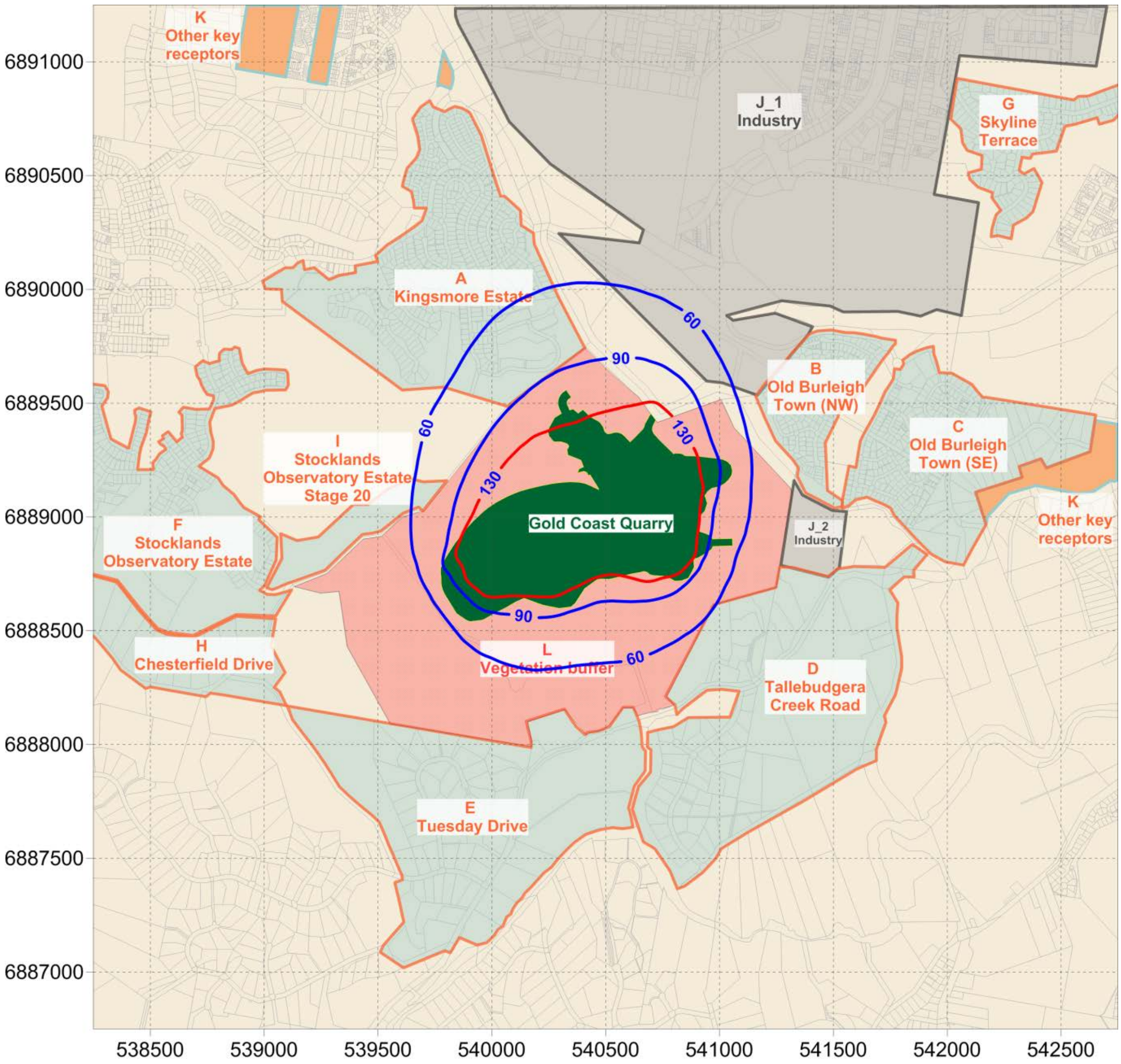

Figure 26 Predicted annual average dust deposition rates due to Project operations and including a background level of 37.8 mg/m²/day

Location: Gold Coast, QLD	**Averaging period:** Annual	**Data source:** Calpuff	**Units:** mg/m²/day
Type: Annual contours	**Criteria:** NSW OEH - 130 mg/m²/day	**Prepared by:** Andrew Vernon	**Date:** February 2013

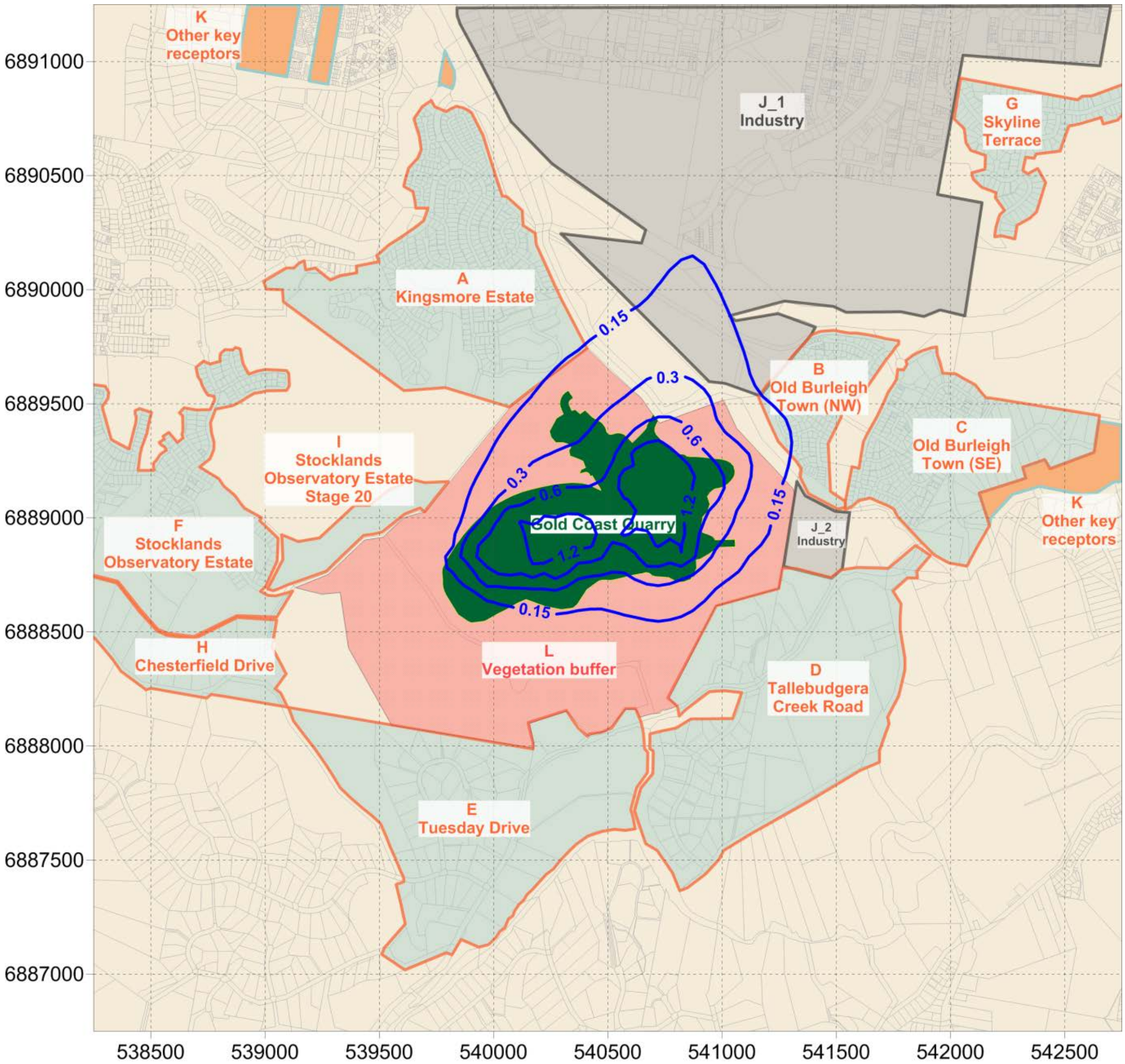

Figure 27 Predicted annual average concentration of respirable crystalline silica due to Project operations in isolation

Location: Gold Coast, QLD	**Averaging period:** Annual	**Data source:** Calpuff	**Units:** µg/m³
Type: Annual contours	**Criteria:** Vic EPA - 3 µg/m³	**Prepared by:** Andrew Vernon	**Date:** February 2013

Appendix A

Methodology and Activity Data for Dust Emissions Inventory

Contents

A1 Gold Coast Quarry Dust Emissions Inventory

Dust emissions for activities related to each stage of the quarry were based on emission factors and methods published by the US EPA (US EPA, 1998; US EPA 2006a; US EPA 2006b; US EPA 2004; US EPA 2003; US EPA 2011).

Operational information, site layouts, quarrying methods and vehicle information were provided by Boral and Cardno HRP. Typical quarry product and overburden characteristics were taken from the US EPA AP-42 documents where information was not available.

The complete dust emissions inventory is detailed in Section 7, Table 13 of the Gold Coast Quarry Air Quality Assessment Report and reproduced below.

Stage	Emission Rate (g/s)		
	TSP	PM_{10}	$PM_{2.5}$
Establishment 1 (E1)	0.52	0.10	0.01
Establishment 2 (E2)	4.15	1.23	0.13
Establishment 3 (E3)	6.26	1.82	0.19
Development 1 and 2 (D1/D2)	8.44	2.83	0.38
Development 3 and 4 (D3/D4)	11.72	3.82	0.50
Operation (Q1 -Q5)[1]	24.01	9.13	1.18

Table note:
[1] Operation expected to last for 40 years at extraction rate of 2 Mtpa. These emissions are based on Operational Stage Q5, which is 2Mtpa extraction with full development of the pit

A summary of the activities from each stage of the quarry is provided in the table below.

	Incremental tonnage per Stage/Phase						
Material	**Phase E1**	**Phase E2**	**Phase E3**	**Phase D1**	**Phase D2**	**Phase D3**	**Phase D4**
Topsoil	4000	15912	8964	26100	0	18900	0
Cut	21900	422240	453180	888942	1441133	1365735	1405650
Fill	1850	95760	115900	0	0	24890	0
Overburden	20050	326480	337280	776652	844625	744338	827775
Product	0	0	0	112290	596507	596507	577875

The following sections describe in detail the methodologies and activity data that was used to calculate the dust emissions inventory for the operational stage (phase Q5) of the Gold Coast Quarry, and used in the air quality assessment.

A2 Methodology and activity data for Operation Q5 dust emissions inventory

The following sections detail how dust emissions from each activity were calculated and list the activity data used for the calculation. Where possible, discussion of the parameters that have the greatest influence on the dust emissions has been included.

A2.1 Quarry hours of operation

Boral provided the following information regarding the operating hours of the proposed quarry. Each section includes detail of how the operating hours for each activity have been incorporated into the dispersion modelling to provide a more accurate prediction of potential impacts.

Parameter	Units	Value	Comments
Number of operating days per week for quarry	Days/ week	6	Quarry operates Monday to Saturday
Quarry operating hours	hours	12	6am - 6pm
Number of days per week for blasting	Days/week	5	Monday to Friday
Blasting hours per day	hours	8	9am - 5pm

A2.2 Drilling

The emission factors for drilling were calculated from the AP42 documents, chapter 11.9 "Western Surface Coal Mining" (October 1998).

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Overburden/raw quarry material	kg/hole	0.59	TSP x 0.52	TSP x 0.03

To estimate peak emissions and therefore the maximum ground-level concentrations of dust over a 24-hour period, one blast per day was assumed, and therefore the drilling of 150 holes per day was also assumed. Calpuff was set up to model the dispersion of dust emissions due to drilling 150 holes released at a constant rate between 6am to 6pm, each day.

Parameter	Units	Value	Source
Number of holes drilled per blast	holes/blast	150	Boral

A2.3 Blasting

The emission factor for blasting was calculated from the AP42 documents, chapter 11.9 "Western Surface Coal Mining" (October 1998).

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Overburden/raw quarry material	kg/blast	$0.00022 \times A^{1.5}$	TSP x 0.52	TSP x 0.03

Where A is the area per blast (m^2). One blast per day was assumed in order to estimate the maximum ground-level concentrations of dust due to quarry operations over a 24-hour period. Actual frequency of blasting is proposed to be once a week.

Parameter	Units	Value	Source
Blasts per day	blasts/day	1	For dispersion modeling purposes, actual frequency of blasting is proposed to be once a week.
Area per blast (A)	m^2	1300	Blastechnology

Calpuff was set up to model the dispersion of dust emissions due to one blast released at a constant rate between 6am to 6pm, each day, which is consistent .with the objectives for PM_{10} and $PM_{2.5}$.

A2.4 Bulldozing

The emission factors for bulldozing were calculated from the AP42 documents, chapter 11.9 “Western Surface Coal Mining” (October 1998).

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Overburden/raw quarry material	kg/hr	$\frac{2.6(s)^{1.2}}{(M)^{1.3}}$	$0.74 \times \frac{0.45(s)^{1.5}}{(M)^{1.4}}$	TSP x 0.105

Where s = material silt content (%)
M = material moisture content (%)

Emissions of dust due to dozer movements in the active pit area were calculated using the following activity data.

Parameter	Units	Value	Source
Number of bulldozers	number	1	Boral
Operations hours/day for each bulldozer	hr	12	Assumed to operate continuously while other quarry operations occur (i.e. from 6am to 6pm)
Silt content of active pit material	%	6.9	US EPA AP42 documents, Chapter 13.3 "Unpaved roads" (US EPA, 2006a). Average value for bulldozing overburden
Moisture content of active pit material	%	7.9	

Calpuff was set to model the continuous use of the bulldozer between 6am to 6pm, each day. While the emissions due to dozer activity are dependent on material characteristics, they are directly proportional to the hours of operation. The estimate of emissions is conservative as it has assumed a 100% utilisation rate for the bulldozer.

A2.5 Material transfers

Material is transferred at various locations and by several types of equipment during quarry operations. The emission rates for transfer points were calculated using the following equation from the AP42 documents, chapter 13.2 "Aggregate Handling and Storage Piles" (November 2006b):

$$E = k0.0016\left(\frac{U}{2.2}\right)^{1.3}\left(\frac{M}{2}\right)^{-1.4} kg/t$$

k = 0.74 for particles less than 30 µm
k = 0.35 for particles less than 10 µm
k = 0.053 for particles less than 10 µm

U = mean wind speed in m/s
M = material moisture content

The following activity data were used to calculate emissions due to material transfers.

Parameter	Units	Value	Source	Comments
Mean wind speed between 6am and 6pm	m/s	3.3	CALMET	All material transfers will occur during quarry operating hours, during which the average wind speed is slightly higher than over a 24-hour period
Overburden moisture content	%	7.9	US EPA AP42 documents, Chapter 13.3 "Unpaved roads" (US EPA, 2006a). Average value for bulldozing overburden	Used for: • front end loaders moving overburden in active pit area • truck dumping overburden
Raw material moisture content	%	2.1	US EPA AP42 documents, chapter 13.2.4, average values for stone quarrying and processing "various limestone products"	Used for: • front end loaders moving raw quarry material
Product moisture content	%	2.1	US EPA AP42 documents, chapter 13.2.4, average values for stone quarrying and processing "crushed limestone"	Used for: • front end loaders • truck dumping • trip feeders • conveyor transfers • surge bins • stacking • reclaiming

Throughputs			
Parameter	**Units**	**Value**	**Source**
Front end loader overburden extraction/dumping rate	tph	100	Assumed to match extraction rate
Front end loader raw material extraction rate	tph	900	Process flow diagrams provided by Boral
Truck dumping to primary crusher	tph	895	
Total transfer capacity through primary crusher stage	tph	3,080	
Stacking and reclaiming rate at scalps/roadbase stockpile	tph	142	
Stacking and reclaiming rate at primary stockpile	tph	752	
Total trip feeder rate near primary stockpile	tph	752	
Stacking and reclaiming rate at scalps/roadbase stockpile	tph	142	Process flow diagrams provided by Boral
Stacking and reclaiming rate at secondary scalps stockpile	tph	292	Assumed equivalent to blending stockpile.
Total transfer capacity through secondary crusher stage	tph	4,343	Process flow diagrams provided by Boral
Total transfer capacity through tertiary crusher stage	tph	5,892	
Stacking and reclaiming rate at ballast stockpile	tph	292	Assumed equivalent to blending stockpile.
Total transfer capacity through final screening stage	tph	1,498	Process flow diagrams provided by Boral
Total transfer capacity in loadout	tph	2,685	
Stacking and reclaiming rate at blending stockpile	tph	292	Assumed reclaiming rate. Stacking rate provided on process flow diagrams from Boral

Calpuff was set up to model dispersion of dust emissions due to material transfers released between 6am and 6pm.

A2.6 Screening

Emission factors for screening at the processing plant were calculated using the AP42 documents, chapter 11.19.2 "Crushed Stone Processing and Pulverized Mineral Processing."

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Raw quarry material and product	kg/Mg	0.0125	0.0043	PM_{10} x 0.000025 / 0.00037 (using the ratio of controlled screening $PM_{2.5}$ and PM_{10} emission factors for as a scaling factor)

The following throughputs, provided by Boral, were used to calculate the peak emissions due to screening over a day of quarry operations. Calpuff was set up to model dispersion of these emissions released at a constant rate between 6am and 6pm each day.

Screen number	Units	Maximum throughput	Comments
1	tph	242	Screens within primary crushing stage
2	tph	242	
3	tph	237	
4	tph	752	Screens within secondary crushing stage
5	tph	442	
6	tph	442	
7	tph	379	Screens within tertiary crushing stage
8	tph	379	
9	tph	749	
10	tph	375	Screens within final screening stage
11	tph	375	
12	tph	291	
13	tph	121	

A2.7 Crushing

Emission factors for primary, secondary and tertiary crushing of quarry products at the processing plant were calculated using the AP42 documents, chapter 11.19.2 "Crushed Stone Processing and Pulverized Mineral processing" (August 2004). Emission factors for all crushing operations have been determined from the emission factor for tertiary crushing.

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Raw and product material	kg/Mg	0.0027	0.0012	TSP x 0.00005 / 0.0027 (using the ratio of controlled tertiary crushing $PM_{2.5}$ and TSP emission factors for as a scaling factor)

The following throughputs, provided by Boral, were used to calculate the peak emissions due to crushing over a day of quarry operations. Calpuff was set up to model dispersion of these emissions released at a constant rate between 6am and 6pm each day.

Crusher number	Units	Maximum throughput	Comments
1	tph	653	Primary crusher
2a	tph	351	Secondary crushers
2b	tph	351	
3	tph	253	Tertiary crushers
4	tph	253	
5	tph	253	
6	tph	600	

A2.8 Conveyor emissions

TSP emissions from conveyors at the quarry processing plant for each hour modelled were estimated using the following equation:

$$EF_{TSP} = 0.031 \times 0.2 \times \frac{0.00006(U+U_{conv})^2 - 0.0002(U+U_{conv})^2 + 0.0001}{0.00006(10+U_{conv})^2 - 0.0002(10+U_{conv})^2 + 0.0001}$$

where:

EF_{TSP}	emission factor for TSP (g/m/s)
U	wind speed (m/s)
U_{CONV}	conveyor speed (m/s)

TSP emissions for each hour modelled were based on the combined speed of prevailing winds and the conveyor, referenced in the study by GHD and Oceanics Australia (GHD-Oceanics, 1975), using the reference emission rate of 0.031 g/s/m at a base wind velocity of 10 m/s.

The factor 0.2 is used to account for the difference in particle size distribution between particulate matter sampled in the GHD Oceanics study and the normal TSP size fraction of PM_{30-50}.

Of TSP emissions, 47% are estimated to be PM_{10} and 7% of TSP emissions are estimated to be $PM_{2.5}$. The particulate matter distribution is based on size ratios of dust emitted from transfers.

The following activity data were used to estimate emissions due to conveyors within the processing plant. Calpuff was set up to model emissions from conveyors operating between 6am and 6pm.

Parameter	Units	Value	Source
Wind speed	m/s	3.3	CALMET
Conveyor speed	m/s	6	Assumed
Total length of conveyors (as viewed on site layouts)	m	1562	Site layouts provided by Boral
Slant angle of conveyors	%	6	Boral
Total length of conveyors	m	1570	Calculated from information and layouts provided by Boral

A2.9 Haulage on Unpaved Roads

The emission factors for wheel generated dust due to haulage along unpaved roads were calculated from the AP42 documents in chapter 13.2.2 titled "unpaved roads" dated December 2003.

The equation included in the assessment is as follows:

$$E = k\,(s/12)^a (W/3)^b$$

Where s = surface material silt content (%)
W = mean vehicle weight (tons) and the following constants were assumed.

Constant	TSP (assumed from PM_{30})	PM_{10}	$PM_{2.5}$
k (lb/VMT)	4.9	1.5	0.15
a	0.7	0.9	0.9
b	0.45	0.45	0.45

The following activity data were used to estimate emissions from haulage activity on unpaved roads onsite. Calpuff was set up to model the dispersion of haulage emissions generated during the quarry operational hours of 6am and 6pm.

Parameter	Units	Value	Source	Comments
Material characteristics				
Surface material silt content	%	8	US EPA AP-42 documents, Chapter 13.3 " Unpaved roads" (US EPA, 2006a). Average value for stone quarrying and processing	Used for: • haulage of raw material from active pit to processing area
Surface material silt content	%	10	US EPA AP-42 documents, Chapter 13.3 " Unpaved roads" (US EPA, 2006a). Plant road average value for stone quarrying and processing	Used for: • haulage of product to main road along unsealed route
Vehicle weights				
Cat 740 ADT payload	tonnes	39.5	Specifications data provided by Boral	Used for: • haulage of raw material and overburden onsite
Cat 740 ADT average weight	tonnes	53		
Product haul truck payload	tonnes	43		Used for: • haulage of product material from processing area offsite
Product haul truck average weight	tonnes	36		
Haul road lengths - one way				
Active pit to processing area	km	1.73	Site layouts provided by Boral	Haulage of raw quarry material
Processing area to product stockpiles	km	0.06		Haulage of product material that is not leaving site immediately
Product stockpile area to paved access road	km	0.16		Haulage of product leaving site

A2.10 Haulage on Paved Roads

The emission factors for wheel generated dust due to haulage along the paved section of road up to the site boundary were calculated from the AP42 documents in chapter 13.2.1 titled “Paved Roads” dated December 2003.

The equation included in the assessment is as follows:

$$E = k\,(sL)^{0.91} \times (W)^{1.02}$$

Where sL = road surface silt loading (g/m^2)

W = mean vehicle weight (tons) and the following constants were assumed.

Constant	TSP (assumed from PM_{30})	PM_{10}	$PM_{2.5}$
k (g/VKT)	3.23	0.62	0.15

The following activity data were used to calculate emissions due to haulage of product material on the section of paved road. Calpuff was set up to model the dispersion of haulage emissions generated between 6am and 6pm.

Parameter	Units	Value	Source
Length of haul road	km	0.85	Site layout provided by Boral
Silt loading	g/m^2	8	US EPA AP-42 documents, Chapter 13.3.1 "Paved roads" (US EPA, 2006a). Plant road average value for quarrying
Product haul truck payload	tonnes	43	Specifications data provided by Boral
Product haul truck average weight	tonnes	36	

A2.11 Grading of Unsealed Haul Roads

The emission factors for grading were calculated from the AP42 documents, chapter 11.9 “Western Surface Coal Mining” (October 1998).

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Unsealed road	kg/VKT	0.0034 (S)$^{2.5}$	0.6 x 0.051 (S)$^{2.0}$	TSP x 0.031

Where S = mean vehicle speed (km/hr), based on specifications data for a 140M grader that would be used by the earthworks crew.

For the modelling assessment a mean vehicle speed of 12.4 km/hr has been adopted. One grader has been assumed to operate 50% of the time during quarry operating hours. Grading emissions have been apportioned to each section of unsealed haul road according to the length of each section. Calpuff was set up to model the dispersion of haulage emissions generated between 6am and 6pm.

A2.12 Wind Erosion

Wind erosion will occur 24 hours per day, regardless of quarry operations. The amount of dust lift-off into the air is dependent on the wind speed. Typically, wind speeds during the daytime are higher than overnight. While this means that there may be more dust lift-off during the day than overnight, conditions for dispersion are typically poorer overnight due to a much lower mixing height and more stable air and there is not a straightforward relationship between the amount of dust lift-off and potential impacts in the area. To accurately represent the variation in dust lift-off and dispersion of these emissions throughout a 24-hour period, Calpuff has been set up with hourly varying emissions for wind erosion.

A2.12.1Wind Erosion of Active Stockpiles

The emission factors for active stockpiles and the active pit area were calculated from the AP42 documents, chapter 11.9 "Western Surface Coal Mining" (October 1998). Scaling factors for the PM_{10} and $PM_{2.5}$ emission factors were taken from the AP42 documents, chapter 13.2 "Industrial Wind Erosion" (November 2006).

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Active stockpiles	kg/(hectare)(hour)	$1.8 \times u \times \frac{365-p}{365}$,	TSP x 0.5 (assumed from the NPI mining version 2.3 where a 50 % ratio of TSP to PM_{10} was found.	PM_{10} x 0.075 (assumed from the NPI mining version 2.3 where a 15 % ratio of TSP to PM_{10} was found.

Where u = wind speed and *p* is the number of days per year with rainfall greater than 0.25mm.

To calculate wind erosion emissions from active stockpiles, a time series of hourly wind speeds over the entire year was extracted from the dataset generated by CALMET at the project site. The equations and activity data in the following sections were then applied to calculate a wind erosion emission rate for each hour of the year.

The following stockpile surface areas were calculated and used to estimate wind erosion emissions.

Stockpile	Units	Surface area	Source
Active pit area	m^2	38,746	Stockpile shapes and footprints provided by Boral, total surface areas calculated by Katestone
ROM pad stockpile	m^2	3,608	
Primary crusher stockpile	m^2	3,608	
Post primary scalps	m^2	885	
Secondary scalps	m^2	885	
Radial stacker stockpiles (blending, ballast and scalps/roadbase)	m^2	1528	
Product stockpiles	m^2	13,145	

A2.12.2 Wind Erosion of Exposed Areas

The emission factors from wind erosion for the exposed, inactive areas of the pit were calculated from the AP42 documents, chapter 11.9 "Western Surface Coal Mining" (October 1998) and adapted to include the effect of rainfall on wind erosion.

Material	Units	TSP	PM_{10}	$PM_{2.5}$
Inactive pit areas	Mg/(hectare)(year)	0.85* Rain Factor	TSP x 0.5 (assumed from the NPI mining version 2.3 where a 50 % ratio of TSP to PM_{10} was found.	PM_{10} x 0.075 (assumed from the AP42, chapter 13.2 "Industrial Wind Erosion").

Where the rain factor is given by $\frac{365-p}{365}$, where *p* is the number of days per year with rainfall greater than 0.25 mm.

The following activity data has been used to estimate wind erosion from the exposed, inactive pit area. To estimate wind erosion emissions for each hour of the year, the total dust emissions for a year were calculated, and these were split between each hour of the year according to the wind speed.

Parameter	Units	Value	Source
Number of days with rainfall > 0.25 mm	number	179	Bureau of Meteorology Coolangatta Aero monitoring station, 2011 year
Exposed, inactive pit area	ha	27.2	Site layouts provided by Boral

A3 References

US EPA (October 1998), AP-42 document, Chapter 11.9 "Western Surface Coal Mining".

US EPA (November 2006a), AP-42 document, Chapter 13.2.2 "Unpaved Roads".

US EPA (November 2006b), AP-42 document, Chapter 13.2.4 "Aggregate Handling and Storage Piles".

US EPA (August 2004), AP-42 document, Chapter 11.19.2 "Crushed Stone Processing and Pulverized Mineral Processing".

US EPA (December 2003), AP-42 document, Chapter 13.2.2 "Unpaved Roads".

US EPA (January 2011), AP-42 document, Chapter 13.2.1 "Paved Roads".

Appendix B

Air Dispersion Modelling Methodology and Evaluation

Contents

Tables

Figures

B1 Air dispersion modelling

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

B1.1 TAPM

The meteorological model, TAPM (The Air Pollution Model) Version 4.0.5, was developed by the CSIRO and has been validated by the CSIRO, Katestone and others for many locations in Australia, in southeast Asia and in North America (see www.cmar.csiro.au/research/tapm for more details on the model and validation results from the CSIRO). Katestone has used TAPM throughout Australia as well as in parts of New Caledonia, Bangladesh, America and Vietnam. This model has performed well for simulating regional meteorological conditions. TAPM has proven to be a useful model for simulating meteorology in locations where monitoring data is unavailable.

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

TAPM requires synoptic meteorological information for the study region. This information is generated by a global model similar to the large-scale models used to forecast the weather. The data are supplied on a grid resolution of approximately 75 kilometres, and at elevations of 100 metres to 5 kilometres above the ground. TAPM uses this synoptic information, along with specific details of the location such as surrounding terrain, land-use, soil moisture content and soil type to simulate the meteorology of a region as well as at a specific location.

TAPM was configured as follows:

- 35 x 35 grid point domain with an outer grid of 30 kilometres and nested grids of 10 kilometres, 3 kilometres and 800 metres
- Grid centred near the project site (latitude –28°7’, longitude 153°25)
- Landuse and coastline refined for TAPM using Geosciences Australia classifications
- Geosciences Australia 9-second DEM terrain data
- Synoptic data used in the simulation for the period of January 2011 to December 2011
- 25 vertical grid levels
- Hourly varying wind speed and wind direction data from the Bureau of Meteorology (BoM) Coolangatta monitoring station was assimilated into TAPM to nudge the predicted solution towards the observation
- Data assimilation was given a 11 kilometre radius of influence
- Data was assimilated over the lowest 4 vertical levels
- Data was given a reliability of 0.9
- All other options set to default

B1.2 Calmet

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

CALMET (version 6.327) was used to simulate meteorological conditions in the study region. The CALMET simulation was initialised with the gridded TAPM three dimensional wind field data from the 800-metre (innermost) grid. CALMET treats the prognostic model output as the initial guess field for the CALMET diagnostic model wind fields. CALMET then adjusts the initial guess field for the kinematic effects of terrain, slope flows, blocking effects and 3-dimensional divergence minimisation. The geophysical data was supplied by Geosciences Australia.

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

- Domain area of 100 by 100 grid points at 100 metre spacing
- Twelve vertical levels set at 20, 60, 100, 150, 200, 250, 350, 500, 800, 1600, 2600 and 4600 metres at each grid point.
- 365 days (1 January 2011 to 31 December 2011)
- Prognostic wind fields generated by TAPM for the 800 metre grid (innermost) used as MM5/3D.dat at surface and upper air for "initial guess" field
- All other options have been set to default.

B1.3 Calpuff

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

CALPUFF (version 6.267) was used to simulate the dispersion characteristics and emissions generated by the proposed activities. Hourly varying meteorological conditions were obtained from CALMET at 100 metre resolution.

Key features of CALPUFF used to simulate dispersion:

- Domain area of 50 by 50 grid points at 50 metre spacing
- 365 days (1 January 2011 to 31 December 2011)
- Partial plume path adjustment for terrain modelled
- Dispersion coefficients calculated internally from sigma v and sigma w using micrometeorological variables
- Minimum turbulence velocity of sigma-v over land set to 0.2 m/s
- Minimum wind speed allowed for non-calm conditions 0.2 m/s
- For dust modelling size fractions for TSP, PM_{10} and $PM_{2.5}$ were based on size fractions from the emission factor handbooks. The geometric mass mean diameters assumed in the modelling were 30 μm (TSP), 10μm (PM_{10}) and 2.5 μm ($PM_{2.5}$). All pollutants were modelled with 0 μm geometric standard deviation as required when using the grouping function in CALPUFF.
- Wind erosion sources modelled with hourly varying emission rates dependant on the wind speed
- All other sources modelled with emissions occurring during hours of operation only (diurnal emission rates)

All other options set to default.

B2 Air dispersion model evaluation

The TAPM meteorological simulations were compared against meteorological monitoring in the region by using statistical measures described here.

B2.1 Statistical measures

Root Mean Square Error (RMSE)

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

The RSME can be described as the standard deviation of the difference for hourly predicted and observed pairings at a specific point. The RMSE is a quadratic scoring rule which measures the average magnitude of the error. The difference between predicted and corresponding observed values are each squared and then averaged over the sample. Finally, the square root of the average is taken. Since the errors are squared before they are averaged, the RMSE gives a relatively high weight to large errors. This means the RMSE is most useful when large errors are particularly undesirable. Overall, the RSME is a good overall measure of model performance, but since large errors are weighted heavily (due to squaring), its value can be distorted. RMSE is equal to the unit of the values being analysed i.e. an RMSE of 1.2 for wind speed = 1.2 m/s^{-1}.

Systematic Root Mean Square Error ($RMSE_s$)

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

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

Unsystematic Root Mean Square Error ($RMSE_u$)

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

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

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

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

Mean Error (ME) and Mean Absolute Error (MAE)

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

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

Index of agreement

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

The IOA is calculated using a method described in Wilmott (1982). The IOA can take a value between 0 and 1, with 1 indicating perfect agreement. The IOA is the ratio of the total RMSE to the sum of two differences: the difference between each prediction and the observed mean, and the difference between each observation and observed mean. From another perspective, the IOA is a measure of the match between the departure of each prediction from the observed mean and the departure of each observation from the observed mean.

(Note: N is the number of observations, P_i are the hourly model predictions, O_i are the hourly observations, O_{mean} is the observed observation mean, and $\hat{P}_i = a + bO_i$ is the linear regression fitted with intercepts *a* and slope *b*.)

A models skill can be measured by the difference in the standard deviation of the modelled and observed values. Skill measure statistics are given in terms of a score, rather than in absolute terms.

SE is indicative of the of how much of the standard deviation in the observations is predicted to be due to random/natural processes (unsystematic) in the atmospheric boundary layer (i.e. turbulence).

SV shows how closely the modelled standard deviation matches the observed standard deviation

SR takes into account systematic and unsystematic errors in relation to the observed standard deviation.

Skill is determined by the following benchmarks:

- SKILL_E (SE) = (RMSE_U/StdvOBS) < 1 shows skill
- SKILL_V (SV) = (Stdv_MOD/Stdv_OBS) close to 1 shows skill
- SKILL_R (SR) = (RMSE/Stdv_OBS) < 1 shows skill

B2.2 Meteorological evaluation

The closest monitoring station to the site for use in the TAPM model evaluation is the Coolangatta Airport monitoring station operated by BoM. TAPM was initialised without data assimilation to determine the model's ability to simulate the range of meteorological conditions. Wind speed, wind direction, surface temperature and relative humidity were extracted from TAPM at the location of Coolangatta Airport. As wind direction has a cross-point at north between 0° and 360°, it has been decomposed into its U component (east-west) and V component (north-south) for statistical analysis.

Concurrent data for the period 1 January 2011 to 31 December 2011 from the Coolangatta observations and those extracted from TAPM for the monitoring site location have been analysed to assess the performance of the model.

The TAPM model evaluation (Table B2.1) shows that there is an acceptable index of agreement (IOA) for temperature (0.93), relative humidity (0.78) and the U (0.70) and V (0.81) components. The wind speed (IOA) is unacceptable (0.57) suggesting that the model is not predicting the wind speed sufficiently. The wind speed root mean square error (RMSE) is 2.46 and the mean absolute error (MAE) is 2.01. Analysis of the frequency distribution (Figure B2.1) shows that the model predicts a higher frequency of light to moderate (1 – 3 m/s) wind speeds with little or no winds predicted above 6 m/s, whilst the observations suggest that moderate to strong winds are common place (3- 8 m/s). Figure B2.2 illustrates the frequency distribution of the modelled and observed wind direction. The plot indicates the model was predicting a lower frequency of winds from the south-southwest compared to the Coolangatta observations.

Table B2.1 Evaluation of TAPM model performance

Statistical measure	Wind speed (m/s)	Temperature (°C)	Relative humidity (%)	U vector (m/s)	V vector (m/s)
intercept	1.20	7.06	29.08	0.02	0.24
slope	0.25	0.67	0.65	0.33	0.43
RMSE	2.46	2.34	13.68	1.86	2.34
RMSE_s	2.36	1.80	6.20	1.56	2.13
RMSE_u	0.68	1.50	12.19	1.02	0.98
IOA	0.57	0.93	0.78	0.70	0.81
SE	0.33	0.29	0.82	0.43	0.27
SV	0.41	0.73	1.05	0.55	0.50
SR	1.18	0.46	0.92	0.80	0.64
MAE	2.01	1.78	10.88	1.44	1.90

These results indicated that data assimilation was required to nudge the TAPM modelled wind fields towards the observations. Wind speed and direction data recorded at Coolangatta Airport were assimilated into TAPM (as described in section B1.1). The frequency distributions of wind speed and wind direction are presented in Figure B2.3 and

Figure B2.4 respectively. These figures demonstrate that the inclusion of the monitoring data in the TAPM model has changed the windfields generated.

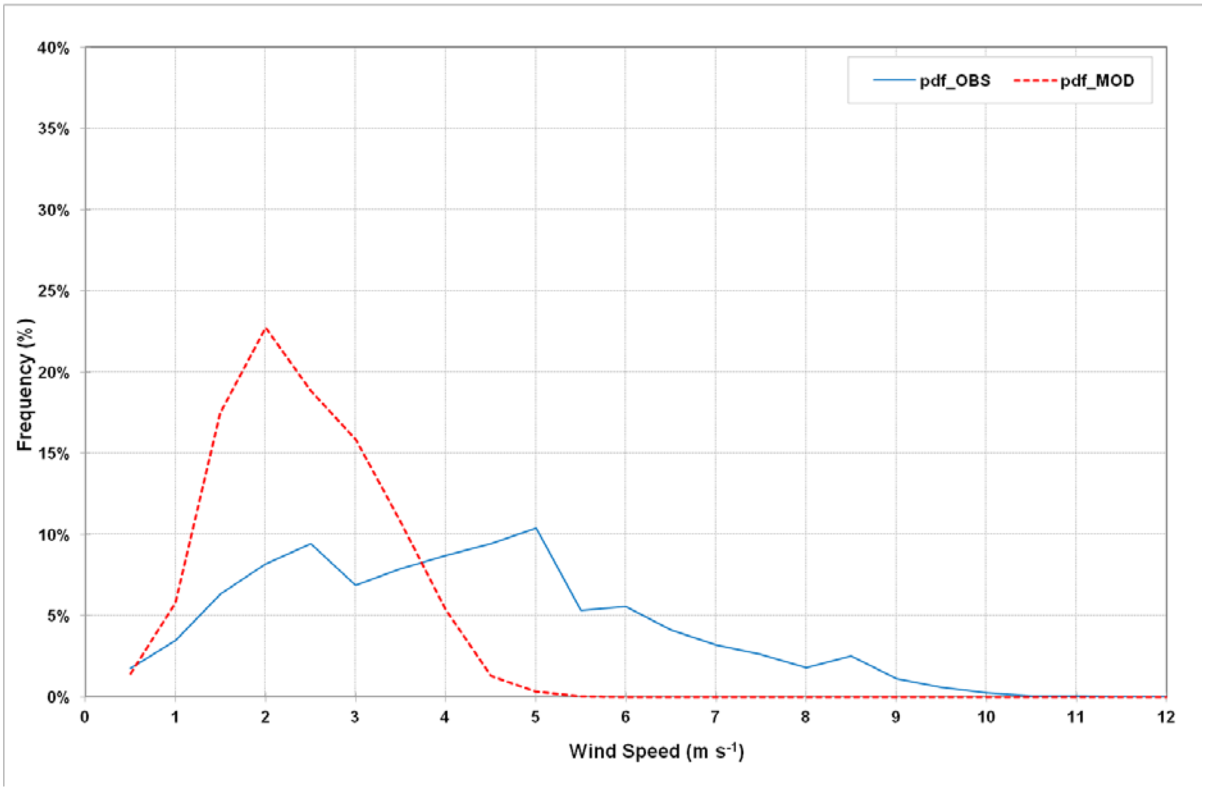

Figure B2.1 Frequency distribution of wind speeds measured at Coolangatta BOM site (blue line) and predicted by TAPM (red line)

Location: Coolangatta	**Period:** January 2011 to December 2011	**Data source:** Bureau of Meteorology meteorological station and TAPM	**Units:** m/s
Type: Probability Density Function (pdf) of the frequency distribution	**Averaging Period:** 1-hour	**Prepared by:** Andrew Vernon	**Date:** November 2012

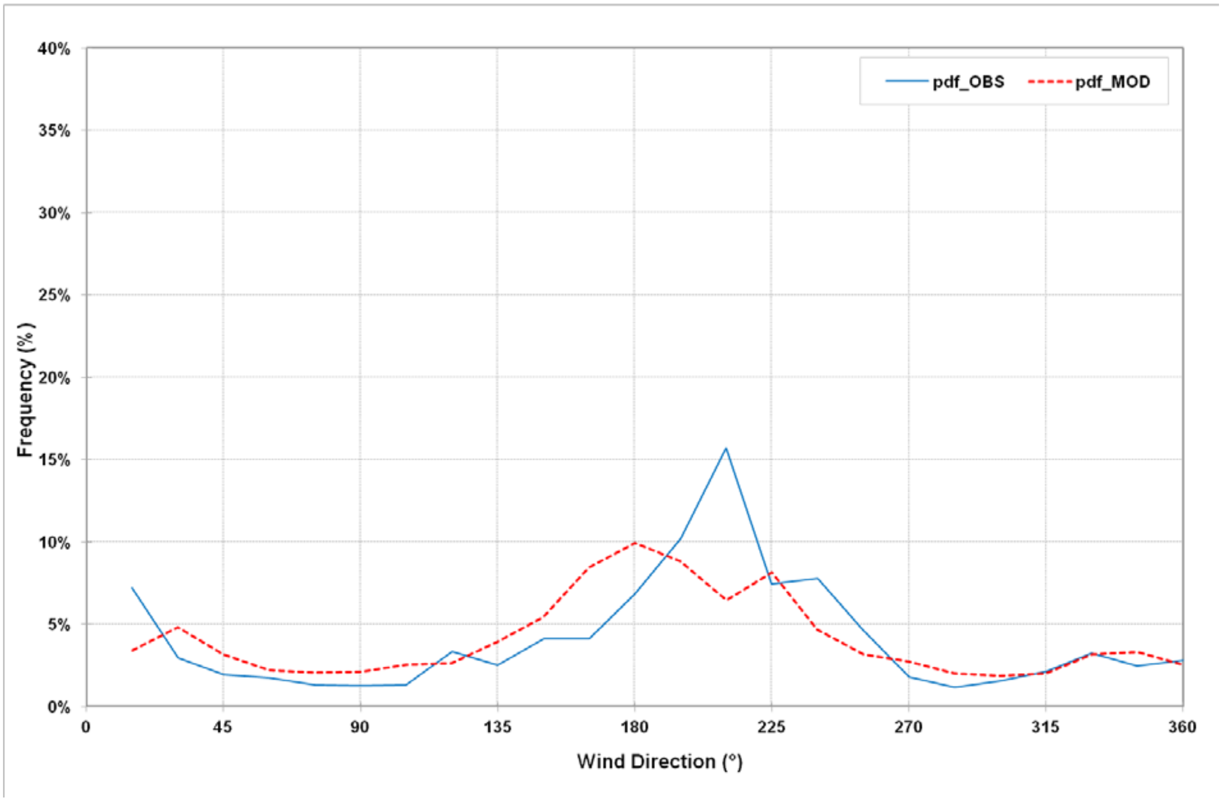

Figure B2.2	**Frequency distribution of wind direction measured at Coolangatta BOM site (blue line) and predicted by TAPM (red line)**

Location: Coolangatta	**Period:** January 2011 to December 2011	**Data source:** Bureau of Meteorology meteorological station and TAPM	**Units:** o
Type: Probability Density Function (pdf) of the frequency distribution	**Averaging Period:** 1-hour	**Prepared by:** Andrew Vernon	**Date:** November 2012

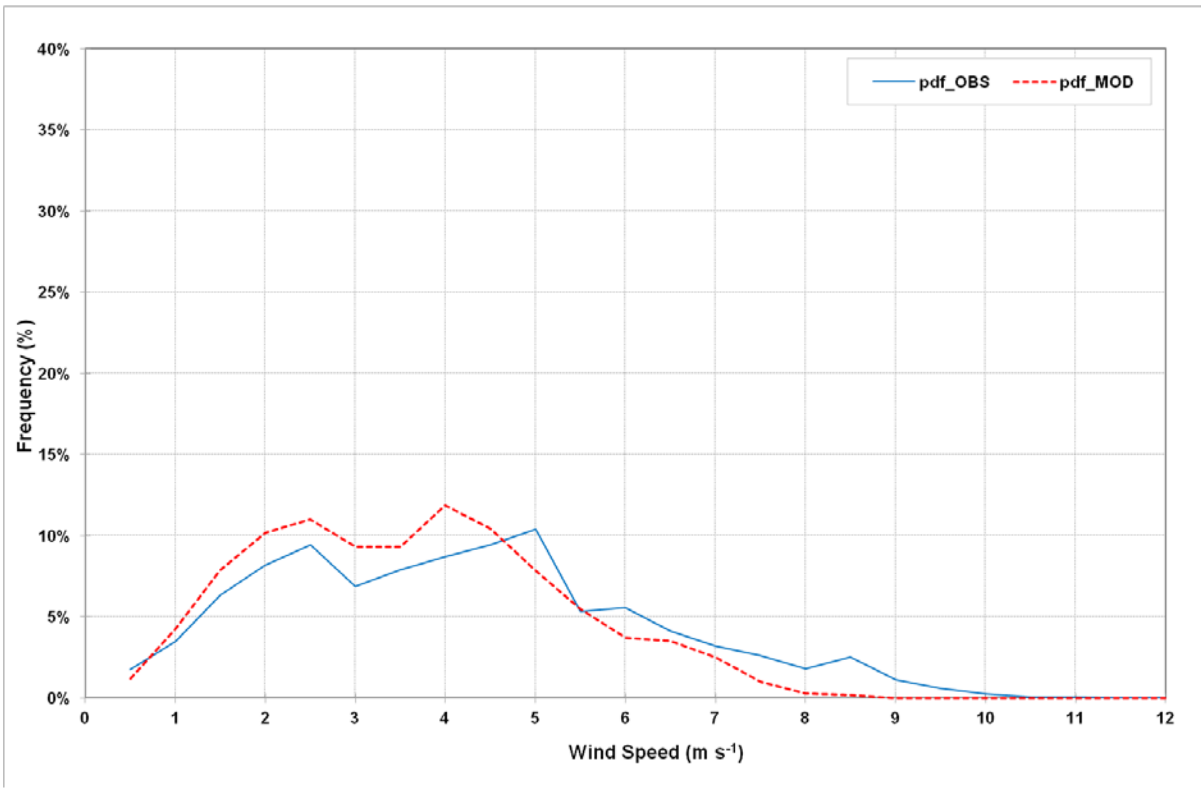

Figure B2.3	**Frequency distribution of wind speeds measured at Coolangatta BOM site (blue line) and predicted by TAPM (red line) with data assimilation**		
Location: Coolangatta	**Period:** January 2011 to December 2011	**Data source:** Bureau of Meteorology meteorological station and TAPM	**Units:** m/s
Type: Probability Density Function (pdf) of the frequency distribution	**Averaging Period:** 1-hour	**Prepared by:** Andrew Vernon	**Date:** November 2012

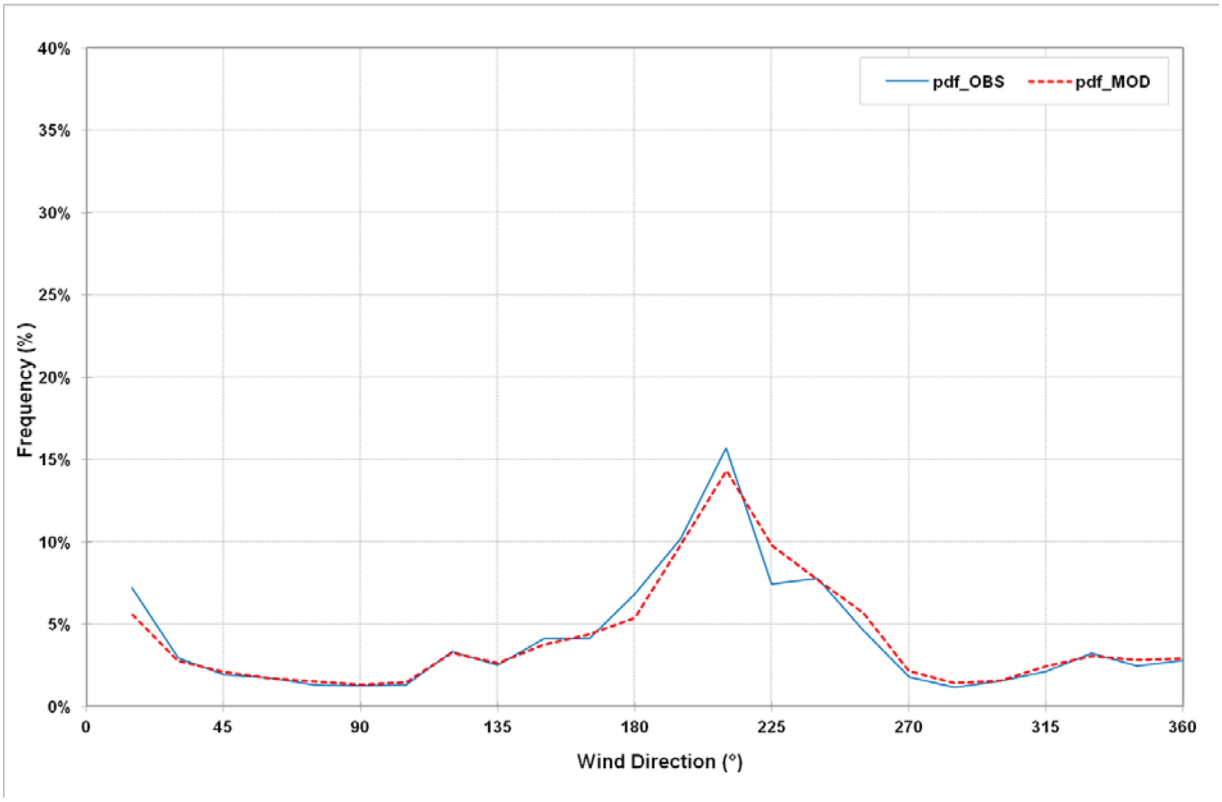

Figure B2.4 Frequency distribution of wind direction measured at Coolangatta BOM site (blue line) and predicted by TAPM (red line) with data assimilation

Location: Coolangatta	**Period:** January 2011 to December 2011	**Data source:** Bureau of Meteorology meteorological station and TAPM	**Units:** o
Type: Probability Density Function (pdf) of the frequency distribution	**Averaging Period:** 1-hour	**Prepared by:** Andrew Vernon	**Date:** November 2012