping, and transport corridors. The objective of this study is to understand the current dispersion of the port emission sources and how the ground level concentration may change in future scenarios.

1.2 Previous Studies

In 2009, a landside and waterside air emission inventory was developed. The inventory showed that diesel combustion from the cargo handling equipment, heavy duty diesel trucks and trains was the primary source (>70%) of fine particulate matter ($PM_{2.5}$) emissions from landside activities. However, the waterside emissions from the combustion of fuel on ships and vessels significantly dwarf the landside emissions, contributing over 90% of the total $PM_{2.5}$ emissions. The emission inventory did not consider the port operators industrial emissions, nearby diffuse sources or biogenic emission sources, such as sea spray or open area wind erosion.

In 2012, PBPL undertook a monitoring campaign to better understand the actual source contribution of particulate matter concentrations at the Port of Brisbane (PoB). The primarily identified sources were sea spray, landside diesel exhaust emissions and the other crustal dust sources at PBPL, such as wind erosion and wheel generated dust. Emissions from marine vessel exhausts were not identified as a significant contributor to ground level concentrations. This finding may seem contrary to what the original emission inventory indicated, but it is not as only a small portion of the shipping emissions occur at berth and the majority of the emissions will be well dispersed prior to reaching land.

1.3 Current Monitoring

In addition to the previous air quality studies, PBPL installed a real-time ‘dust’ monitoring network in June 2013. The monitoring network consists of three locations with real-time PM_{10}[b] monitors, as shown in Figure 1.1.

The aim of the monitoring program, as stated by PBPL, is to determine if the emissions from the PBPL operations is causing a unacceptable impact to the neighbouring areas. In relation to determining this it is noted that the monitors capture both the PBPL operator emissions and background emission sources, such as sea spray, bush fires, re-entrained material from wind erosion, and general diffuse emissions from the local community. The data for each site is calculated and compared against the National Environmental Protection (Ambient Air Quality) Measure air quality standard of 50 µg/m³ for a 24-hour average.

[a] $PM_{2.5}$ is particles with an aerodynamic diameter less than 2.5 µm.

[b] PM_{10} is particles with an aerodynamic diameter less than 10 µm.

PBPL investigates when the monitoring data shows 24-hour averages above the air quality standard to determine if there was an event or emission source that could be further controlled to prevent further elevated measurements or whether the exceedance was due background sources. Often the cause of elevated measurements are from background sources not related to PBPL activities.

Figure 1.1: *Locations of PBPL PM_{10} Monitors*

1.4 Scope of Work

The scope of work for this air quality assessment included:

- Establishing the port wide dust emissions, including other relevant sources not contained in the previous landside and waterside emission inventories.
- Performing 3-D meteorological modelling for a meteorological representative year.
- Dispersion modelling of port and background sources.
- Determining model validation with monitoring data.
- Using the dispersion model results to forecast future air quality based on PBPL operations projections.
- Providing the methodology, results and recommendations in a report appropriate for the use of PBPL.

1.5 Study Objective

The purpose of this study is to better understand the source of PBPL fine particulate emissions and how these emissions contribute to ground level concentrations at PBPL and at nearby receptors. In particular, the objective of the study is to better understand the role of waterside emissions in PBPL contributions to the ground level concentrations in the community.

2. Update of Emissions Inventory

Particulate matter emissions were estimated for all emission sources at the PBPL. The PBPL emission sources and general assumptions applied in the modelling are summarised in Table 2.1. Detailed activity data and emission estimation methodology are provided in Appendix A.

A total of four scenarios were modelled for the PBPL Operations. The assumptions associated with each scenario described in each section:

- Base Case (Section 2.1)
- Year 2025 (Section 2.2)
- Year 2035 (Section 2.2)
- Year 2035 – High Technology (Section 2.3)

Background particulate matter concentrations were determined using monitoring data and were kept constant for all assessment scenarios. Section 2.4 describes how the background concentrations were determined.

Table 2.1: Summary of *Emissions Source Types and Modelling Assumptions*

Emission Source	Source Type	Assumptions
Truck Emissions	Area source	Truck idling emissions included in CHE emissions.
Rail Emissions	Volume source	
Cargo Handling Equipment (CHE) Emissions	Area source for outdoor operations Volume source for indoor operations	
Shipping Emissions	Area source	All shipping emissions occur within the domain for conservatism. Shipping emissions divided into the different operation types.
Materials Handling Emissions	Area source for handling operations Volume source for loading and unloading operations	
Wind Erosion Emissions	Area source	Emissions from materials stored on site only (i.e. coal stockpiles, cement stockpiles, etc.)
Background Concentrations (sea spray, open area wind erosion and nearby diffuse sources)	Not applicable	Same value assumed across whole grid. Further discussed in Section 2.4.

2.1 Base Case

Where possible, previously determined emissions were used for this assessment. The emissions were sourced from the landside and waterside emission inventories by Pacific Environment (previously PAEHolmes) and AMCSearch, respectively. The activity rates provided in the landside (shipping) and waterside (rail, trucks and CHE) emission inventories were assumed to be the same as estimated in 2009. The materials handling emissions estimates were based on the NPI emissions estimates (NPI, 2016) and calculated using annual handling rates and US EPA AP-42 Chapter 9.9.1 Grain Elevators and Processed (US EPA, 2003). The wind erosion emissions were estimated based NPI emissions estimates (NPI, 2016) or the NPI EET Manual for Mining V3.1 (DSEWPaC, 2012).

If required, the emission estimates were updated to be in-line with the current understanding of activities and emissions factors. The Base Case emission sources and modifications for each PBPL source is described in Table 2.2.

The resulting base case $PM_{2.5}$ emissions and the apportionment to each source is shown in Figure 2.1. This figure shows that shipping emissions are the highest contributor to the emissions inventory. This is largely due to the large sea area the shipping inventory considers. One objective of the dispersion modelling is to understand if this large source is contributing significantly to the ground level concentration in the community. It is noted that the monitoring study conducted in 2013 did not measure a significant mass of $PM_{2.5}$ from shipping exhaust (Pacific Environment. 2013).

Table 2.2: *Base Case Emission Sources*

Emission	Source
Truck Emissions	Landside Emissions Inventory (PAEHolmes, 2009) Emissions were scaled to reflect the updated emission factors for the Australian vehicle fleet (*COPERT Australia* 1.2). The scaling factor (3.8) was determined based on comparison of the emission factors for the two most prevalent vehicles in the PBPL inventory.
Rail Emissions	Landside Emissions Inventory (PAEHolmes, 2009)
Cargo Handling Equipment (CHE) Emissions	Landside Emissions Inventory (PAEHolmes, 2009)
Shipping Emissions	Waterside Emissions Inventory (AMCsearch Ltd, 2009)
Materials Handling Emissions	NPI Emissions Estimates, NPI Emission Estimation Techniques Manuals, AWMA Air Pollution Engineering Manual and US EPA AP-42
Wind Erosion Emissions from Stored Materials	NPI Emissions Estimates and NPI Emission Estimation Techniques Manual
Background Concentrations (sea spray, open area wind erosion and nearby diffuse sources)	Daily values based on monitoring data. Further discussed in Section 2.4.

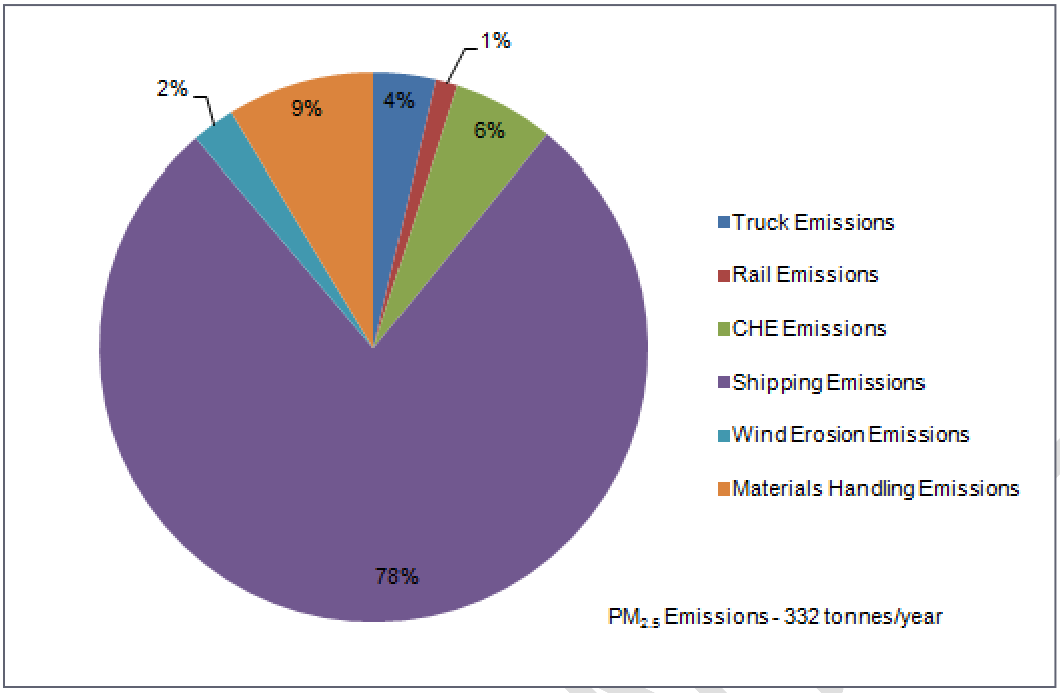


Figure 2.1: *Base Case Scenario $PM_{2.5}$ Emission Inventory Source Contribution*

2.2 Year 2025 and 2035

Emissions for the future scenarios were estimated using a scaling factor for each emission source. The 2025 and 2035 scenario scaling factors were estimated using the same method assuming that emissions increase with the projected activity data along with the general trends associated with emission reduction technology. For example, automation of cargo handling equipment has been included in the future projections. Projected operations were provided by PBPL (PBPL, 2016A, PBPL, 2016B, PBPL, 2016C). Table 2.3 lists the activity and data the emission projections were based on.

The Year 2025 and 2035 $PM_{2.5}$ emissions and the apportionment to each source are summarised in Figure 2.2 and Figure 2.3. As with the Base Case these figures show that shipping emissions are the highest contributor to the emission inventories. The inventories shows that $PM_{2.5}$ emissions are projected to increase by 15% in the Year 2025 and 30% by the Year 2035 from the Base Case.

Table 2.3: *Future Emissions Estimation Scaling Sources*

Emission	Projected Information Source
Truck Emissions	Projected Truck Data for the Port of Brisbane (PBPL, 2016A)
Rail Emissions	Projected based on projected TEU and projected materials handling rates (PBPL, 2016C)
Cargo Handling Equipment (CHE) Emissions	Projected based on rail projections
Shipping Emissions	Linearly extrapolated from data provided by Port of Brisbane (PBPL, 2016B)
Materials Handling Emissions	Projected based on shipping data (PBPL, 2016)
Wind Erosion Emissions from Stored Materials	No change from Base Case
Background Concentrations (sea spray, open area wind erosion and nearby diffuse sources)	No change from Base Case (see Section 2.4)

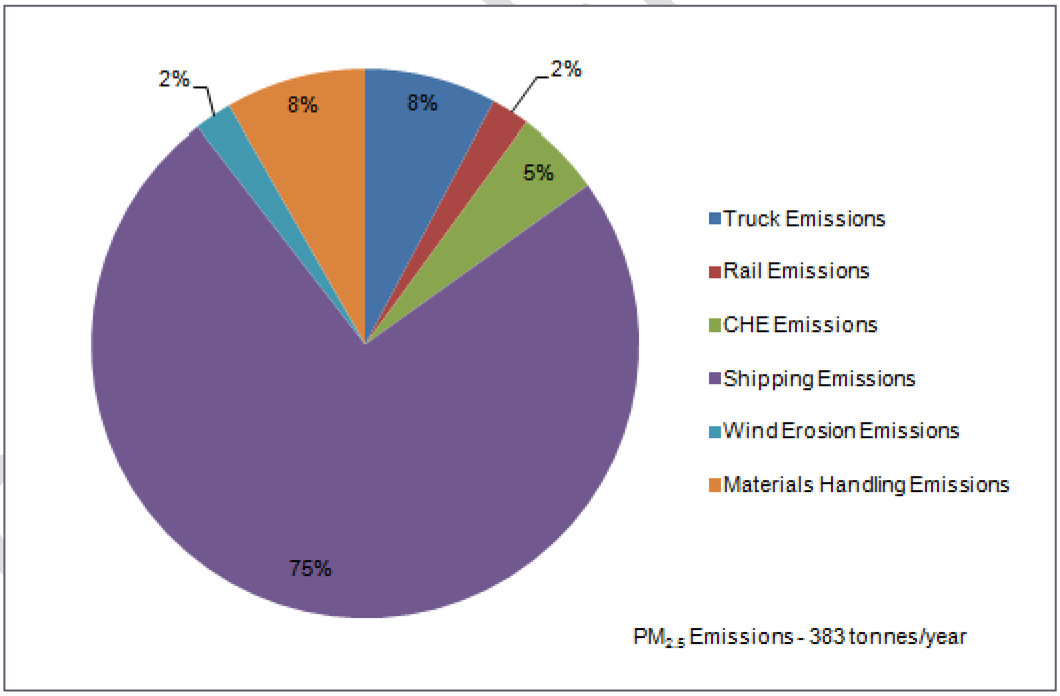


Figure 2.2: Year *2025 Scenario $PM_{2.5}$ Emission Inventory Source Contribution*

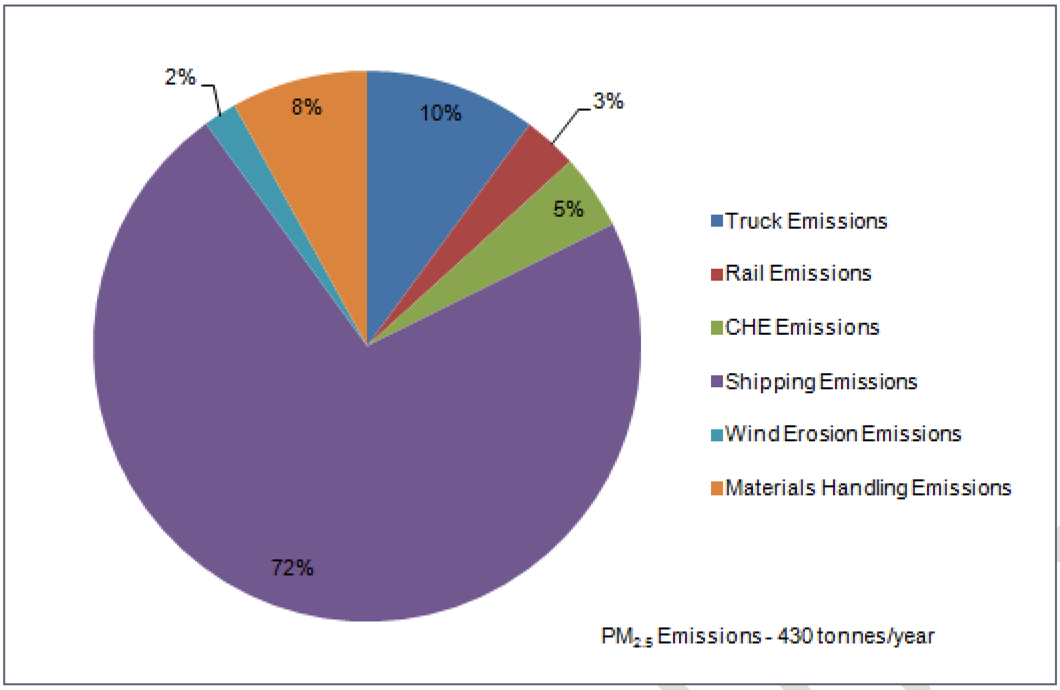


Figure 2.3: Year *2035 Scenario $PM_{2.5}$ Emission Inventory Source Contribution*

2.3 Year 2035 – High Technology

To understand the potential emissions reduction from improvements in future technology, a scenario was considered where emissions control technology was used at PBPL. The technology was selected based on what other ports currently use or are in process of implementing. The following assumptions were selected to represent the 2035 high technology scenario:

- Cargo Handling Equipment – 90% Electric and 10% Diesel
- Shipping –
  - 100% of ships plug in at berth (i.e. auxiliary engines not used so no emission during hoteling)
  - 25% of ships burning LNG in ship lanes
  - 75% of ships burning low sulphur distillates in ship lanes
- Rail – 50% electric
- Trucks – Heavy duty trucks move to EU Tier VI and US EPA 2015 PM standards

It was assumed that materials handling emissions, wind erosion from stored materials and background concentrations would remain the same as for Year 2035.

The resulting Year 2035 – High Technology $PM_{2.5}$ emissions and the apportionment to each source is shown in Figure 2.4. This figure shows a significantly different trend total emission (72% less than Base Case) and in source apportionment. Due to the ships using electricity at Berth and the use of LNG, the $PM_{2.5}$ emission from shipping activity is no longer the overwhelming source of emissions. Since no improvements in technology was assumed for materials handling, this source is now the large component of the total emissions, even though its quantity hasn't changed from the Year 2035 emissions.

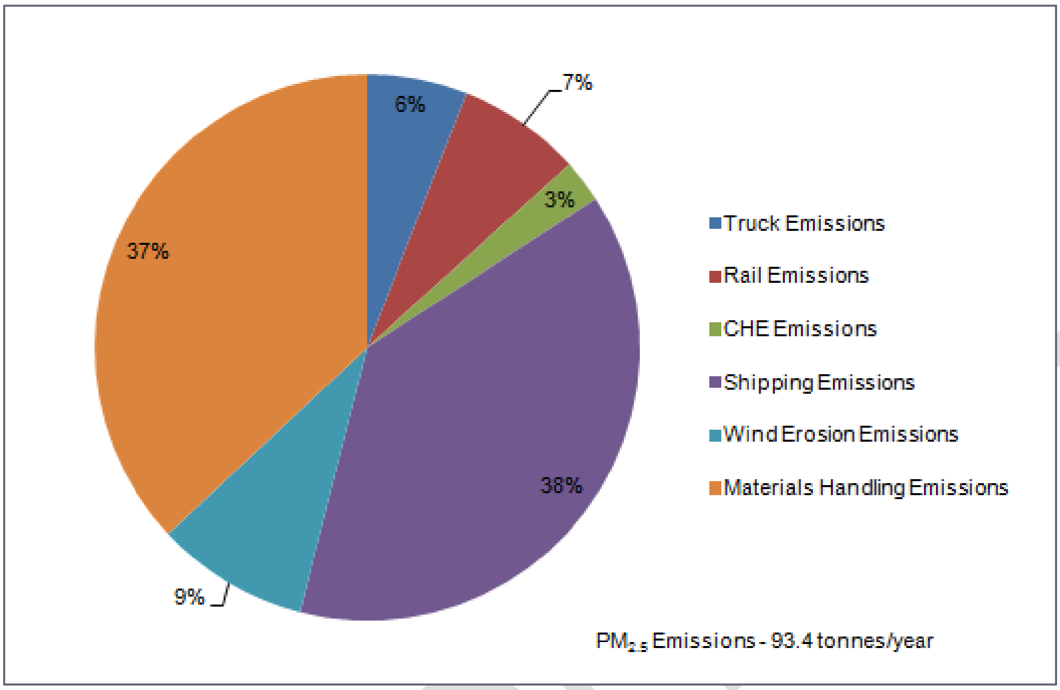


Figure 2.4: Year *2035 High Tech Scenario $PM_{2.5}$ Emission Inventory Source Contribution*

2.4 Background Concentrations

Background concentrations from sea spray and nearby diffuse emissions sources were determined using the monitoring and modelling data. The modelled 24-hour averaged PM_{10} concentrations resulting from the PBPL operations emissions were subtracted from the FY2014-2015 operations base line monitoring data. The resulting PM_{10} concentrations were assumed to be from background sources. These values were then randomised over a one year period in a Monte Carlo type simulation. The resulting 365 24-hour concentrations were then added to modelled results as the background concentrations. The $PM_{2.5}$ background concentrations were assumed to be 40% of the background PM_{10} concentrations. This ratio of based on the particle size distribution of sea spray (Seinfeld J.H. and Pandis S.N., 1998 pg 434).

The yearly $PM_{2.5}$ randomised background data is presented in Figure 2.5. The average background $PM_{2.5}$ is 3.4 µg/m³. The source apportionment monitoring study found similar concentrations of sea spray for the 24-hour averaged measurement. The maximum sea salt concentration at the monitor closest to the Osprey Drive location was 10.3 µg/m³, while the minimum was 0.3 µg/m³ and the average was 3.6 µg/m³ (Pacific Environment. 2013).

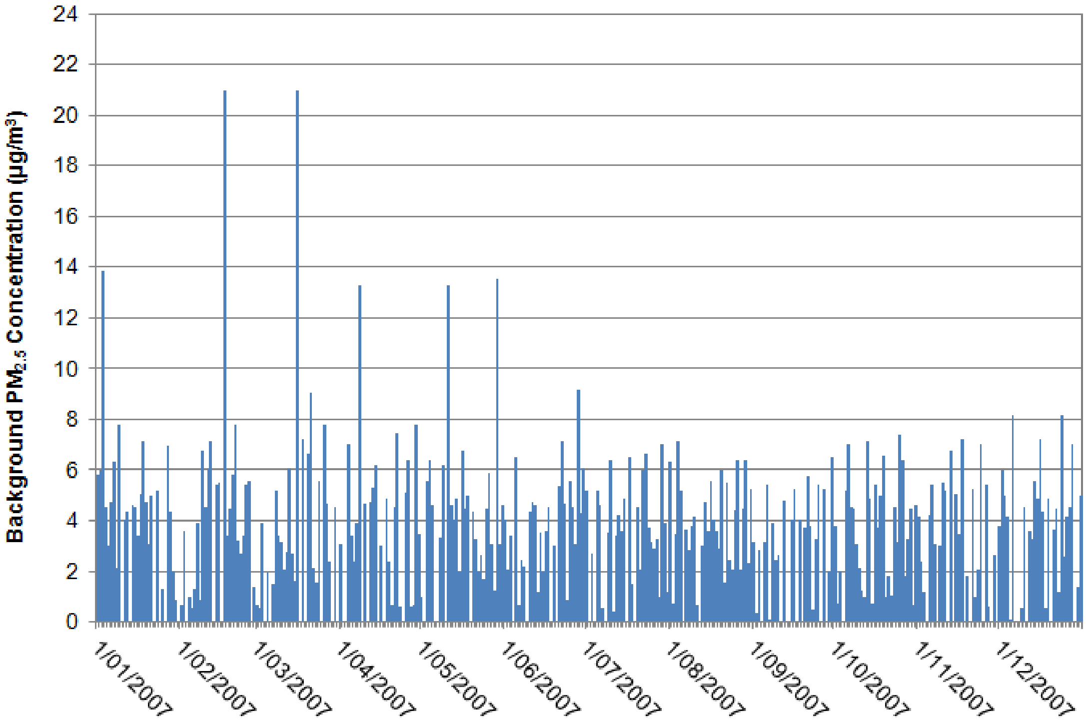


Figure 2.5: *PM2.5 Background Data*

3. Meteorological and Dispersion Modelling Methodology

This assessment methodology is based on the TAPM/CALMET/CALPUFF atmospheric modelling system. The meteorological and air dispersion modelling component of the study included the following main steps:

- a diagnostic meteorological model of the region was developed using the CALMET module of the CALPUFF modelling system. Regional weather station data was supplemented by pseudo-observations of upper air conditions derived from TAPM and a 1-year representative dataset was compiled. The year 2007 was selected as the representative year.
- The meteorological dataset and the emissions data from the emission inventory were used as inputs to the CALPUFF dispersion model to predict ground level concentrations for the modelling domain.
- The predicted concentrations were assessed against relevant regulatory criteria to determine whether predicted concentrations are acceptable.

Additional details on the model configuration and data inputs are provided in the following sections.

3.1 TAPM

The Air Pollution Model, or TAPM (version 4), is a three-dimensional meteorological and air emissions model developed by the CSIRO Division of Atmospheric Research. The Technical Paper by Hurley (2008a) describes technical details of the model equations, parameterisations, and numerical methods. A summary of some verification studies using TAPM is also given in Hurley *et al*. (2008b, 2008c). The model predicts airflow important to local scale air dispersion, such as sea breezes and terrain-induced flows, against a background of larger scale meteorology provided by synoptic analyses.

Modelling meteorological conditions using TAPM has proven to be an effective method of providing datasets required by CALMET. Surface and upper air point data can be extracted from any grid point in TAPM and can be used as surface or upper air stations in CALMET.

To further improve model performance, the default geophysical characteristics used by TAPM were replaced by higher resolution data whenever possible. Geographic Information System (GIS) methods were used to determine average terrain and dominant land use and soils data for each grid point.

Default TAPM terrain values are based on a global 30-second resolution (approximately 1 km) dataset provided by the US Geological Survey, Earth Resources Observation Systems (EROS). For the purposes of modelling, a higher resolution terrain dataset was extracted from the 9-second resolution (approximately 250 m) Digital Elevation Model (DEM) from Geoscience Australia.

Default land use and soils data for TAPM are based on a three-minute resolution dataset of Australian vegetation and soils, available from CSIRO Wildlife and Ecology. The default land use data was replaced with data extracted from the 1996/97 Land Use of Australia, Version 2, Land and Water Resources Audit.

The meteorological conditions for the domain were run from January to December 2007, which was determined to be a representative year for the area. Missing meteorological variables required by CALMET, such as upper air data, were extracted from the TAPM output.

3.2 CALMET

CALMET is a meteorological pre-processor that provides the meteorological inputs required to run the CALPUFF dispersion model (TRC, 2006). It creates a fine resolution, three-dimensional meteorological field and includes a wind field generator that takes into account slope flows, terrain effects and terrain blocking effects. This methodology for generating meteorological files meets the expectations detailed in section 4.2.5 of the Brisbane City Plan 2014 Air Quality Planning Scheme Policy.

Observational data from regional meteorological sites operated by the Bureau of Meteorology were used in deriving CALMET input. Surface observational stations included Brisbane Airport, Brisbane CBD, Pinkenba, and Archerfield Airport. Upper air observational data was sourced from Brisbane Airport with TAPM data to infill data gaps. CALMET uses these meteorological inputs in combination with land use and geophysical information for the modelling domain to predict gridded meteorological fields for the region.

The domain for CALMET covers a 32.5 km x 32.5 km area, with the origin (SW corner) at 496,100 m Easting and 6,952,200 m Northing (UTM Zone 56 S). This consists of 130 grid points with a 250 m resolution along both the x and y axes. To improve model performance, a high-resolution terrain dataset was extracted from the 9-second resolution (approximately 250 metres) Digital Elevation Model (DEM) from Geoscience Australia. The land use data was sourced from the high-resolution (~110 metres resolution) data extracted from land cover data from the Department of Natural Resources and Mines (Queensland Packaged Data) for 1991-2005. GIS methods were used to calculate average terrain and dominant land use for each grid cell.

3.3 CALPUFF

CALPUFF is a multi layer, multi species, non-steady state puff dispersion model that can simulate the effects of time and space varying meteorological conditions on emissions transport, transformation and removal. The model contains algorithms for near source effects such as building downwash, partial plume penetration, sub-grid scale interactions as well as longer range effects such as pollutant removal, chemical transformation, vertical wind shear and coastal interaction effects. The model uses dispersion equations based on a Gaussian distribution of emissions across released puffs and takes into account the complex arrangement of emissions from point, area, volume and line sources.

CALPUFF is a US EPA regulatory model for long-range transport or for modelling in regions of complex meteorology. It is the preferred dispersion model for use in coastal and complex terrain situations in Australia. A detailed description of CALPUFF is provided in the user manual (TRC, 2006). CALPUFF requires input relating to:

- emissions
- source parameters
- meteorology
- receptors.

For the purpose of this project, meteorology derived using CALMET was used as an input. Model settings were optimised for the coastline location. The domain for CALPUFF covers the same area as the CAMLMET gird, 32.5 km x 32.5 km area, with the origin (SW corner) at 496,100 m Easting and 6,952,200 m Northing (UTM Zone 56 S). This consists of 130 grid points with a 250 m resolution along both the x and y axes.

4. Model Inputs

The sections below identify the dispersion modelling inputs that were used in this assessment.

4.1 Meteorology

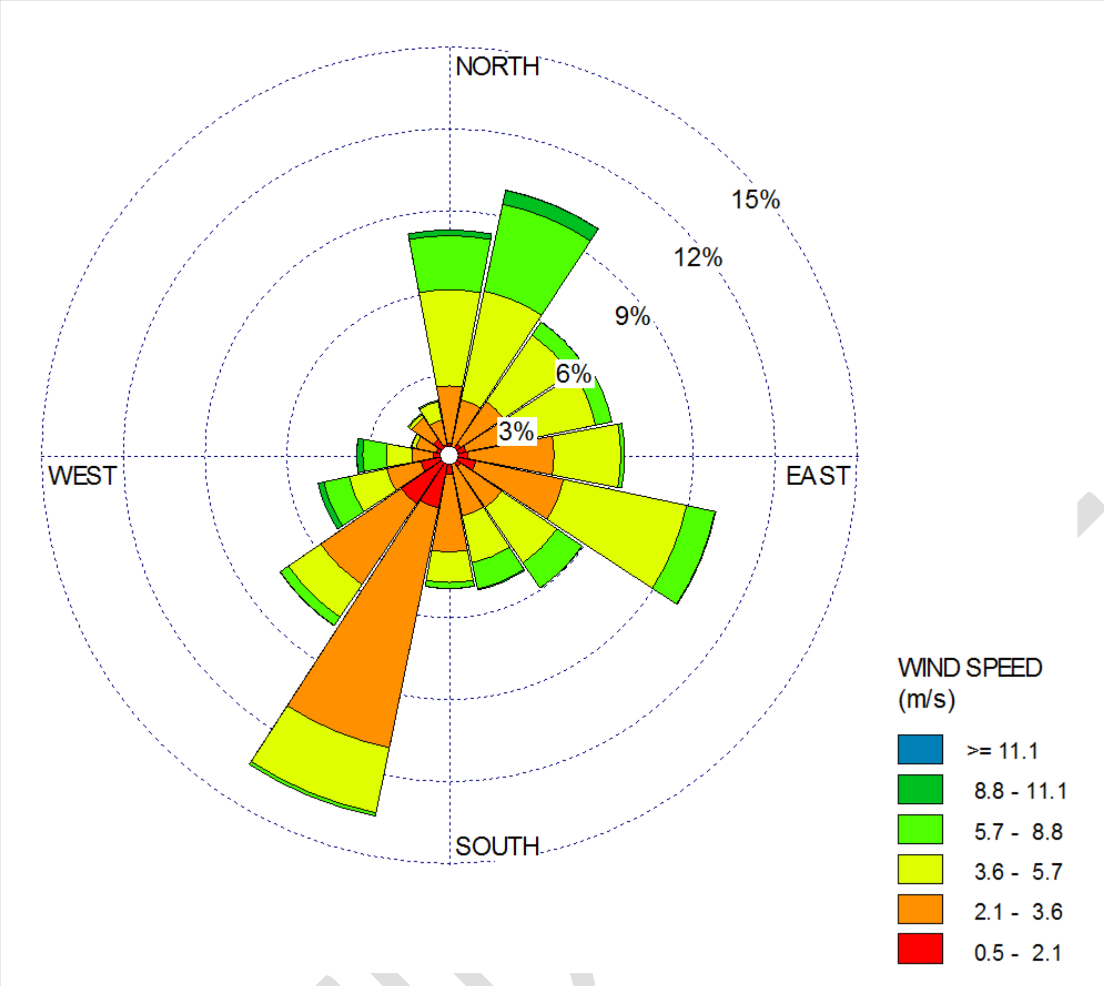
4.1.1 Wind

Wind roses show the frequency of occurrence of winds by direction and strength. The bars correspond to the 16 compass points – N, NNE, NE, etc. The bar at the top of each wind rose diagram represents winds blowing from the north (i.e. northerly winds), and so on. The length of the bar represents the frequency of occurrence of winds from that direction, and the colours of the bar sections correspond to wind speed categories. Thus it is possible to visualise how often winds of a certain direction and strength occur over a long period, either for all hours of the day, or for particular periods during the day.

The model-generated site-specific wind rose for 2007 is shown in Figure 4.1. Wind roses for different periods of the day are shown in Figure 4.2. During the midnight to 6am period, the winds are typically light, with the land breeze from the southwest dominating. During the morning, wind speeds normally increase, with an increasing easterly component. However, the land breeze still dominates this period. During the afternoon, and through the evening, winds from the eastern sector dominate due to the seabreeze effect and prevailing synoptic conditions.

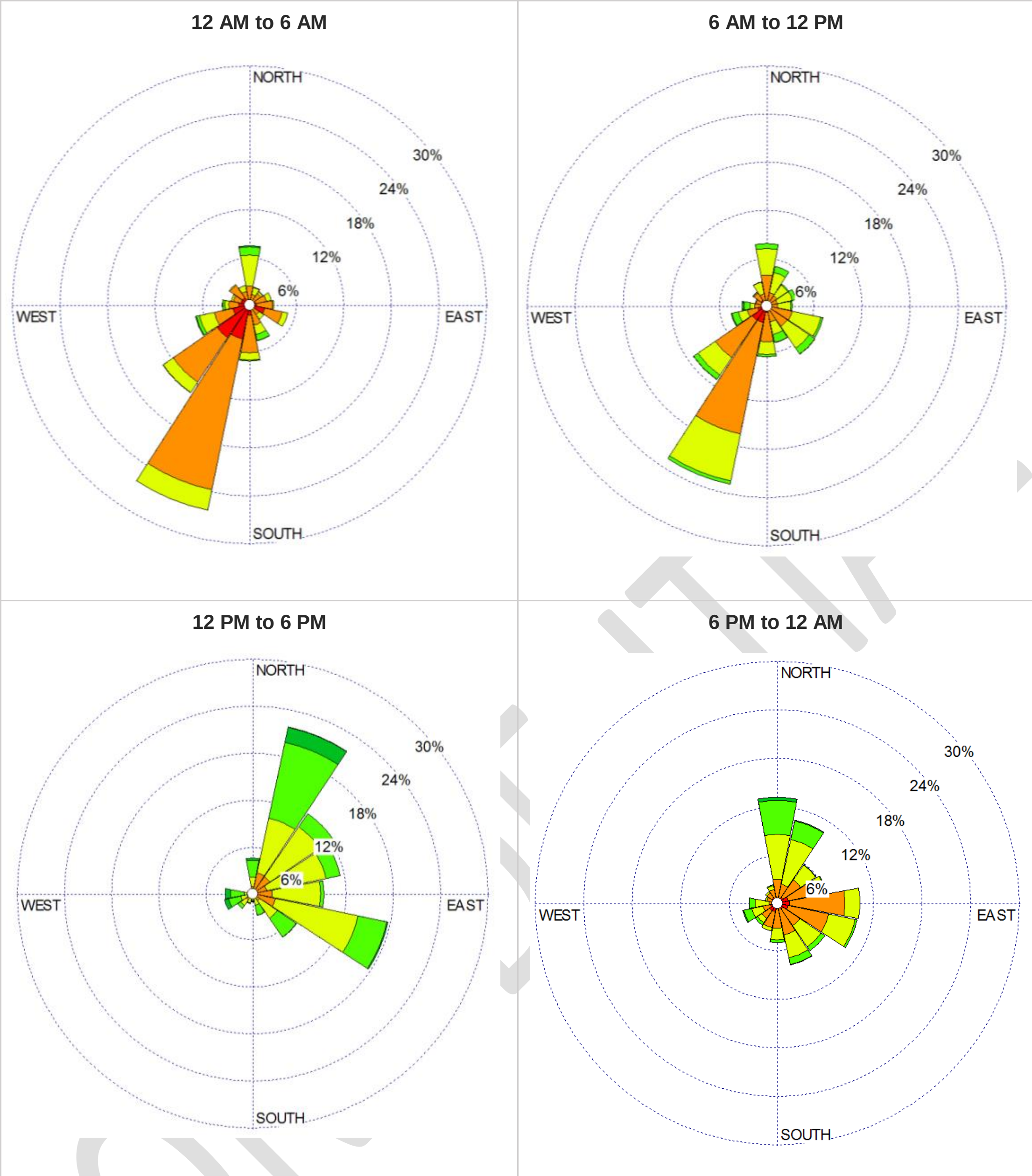
The seasonal wind roses are presented in Figure 4.3. Easterly winds dominate during the summer period. During the autumn and winter period, light winds dominate. Stronger northerly winds are more common during spring.

The frequency distribution of hourly averaged wind speed values is shown in Figure 4.4. Light wind speeds (up to 3.6 m/s) occur relatively frequently, at approximately 50% of the time. Moderate to strong winds (greater than 5 m/s) occur approximately 13% of the time.



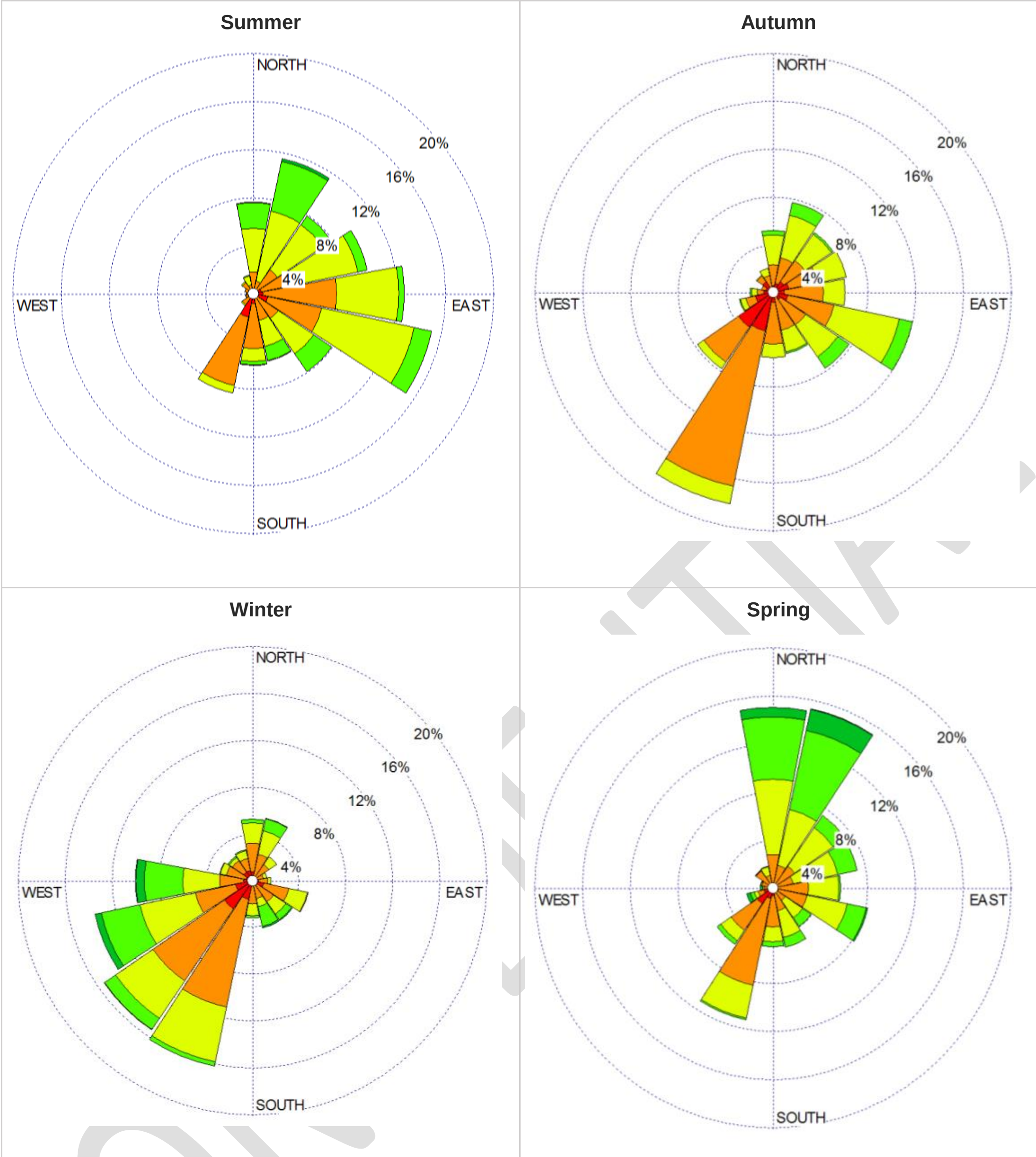
Location:	Data Period:	Data Type:
Port of Brisbane	2007 (100% data availability)	CALMET Extract
Calm wind frequency:	**Average wind speed:**	**Plot:**
2.4%	3.7 m/s	R Chalmer

Figure 4.1: *Wind Rose at Port of Brisbane*



Time of day	Average wind speed (m/s)	Calm wind frequency	WIND SPEED (m/s)
12 AM to 6 AM	2.7	4.5%	>= 11.1 8.8 - 11.1
6 AM to 12 PM	3.5	2.0%	5.7 - 8.8
12 PM to 6 PM	5.1	0.1%	3.6 - 5.7 2.1 - 3.6
6 PM to 12 AM	3.6	2.8%	0.5 - 2.1
Location: Port of Brisbane	**Data Period:** 2007 (100% data availability)	**Data Type:** CALMET Extract	**Plot:** R Chalmer

Figure 4.2: *Time of Day Wind Rose at Port of Brisbane*



Time of day	Average wind speed (m/s)	Calm wind frequency	WIND SPEED (m/s)
Summer	3.9	1.1%	>= 11.1
Autumn	3.1	2.4%	8.8 - 11.1 5.7 - 8.8
Winter	3.6	3.9%	3.6 - 5.7 2.1 - 3.6
Spring	4.3	2.0%	0.5 - 2.1
Location:	**Data Period:**	**Data Type:**	**Plot:**
Port of Brisbane	2007 (100% data availability)	CALMET Extract	R Chalmer

Figure 4.3: *Time of Year Wind Rose at Port of Brisbane*

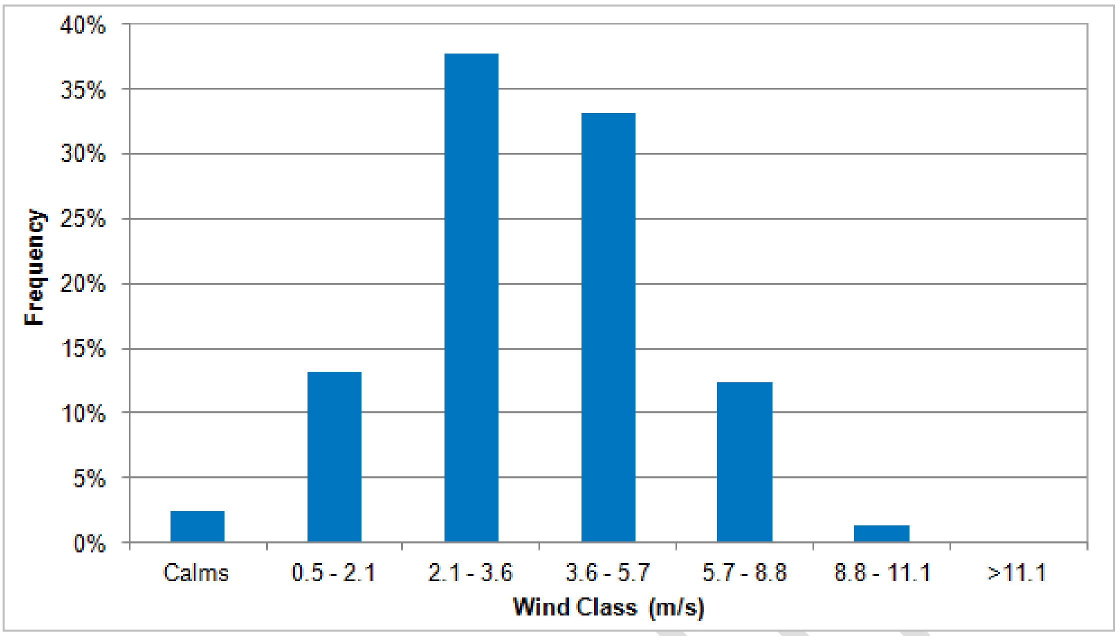


Figure 4.4: *Frequency Distribution of Wind Classes*

4.1.2 Stability

Atmospheric turbulence is an important factor in plume dispersion. Turbulence acts to increase the cross-sectional area of the plume due to random motions, thus diluting or diffusing a plume. As turbulence increases, the rate of plume dilution or diffusion increases. Weak turbulence limits plume diffusion and is a critical factor in causing high plume concentrations downwind of a source, particularly when combined with very low wind speeds.

Turbulence is related to the vertical temperature gradient, the condition of which determines what is known as stability, or thermal stability. For traditional dispersion modelling using Gaussian plume models, categories of atmospheric stability are used in conjunction with other meteorological data to describe atmospheric conditions and thus dispersion.

The most well-known stability classification is the Pasquill-Gifford scheme[c], which denotes stability classes from A to F. Class A is described as highly unstable and occurs in association with strong surface heating and light winds, leading to intense convective turbulence and enhanced plume dilution. At the other extreme, class F denotes very stable conditions associated with strong temperature inversions and light winds, which commonly occur under clear skies at night and in the early morning. Under these conditions plumes can remain relatively undiluted for considerable distances downwind.

Intermediate stability classes grade from moderately unstable (B), through neutral (D) to slightly stable (E). Whilst classes A and F are strongly associated with clear skies, class D is linked to windy and/or cloudy weather, and short periods around sunset and sunrise when surface heating or cooling is small.

As a general rule, unstable (or convective) conditions dominate during the daytime and stable flows are dominant at night. This diurnal pattern is most pronounced when there is relatively little cloud cover and light to moderate winds.

[c]A more accurate turbulence scheme within CALPUFF, based on micrometeorology parameters, was used for modelling.

The frequency distribution of estimated stability classes in the meteorology used in the assessment[d] is presented in Figure 4.5. The data shows that stable, or very stable, stability classes are common during overnight conditions, which is typical of costal locations with frequent light land breezes

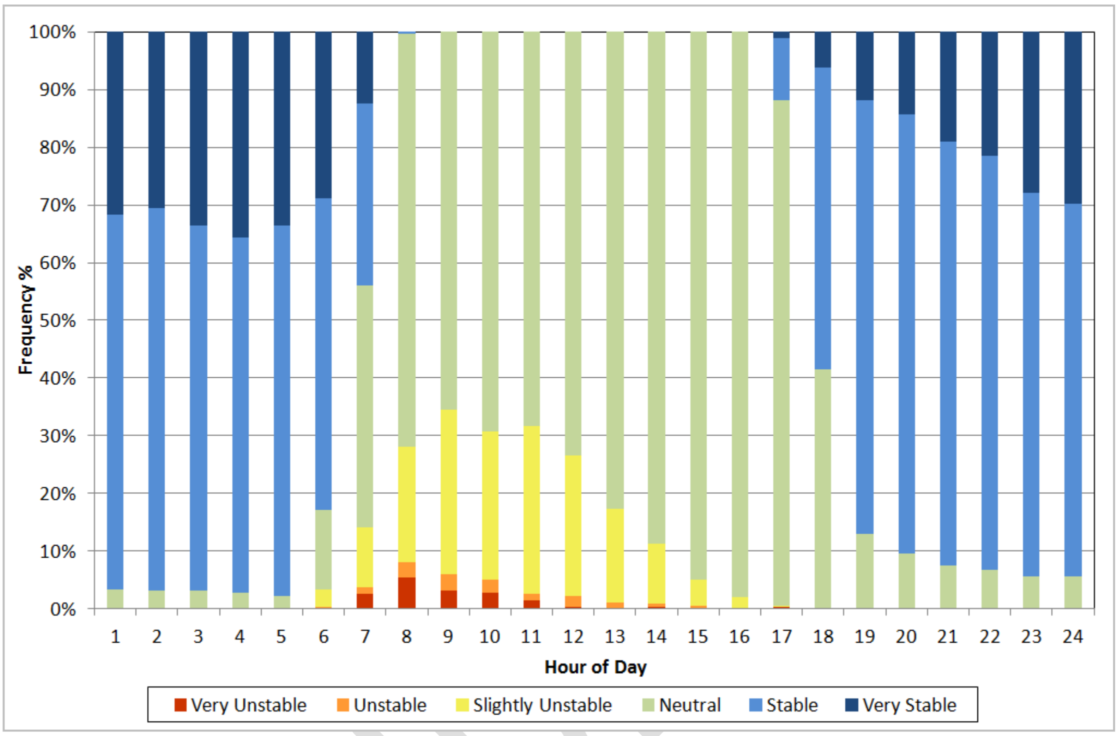


Figure 4.5: *Frequency Distribution of Stability Class for Each Hour of the Day*

4.1.3 Mixing Heights

Mixing height is the depth of the atmospheric surface layer beneath an elevated temperature inversion. It is an important parameter in air pollution meteorology as vertical diffusion or mixing of a plume is generally considered to be limited by the mixing height. This is because the air above this layer tends to be stable, with restricted vertical motions.

A series of internal algorithms within CALMET are used to calculate mixing heights for the subject site.

The diurnal variation of mixing height is summarised in Figure 4.6. The box and whisker plot indicates the range of values for each hour. The average value for each hour is indicated by a red dot. The bar across the shaded rectangle is the median. The rectangle contains values between 10^{th} and 90^{th} percentiles. The extremes of the whisker sections are the maximum and minimum values in the dataset for each hour.

The diurnal cycle is clear in this figure. At night, mixing height is normally low (approximately 500 m). After sunrise, it typically increases to between 500 m and 3,000 m in response to convective mixing that results from solar heating of the earth’s surface. The mixing height in the model was limited to 3,000 m. This has no effect on predicted impacts due to the low level nature of the plume and short-range dispersion under consideration.

[d] Note that CALPUFF did not use stability classes directly in calculations as it was configured to run in micro-meteorological mode, which relies on Monin-Obukhov Similarity Theory for boundary layer parameterisation.

At night, higher mixing height values are associated with neutral conditions and strong winds. The CALMET mixing height estimate for night-time non-stable (neutral) conditions are dependent on wind speed. The highest daytime mixing height values are calculated using a different algorithm, hence there are some potential inaccuracies in the extreme mixing height values. Such inaccuracies have no impact on the critical model results of interest in this assessment.

Lower maximum mixing heights are expected for the costal location at the port.

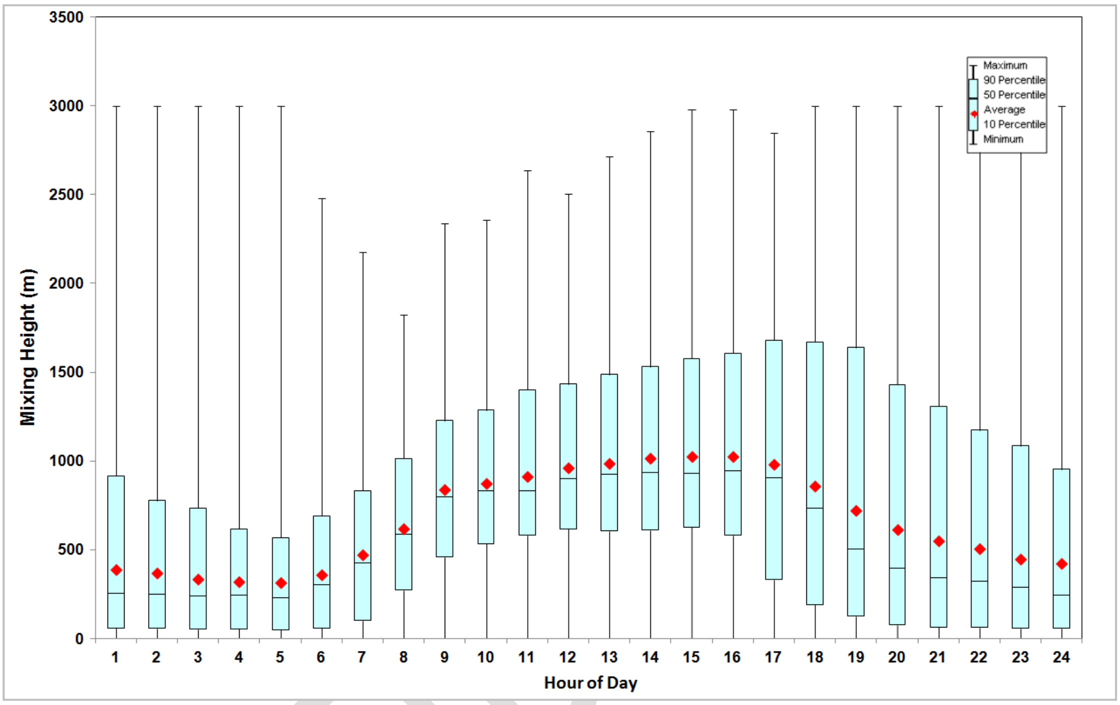


Figure 4.6: *Estimated Model Mixing Heights for Each Hour of the Day*

4.2 CALPUFF

The dispersion modelling inputs for this assessment are summarised in the sections below.

4.2.1 Assessment Scenarios

As described in Section 2, a total of four scenarios were modelled for the Port of Brisbane Operations. These scenario were:

- Base Case
- Year 2025
- Year 2035
- Year 2035 – High Technology

4.2.2 Discrete Receptors

In addition to the gridded receptors described in Section 3.3, the monitoring locations shown in Figure 1.1 were included as discrete receptors for analysis of the model outputs.

4.2.3 Emissions Data and Source Parameters

Emissions were modelled as unit emission rates, expect wind erosion, to allow for scaling between scenarios. A scaling factor for each individual source was calculated based on the activities occurring in that location. All scaling factors are presented in Appendix D. Sources were modelled at heights to reflect the operations occurring, for example trucking emissions were assumed to be a low level source while conveying and crane activities would be higher above the ground.

The source locations are presented in Figure 4.7 and Figure 4.8. Figure 4.7 shows the landside emission sources separated by emission source and model type. It is noted that the CHE emissions are modelled as both areas sources (shown as the red hollow polygons) and volume sources (shown as the solid orange triangles) to represent the emissions from CHE that occur outside (areas sources) and inside warehouses released through building ventilations (volume sources). The material handling emissions are also modelled as both areas sources (shown as the blue hollow polygons) and volume sources (shown as the solid pink circles) to represent the different sources of the material handling emissions. Figure 4.8 shows that that shipping emissions are modelled as area sources across the different shipping lanes. Both the land side and water side emissions were modelled following the methodology used for the modelling $PM_{2.5}$ emissions from Port of Oakland, California (CARB, 2008). This modelling method is best practice for ports.

The source contribution for the $PM_{2.5}$ annual emissions inventory for each scenario is presented in Figure 2.1 to Figure 2.4.

Figure 4.7: *Dispersion Model Landside Emission Source Locations*

Figure 4.8: *Dispersion Model Shipping Emissions Area Source Locations*

4.3 Assessment Criteria

The assessment criteria were sourced from the relevant objective in the Queensland *Environmental Protection (Air) Policy 2008*, which are consistent the Brisbane City Plan 2014 air quality criteria and the National Environment Protection (Ambient Air Quality) Measure air quality standards.

Table 4.1: $PM_{2.5}$ *Assessment Criteria*

Compound	Averaging Period	Criteria	Units
$PM_{2.5}$	24 hour	25	µg/m^3
	Annual	8	µg/m^3

4.4 Model Validation

The model was validated using the PM_{10} modelling results and the site PM_{10} monitoring data. The background data was calculated based on the FY2014-15 of the Operations Base PM_{10} data.

Quantile-Quantile plots (Q-Q plots) show the sorted PM_{10} daily concentrations as modelled on the y-axis with the monitoring data values on the x-axis. Perfect modelled predictions achieve a 1:1 ratio for all data points. Generally, dispersion model performance is evaluated and considered reasonable within a factor of two (1:2 and 2:1). The 3 monitoring locations results are presented as Q-Q plots against the 2014, 2015 and FY2014-15 monitoring data in Figure 4.9 to Figure 4.11.

The Q-Q plots show reasonable model validation within a factor of two to the monitoring results. Model performance could be improved with a better understanding of the background concentration. For example, it is likely that the Bingera Drive monitor measures a higher concentration of sea spray than the other locations, due to its proximity to the coast line, which is resulting in the model under prediction. As the community is not as close to the coast line as this monitor, the background concentration assumed is likely conservative for the locations further from the coast line than the Operations Base and Osprey Drive monitors.

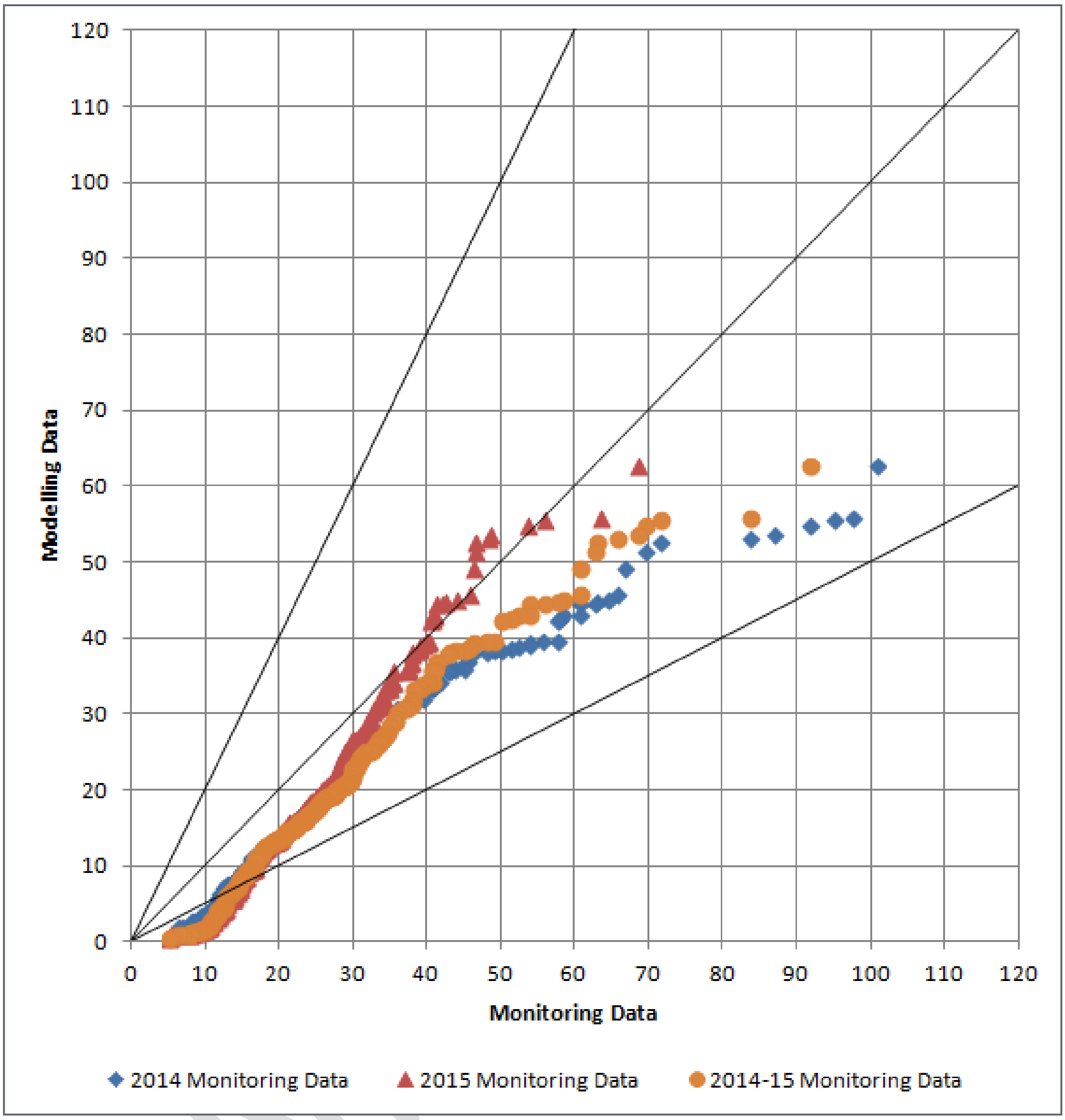


Figure 4.9: *Bingera Drive Q-Q Plot of PM_{10} 24 Hour Averages*

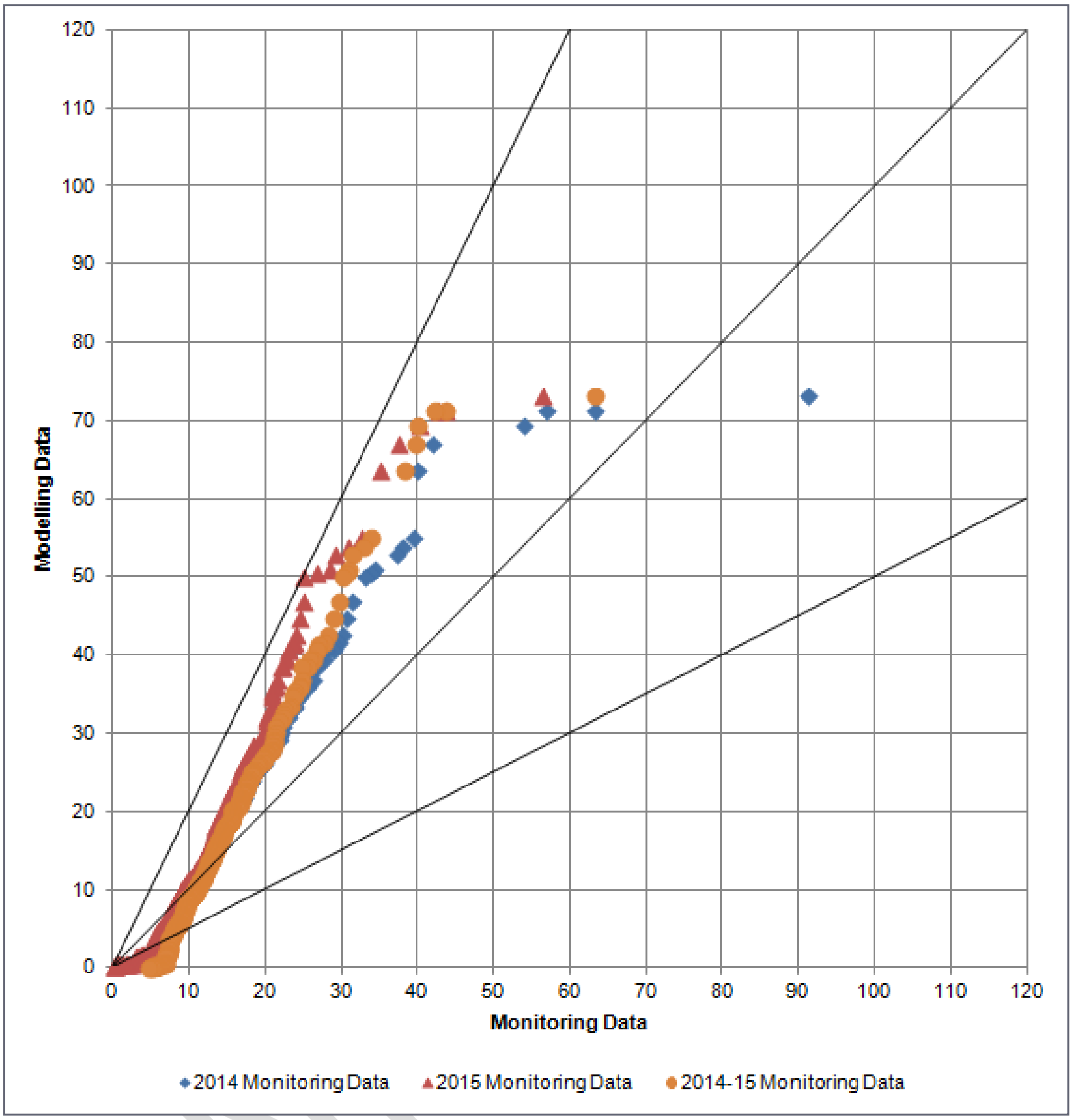


Figure 4.10: *Operations Base Q-Q Plot of PM_{10} 24 Hour Averages*

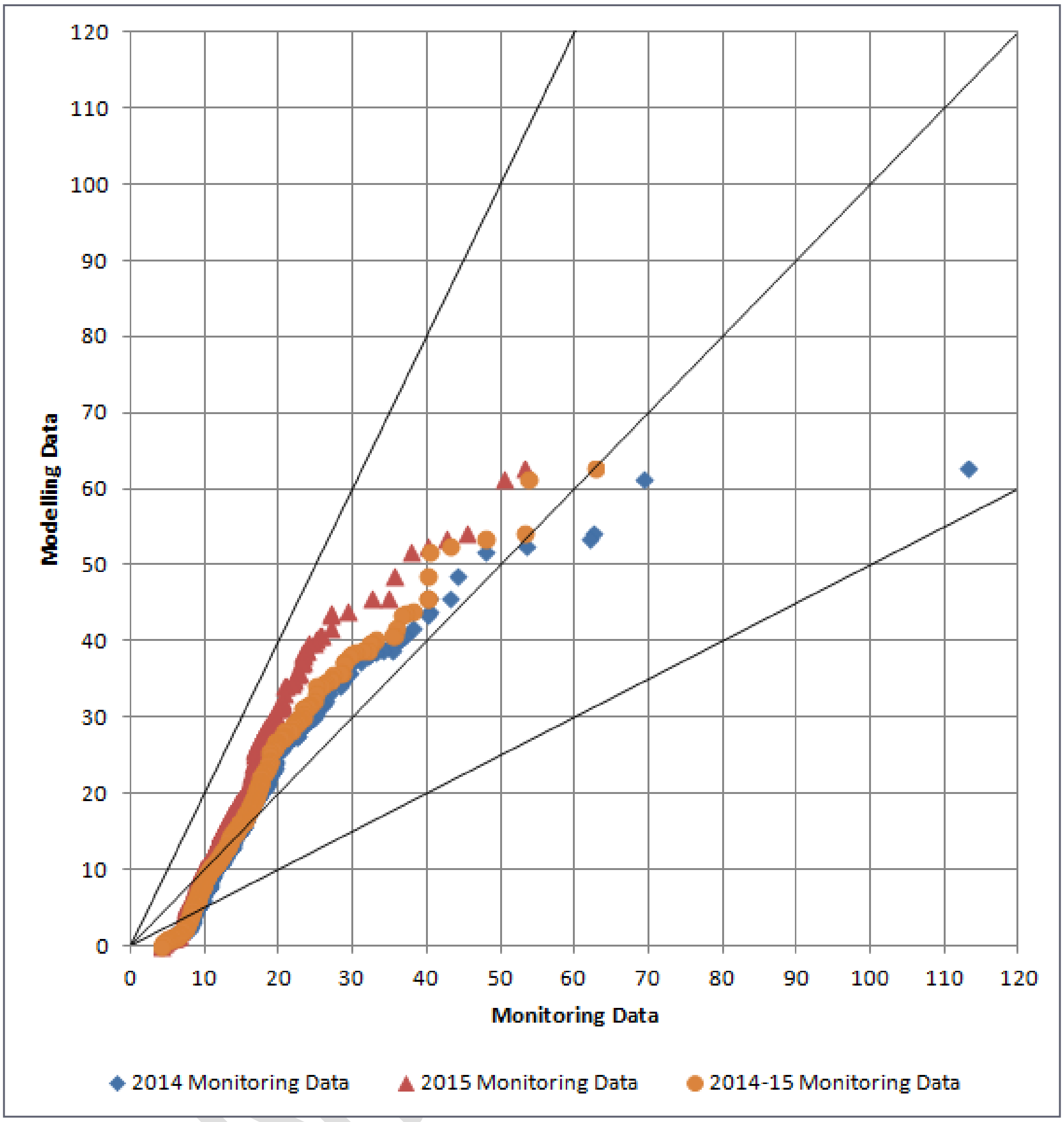


Figure 4.11: *Osprey Drive Q-Q Plot of PM_{10} 24 Hour Averages*

4.5 Assessment Uncertainties

There are a number of uncertainties within the modelling. These uncertainties include:

- Continuous emissions were assumed in the modelling based on annual emission estimations. In reality, the port operations are not continuous, but occur in random bursts of activity.
- The modelling was based on the previously completed landside and waterside emission inventories. While there has been an attempt to update the activities, the source data was not as detailed as the previous assessment and activities at facilities may have changed from these studies which may not be captured.
- Some small facilities are not directly included within the modelling as data for these facilities were not provided in the initial landside and waterside emissions inventories.

- Facilities were modelled as a general area source or a volume to source to take into account movement of vehicles or activity. Each activity was not modelled separately due to limited information on movement of individual activities.
- The future scenarios were scaled based on the 2009 emission inventories and any new/decommissioned facilities or activities would not be represented in the future inventories.
- The materials handling emissions have an uncertainty due to limited information know about controls and activities. Emissions were estimated based on previous experience of coal and grain handling projects and National Pollutant Inventory reports.
- The background concentration is another aspect with a significant uncertainty due to limited understanding of the contribution of diffuse emissions and sea salt spray to background concentrations as well as the PM_{10} to $PM_{2.5}$ ratio of this source.
- The model validation was performed with PM_{10} data while the objective of the project of the project is understand the $PM_{2.5}$ trends. While the PM_{10} validation is a good indication of the emission inventory and model performance, there is uncertainty associated with the PM_{10} to $PM_{2.5}$ ratio assumption, which has not been validated.
- Inherent uncertainties with dispersion modelling associated with the meteorological and source inputs. It is best estimated that a reasonable dispersion model will perform within 40% of monitoring data (US EPA, 2005).

5. Results

All $PM_{2.5}$ maximum 24-hour average and annual average concentration contours are provided in Appendix C. The contour plot results show an area exceeding the $PM_{2.5}$ assessment criteria near the port ship loading areas and major heavy duty truck thoroughfares. The size of the area exceeding the criteria slightly increases for the Year 2025 and again for the Year 2035 scenario.

The $PM_{2.5}$ maximum 24-hour average contour results for the Year 2035 and Year 2035 – High Technology are presented in Figure 5.5 and the annual average contours Figure 5.6. This comparison shows that including additional emission reduction technology can greatly reduce the ground level concentrations from PBPL operations. This result indicates that if a $PM_{2.5}$ emission reduction programs is implemented at the PBPL, it should result in decreased concentrations.

To further understand the predicted maximum 24-hour average concentrations, source contribution of the top five concentrations at the monitoring locations for each scenario were reviewed. Figure 5.1 shows the model results source apportionment at the Operations Base location. This figure shows that the majority of the $PM_{2.5}$ is a results from background concentrations. This is similar to the result from the source contribution measurement from 2013. The 2013 measurements shows that mass contribution from sources other than shipping exhaust and landside diesel emissions could be as high as 99% on days with elevated concentrations.

Figure 5.2 to Figure 5.4 shows the future scenarios source apportionment at the Operations Base location. The composition trends are generally consistent with the Base Case, where background sources re the major component of peak 24-hour concentrations. The Year 2035 does show that with the increase in PBPL operations the PBPL emissions do contribute to elevated concentrations. The Year 2035 – High Technology results show that a fine particulate matter ($PM_{2.5}$) emission reduction programs would minimise the risk of PBPL emissions causing elevated concentrations.

The source contributions for the top five highest 24-hour average $PM_{2.5}$ concentrations for the other two monitoring locations are presented in Appendix D.

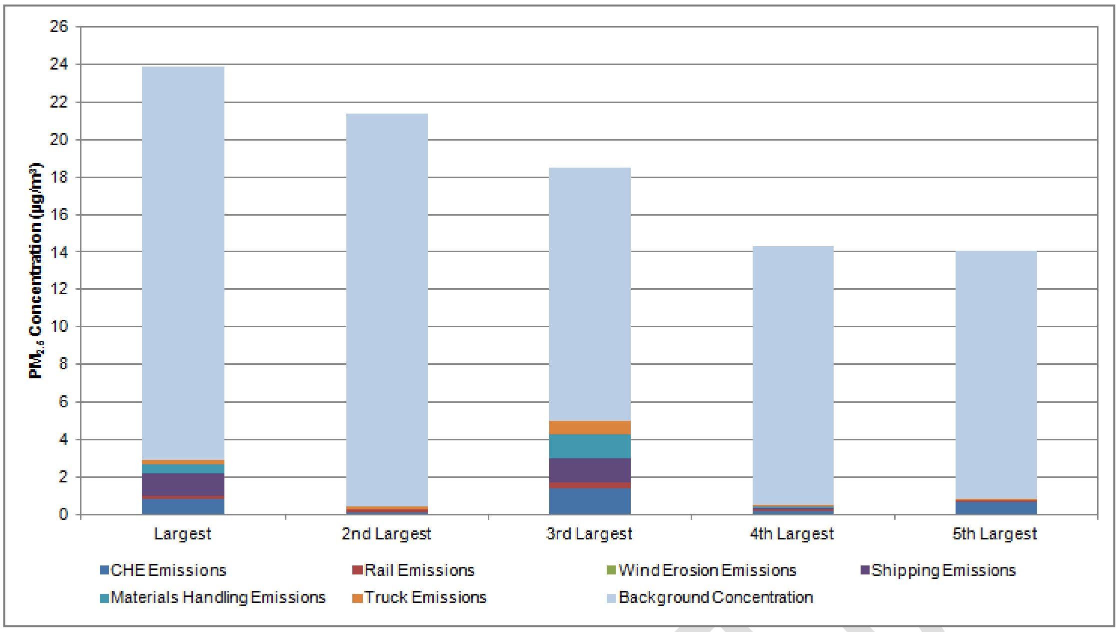


Figure 5.1: *$PM_{2.5}$ Concentration Source Contribution for Base Case Scenario – Operations Base*

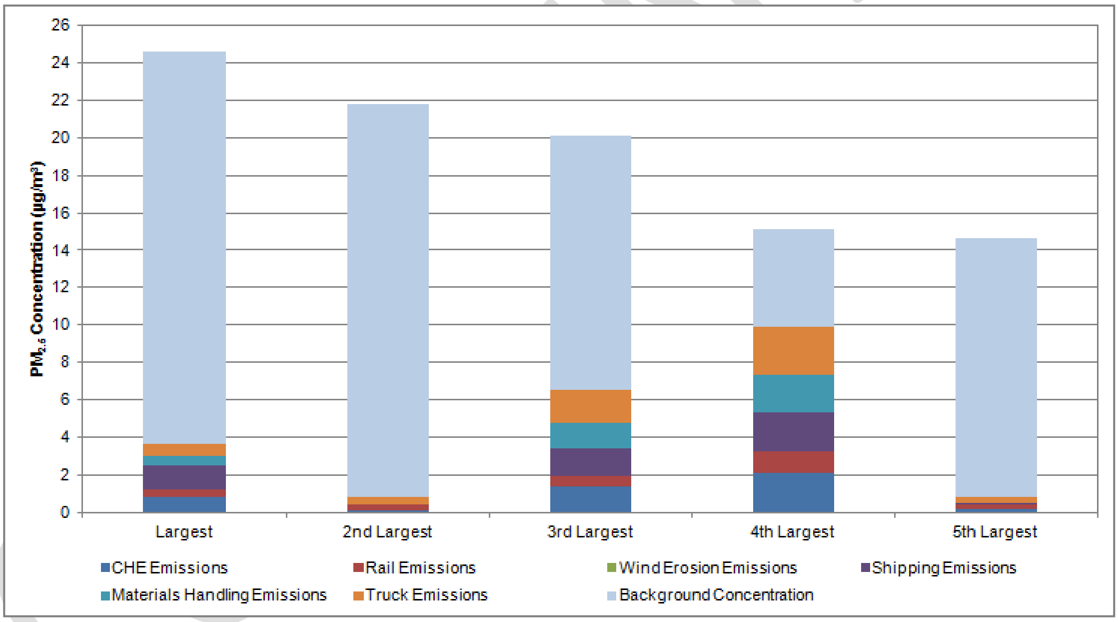


Figure 5.2: *$PM_{2.5}$ Concentration Source Contribution for Year 2025 Scenario – Operations Base*

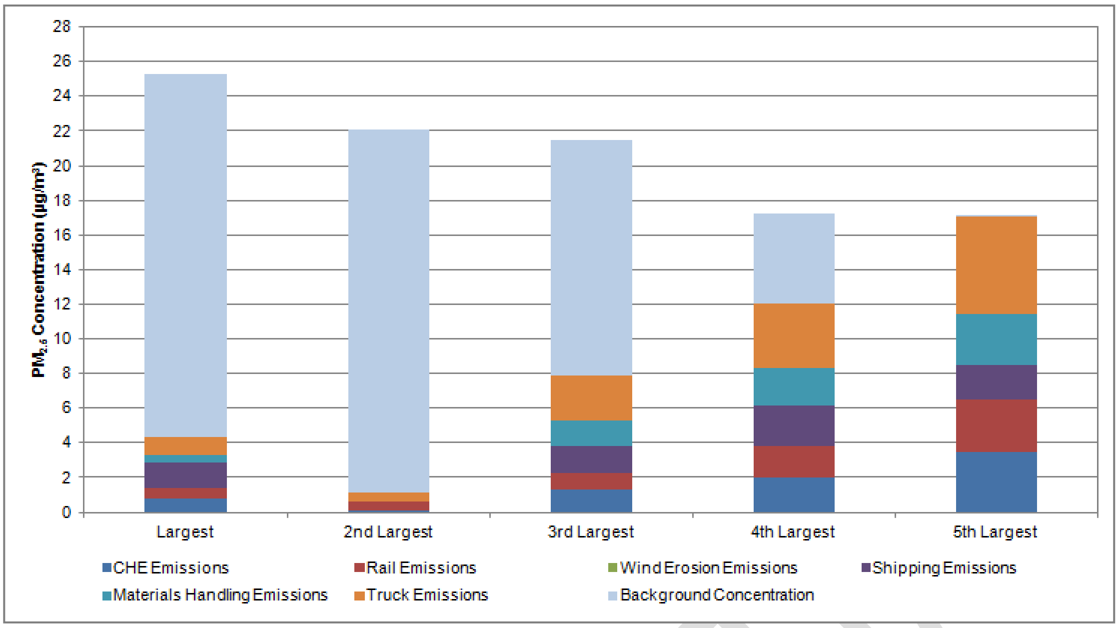


Figure 5.3: *$PM_{2.5}$ Concentration Source Contribution for Year 2035 Scenario – Operations Base*

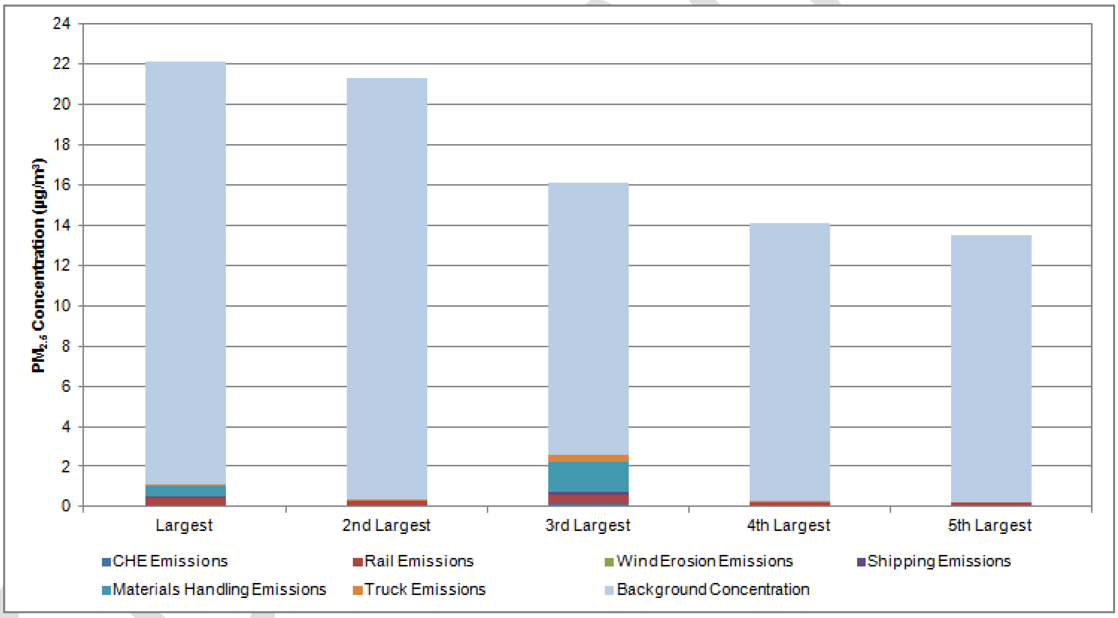


Figure 5.4: *$PM_{2.5}$ Concentration Source Contribution for Year 2035 High Tech Scenario – Operations Base*

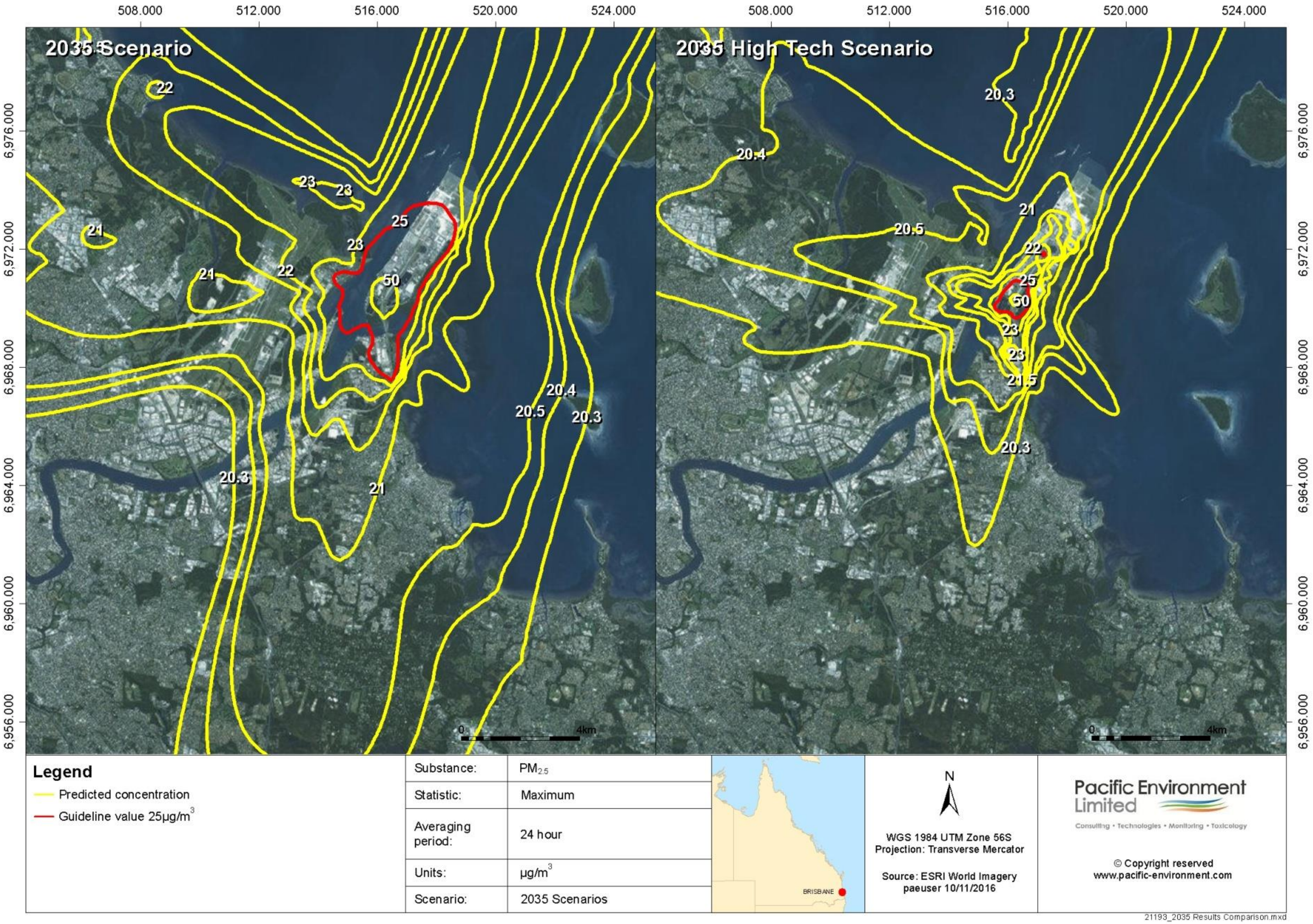


Figure 5.5: *2035 Scenarios for $PM_{2.5}$ 24 Hour Averages*

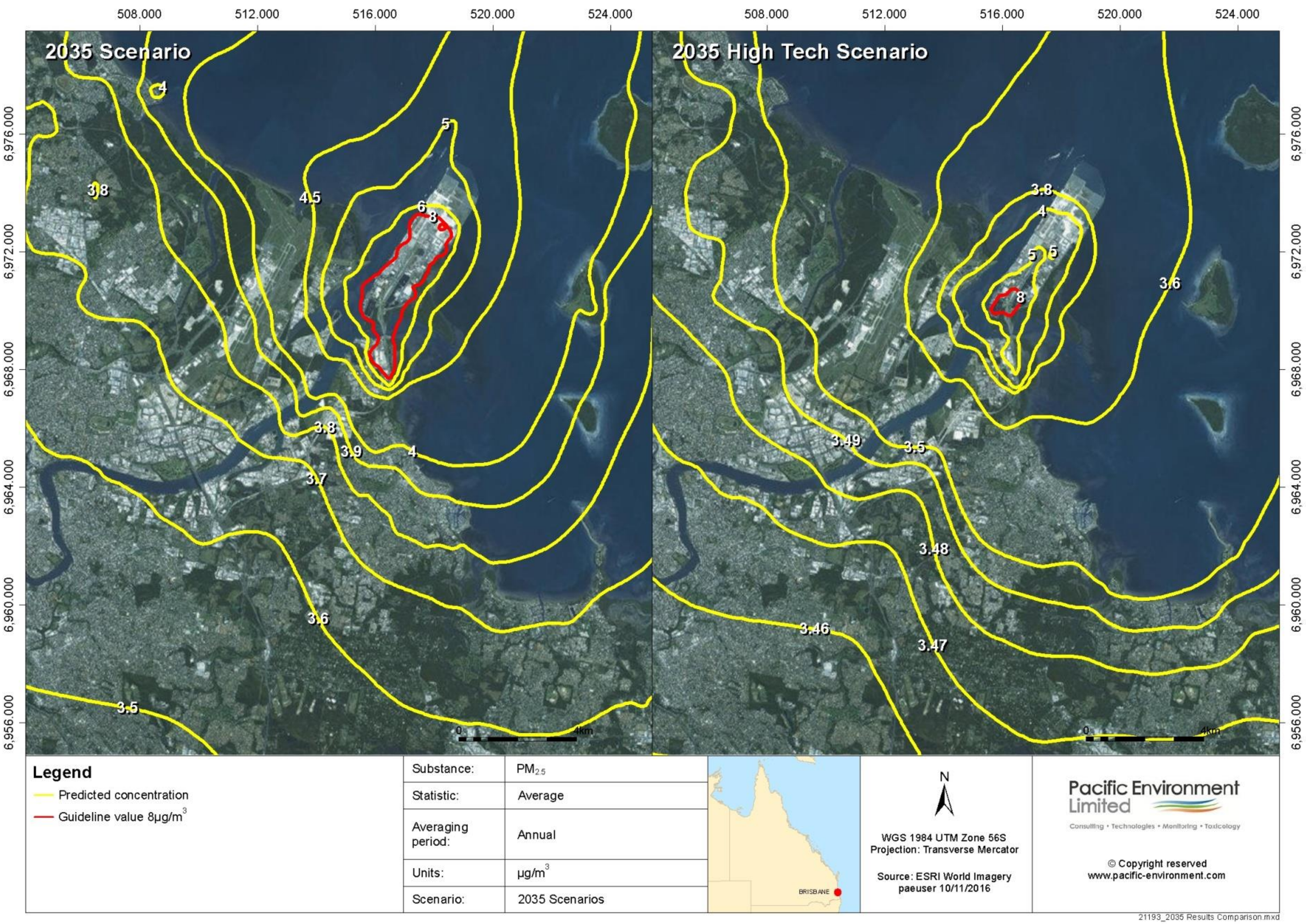


Figure 5.6: *2035 Scenarios for $PM_{2.5}$ Annual Averages*

6. Summary and Recommendations

PBPL engaged Pacific Environment to perform an air quality assessment of PBPL's $PM_{2.5}$ emission sources. The objective of this study was to better understand PBPL's fine particulate matter emissions and how they contribute to ground level concentrations as well as providing a model for prediction of how $PM_{2.5}$ ground level concentrations may change in future scenarios. The scenarios considered were:

- Base Case
- Year 2025
- Year 2035
- Year 2035 – High Technology

Where possible, previously determined emissions were used for this assessment. If required, the emission estimates were updated using to be in-line with the current understanding of activities and emissions factors. For sources not included in the previous assessment, emission were estimated using generalised activity data and industry emission factors. Background concentrations were determined using available PBPL monitoring data.

The TAPM/CALMET/CALPUFF atmospheric dispersion modelling system was used to predict ground level particulate matter concentrations from all PBPL and background sources. Model validation was performed using the PM_{10} results and monitoring data. The model performed within expectations. As with all dispersion modelling studies, there are uncertainties associated with the assessment. Two major uncertainties are the emissions inventories and the determined background concentrations.

The modelling predicted no exceedances of the $PM_{2.5}$ assessment criteria at any residential receptors for any of the scenarios.

The $PM_{2.5}$ maximum 24-hour average and annual average concentration contours show an area exceeding the assessment criteria near the port ship loading areas and major heavy duty truck thoroughfares. The area exceeding the criteria is predicted to increase in size for the Year 2025 and again for the Year 2035 scenario. The exceedance contour is significantly decreased for the Year 2035 – High Technology scenario. This result indicates that $PM_{2.5}$ emission reduction programs implemented at PBPL should result in decreased concentrations in the future.

The model source apportionment results show that the largest contributing source for the five days with highest predicted $PM_{2.5}$ concentrations is background concentrations. This result is similar to the result from the source contribution measurement study from 2013, which showed that mass contribution from sources other than shipping exhaust and landside diesel emissions could be as high as 99% on days with elevated concentrations.

The Queensland Department of Science, Information Technology and Innovation (DSITI) is currently developing a port emissions inventory and it is recommended that PBPL assist where possible. If this inventory results in different emission estimates than considered in the modelling, we recommend updating the model results accordingly. This will help reduce the uncertainty associated with the emission inventory. This may also help confirm that the background concentrations are appropriate for the area.

It is also recommended to use $PM_{2.5}$ monitoring to confirm the models overall predictions. It is understood that PBPL has established a monitoring program and recently installed the equipment. It is recommended that after a year of valid monitoring data, that the statistics be reviewed and compared to modelling results. If the monitoring results differ significantly from the model, then the model assumption should be review and updated to ensure the most accurate predictions.

Once the $PM_{2.5}$ model has been validated with both the DSITI emissions inventory and the $PM_{2.5}$ monitoring data, it is recommended that PBPL develop a $PM_{2.5}$ emissions reduction program.

7. References

AMCsearch LTD (2009) *Waterside Air Emission Inventory for the Port of Brisbane 2007/8 – Final Report*, AMCsearch LTD.

AWMA (2000) Air Pollution Engineering Manual – Second Edition, Air & Waste Management Association.

BoM (2016) *Daily Rainfall – Brisbane Aero*, [ONLINE] Available at: http://www.bom.gov.au/climate/data/index.shtml, [Accessed June 2016].

CARB (2008) *Diesel Particulate Matter Health Risk Assessment for the West Oakland Community*, California Air Resources Board, December 2008.

DEWHA (2008) *NPI Emission Estimation Technique Manual for Railway Yard Operations V2.0*, Department of the Environment, Water, Heritage and the Arts.

DieselNet (2016) Emission Standards- European Union - Heavy-Duty Truck and Bus Engines – Regulatory Framework [ONLINE] Available at: https://dieselnet.com//standards/eu/hd.php [Accessed October 2016]

DSEWPaC (2012) NPI *Emission Estimation Technique Manual for Mining V3.1*, Department of Sustainability, Environment, Water, Population and Communities.

DVN GL (2015) *NSW Ship Emissions Study – Emissions from Ships Operating in the Greater Metropolitan Area* prepared for the NSW EPA

NPI (2016) *National Pollutant Inventory - 2014/2015 data within Australia - All Substances from Facility (Industry)*, [ONLINE] Available at: http://www.npi.gov.au/npidata/action/load/emission-by-facility-result/criteria/destination/ALL/source-type/INDUSTRY/subthreshold-data/Yes/substance-name/All/year/2015, [Accessed June 2016].

Pace, T.G. (2005) Examination of the Multiplier Used to Estimate $PM_{2.5}$ Fugitive Dust Emissions from PM_{10}, US EPA.

PAEHolmes (2010) *Landside Emission Inventory for the Port of Brisbane Precinct 2007/2008 – Job No: 3267*, PAEHolmes.

PBPL (2016A) Email received from Jessica Rudd to Bethany Warren 29 July 2016 – PoB Air Quality Modelling with Attachment: Projected Truck Data for the Port of Brisbane.pdf.

PBPL (2016B) Email received from Jessica Rudd to Bethany Warren 29 July 2016 – Port of Brisbane Ship Data with Attachment: Port of Brisbane Ship Projections.xlsx.

PBPL (2016C) Email received from Jessica Rudd to Bethany Warren 4 August 2016 – Rail and Container Data.

PBPL (2016D) Email communication between Bethany Warren, Nadene Perry and Craig Wilson 1 September 2016 – High Tech Scenarios.

Seinfeld J.H. and Pandis S.N. (1998) *Atmospheric Chemistry and Physics From Air Pollution to Climate Change,* page 434*.* A Wiley-Interscience publication.

TRANSPHORM (2012) *Transport related Air Pollution and Health Impacts – Integrated Methodologies for Assessing Particulate Matter – Emission factors for shipping – final dataset for use in Transphorm emission inventories*, Transmorph

US EPA (1998) AP-42 Fifth Edition Volume I Chapter 11.9 Western Surface Coal Mining – Final Section, US EPA.

US EPA (2003) AP-42 Fifth Edition Volume I Chapter 9.9.1 Grain Elevators and Processes – Final Section, US EPA.

US EPA (2005) *40 CFR Part 51 Revision to the Guideline on Air Quality Models: Adoption of a Preferred General Purpose (Flat and Complex Terrain) Dispersion Model and Other Revisions; Final Rule*. 9 November 2005.
https://www3.epa.gov/scram001/guidance/guide/appw_05.pdf

Appendix A Emission Estimation

A.1 Emission Estimation

The type of source and assumptions used in the modelling are summarised in Table A.1.

Table A.1: *Emissions Source Type*

Emission Source	Source Type	Assumptions
Truck Emissions	Area source	Truck idling emissions included in CHE emissions
Rail Emissions	Volume source	
Cargo Handling Equipment (CHE) Emissions	Area source for outdoor operations Volume source for indoor operations	
Shipping Emissions	Area source	All shipping emissions occur within the domain for conservatism Shipping emissions divided into the different operation types
Materials Handling Emissions	Area source for handling operations Volume source for loading and unloading operations	
Wind Erosion Emissions	Area source	

The emissions inventories for the scenarios modelled are presented in Table A.2.

Table A.2: *$PM_{2.5}$ Emissions Inventory (tonnes/year)*

Emission Source	Base Case	2025	2035	2035 High Tech
Truck Emissions	12.0	29.7	43.4	5.52
Rail Emissions	4.23	8.68	13.7	6.87
CHE Emissions	19.7	19.6	19.0	2.37
Shipping Emissions	259	285	311	35.6
Wind Erosion Emissions	8.45	8.45	8.45	8.45
Materials Handling Emissions	28.7	31.6	34.5	34.5
Total Emissions	**332**	**383**	**430**	**93.4**

A.1.1 Base Case Scenario

A.1.1.1 Truck Emissions

The trucking emissions were sourced from the Landside Emission Inventory for the Port of Brisbane Precinct 2007/2008 (PAEHolmes, 2010). Truck emissions were estimated using the truck activity, fuel consumption and emission rates. Trucks were classified with truck numbers calculated from traffic count data and information supplied from bulk operators. Idling time and number of starts (hot or cold) were also included in truck emissions. Emission factors were sourced from the in house emission factor database originally developed in 2002 for Queensland EPA, and updated in 2008.

The total emissions and fuel consumption from trucks by vehicle type are summarised in Table A.3.

Table A.3: *Total Emissions and Fuel Consumption from Trucks by Vehicle Type*

Pollutant	MCV (kg/year)	HCV (kg/year)	Articulated Truck (kg/year)	B-Double (kg/year)	Super B-Double (kg/year)
$PM_{10,\ exhaust}$	199	231	1,461	447	41
$PM_{2.5,\ exhaust}$	189	220	1,390	425	39
$PM_{10,\ non\text{-}exhaust}$	119	178	883	397	51
$PM_{2.5,\ non\text{-}exhaust}$	61	94	487	229	29
$PM_{10,\ total}$	318	410	2,345	844	92
$PM_{2.5,\ total}$	250	314	1,877	654	68
Fuel Consumption	285,110	565,565	3,809,732	2,171,652	199,949

A scaling factor of 3.8 was applied to the truck emissions based on the comparison of the emission factors for the two most prevalent vehicles in the PBPL inventory.

A.1.1.2 Rail Emissions

Rail emissions were sourced from the Landside Emission Inventory for the Port of Brisbane Precinct 2007/2008 (PAEHolmes, 2010). Rail emissions were estimated from the rail activity, fuel consumption and emission factors. The rail data was provided by Queensland Rail (QR). The data provided included the typical number of trains operating within the study area, train configurations and total time each train spent within the study area. Emission factors were re-calculated from the source used by the NPI EET Manual for Railway Yard Operations (DEWHA, 2008).

The total emissions and fuel consumption from Rail Operations are presented in Table A.4.

Table A.4: *Total Emissions and Fuel Consumption from Rail Operations*

Pollutant	Total Rail Emissions (kg/year)
$PM_{10, exhaust}$	4,413
$PM_{2.5, exhaust}$	4,233
$PM_{10, non-exhaust}$	N/A
$PM_{2.5, non-exhaust}$	N/A
$PM_{10, total}$	4,413
$PM_{2.5, total}$	4,233
Fuel Consumption	1,043,964

A.1.1.3 Cargo Handling Equipment Emissions

Cargo Handling Equipment (CHE) emissions were sourced from the Landside Emission Inventory for the Port of Brisbane Precinct 2007/2008 (PAEHolmes, 2010). CHE emissions were estimated based on activity data and emission factors. The activity data was sourced from a survey requested from all operating facilities within the port. Emission factors were sourced from the US EPA NONROAD 2008 Model.

The total emissions and fuel consumption from Rail Operations are presented in Table A.5.

Table A.5: *Total Emissions and Fuel Consumption from CHE Operations*

Pollutant	Total CHE Emissions (kg/year)
$PM_{10, exhaust}$	20,582
$PM_{2.5, exhaust}$	19,738
$PM_{10, non-exhaust}$	N/A
$PM_{2.5, non-exhaust}$	N/A
$PM_{10, total}$	20,582
$PM_{2.5, total}$	19,738
Fuel Consumption	11,233,551

A.1.1.4 Shipping Emissions

Shipping emissions were sourced from Waterside Air Emission Inventory for the Port of Brisbane 2007/8 (AMCsearch, 2009). Emissions were estimated based on activity data, fuel consumption and emission factors. The activity data was sourced from movement records at the Pilot Boarding Ground, the entrance beacons and the berth for each individual moment. Emission factors were sourced from California EPA Air Resources Board Reports and US EPA methodologies.

The total emissions from shipping emissions are presented in Table A.6.

Table A.6: *Total Emissions from Shipping by Vessel Type and Operating Mode*

Vessel Type	Operating Mode	PM_{10} Emissions (t/year)	$PM_{2.5}$ Emissions (t/year)
Bulk Carrier	Anchorage	0.6	0.6
Bulk Carrier	Hotelling	9.0	8.7
Bulk Carrier	Manuvering	1.4	1.4
Bulk Carrier	Repositioning	0.2	0.2
Bulk Carrier	Transit	14.1	13.7
Container	Anchorage	0.5	0.5
Container	Hotelling	40.5	39.3
Container	Manuvering	8.8	8.6
Container	Repositioning	3.6	3.5
Container	Transit	71.6	69.7
Cruise	Hotelling	6.7	6.5
Cruise	Manuvering	1.7	1.6
Cruise	Repositioning	0.0	0
Cruise	Transit	7.0	6.8
General Cargo	Anchorage	0.5	0.4
General Cargo	Hotelling	5.0	4.8
General Cargo	Manuvering	0.9	0.9
General Cargo	Repositioning	0.2	0.2
General Cargo	Transit	11.3	11
Navy	Anchorage	0.0	0
Navy	Hotelling	0.9	0.9
Navy	Manuvering	0.0	0
Navy	Repositioning	0.0	0
Navy	Transit	0.5	0.3
Others	Anchorage	0.0	0
Others	Hotelling	0.2	0.2
Others	Manuvering	0.0	0
Others	Repositioning	0.0	0
Others	Transit	0.1	0.1
Ro-Ro Cargo	Hotelling	1.0	0.9

Vessel Type	Operating Mode	PM_{10} Emissions (t/year)	$PM_{2.5}$ Emissions (t/year)
Ro-Ro Cargo	Manuvering	0.2	0.2
Ro-Ro Cargo	Repositioning	0.0	0
Ro-Ro Cargo	Transit	1.7	1.6
Tanker	Anchorage	5.2	5.1
Tanker	Hotelling	19.0	18.4
Tanker	Manuvering	2.5	2.4
Tanker	Repositioning	0.5	0.5
Tanker	Transit	24.4	23.7
Vehicles Carrier	Anchorage	0.0	0
Vehicles Carrier	Hotelling	7.6	7.3
Vehicles Carrier	Manuvering	1.7	1.7
Vehicles Carrier	Repositioning	0.1	0.1
Vehicles Carrier	Transit	17.6	17.1

Shipping emissions distributed by size of vessel and operation mode across the sources modelled.

A.1.1.5 Materials Handling Emissions

Materials handling emissions were sourced from the 2014/2015 NPI Data provided by the facility (NPI, 2016) and calculated based on emission factor methodologies outlined in the US EPA AP-42 Chapter 9.9.1 Grain Handling and Processes (US EPA, 2003), NPI Emission Estimation Technique Manual for Mining V3.1 (DSEWPaC, 2012) and Air Pollution Engineering Manual (AWMA, 2000). For one of the facilities a portion of fugitive dust from the NPI Data from site was assumed to be wind erosion. The NPI emissions were separated out by assumed activities onsite. The emissions from materials handling are summarised in Table A.7.

Table A.7: *Total Emissions from Materials Handling*

Pollutant	Total Materials Handling Emissions (t/year)
PM_{10}	507
$PM_{2.5}$	29

A.1.1.6 Wind Erosion Emissions

Wind Erosions emissions were estimated for the open stockpiles onsite. One facility's wind erosion emissions were assumed to be a proportion of the fugitive dust from the NPI Data. The other facilities emissions were estimated using the methodology outlined the NPI Emission Estimation Technique Manual for Mining V3.1 (DSEWPaC, 2012). The equation used to calculate the emission factor for PM_{10} is shown below. The emissions for $PM_{2.5}$ were assumed to be 10% of PM_{10} emissions for windblown dust (Pace, 2005). The emission factor inputs for wind erosions are summarised in Table A.8.

$$EF_{PM_{10}} = 0.5 \times 1.9 \times \left(\frac{s_{(\%)}}{1.5}\right) \times 365 \times \left(\frac{365 - p}{235}\right) \times \left(\frac{f_{(\%)}}{15}\right)$$

where:

$EF_{PM_{10}}$	=	Emission factor for PM_{10}	(kg/ha/annum)
$s_{(\%)}$	=	silt content	(%)
p	=	Number of days per year when rainfall is greater than 0.25 mm	(days)
$f_{(\%)}$	=	Percentage of time that wind speed is greater than 5.4 m/s at the mean height of the stockpile	(%)

Table A.8: *Emission Factor Input Equations for Wind Erosion*

Data Input	Value	Units
Silt Content ($s_{(\%)}$)	8.6 [a]	%
Percentage of time with wind speed >5.4 m/s	110 [b]	%
Days of rainfall >0.25 mm	10.4 [c]	days

a. Geometric mean silt content for bulldozers on coal, Source: (US EPA, 1998)

b. Number of days from Brisbane Aero for average for the past 10 years, Source: (BoM, 2016)

c. Geometric mean moisture content for bulldozers on coal, Source: (US EPA, 1998)

The total emissions from wind erosions are summarised in Table A.9.

Table A.9: *Total Emissions from Wind Erosion*

Pollutant	Total Wind Erosion Emissions (t/year)
PM_{10}	42.5
$PM_{2.5}$	8.5

A.1.2 Future Scenarios

The future scenarios were scaled based on projected data provided by Port of Brisbane (2016A, 2016B, 2016C). The high technology 2035 scenario was developed with PBPL (2016D). The scaling factors for each future scenario are presented in Table A.10.

Table A.10: *Future Scenario Scaling Factors*

Emission	2025	2035	2035 High Tech
Truck Emissions	2.47	3.61	0.43
Rail Emissions	1.16	1.16	1.62
Cargo Handling Equipment (CHE) Emissions	0.99	0.96	0.12
Shipping Emissions	1.10	1.20	0.21 with zero emissions while at berth
Materials Handling Emissions	1.10	1.20	1.20
Wind Erosion Emissions	1.00	1.00	1.00

A.1.2.1 Year 2025 and 2035

The sources of the future scaling factors are presented in Table A.11. A simple ratio between 2015 and the future year was used as the scaling factor for the future scenarios. To account for advances in technology and automation a 10% reduction in emissions in 2025 and 20% reduction in emissions in 2035 was applied to the CHE emissions.

Table A.11: Future *Emissions Estimation Scaling Sources*

Emission	Projected Information Source
Truck Emissions	Projected Truck Data for the Port of Brisbane (PBPL, 2016A)
Rail Emissions	Projected based on coal handling rates (PBPL, 2016C)
Cargo Handling Equipment (CHE) Emissions	Projected based on coal handling rates (PBPL, 2016)
Shipping Emissions	Linearly extrapolated from data provided by Port of Brisbane (PBPL, 2016B)
Materials Handling Emissions	Projected based on shipping data (PBPL, 2016)
Wind Erosion Emissions	No change to wind erosion estimates

A.1.2.2 Year 2035 - High Technology

The following assumptions were selected to represent the 2035 high technology scenario.

- Cargo Handling Equipment – 90% Electric and 10% Diesel
- Shipping –

    - 100% of ships plug in at berth (auxiliary engines not used)
    - 25% of ships burning LNG in ship lanes
    - 75% of ships burning low sulphur distillates in ship lanes
- Rail – 50% electric
- Trucks – Heavy duty trucks move to EU Tier VI and US EPA 2015 PM standards

It was assumed that materials handling would be the same for 2035 as for the 2035 high tech scenario. Wind erosion emissions would also remain the same.

Emission reduction for ships burning LNG fuels in ship lanes was sourced from *Emissions from Ships operating in the Greater Metropolitan Area* prepared for the NSW EPA (DNV GL, 2015). This report states that PM reductions using LNG as fuel would be more that 90%.

Emission reductions for ships burning low sulphur distillate was sourced from *Emission factors for shipping* (Transphorm, 2010). Based on the waterside inventory, the average sulphur fuel content was approximately 2.7% (AMCsearch, 2009). It was assumed that for the high tech scenario, the sulphur content of the fuel would be 0.1%, based on this assumption an 80% reduction was expected.

Emission reductions for trucks adopting the EU Tier VI and US EPA 2015 PM standards were sourced from *Regulatory Framework* (DieselNet, 2016). An average reduction was assumed based on ratios of the current emissions factors and the EU Tier VI emission standards.

Appendix B Modelling Scaling Factors

B.1 Modelling Scaling Factors

The Base Case Scenario scaling factors for each modelled sources unit emission rate are presented in Table B.1 to Table B.5.

Table B.1: *Truck PM_{10} and $PM_{2.5}$ Emission Scaling Factors*

Truck Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
R_001	5.18E-07	4.05E-07
R_002	5.18E-07	4.05E-07
R_003	5.18E-07	4.05E-07
R_004	5.18E-07	4.05E-07
R_005	5.18E-07	4.05E-07
R_006	5.18E-07	4.05E-07
R_007	5.18E-07	4.05E-07
R_008	5.18E-07	4.05E-07
R_009	5.18E-07	4.05E-07
R_010	5.18E-07	4.05E-07
R_011	5.18E-07	4.05E-07
R_012	5.18E-07	4.05E-07
R_013	5.18E-07	4.05E-07
R_014	5.18E-07	4.05E-07
R_015	5.18E-07	4.05E-07
R_016	5.18E-07	4.05E-07
R_017	5.18E-07	4.05E-07
R_018	5.18E-07	4.05E-07
R_019	5.18E-07	4.05E-07
R_020	5.18E-07	4.05E-07
R_021	5.18E-07	4.05E-07
R_022	5.18E-07	4.05E-07
R_023	5.18E-07	4.05E-07
R_024	5.18E-07	4.05E-07
R_025	5.18E-07	4.05E-07
R_026	5.18E-07	4.05E-07
R_027	5.18E-07	4.05E-07

Truck Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
R_028	5.18E-07	4.05E-07
R_029	5.18E-07	4.05E-07
R_030	5.18E-07	4.05E-07
R_031	5.18E-07	4.05E-07
R_032	5.18E-07	4.05E-07
R_033	5.18E-07	4.05E-07
R_034	5.18E-07	4.05E-07
R_035	5.18E-07	4.05E-07
R_036	5.18E-07	4.05E-07
R_037	5.18E-07	4.05E-07
R_038	5.18E-07	4.05E-07
R_039	5.18E-07	4.05E-07
R_040	5.18E-07	4.05E-07
R_041	5.18E-07	4.05E-07
R_042	5.18E-07	4.05E-07
R_043	5.18E-07	4.05E-07
R_044	5.18E-07	4.05E-07
R_045	5.18E-07	4.05E-07
R_046	5.00E-07	3.93E-07
R_047	5.00E-07	3.93E-07
R_048	5.00E-07	3.93E-07
R_049	5.00E-07	3.93E-07
R_050	5.00E-07	3.93E-07
R_051	5.00E-07	3.93E-07
R_052	5.00E-07	3.93E-07
R_053	5.00E-07	3.93E-07
R_054	5.00E-07	3.93E-07
R_055	5.18E-07	4.05E-07
R_056	5.18E-07	4.05E-07
R_057	5.18E-07	4.05E-07
R_058	5.18E-07	4.05E-07
R_059	5.18E-07	4.05E-07
R_060	5.18E-07	4.05E-07

Truck Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
R_061	5.18E-07	4.05E-07
R_062	5.18E-07	4.05E-07
R_063	5.18E-07	4.05E-07
R_064	5.18E-07	4.05E-07
R_065	5.18E-07	4.05E-07
R_066	5.18E-07	4.05E-07
R_067	5.00E-07	3.93E-07
R_068	5.00E-07	3.93E-07
R_069	5.00E-07	3.93E-07
R_070	5.00E-07	3.93E-07
R_071	5.00E-07	3.93E-07
R_072	5.00E-07	3.93E-07
R_073	5.00E-07	3.93E-07
R_074	5.00E-07	3.93E-07
R_075	5.00E-07	3.93E-07
R_076	5.00E-07	3.93E-07
R_077	5.00E-07	3.93E-07
R_078	5.00E-07	3.93E-07
R_079	5.00E-07	3.93E-07
R_080	5.00E-07	3.93E-07
R_081	5.00E-07	3.93E-07
R_082	5.00E-07	3.93E-07
R_083	5.00E-07	3.93E-07
R_084	5.00E-07	3.93E-07
R_085	5.00E-07	3.93E-07
R_086	5.00E-07	3.93E-07
R_087	5.18E-07	4.05E-07
R_088	5.18E-07	4.05E-07
R_089	5.18E-07	4.05E-07
R_090	5.18E-07	4.05E-07
R_091	5.18E-07	4.05E-07
R_092	5.18E-07	4.05E-07
R_093	5.18E-07	4.05E-07

Truck Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
R_094	5.18E-07	4.05E-07
R_095	5.18E-07	4.05E-07
R_096	5.18E-07	4.05E-07
R_097	5.18E-07	4.05E-07
R_098	5.18E-07	4.05E-07
R_099	5.18E-07	4.05E-07
R_100	5.18E-07	4.05E-07
R_101	5.00E-07	3.93E-07
R_102	5.00E-07	3.93E-07
R_103	5.00E-07	3.93E-07
R_104	5.00E-07	3.93E-07
R_105	5.00E-07	3.93E-07
R_106	5.00E-07	3.93E-07
R_107	5.00E-07	3.93E-07

Table B.2: *Rail PM_{10} and $PM_{2.5}$ Emission Scaling Factors*

Rail Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
Rail_01	5.83E-03	5.59E-03
Rail_02	5.83E-03	5.59E-03
Rail_03	5.83E-03	5.59E-03
Rail_04	5.83E-03	5.59E-03
Rail_05	5.83E-03	5.59E-03
Rail_06	5.83E-03	5.59E-03
Rail_07	5.83E-03	5.59E-03
Rail_08	5.83E-03	5.59E-03
Rail_09	5.83E-03	5.59E-03
Rail_10	5.83E-03	5.59E-03
Rail_11	5.83E-03	5.59E-03
Rail_12	5.83E-03	5.59E-03
Rail_13	5.83E-03	5.59E-03
Rail_14	5.83E-03	5.59E-03
Rail_15	5.83E-03	5.59E-03

Rail Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
Rail_16	5.83E-03	5.59E-03
Rail_17	5.83E-03	5.59E-03
Rail_18	5.83E-03	5.59E-03
Rail_19	5.83E-03	5.59E-03
Rail_20	5.83E-03	5.59E-03
Rail_21	5.83E-03	5.59E-03
Rail_22	5.83E-03	5.59E-03
Rail_23	2.92E-03	2.80E-03
Rail_24	2.92E-03	2.80E-03
Rail_25	2.92E-03	2.80E-03
Rail_26	2.92E-03	2.80E-03

Table B.3: *Cargo Handling Equipment PM_{10} and $PM_{2.5}$ Emission Scaling Factors*

CHE Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
AAT_01	1.02E-07	9.80E-08
AAT_02	1.02E-07	9.80E-08
AAT_03	1.02E-07	9.80E-08
AAT_04	1.02E-07	9.80E-08
AAT_05	1.02E-07	9.80E-08
Baulderstone_01	9.68E-09	9.27E-09
Baulderstone_02	9.68E-09	9.27E-09
Baulderstone_03	9.68E-09	9.27E-09
Chalmers_01	3.37E-07	3.23E-07
Chalmers_02	3.37E-07	3.23E-07
DP_01	9.67E-08	9.28E-08
DP_02	1.87E-07	1.80E-07
DP_03	1.28E-07	1.22E-07
DP_04	1.97E-07	1.89E-07
DP_05	4.20E-07	4.03E-07
Multimodal Terminal	5.22E-07	5.00E-07
Patrick Port_01	4.14E-07	3.97E-07
Patrick Port_02	4.14E-07	3.97E-07

CHE Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
Patricks_01	2.08E-07	2.00E-07
Patricks_02	6.48E-07	6.21E-07
Patricks_03	3.48E-07	3.34E-07
Queensland Commodity Exports	1.45E-07	1.39E-07
AFCS	3.02E-03	2.90E-03
POL	9.46E-04	9.06E-04
Tza	7.79E-02	7.47E-02
CHH	3.89E-02	3.73E-02
SF	3.89E-02	3.73E-02
Toll	3.89E-02	3.73E-02
IPS_1	1.87E-02	1.79E-02
IPS_2	1.87E-02	1.79E-02
IPS_3	1.87E-02	1.79E-02
IPS_4	1.87E-02	1.79E-02
GrainCorp	1.70E-07	1.63E-07
Sunstate_01	1.89E-04	5.49E-05
Sunstate_02	1.67E-04	4.86E-05
Sunstate_03	1.06E-04	3.09E-05
Queensland Bulk Handling_01	4.36E-08	4.18E-08
Queensland Bulk Handling_02	4.36E-08	4.18E-08
Caltex	2.33E-07	2.23E-07

Table B.4: *Shipping PM_{10} and $PM_{2.5}$ Emission Scaling Factors*

Shipping Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
S_01_L	2.24E-07	2.18E-07
S_02_L	2.24E-07	2.18E-07
S_03_L	2.24E-07	2.18E-07
S_04_L	2.24E-07	2.18E-07
S_05_L	2.24E-07	2.18E-07
S_06_L	3.65E-07	3.55E-07
S_07_L	1.34E-06	1.30E-06
S_08_L	1.34E-06	1.30E-06

Shipping Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
Ship_01	2.66E-10	2.35E-10
Ship_02	2.66E-10	2.35E-10
Ship_03	2.66E-10	2.35E-10
Ship_04	2.66E-10	2.35E-10
Ship_05	2.66E-10	2.35E-10
Ship_06	2.66E-10	2.35E-10
Ship_07	2.66E-10	2.35E-10
Ship_08	2.66E-10	2.35E-10
Ship_09	2.66E-10	2.35E-10
Ship_10	2.66E-10	2.35E-10
Ship_11	2.66E-10	2.35E-10
Ship_12	2.66E-10	2.35E-10
Ship_13	2.66E-10	2.35E-10
Ship_14	2.66E-10	2.35E-10
Ship_15	2.66E-10	2.35E-10
Ship_16	2.66E-10	2.35E-10
Ship_17	2.66E-10	2.35E-10
Ship_18	2.66E-10	2.35E-10
Ship_19	2.66E-10	2.35E-10
Ship_20	2.66E-10	2.35E-10
Ship_21	2.66E-10	2.35E-10
Ship_22	2.66E-10	2.35E-10
Ship_23	2.66E-10	2.35E-10
Ship_24	2.66E-10	2.35E-10
Ship_25	2.66E-10	2.35E-10
Ship_26	2.66E-10	2.35E-10
Ship_27	2.66E-10	2.35E-10
Ship_28	2.66E-10	2.35E-10
Ship_29	2.66E-10	2.35E-10
Ship_30	2.66E-10	2.35E-10
Ship_31	2.66E-10	2.35E-10
Ship_32	2.66E-10	2.35E-10
Ship_33	2.66E-10	2.35E-10

Shipping Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
Ship_34	2.66E-10	2.35E-10
Ship_35	2.66E-10	2.35E-10
Ship_36	2.66E-10	2.35E-10
Ship_37	2.66E-10	2.35E-10
Ship_38	2.66E-10	2.35E-10
Ship_39	2.66E-10	2.35E-10
Ship_40	2.66E-10	2.35E-10
Ship_41	2.66E-10	2.35E-10

Table B.5: *Materials Handling PM_{10} and $PM_{2.5}$ Emission Scaling Factors*

Materials Handling Source Name	PM_{10} Scaling Factor	$PM_{2.5}$ Scaling Factor
G_UL	2.39E-02	3.99E-03
G_SL	3.07E-02	5.63E-03
C_SL	1.90E+00	4.81E-02
C_UL	1.14E+01	2.88E-01
GC	8.46E-06	1.52E-07
QBH_01	7.45E-06	7.72E-07
QBH_02	7.45E-06	7.72E-07

Appendix C PM$_{2.5}$ Results Contours

C.1 $PM_{2.5}$ 24 Hour Average Contour Results

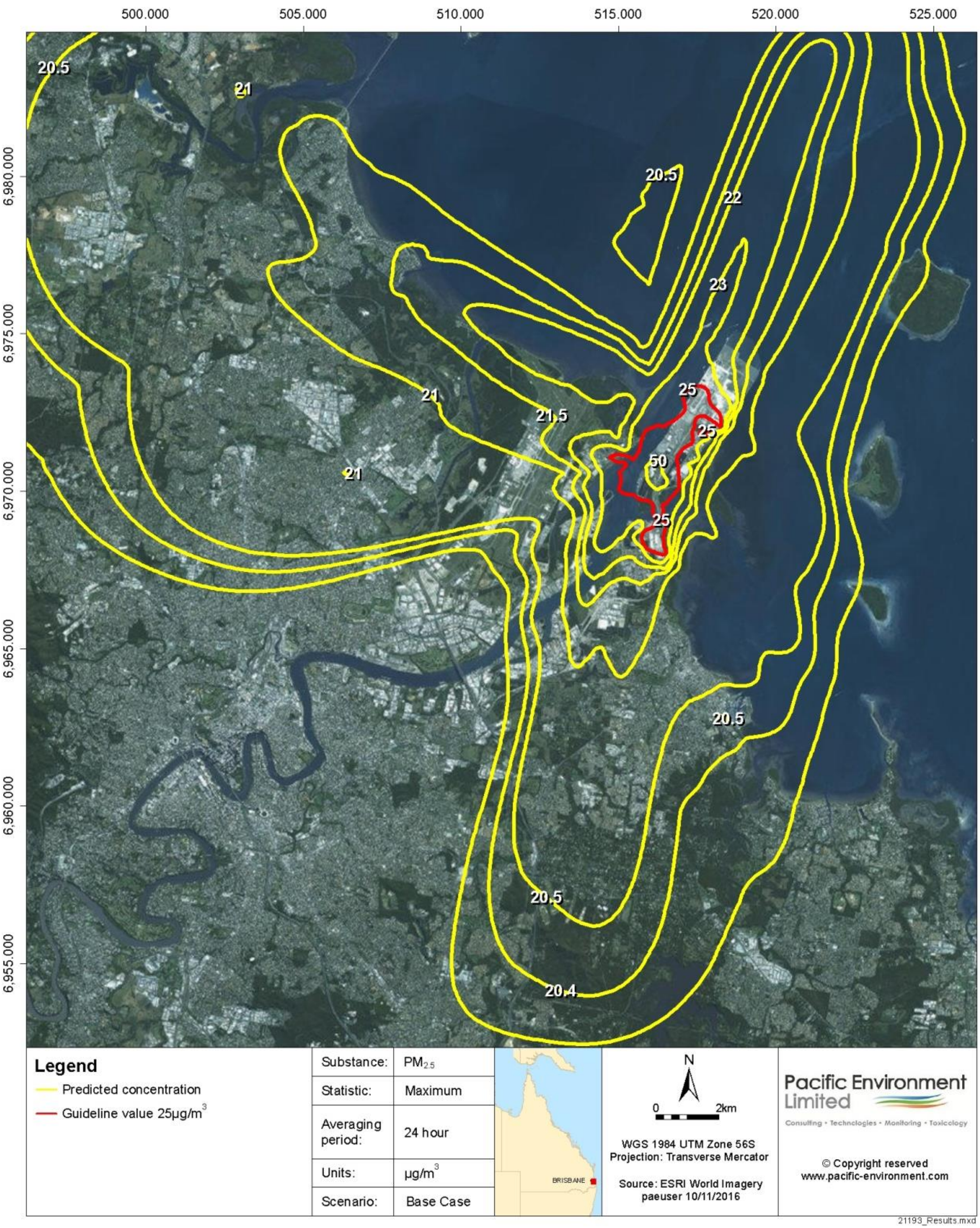


Figure C.1: *Base Case Scenario $PM_{2.5}$ 24 Hour Average Contour Results*

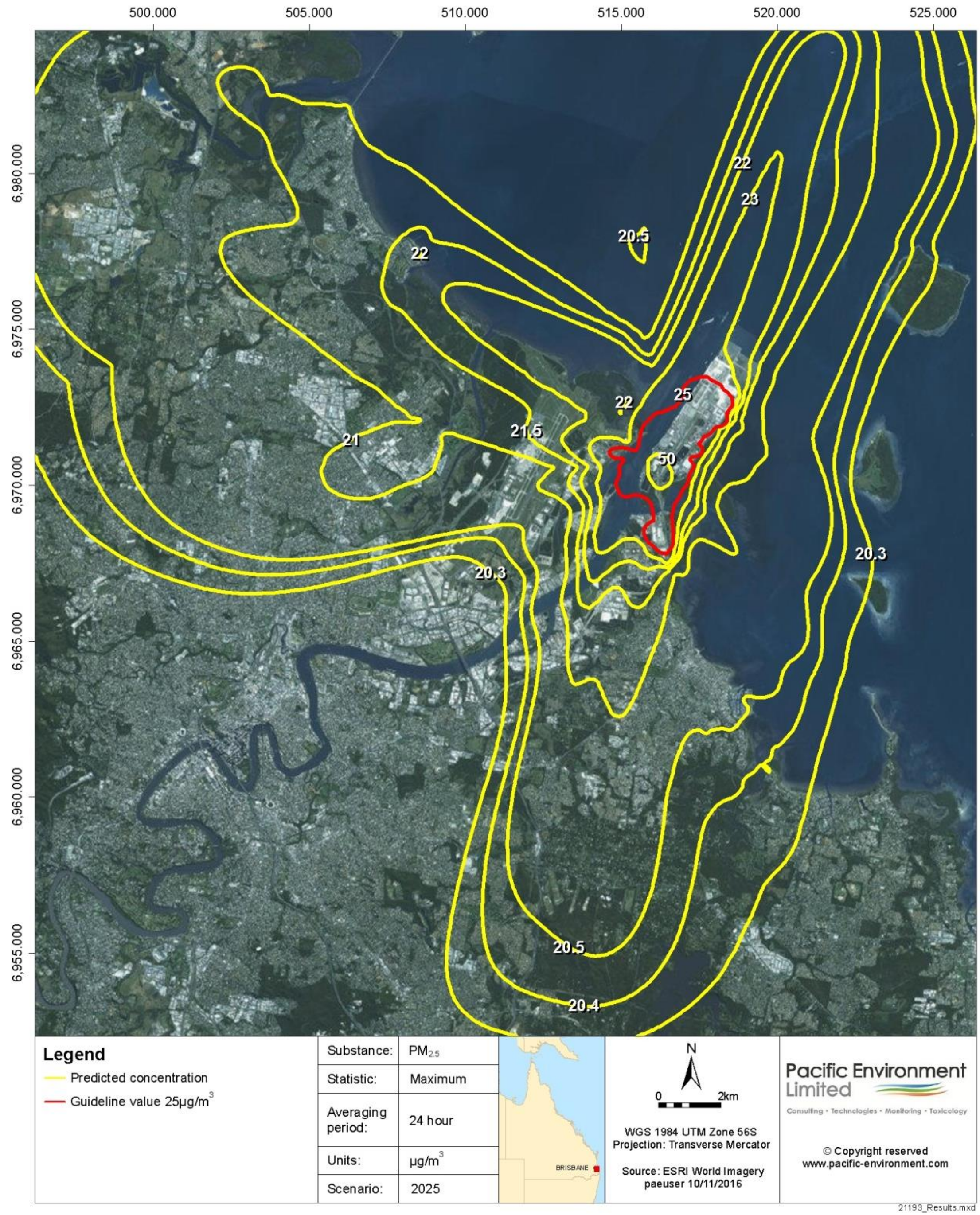


Figure C.2: *2025 Scenario $PM_{2.5}$ 24 Hour Average Contour Results*

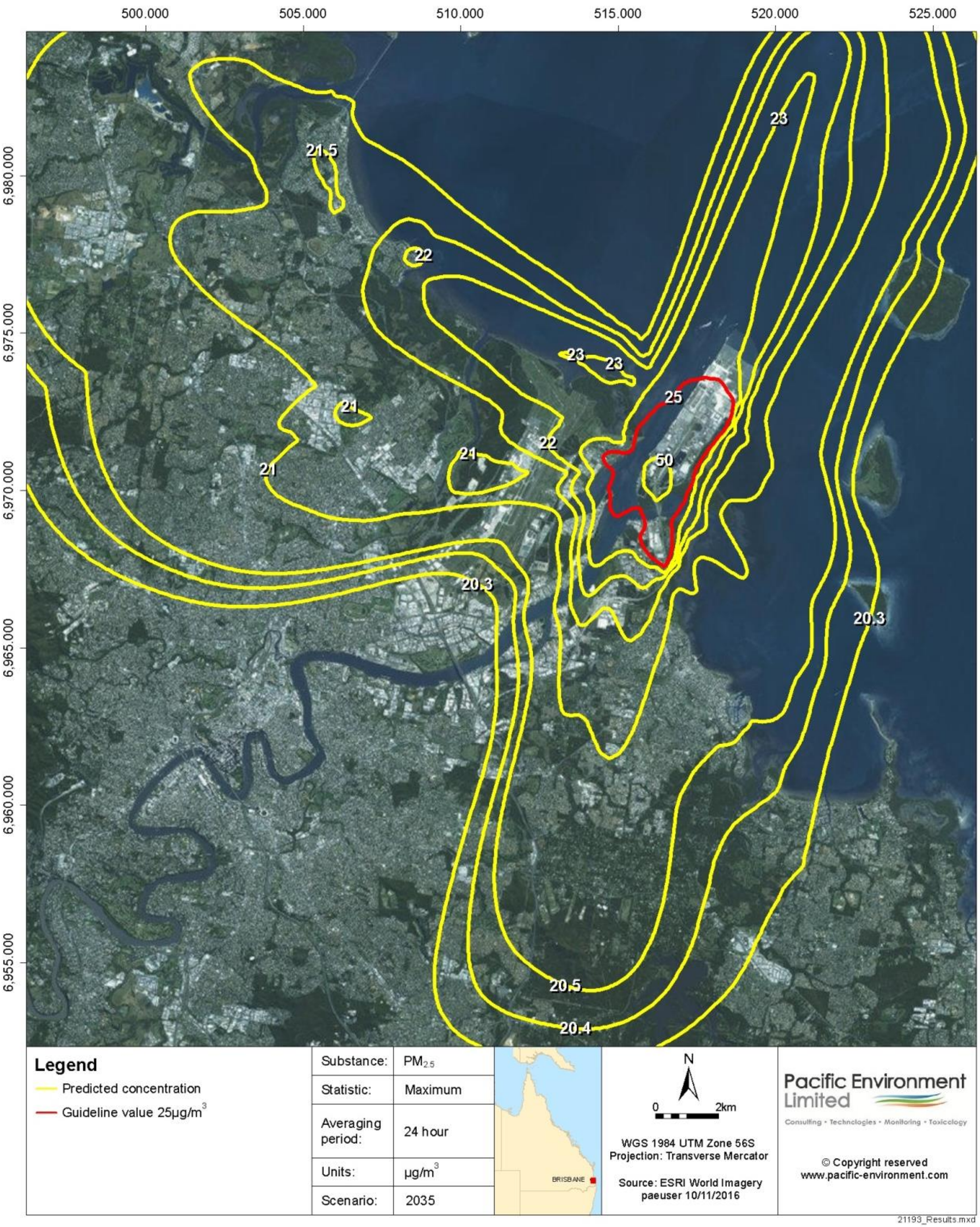


Figure C.3: *2035 Scenario $PM_{2.5}$ 24 Hour Average Contour Results*

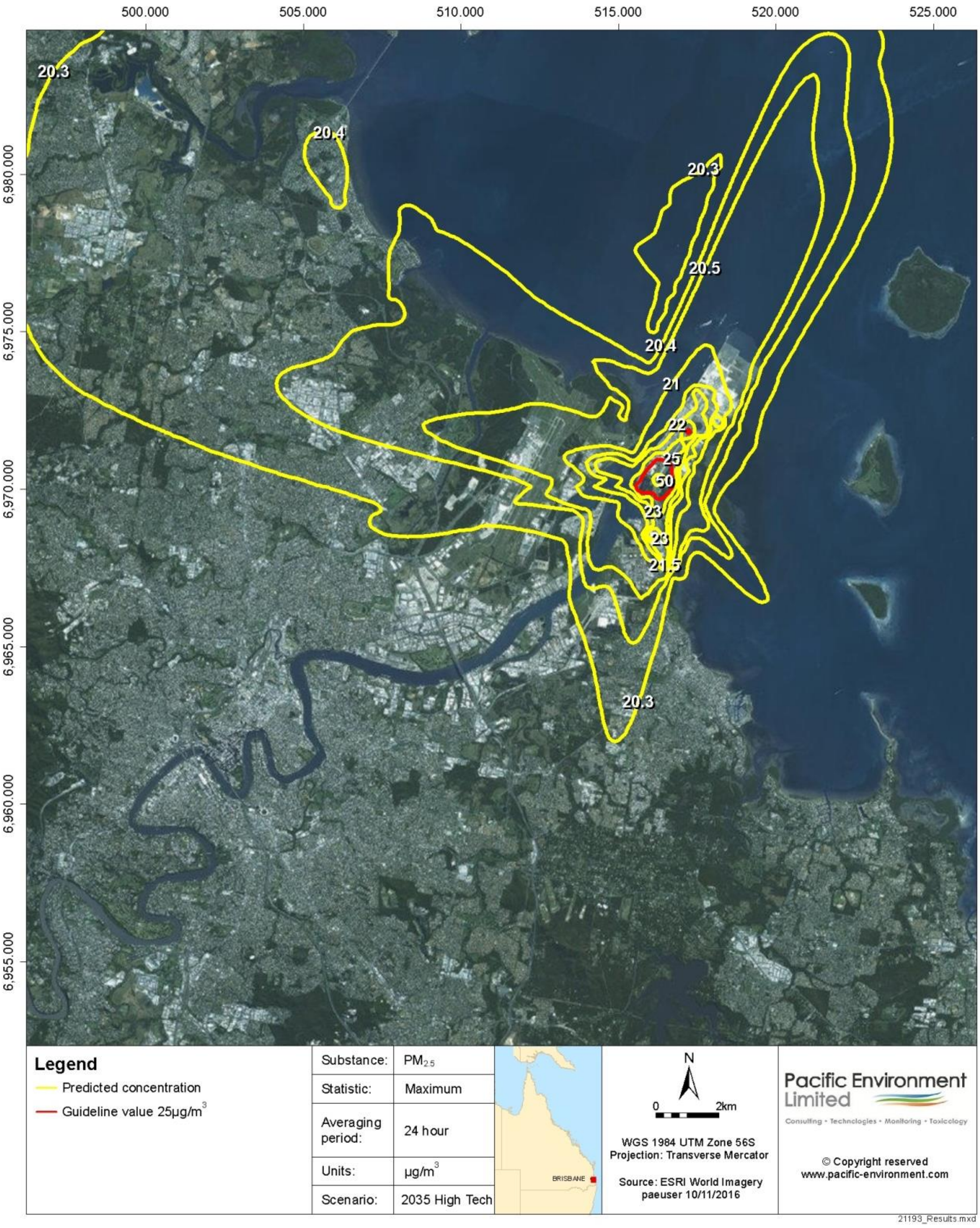


Figure C.4: *2035 High Tech Scenario $PM_{2.5}$ 24 Hour Average Contour Results*

C.2 $PM_{2.5}$ Annual Average Contour Results

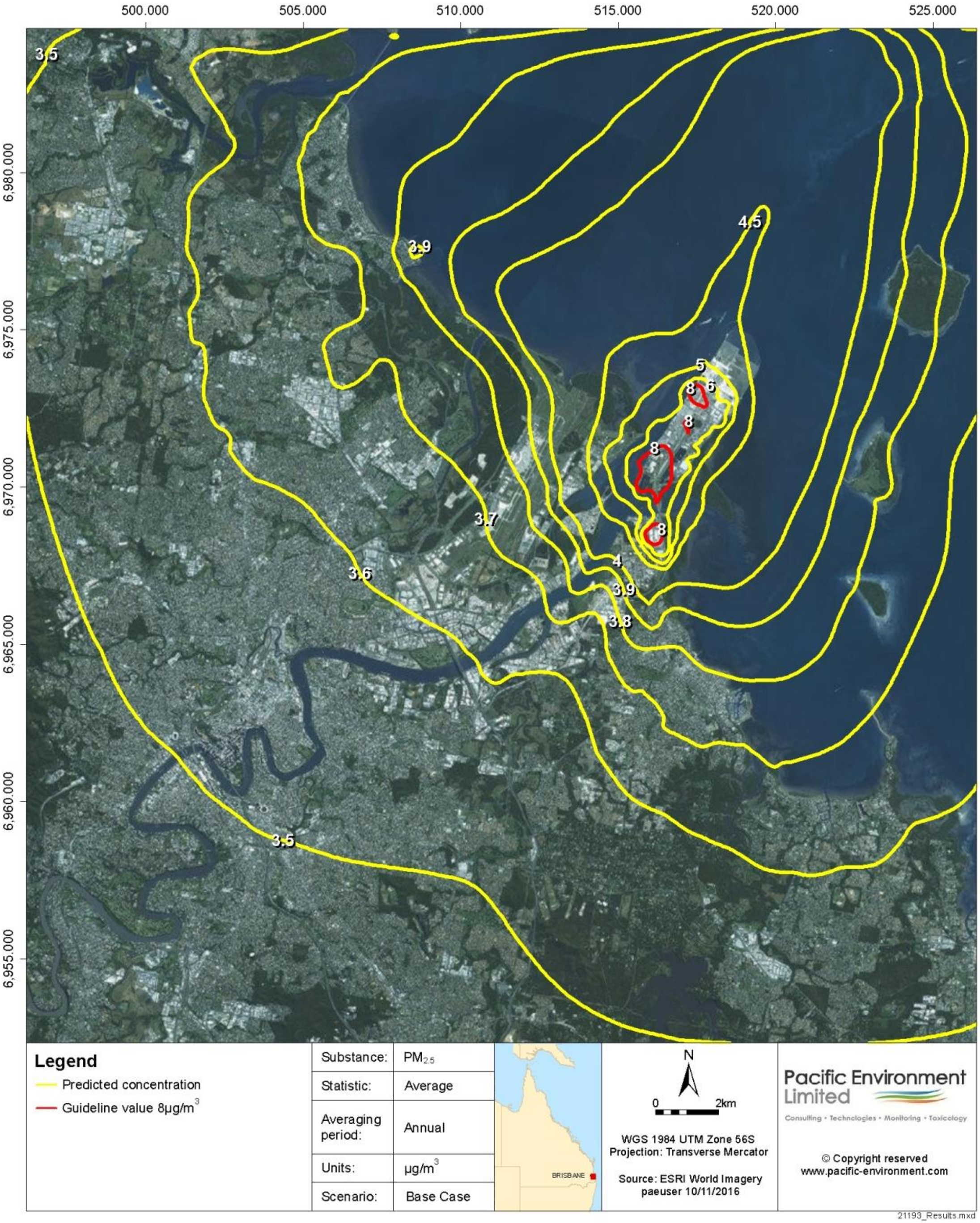


Figure C.5: *Base Case Scenario $PM_{2.5}$ Annual Average Contour Results*

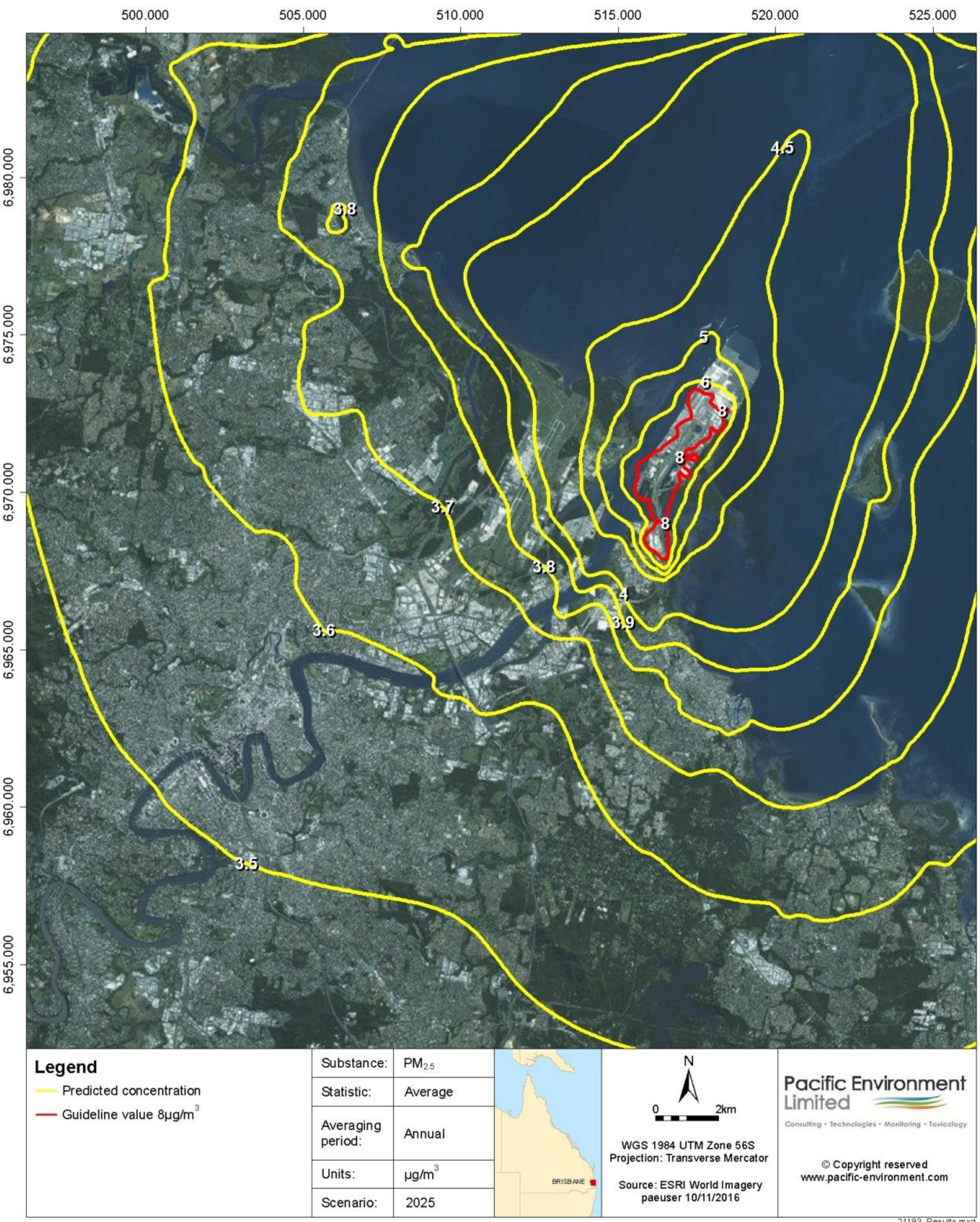


Figure C.6: *2025 Scenario $PM_{2.5}$ Annual Average Contour Results*

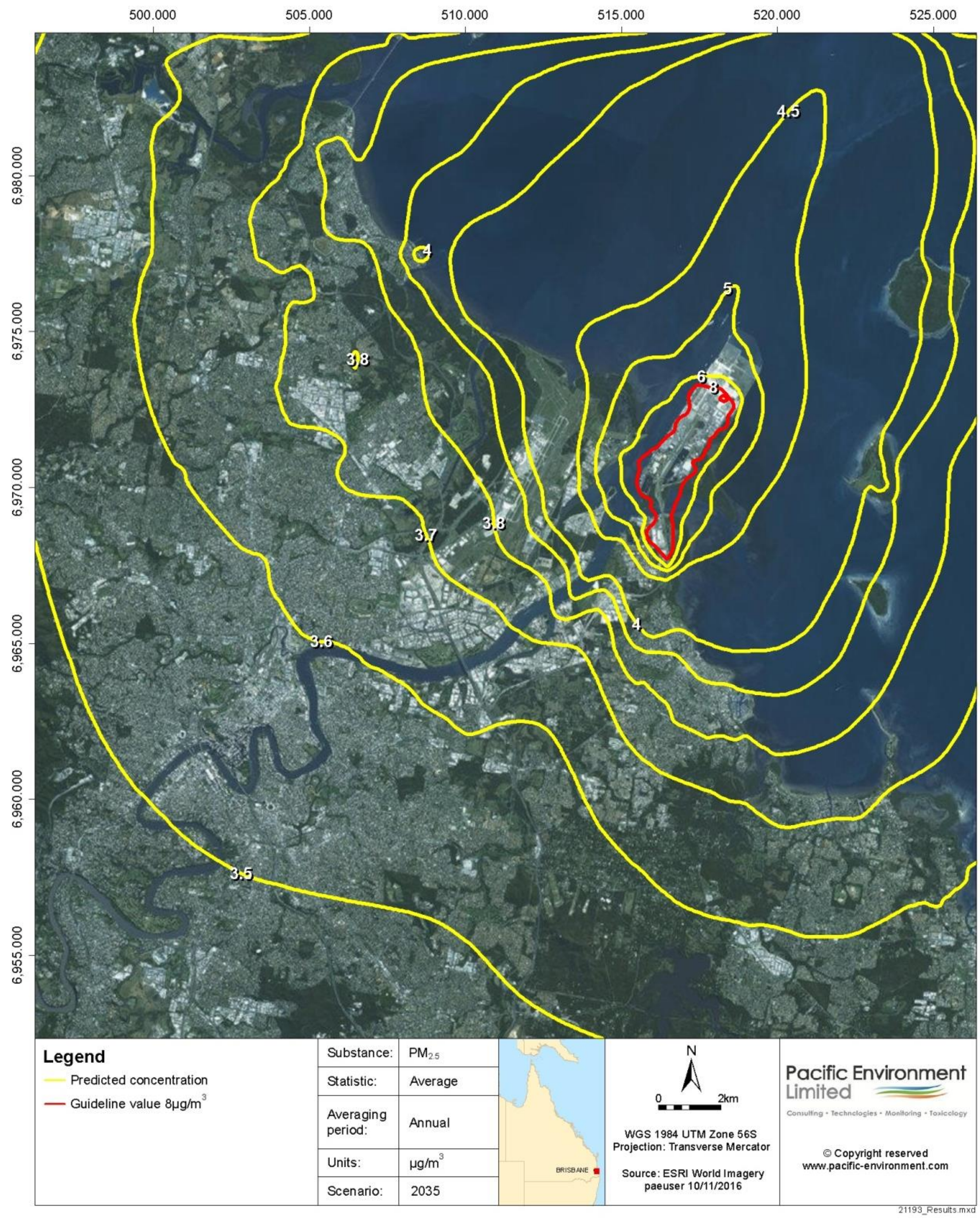


Figure C.7: *2035 Scenario $PM_{2.5}$ Annual Average Contour Results*

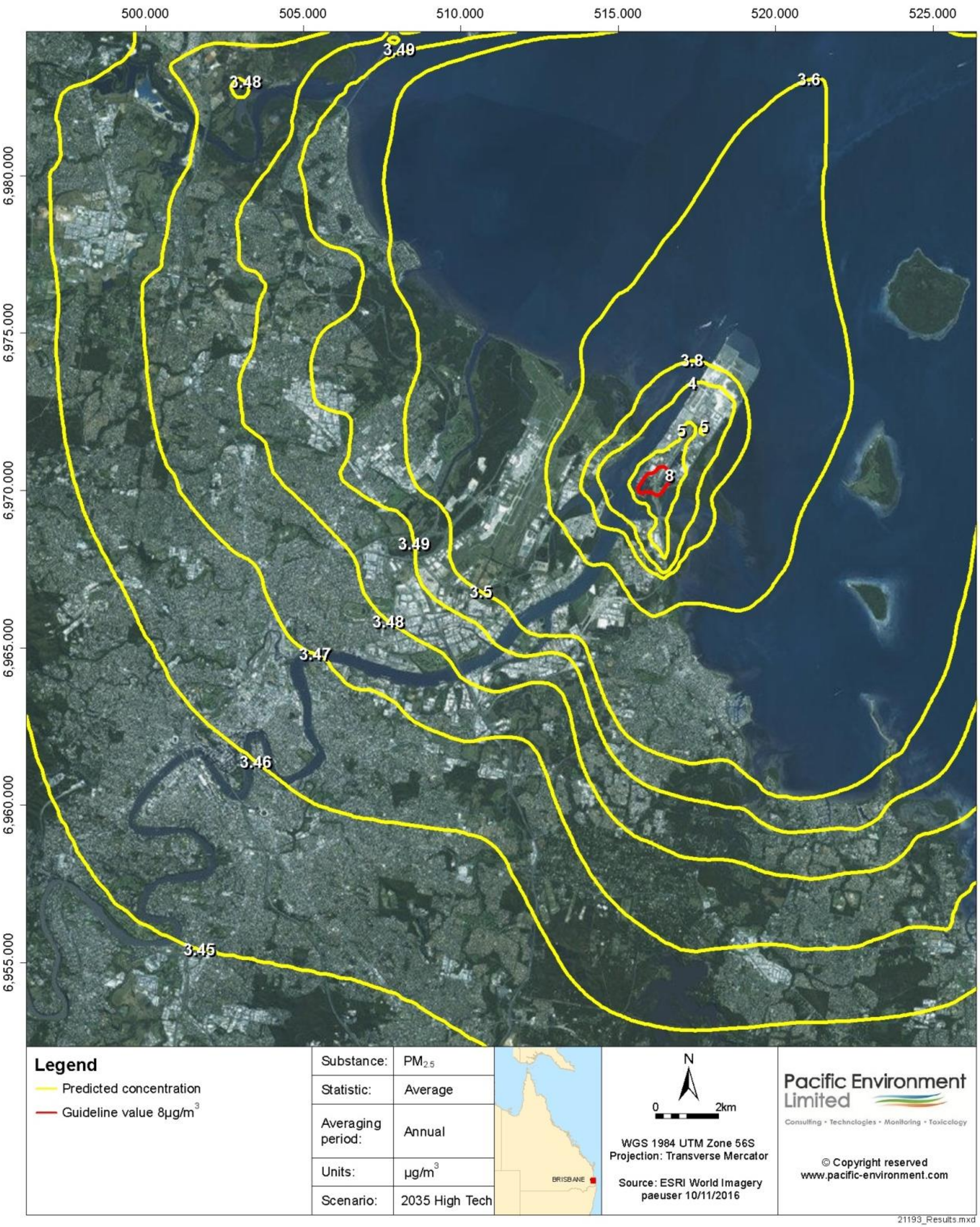


Figure C.8: *2035 High Tech Scenario $PM_{2.5}$ Annual Average Contour Results*

Appendix D $PM_{2.5}$ Source Contribution

D.1 Bingera Drive Source Contribution

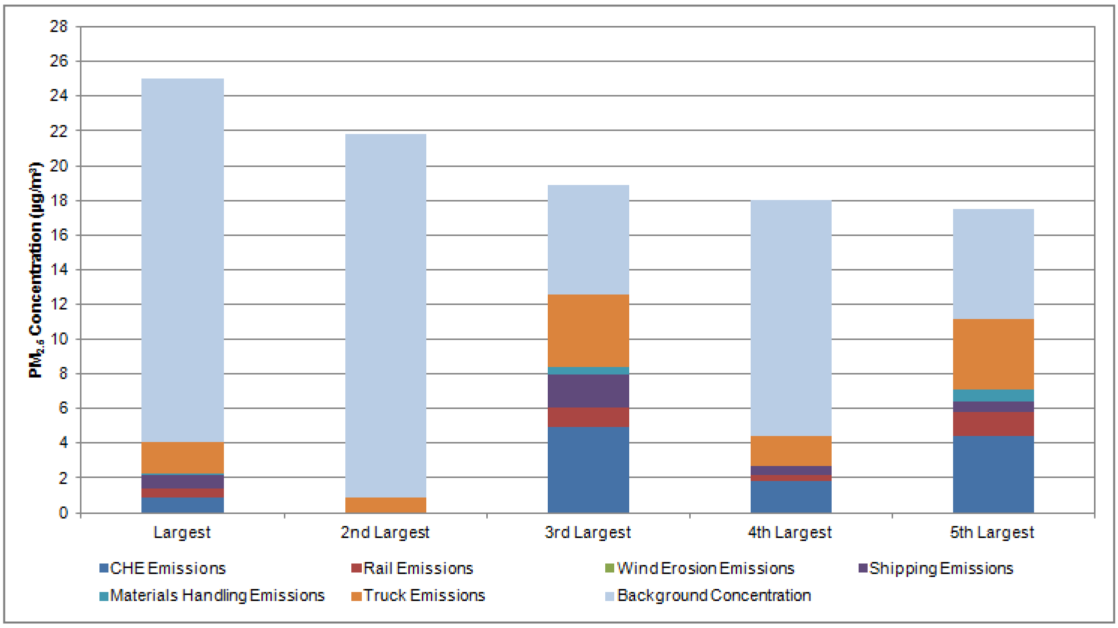


Figure D.1: *$PM_{2.5}$ Concentration Source Contribution for Base Case Scenario – Bingera Drive*

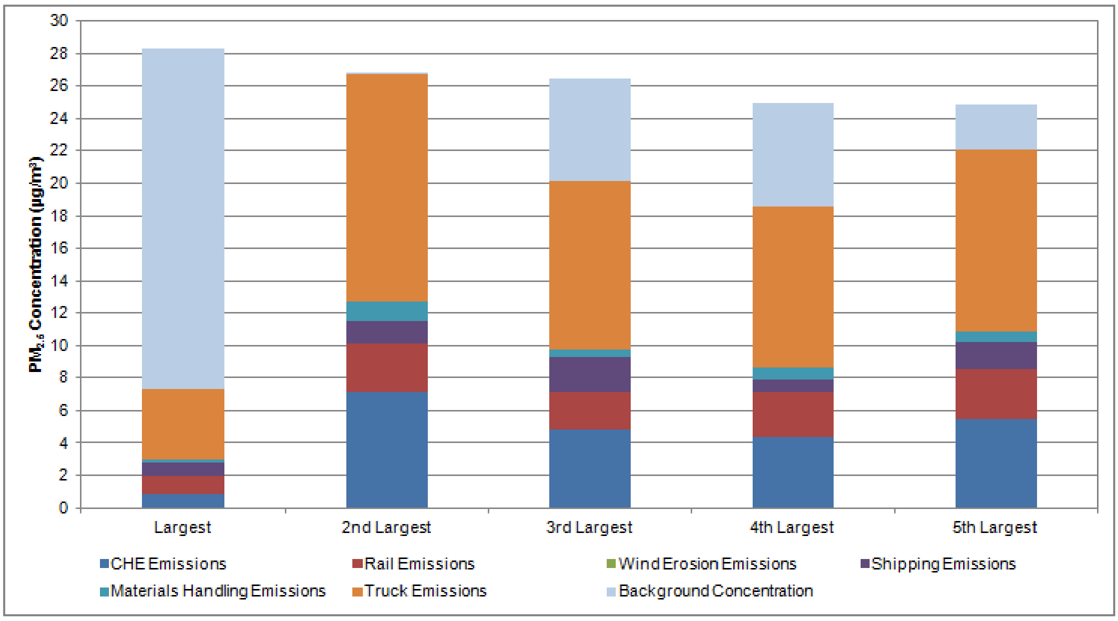


Figure D.2: *$PM_{2.5}$ Concentration Source Contribution for Year 2025 Scenario – Bingera Drive*

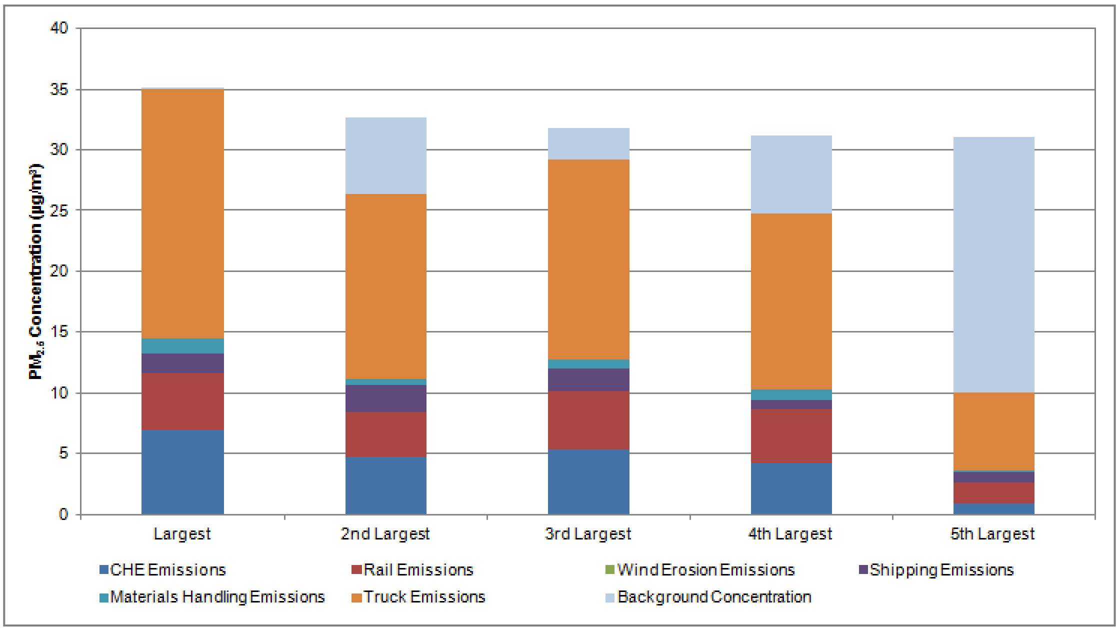


Figure D.3: *$PM_{2.5}$ Concentration Source Contribution for Year 2035– Bingera Drive*

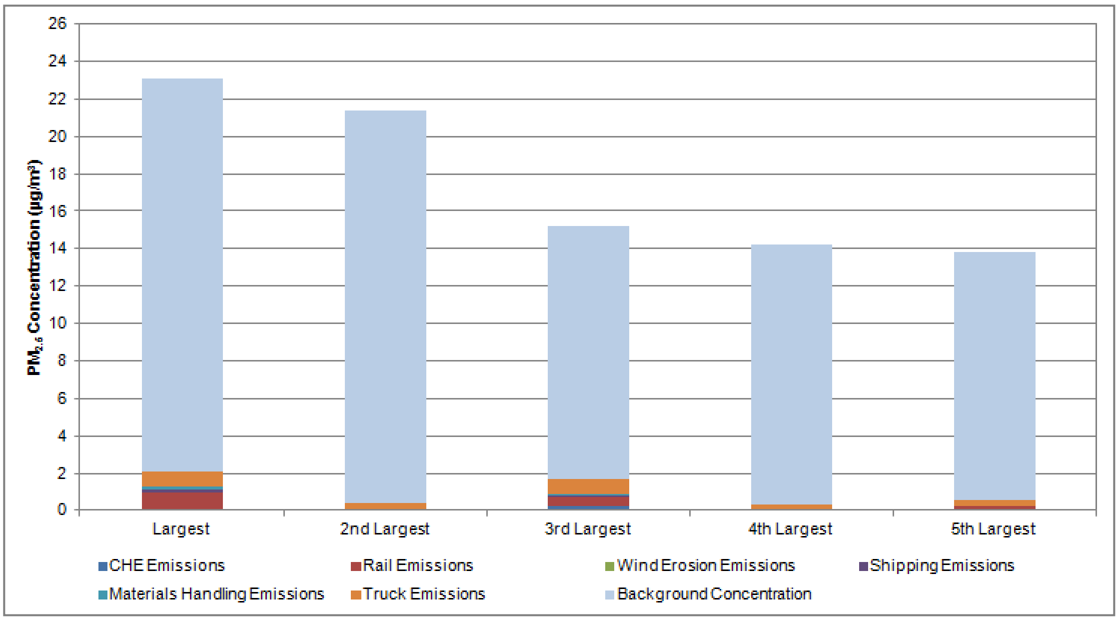


Figure D.4*: $PM_{2.5}$ Concentration Source Contribution for Year 2035 - High Technology– Bingera Drive*

D.2 Osprey Drive Source Contribution

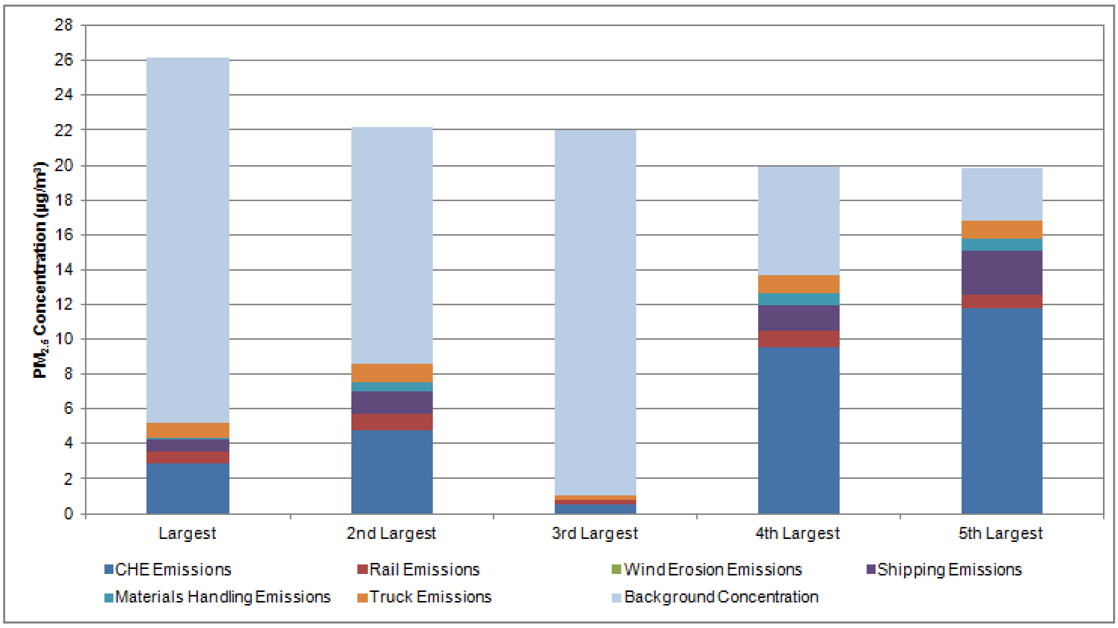


Figure D.5: *$PM_{2.5}$ Concentration Source Contribution for Base Case – Osprey Drive*

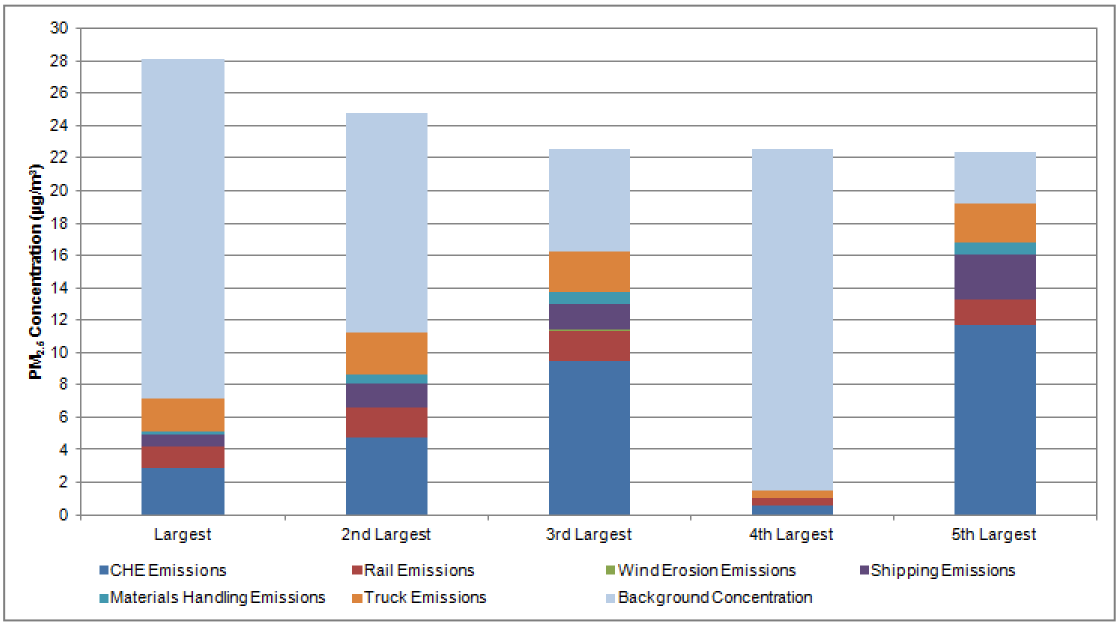


Figure D.6: *$PM_{2.5}$ Concentration Source Contribution for Year 2025 – Osprey Drive*

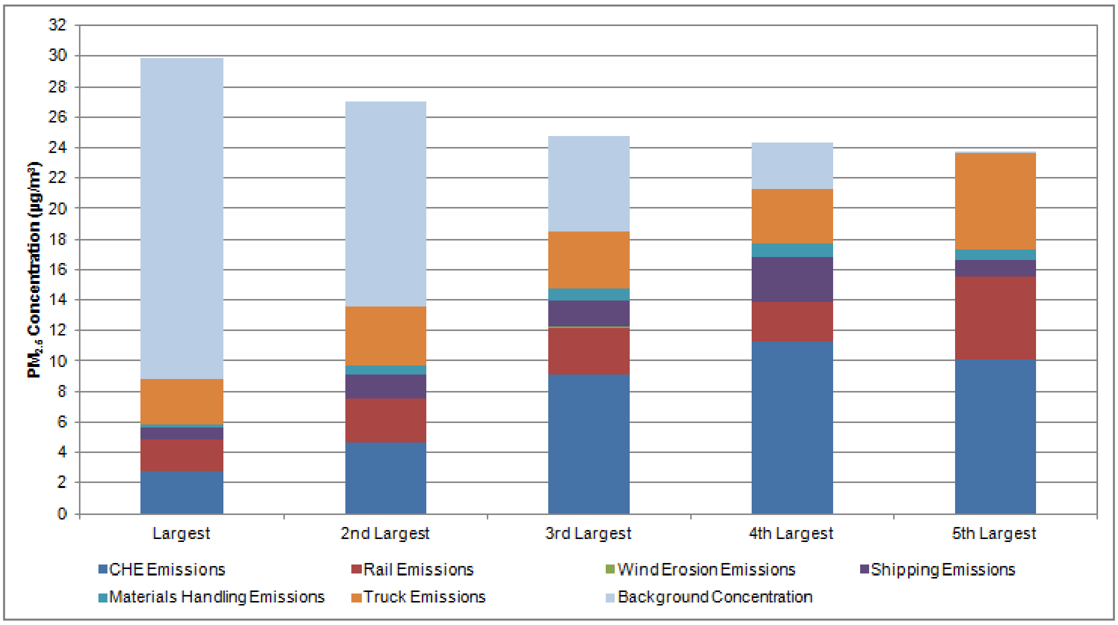


Figure D.7: *$PM_{2.5}$ Concentration Source Contribution for Year 2035 – Osprey Drive*

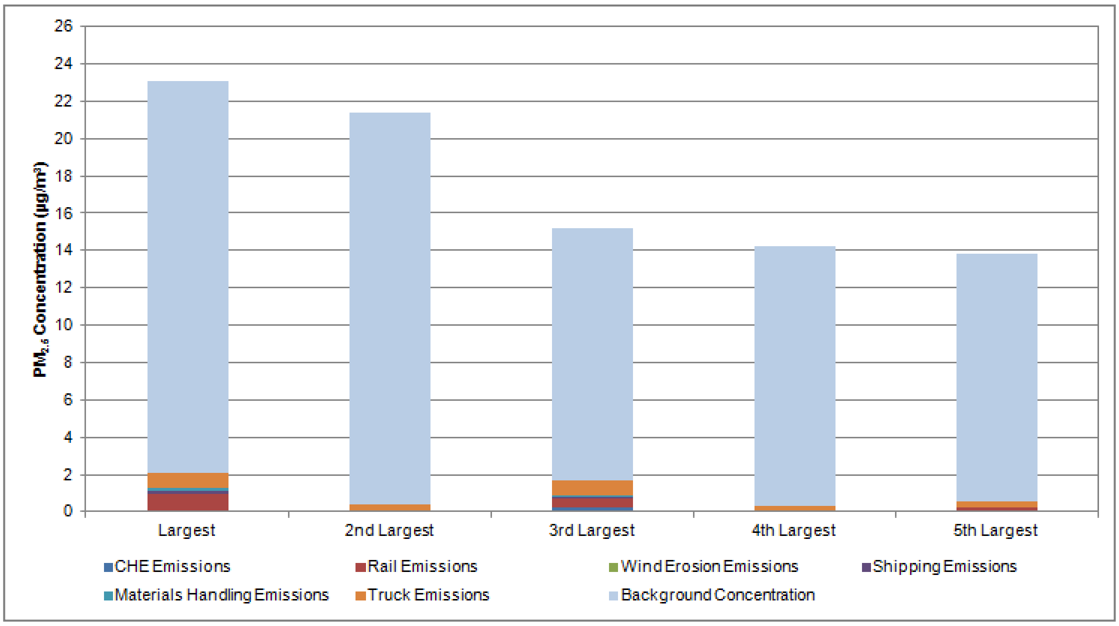


Figure D.8: *$PM_{2.5}$ Concentration Source Contribution for Year 2035 - High Technology – Osprey Drive*