CLARIFICATION OF IDENTIFIED AIR QUALITY MATTERS

ATTACHMENT A

ADDITIONAL INFORMATION:
ENVIRONMENTAL IMPACT STATEMENT

22 October 2013

Attn: Scott Clarke
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Carrara,
QLD, 4211
Email: Scott.Clarke@cardno.com.au

Re: Gold Coast Quarry – Additional Information to the EIS

Dear Scott,

Please find below the additional information relating to the Gold Coast Quarry's Environmental Impact Statement (EIS) Section 4.5 Air Quality.

Key Matter 1 – Dust Deposition

The use of maximum monthly averages of dust deposition of 120 mg/m2/day as an indicator of dust nuisance and as the sole measure of performance would potentially allow short-term dust release and deposition rate exceedences. Clarify the mitigation measures to be set in place to quickly prevent and minimise the duration of any such event.

Response:

The dust deposition guideline commonly used in Queensland as a benchmark for avoiding amenity impacts is 120 mg/m^2/day as a maximum monthly average. The guideline is not defined in the Air EPP and is therefore not enforceable by legislation, but was recommended by the EHP as a design objective. There are no short term objectives or indicators for dust deposition nuisance impacts and therefore only the maximum monthly average was used. Notwithstanding this, the dust management plan for Gold Coast Quarry will include measures to prevent and control short term nuisance dust.

Key Matter 2 – Dust Impacts on Vegetation

Demonstrate that the predicted levels of dust deposition in the buffer zone will not adversely affect the health of ecologically sensitive vegetation.

Response:

Dr D. Doley from the University of Queensland, an expert in the effects of dust on vegetation, was commissioned to review the Flora and Fauna Assessment (Cardno Chenoweth) and the Air Quality Assessment for Gold Coast Quarry (Katestone), Appendix X and Appendix GG of the Gold Coast Quarry's EIS, respectively. A summary of Dr Doley's review is provided below and a draft copy is attached to this letter as Appendix A.

"A model was developed to indicate the effects of dust deposition from the proposed Boral Gold Coast Quarry on vegetation within and surrounding the Boral property. The modelling results suggest that dominant components of vegetation types, particularly Eucalyptus species, are very unlikely to be affected adversely by the predicted dust loads within the Boral property, and in existing and proposed residential areas.

Predicted maximum dust deposition rates could impact on vegetation layers within plant communities that have a deeply shaded understorey of Regional Ecosystem 12.11.23. If the maximum rate of dust deposition predicted to be recorded in a deposit gauge applies uniformly throughout a vegetation profile, there could be sufficient additional shading by dust on leaves of ground cover species that their integrity could be threatened.

However, the ground layer of RE 12.11.23, occurs at a distance of more than 100 m and at least 20 m below the crest of a hill between the proposed quarry surface and the site in question. In addition, there is likely to be progressive interception of dust as it moves through vegetation (both laterally and vertically). This interception would reduce the risk to sensitive vegetation.

Practical mitigation measures, especially the establishment and maintenance of a Casuarina windbreak at the quarry edge is likely to reduce the concentration of dust in air moving laterally into the native vegetation by up to 80%".

Key Matter 3 – Guidelines for Crystalline Silica
Demonstrate that the appropriate guidelines and calculations have been used to determine the dust deposition rate and that crystalline silica emissions in particular will not present an increased risk to human health in terms of respiratory illnesses.

Response:
The air quality assessment (Appendix GG of the EIS) includes a respirable crystalline silica assessment. The silica assessment is presented in Section 10 of the air quality assessment report. The Silica assessment has used appropriate guidelines and calculations to determine that crystalline silica emission will not present an increased risk to human health. Notwithstanding this, Boral will conduct routine monitoring of the exposure of its workforce to respirable crystalline silica throughout the lifetime of the Gold Coast Quarry.

Kay Matter 4 – Meteorological Modelling
Clarification that the land breeze and sea breeze cycle, drainage wind and valley wind effects have been appropriately addressed in modelling.

Response:
The meteorological modelling that was conducted for the Gold Coast Quarry EIS characterises the full range of meteorological conditions that would occur in the region including land and sea breeze cycles and drainage flows. This is evident in the wind roses and analysis presented in the air quality assessment (Appendix GG of the EIS).

A description of the meteorology generated by the model at the quarry location is provided in Section 6.2 of the air quality assessment (Appendix GG of the EIS) and includes a description of sea breeze and valley winds experienced at the site. Meteorological data from the Bureau of Meteorology's station at Coolangatta Airport (nearest station to the Gold coast Quarry site) was used to generate meteorological modelling data. The meteorological model setup and validation is provided in Appendix B of the air quality assessment (Appendix GG of the EIS). The meteorological modelling methodology is appropriate.

Key Matter 5 – Determination of Control Efficiencies
Clarification of how dust control efficiencies to estimate emissions have been determined.

Response:
An updated table with literature references and justifications for the for the dust control reduction efficiencies applied for the Gold Coast Quarry design is presented in Appendix B of this letter.

Key Matter 6 – Air Emission Sources
Confirmation that all air emission sources have been included in the inventory, including any derivation of conveyor emissions. Demonstrate the applicability of coal mining equation for wind erosion of stockpiles to quarry material stockpiles.

Response:
All air emissions sources have been included in the inventory. Section 2.2.4 of the air quality assessment (Appendix GG of the EIS) details the potential emission sources from the Gold Coast Quarry and section 7.2.1 Table 14 details the calculated emission rate for the worst case scenario of the Gold Coast Quarry operation. Technical descriptions of how the dust emission rates have been calculated is provided in Appendix A of the air quality assessment (Appendix GG of the EIS).

The loading of fragmented rock and product material has been characterised as material handling operations, which are included in the emissions inventory (See "extraction from pit" and "product loadout" in Table 14 of the air quality assessment report (Appendix GG)).

Appendix A section 2.8 and section 2.12 details how the conveyor emissions and stockpile emissions, respectively, have been determined for the air quality assessment (Appendix GG of the EIS).

There are no wind erosion emission factor equations explicitly for quarry stockpiles and therefore the coal mining equation for wind erosion of stockpiles has been used. This is valid as the coal mining equation represents an active stockpile i.e. material is being added and taken away on a regular basis. The Gold Coast Quarry product stockpiles can be classed as active stockpiles.

Key Matter 7 – Clarification of $PM_{2.5}$ Emission Calculation
Clarification of how the $PM_{2.5}$ emissions have been estimated to confirm that appropriate modelling has been undertaken for air quality.

Response:
The $PM_{2.5}$ dust emissions estimation for each activity is detailed in the tables in Appendix A of the air quality assessment (Appendix GG of the EIS). $PM_{2.5}$ has different TSP ratios depending on the activity and is guided by the relevant emissions estimation handbooks. The appropriate modelling has been undertaken for the air quality assessment.

Key Matter 8 – Miscellaneous Emission Assessment Matters
Confirmation that the emission assessment has adequately addressed the following matters:
- *location of the quarry pit operation with respect to the closest sensitive receptor;*
- *location of overburden stockpile;*
- *truck loading and dumping of the overburden material, particularly important during the early stage of site development; and*
- *mobile crushing plant during the early stage of development*

Response:
The air quality assessment investigated the worst case scenario for operation of the quarry - Q5 operation (full development of the quarry), as detailed in Section 7.2 of the air quality assessment (Appendix GG of the EIS). It is not practical to assess the locations of all air emissions sources over the proposed 40 year lifetime of the Gold Coast Quarry and therefore, a conservative approach was adopted for the worst case assessment.

The locations of sensitive receptors and the location of the most important sources were taken into consideration. The most important source in terms of dust generation is the haul of material from the pit to the processing plant along unsealed roads. The worst case modelled year represented the longest haul road from pit to plant which passes to the northwest, near to the closest receptors. (Figure 14 shows the location of sources used in the air quality assessment modelling).

As detailed in Section 7.2 of the air quality assessment (Appendix GG of the EIS), a dust inventory was calculated for each stage of the Gold Coast Quarry (Table 13) and then a worst case scenario selected. Detailed information on the dust inventories of each stage of the Gold Coast Quarry other than Q5 is provided in Appendix C of this memorandum.

Key Matter 9 – Maximum 24-hour Average
Clarification of the maximum 24-hour average PM10 and TSP ground level concentration that has been utilised in the modelling.

Response:
The Air EPP allows for 5 exceedance days of the 24-hour average PM_{10} objective. Therefore, the 6th highest 24-hour average PM_{10} concentration was provided in the air quality assessment. The maximum 24-hour average ground-level concentration of PM_{10} was not provided in the air quality assessment (Appendix GG of the EIS). This approach has previously been accepted by EHP for quarry and mining projects. There is no 24-hour average ground-level concentration objective for TSP and therefore this was not provided in the air quality assessment. The dust management plan for Gold Coast Quarry will include measures to prevent and control short term release of dust to ensure no offsite health and nuisance impacts.

Key Matter 10 – Cumulative Impacts
Clarification that the cumulative impact assessment has included other industrial sources in the area.

Response:
The cumulative impact was estimated by addition of a representative background to the increment due to the Gold Coast Quarry. We assessed the worst case scenario of dust from the Gold Coast Quarry, which was operation (Q5 - full pit development). A dust inventory showed that emissions from the operational stages of the Gold Coast Quarry were double the establishment and development stages. West Burleigh Quarry was not modelled as a background source because it will be closed by the time the operation stages of the Gold Coast Quarry are underway so its inclusion in the cumulative assessment of worst case operation at the Gold Coast Quarry would be an overestimation. It should also be noted that the boundary dust deposition monitoring at WBQ shows that dust rarely leaves the site and in the instance that it does it occurs in an area to the north of the site near the product stockpiles. There is no information available regarding emissions from Reedy Creek waste disposal site and therefore it was not included in the cumulative assessment. However, its influence on dust levels within the Gold Coast Quarry modelling domain would be minimal.

Notwithstanding this, a representative background was selected based on historical long term air quality monitoring data at a representative monitoring station. As detailed in Section 8.3 of the air quality assessment report, there are no air quality monitoring stations in the Gold Coast area and therefore, monitoring data from the EHP Springwood station was chosen as it represents a 'population average' for Southeast Queensland. It is also located in proximity to the Pacific Highway (M1).

If you have any questions please do not hesitate to contact either Simon Welchman or the undersigned.

Yours sincerely,

Andrew Vernon – Senior Consultant

APPENDIX A – Dr David Doley's Report

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Prepared for

Katestone Environmental Pty Ltd

Subject

Report on the Potential Effects of Quarry Dust on Selected Vegetation Communities on the Gold Coast, Queensland

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2 September 2013

UniQuest Project No: C01455

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Report on the Potential Effects of Quarry Dust on Selected Vegetation Communities on the Gold Coast, Queensland

Disclaimer

SUMMARY

A model was developed to indicate the effects of dust deposition from the proposed Boral Gold Coast Quarry on vegetation within and surrounding the Boral property. The modelling results suggest that dominant components of vegetation types, particularly *Eucalyptus* species, are very unlikely to be affected adversely by the predicted dust loads within the Boral property, and in existing and proposed residential areas.

Predicted maximum dust deposition rates could impact on vegetation layers within plant communities that have a deeply shaded understorey of Regional Ecosystem 12.11.23. If the maximum rate of dust deposition predicted to be recorded in a deposit gauge applies uniformly throughout a vegetation profile, there could be sufficient additional shading by dust on leaves of ground cover species that their integrity could be threatened.

However, the ground layer of RE 12.11.23, occurs at a distance of more than 100 m and at least 20 m below the crest of a hill between the proposed quarry surface and the site in question. In addition, there is likely to be progressive interception of dust as it moves through vegetation (both laterally and vertically). This interception would reduce the risk to sensitive vegetation.

Practical mitigation measures, especially the establishment and maintenance of a *Casuarina* windbreak at the quarry edge is likely to reduce the concentration of dust in air moving laterally into the native vegetation by up to 80%.

TABLE OF CONTENTS

SUMMARY 1

1. INTRODUCTION 3

2. ENVIRONMENTAL CONDITIONS AND SPECIES CHARACTERISTICS RELEVANT TO THE EFFECT OF DUST DEPOSITION ON VEGETATION 4

2.1 Physical factors 4

2.2 Dominant vegetation types and plant species 8

2.3 Estimation of dust deposition rates 10

3. ESTIMATED EFFECTS OF DUST DEPOSITION RATES ON PHOTOSYNTHESIS IN PLANT SPECIES 14

3.1 Dust characteristics and assumptions 14

3.2 Species characteristics and assumptions 15

3.3 Model calculations 19

4. DISCUSSION AND CONCLUSIONS 24

4.1 Effects of dust on vegetation 24

4.2 Possible mitigation measures 25

4.3 Conclusions 26

5. REFERENCES 27

1. INTRODUCTION

This report provides an analysis of the potential effect of dusts generated by the proposed quarrying operation at Boral Gold Coast Quarry, Burleigh, Queensland on adjacent vegetation. It draws on vegetation surveys (Cardno Chenoweth 2013), meteorological and dust deposition observations and modelling (Katestone Environmental 2013) carried out for the Boral Gold Coast Quarry Environmental Impact Statement (EIS). The predictions of possible effects of dust deposition on selected plant species are made through modelling of the effects of dust loads on photosynthesis and dry matter production. They are necessarily constrained by the assumptions made regarding each component of the model, which has been modified to take account of the different structural and physiological characteristics of different components of a eucalypt forest such as that dominated by blackbutt (*Eucalyptus pilularis*), which occurs on part of the Boral site.

2. ENVIRONMENTAL CONDITIONS AND SPECIES CHARACTERISTICS RELEVANT TO THE EFFECT OF DUST DEPOSITION ON VEGETATION

2.1 Physical factors

Dust deposition on vegetation surfaces can influence both the radiation environment and the diffusion of gases to and from leaves. The effect of a given dust load depends sensitively on the particle size, especially in relation to the interception of light by leaves and the consequent effects on the rates of photosynthesis, plant health and growth (Doley 2006). Small particles (2 μm diameter) may become lodged in the apertures of stomata on leaves (which open and close in response to light, water and carbon dioxide availability and are the pathway for gaseous diffusion into and out of leaves). A first assumption may be that particles would reduce the rate of gas diffusion through stomata by blocking part of the aperture, thereby reducing the rates of water loss from and carbon dioxide uptake by leaves. Particle lodgement in the stomatal apertures may also prevent their effective closure in darkness or under conditions of water deficit, and could thereby tend to increase water loss from leaves. Because the maximum aperture of stomata in most species is less than 5 μm (Connor and Doley 1981), particles of diameter greater than about 5 μm are unlikely to become lodged within stomatal apertures and there is no evidence that such particles exert any effect on plant function by blocking gas diffusion through the stomatal pores (Paling et al. 2001). However, dust accumulation is only likely to reduce the rate of gaseous diffusion if the dust layer is thick, and therefore very obvious (Sharifi et al., 1997). Therefore, the physical effects of dust deposition on gas exchange can be discounted and attention can be directed towards the effects on light penetration into the leaf (Doley 2006).

The most important factor in the assessment of dust effects is the load on the leaf surface. This is affected by the:

- rate of dust deposition;
- duration of deposition;
- particle diameter class distribution;
- frequency of heavy rain events (e.g. > 5 mm);
- frequency of strong wind events (e.g. > 5 m/s);
- functional life of the leaf;
- structural features of the plant that may lead to shedding or retention of particles:
  - Branching habit of the tree or shrub (erect or pendant leaf disposition and sparse branching minimise deposition in low winds).
  - Foliage density (dense foliage increases particle impaction).

   - Foliage element size (small cylindrical elements intercept particles more effectively per unit surface area than large flat elements).
   - Leaf orientation (horizontal display maximises particle retention, vertical display minimises retention in a low wind environment).
   - Stiffness of display of branches and leaves (stiff branches and leaves retain their profile in wind; flexible branches and leaves stream in wind, greatly reducing the surface area presented for deposition, and flapping with resulting dislodgment of particles).
- structural features of the leaf that may lead to shedding or retention of particles:
   - Smoothness of leaf surface (this may differ between upper and lower surfaces, with the upper surface generally being smoother).
   - Presence of long, branched or expanded hairs on the leaf surface (more common on lower than on upper surfaces).
   - Presence of salt or resin secreting glands on the leaf surface that may increase leaf surface wetness; and

For a ground level source, there is a close relationship between total dust deposition rate and distance from the source because of preferential sedimentation of large particles close to the source and changes in both total dust concentration in the air and particle size class distribution with increasing distance from the source. One of the best documented examples of this variation in particle size distribution due to sedimentation with increasing distance from a road edge is from the Dalton Highway, Alaska (Walker and Everett 1987), shown in Figure 1.

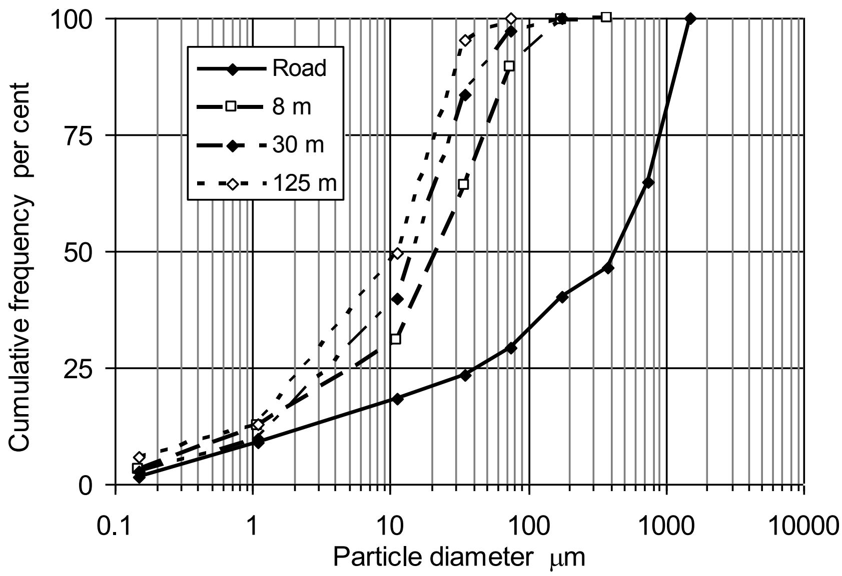

Figure 1. Distribution of particle sizes in dusts originating from a gravel road at Toolik, Alaska and carried for different distances from the roadway. Data from Walker and Everett (1987).

The Dalton Highway is a gravel road crossing the Alaskan tundra, which is occupied by very short vegetation. Consequently, the change in particle characteristics with increasing distance from the road is due solely to deposition from the atmosphere. Where tall vegetation occurs close to a low level dust source, it may have additional effects on the transport and deposition of dusts. This latter condition applies in the case of the proposed Boral Gold Coast Quarry.

The interception of suspended particles by vegetation is affected by the relationship between particle diameter and the size and density of foliage in the vegetation canopy (Raupach et al., 2001). The effectiveness of a windbreak can be described in terms of the particle impaction efficiency, or the fraction of particles travelling through the barrier that are intercepted by elements of that barrier. Calculations based on the work of Raupach et al. (1981) show that the interception efficiency of narrow elements (1 mm wide) is much greater than that of broad elements (10 mm wide, especially for particles between 3 and 10 um diameter (Figure 2). Therefore, tree species with narrow foliage elements (*Pinus* or *Casuarina* species) are likely to be much more effective for intercepting dust than are species with larger leaves, especially if the crowns of the fine-foliaged species do not deform greatly at higher wind speeds. The calculations shown in Figure 1 assume optimum foliage density and windbreak thickness, but it indicates the importance of establishing and maintaining windbreak conditions that will optimise particle interception and the greater effectiveness of windbreaks for interception PM_{10} particles than very coarse dust.

Light interception by the particles on plant canopies is also affected predictably by particle diameter, with the light extinction coefficient (the fraction of light incident on a surface that is absorbed by that surface) increasing exponentially as particle diameter decreases (Figure 3; Doley, 2006). The shading caused by dust is additional to the shading attributable to the foliage of each vegetation canopy layer.

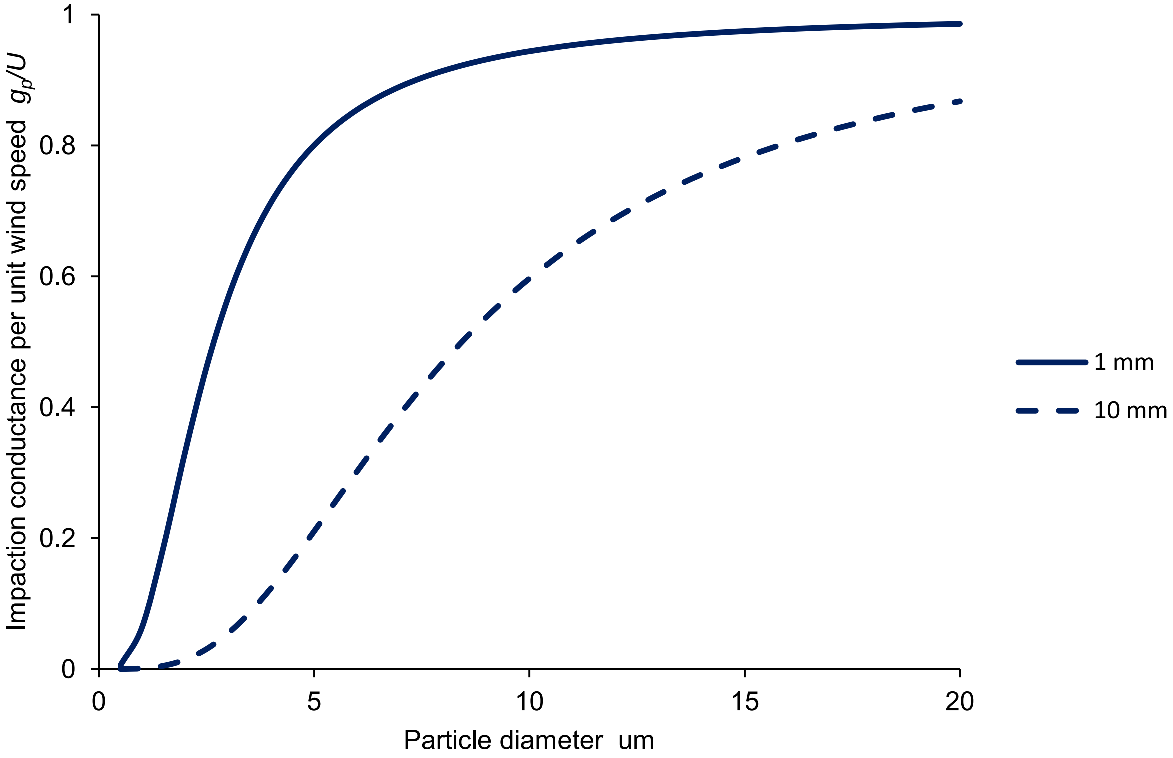

Figure 2. Relationships between the relative rates of impaction of particles (impaction conductance, g_p, per unit of wind speed, U) on vegetation elements of 1 or 10 mm diameter at a wind speed of 2 m/s for particles of specific gravity 2000 kg/m^3. Calculated after Raupach et al. (2001).

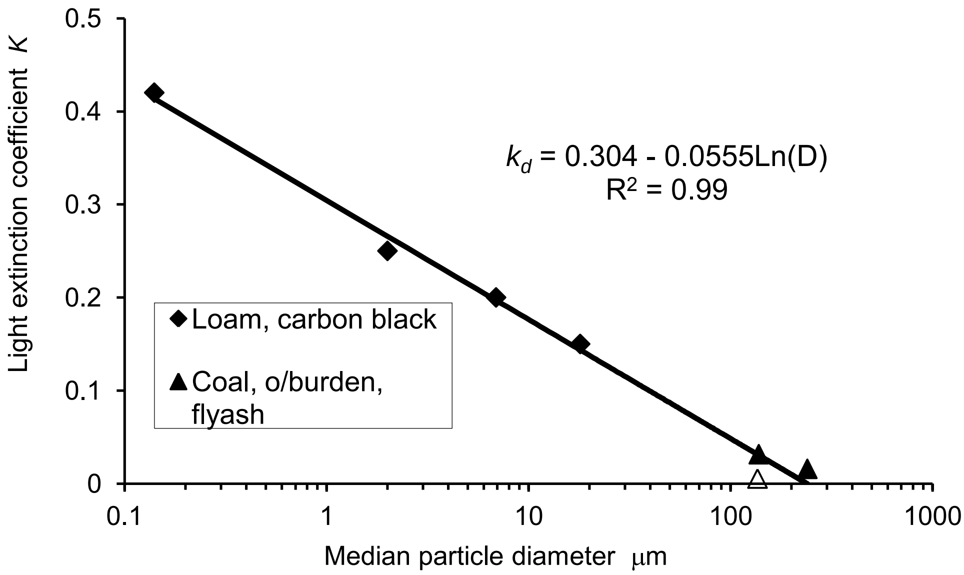

Figure 3. Relationship between light extinction coefficient, k_d, of unit dust load (1 g/m^2) and median particle diameter (D) for various materials (from Doley 2006).

2.2 Dominant vegetation types and plant species

The vegetation types and plant species at locations most exposed to dust deposition are described by Cardno Chenoweth (2013), reproduced below as Table 1.

Table 1 Regional Ecosystems (reproduced from Cardno Chenoweth (2013); Table 2-4).

Regional Ecosystem	VMA Status	Area in Study Area (ha)	Area in Disturbance Footprint (ha)	Short Description (DEHP, 2012d)
12.3.11	Of concern	0.01		*Eucalyptus siderophloia*, *E. tereticornis*, *Corymbia intermedia* open forest on alluvial plains usually near coast.
12.11.3	Least concern	7.9		Open forest generally with *Eucalyptus siderophloia*, *E. propinqua* on metamorphics +/- interbedded volcanics.
12.11.5a	Least concern	13.5	1.11	Open forest of *Eucalyptus tindaliae, Eucalyptus carnea* +/- *Corymbia citriodora* subsp. *variegata, Eucalyptus crebra, Eucalyptus major, E. helidonica, Corymbia henryi, Angophora woodsiana, C. trachyphloia* (away from the coast) or *E. siderophloia, E. microcorys, E. racemosa* subsp. *racemosa, E. propinqua* (closer to the coast). Occurs on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics.
12.11.5k	Least concern	0.07		Open forest of *Corymbia henryi* and/or *Eucalyptus fibrosa* subsp. *fibrosa* +/- *C. citriodora, Angophora leiocarpa, E. carnea, E. tindaliae, E. acmenoides, E. helidonica, E. propinqua, C. intermedia.* Includes patches of *E. dura*. Occurs on drier ridges and slopes in near coastal areas on Palaeozoic and older moderately to strongly deformed and metamorphosed sediments and interbedded volcanics.
12.11.23	Endangered	2.8	0.34	Tall open forest of *Eucalyptus pilularis* open forest on metamorphics and interbedded volcanics.

The distributions of REs in the subject area are reproduced in Figure 4 below from Cardno Chenoweth (2013; Figure 7).

RE 12.11.23, dominated by *E. pilularis*, occupies an area immediately to the south of the materials handling area, and to the north of the site (Figure 4). The overstorey layer of this forest type is open and deep, but a well-developed understorey and ground layer of vegetation is common. The locally endangered status of this RE means that it should be the focus of attention for potential dust effects. While the RE identity is determined principally by the dominant tree species, other components, including understorey species are important contributors to species diversity and some are of conservation concern.

REs 12.11.5a and 12.11.5k occur in distinct and mixed formations on all sides of the proposed quarry area, at locations away from valley bottoms. These REs are of least concern ecologically and are well represented in the locality. They are dominated by spotted gum (*Corymbia citriodora ssp. variegata, C. henryi*) and ironbarks (*Eucalyptus crebra, E. fibrosa* *ssp. fibrosa, E. siderophloia*) which have open canopies, a relatively sparse understorey and often a grassy ground layer.

An area of regrowth forest also occurs to the south of the quarry footprint (Figure 4). At this stage, the ecological value of this area would be indeterminate, but might develop into RE 12.11.23 on account of its topographic location.

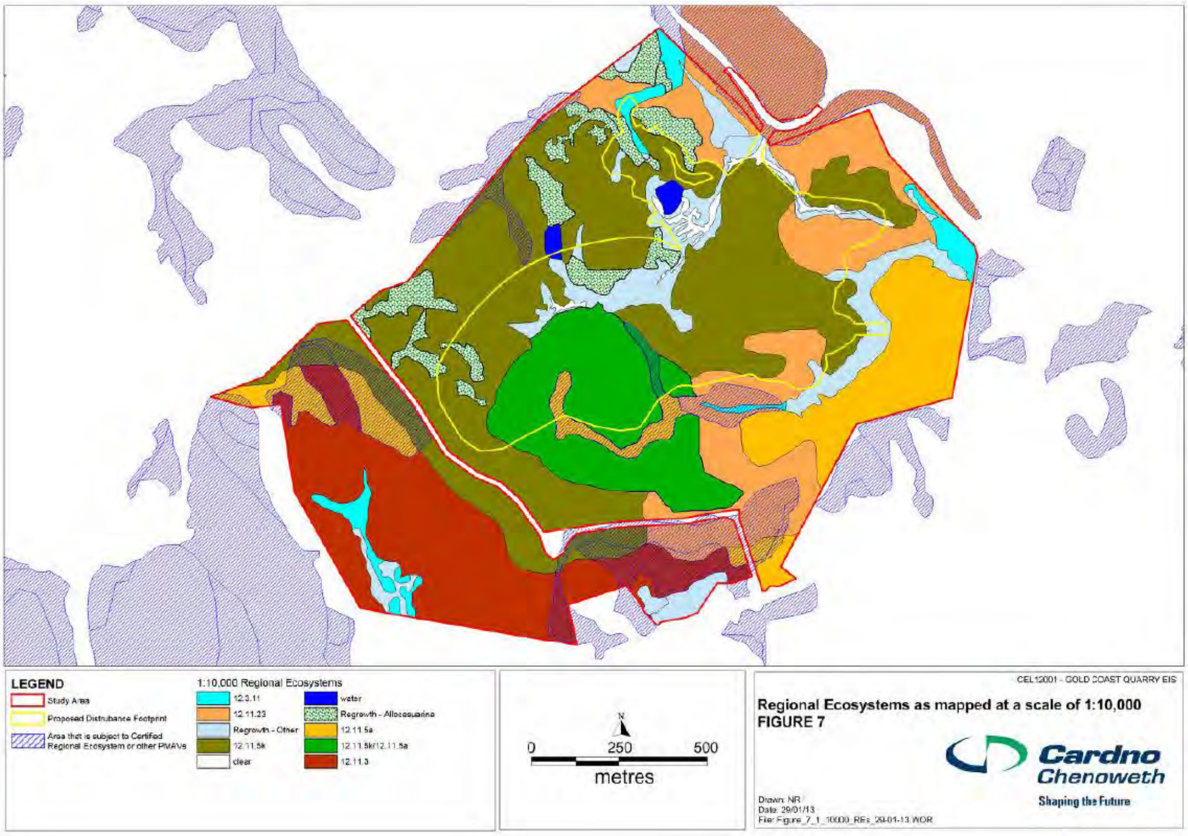

Figure 4. Distribution of Regional Ecosystems (from Cardno Chenoweth (2013); Figure 7).

The area of RE 12.11.23 immediately to the south of the quarry disturbance footprint is proposed to be used as an ecological offset for a portion of this RE is within the disturbance footprint that will be cleared. Consequently, attention will be directed to possible effects of estimated dust deposition rates in this RE.

2.3 Estimation of dust deposition rates

Sensitive receptor areas in the vicinity of the proposed quarry were identified, covering a range of land uses from residential to industrial, commercial and ecological (Table 2; reproduced from Katestone Environmental (2013).

Table 2 Receptor locations (reproduced from Katestone Environmental (2013); Table 3).

Sensitive Receptor Area		
ID	**Name**	**Type**
A	Kingsmore Estate	Residential
B	Old Burleigh Town (NW)	
C	Old Burleigh Town (SE)	
D	Tallebudgera Creek Road	
E	Tuesday Drive	
F	Stocklands Observatory Estate	
G	Skyline Terrace	
H	Chesterfield Drive	
I	Stocklands Observatory Estate (Stage 20)	Proposed residential
J	Industry	Industrial
K	Other key receptors (schools, aged care homes and commercial places)	Residential and Commercial
L	Vegetated buffer within Boral lease (sensitive flora and fauna)	Ecological

Because of their relative proximity to the quarry, a receptor areas of particular concern for this review are A, B, I and L.

Katestone Environmental provided measurements and estimates of dust deposition rates at the locations listed in Table 2 (Katestone Environmental, 2013). The predicted annual mean dust deposition rates at the various receptor locations for the quarry operations alone and in combination with background dust deposition are presented in Table 3, reproduced from Katestone Environmental (2013). For the purposes of discussion, the cumulative dust deposition rates will be used here.

The only receptor area where the predicted cumulative dust deposition rate exceeded the EPP Air objective was Area L, the vegetation buffer within the quarry property. Under the worst conditions, an annual mean deposition rate of about 250 $mg/m^2/d$ could occur in Area L.

Table 3 Predicted mean annual dust deposition rates (reproduced from Katestone Environmental (2013); Table 21).

Receptor Area	Predicted annual average dust deposition rate (mg/m²/day) (isolation)			Predicted annual average dust deposition rate (mg/m²/day) (cumulative)		
	Minimum	Mean	Maximum	Minimum	Mean	Maximum
A	3.7	16.2	50.8	41.5	54.0	88.6
B	3.6	7.8	14.9	41.4	45.6	52.7
C	1.0	2.8	6.4	38.8	40.6	44.2
D	1.6	4.2	21.3	39.4	42.0	59.1
E	1.5	4.1	11.8	39.3	41.9	49.6
F	1.0	2.1	5.0	38.8	39.9	42.8
G	0.7	1.5	1.9	38.5	39.3	39.7
H	0.9	1.7	3.2	38.7	39.5	41.0
I	4.0	11.8	34.6	41.8	49.6	72.4
J_1	0.6	6.9	37.8	38.4	44.7	75.6
J_2	4.7	8.1	12.2	42.5	45.9	50.0
K	0.8	2.3	7.0	38.6	40.1	44.8
Vegetation buffer (L)	5.1	37.7	216.9	42.9	75.5	254.7
Background	-			*37.8**		
Air EPP objective	*130 mg/m²/day*					

Table note:
* Dust deposition rate background derived from measurements at West Burleigh Quarry (Table 15)

The monthly maximum dust deposition rates due to the quarry operations alone and in combination with background dust deposition, are presented as Table 4, reproduced from (Katestone Environmental, 2013). These data are supplemented by graphical estimates of dust deposition rates across the Project area, prepared for the purpose of this report by Katestone Environmental Pty Ltd and presented in Figure 5.

The mean and maximum monthly dust deposition rates are similar for Sites A, B and I, but are substantially higher for Site L. For the purpose of this discussion, the cumulative dust deposition totals will be considered, even though this may contain a contribution from the present quarry located to the east of the proposed site. It is assumed that a monthly dust deposition rate of about 340 mg/m^2 per day must be considered for one month. As there may be two or three months during the year when rainfall is low and dust may not be washed from leaves, a longer period of deposition at a lower rate would be appropriate. For the other locations, a maximum monthly deposition rate of about 120 mg/m^2 per day would appear to be relevant for the purposes of this review.

Table 4 Predicted monthly maximum dust deposition rates (reproduced from Katestone Environmental (2013); Table 20).

Receptor Area	Predicted monthly maximum dust deposition rate ($mg/m^2/day$) (isolation)			Predicted monthly maximum dust deposition rate ($mg/m^2/day$) (cumulative)		
	Minimum	**Mean**	**Maximum**	**Minimum**	**Mean**	**Maximum**
A	8.4	27.9	80.6	46.2	65.7	118.4
B	9.6	21.4	42.0	47.4	59.2	79.8
C	2.5	6.8	15.4	40.3	44.6	53.2
D	3.0	11.1	56.9	40.8	48.9	94.7
E	4.6	13.0	40.5	42.4	50.8	78.3
F	2.0	4.3	11.8	39.8	42.1	49.6
G	2.5	5.2	6.9	40.3	43.0	44.7
H	1.6	3.3	6.0	39.4	41.1	43.8
I	7.9	26.2	72.1	45.7	64.0	109.9
J_1	2.4	15.1	78.1	40.2	52.9	115.9
J_2	10.3	17.5	28.5	48.1	55.3	66.3
K	1.9	4.5	13.2	39.7	42.3	51.0
Vegetation buffer (L)	10.5	80.7	301.5	48.3	118.5	339.3
Background	**-**			***37.8****		
Air EPP objective	***120 mg/m²/day***					

Table note:
* Dust deposition rate background derived from measurements at West Burleigh Quarry (Table 15)

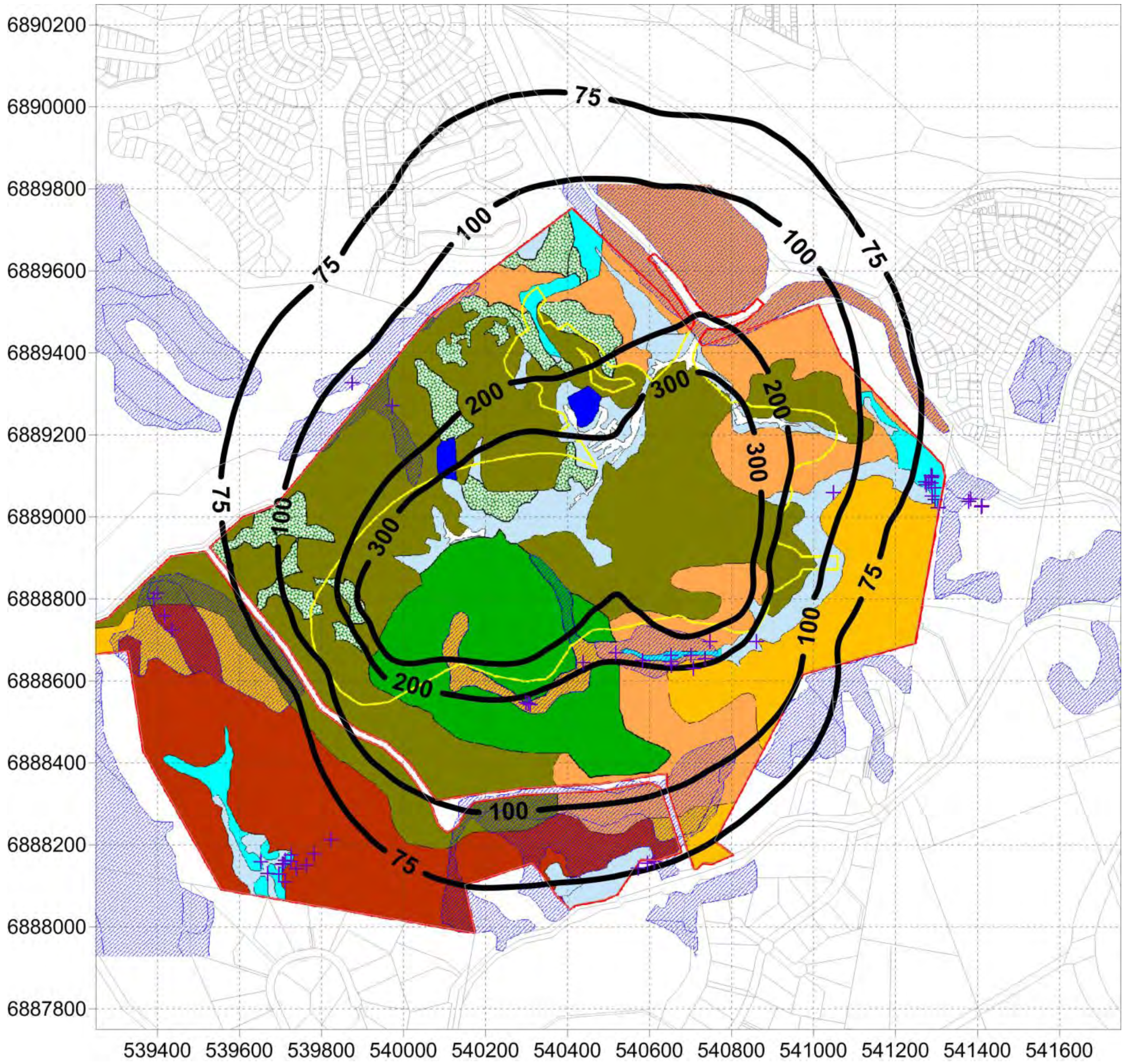

Figure 5 Predicted distribution of highest mean monthly maximum dust deposition rates ($mg/m^2/d$) around the Project site (provided by Katestone Environmental).

Notes: Quarry disturbance perimeter is indicated by a yellow line. RE12.11.23 (*Eucalyptus pilularis* forest) is shown in orange. Certified Regional Ecosystems are hatched in blue. Occurrences of threatened species are indicated by blue crosses (*Marsdenia mucronata* is the principal threatened species in the area of RE12.11.23 to the south of the quarry footprint.

3. ESTIMATED EFFECTS OF DUST DEPOSITION RATES ON PHOTOSYNTHESIS IN PLANT SPECIES

3.1 Dust characteristics and assumptions

The characteristics of dust that affect vegetation are chiefly those that reduce photosynthetic activity, and therefore the capacity of plants to accumulate reserves for seasonal growth and reproduction. As shown in Figure 3 (Section 2), the light-absorbing properties of mineral dusts are related closely to the particle diameter, regardless of the source or colour of the material.

While the particle size distribution of the quarry dust in the present case is not known, it is assumed that the median particle diameter for PM_{10} is 5 μm. The relationship between particle diameter (D) and light extinction coefficient (k_d) of the dust for a unit load (1 g/m^2):

$$k_d = 0.304 - 0.0555 \ln D. \qquad (1)$$

The combination of k_d and dust load allows the light absorption of a given dust load to be determined directly for any layer of leaves in the canopy.

The movement and interception of dust within a vegetation canopy will result in a decrease in dust concentration, and therefore in rate of dust deposition (Raupach et al. 2001). There is not enough information available to make a reliable calculation of dust interception by the vegetation in any RE of relevance to this report. Consequently, it is assumed that the concentration of particles is uniform throughout the vegetation profile, so that the instrumental dust deposition rate applies uniformly on each layer of vegetation. This is a very conservative assumption for all situations except the edge of a vegetation block immediately facing the cleared quarry area. Factors that may reduce the dust deposition rate within a block of vegetation will be discussed later (Section 4).

It can be expected that all dust will be effectively removed by a rain event of 5mm or greater. Therefore, the length of rain-free periods during which dust accumulation may affect plant productivity can be taken as those terminated by rain events of 5 mm or more.

Due to the climate of the area, it can be expected that dust accumulation on vegetation would be very limited during the wet season (December to March), and variable during the remainder of the year depending on the frequency of rainfall events and the duration of rainless periods of low wind. The period when extended dust deposition events are most likely would be during spring, from September to November. Dust dispersion under air drainage conditions during the morning might be expected to lead to maximum rates of deposition and the retention of this dust would depend on the absence of strong sea breeze conditions during the afternoon.

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3.2 Species characteristics and assumptions

The following discussion will be concerned with RE 12.11.23, the *E. pilularis* dominated forest located in a gully to the south of the quarry operating area.

Eucalyptus pilularis is a tall tree with a large crown of relatively distinct branch units bearing leaves displayed at an angle to the horizontal. Leaves are retained only in well illuminated conditions and the usual life span of leaves is slightly longer than one year. *Eucalyptus crebra, E. fibrosa ssp. fibrosa, E. tindaliae* and *Corymbia henryi* are also large trees that occur on slightly drier sites than *E. pilularis*. The leaf surfaces of all these species are waxy and relatively smooth, especially on the upper surfaces.

If the leaves in a vegetation canopy are assumed to be distributed uniformly over the ground surface, the penetration of sunlight through the canopy will be a function of the cumulative leaf area index (LAI) (leaf area per unit ground area), L, between the upper surface of the vegetation and any point of interest, and the orientation of the leaves with respect to the direction of the solar beam. The orientation of the foliage is described by the light extinction coefficient, k, which is the proportion of incident light that is not transmitted through unit leaf area index, averaged for a day. These parameters are related by

$$I = I_o e^{-kL} \qquad (2)$$

where I is the amount of light penetrating to a point in the plant canopy, I_o is the amount of light incident on the upper surface of the plant canopy, k is the light extinction coefficient, and L is the LAI above the point of determination of I (Warren Wilson 1965).

The value of k varies from 0.2 for plants with pendant or vertically oriented leaves to 0.9 for plants with nearly horizontal leaves. For leaves of overstorey eucalypts, a value of 0.4 has been assumed, while k is assumed to be 0.6 for the understorey species and 0.8 for the ground layer species, which tend to have horizontally displayed leaves.

There is no accepted means of converting dust deposition rates to dust loads on leaves. For the present purpose, assumptions have been made of the disposition and orientation of foliage in different layers of the vegetation, and their possible interactions with dust.

- It is assumed that two leaf area index layers at the top of the canopy are occupied by trees with leaves that hang downwards or are carried on sufficiently flexible stems that they flutter in light winds. This leaf movement is assumed to dislodge most of the dust that falls on the leaf surface, so that 5% of the dust that would fall into a dust gauge is retained on a canopy eucalypt leaf.
- It is assumed that understorey tree and shrub species contribute one leaf area index layer, and that their leaves are less steeply inclined, that they are subjected to lower wind speeds than the overstorey tree leaves, and that they retain 10% of the dust that would fall into a deposit gauge.
- It is assumed that the ground vegetation layer accounts for one leaf area index layer, that it has leaves that are nearly horizontal in their display, that lower wind speeds result in less leaf fluttering, so that these leaves retain 20% of the dust that would fall into a deposit gauge.

Photosynthesis is described as the net rate of carbon dioxide (CO_2) assimilation (A_{net}) in relation to the incident photosynthetically active photon flux density (PPFD) (I). A_{net} for a leaf is described very conveniently and with acceptable precision by a non-rectangular hyperbola (Cannell and Thornley 2002)

$$A_{net} = (\alpha I + A_{max} - [(\alpha I + A_{max})^2 - 4\phi\alpha I A_{max}]^{0.5})/2\phi - R \qquad (2)$$

where α is the efficiency of light conversion of CO_2, I is the PPFD incident on a leaf surface beneath the dust load, A_{max} is the maximum (light-saturated) rate of gross photosynthesis at the top of the canopy, ϕ is a convexity factor of the non-rectangular hyperbola, and R is the rate of dark respiration.

The rate of photosynthesis becomes light-saturated in most species at about half of full sunlight. Species that are adapted to a shaded environment tend to reach light saturation of photosynthesis at lower quantum flux rates (light intensities). However, they also tend to have lower maximum rates of photosynthesis than species adapted to high light environments. As a result, dry matter production in the lower layers of a vegetation canopy is less than at the top and the response of photosynthesis to shading by dust is more sensitive in the low light environment of the forest understorey than at the top of the canopy.

In calculating the radiation incident on a particular leaf layer, the light extinction coefficient of the dust (k_d) is added to the value the canopy light extinction coefficient (k) for the overlying leaf layers. The maximum value of the combined light extinction coefficient is 1.0.

Figure 6 shows an example of RE 12.11.23 (blackbutt forest) on the Boral property that has been classified as remnant. The well-developed understorey is clear, and the tree density and heights suggest that the overstorey canopy is also well developed.

Figure 6. Example of remnant blackbutt forest (RE 12.11.23) on Boral property. (Image supplied by Cardno Chenoweth Pty Ltd).

Some photosynthetic characteristics of blackbutt (*E. pilularis*) have been described by Mooney et al. (1978) and Alcorn et al. (2008) and are reproduced in Table 5. Equivalent data for notional understorey and ground layer species have been assembled from studies on other forest species or from best estimates where there is no relevant information.

Table 5. Attributes of vegetation canopy layers of remnant RE 12.11.23 relevant to effects of dust deposition on dry matter production of individual layers.

LAI	Species	*k*	*dr*	α	ϕ	A_{max}	*R*
1	*Eucalyptus pilularis*	0.4	0.05	0.053	0.7	25	3.3
2	*Eucalyptus pilularis*	0.4	0.05	0.058	0.7	23	3.1
3	Understorey	0.6	0.1	0.064	0.8	10	1.3
4	Ground species	0.8	0.2	0.069	0.9	7	0.9

Abbreviations:
LAI, leaf area index layer (m^2 of foliage / m^2 ground area).
k, light extinction coefficient of LAI layer (dimensionless).
dr, dust retained on foliage surfaces as a fraction of dust retained in a dust fall gauge.
α, initial carbon dioxide uptake efficiency of photosynthesis (mol CO_2/mol quanta)
ϕ, curvature coefficient of photosynthetic light response curve (dimensionless).
A_{max}, maximum (light-saturated) rate of photosynthesis at ambient CO_2 concentration (umol $CO_2/m^2/s$).
R, rate of dark respiration (umol $CO_2/m^2/s$).

It is also appropriate to make estimates of dry matter production in another area of RE 12.11.23, identified as the ecological offset area (Figure 7).

Figure 7. Example of blackbutt forest (RE 12.11.23) on Boral property identified as an ecological offset area. (Image supplied by Cardno Chenoweth Pty Ltd).

The two areas of forest have sufficient different structures that it is useful to examine the potential effects of dust. The overstorey canopy of blackbutt and associated species is more sparse in the offset area than in the remnant, the understorey layer is also sparse, and a dense ground layer is composed principally of grass (*Imperata cylinidrica*). Consequently, the attributes of the LAI layers are different, as shown in Table 6.

Table 6. Attributes of vegetation canopy layers of remnant RE 12.11.23 relevant to effects of dust deposition on dry matter production of individual layers.

LAI	Species	k	dr	α	ϕ	A_{max}	R
1	*Eucalyptus pilularis*	0.4	0.05	0	0.4	0.7	25
2	Understorey	0.5	0.05	0	0.5	0.7	23
3	Ground species	0.4	0.1	0	0.4	0.7	20
4	Ground species	0.4	0.1	0	0.4	0.7	16

Abbreviations as for Table 5:

3.3 Model calculations

The calculations defined in Equation 2 were repeated for each hour of a sunlit day, assuming a sinusoidal variation in incident solar radiation (Charles-Edwards et al. 1986) and a 12-hour day. The daily integral of net photosynthesis (carbon dioxide assimilation) for each LAI layer was converted to dry matter assuming that all of the dry matter produced was carbohydrate with the relative composition of CH_2O (Doley and Rossato 2010). Whilst in many situations the total dry matter production of a vegetation canopy is the principal concern, for the present purpose, the dry matter production within each LAI layer was of greater interest because of the occurrence of different species in various LAI layers.

In a dust-free environment, dry matter production decreases with increasing leaf area index layers from the top of the canopy due to the decreasing light penetration through successive leaf layers. The effect of differences in environment and leaf characteristics described in Table 5 are demonstrated in Figure 8. For a dust-free environment, there is a progressive reduction in dry matter production with increasing depth in the vegetation canopy. Even with a species (*E. pilularis*), shading causes a reduction in productivity between LAI layers 1 and 2. Further reductions in light energy availability and in species characteristics result in distinct decreases in potential dry matter production in the understorey and ground vegetation layers respectively (Figure 8).

The absolute effects of dust deposition on dry matter production in the upper three LAI layers appear to be similar while there appears to be a greater absolute effect on the ground vegetation layer (LAI 4) when dust accumulates on the foliage for 30 days (Figure 6). However, these dust effects are difficult to compare because the dust-free rates of dry matter production are relatively large.

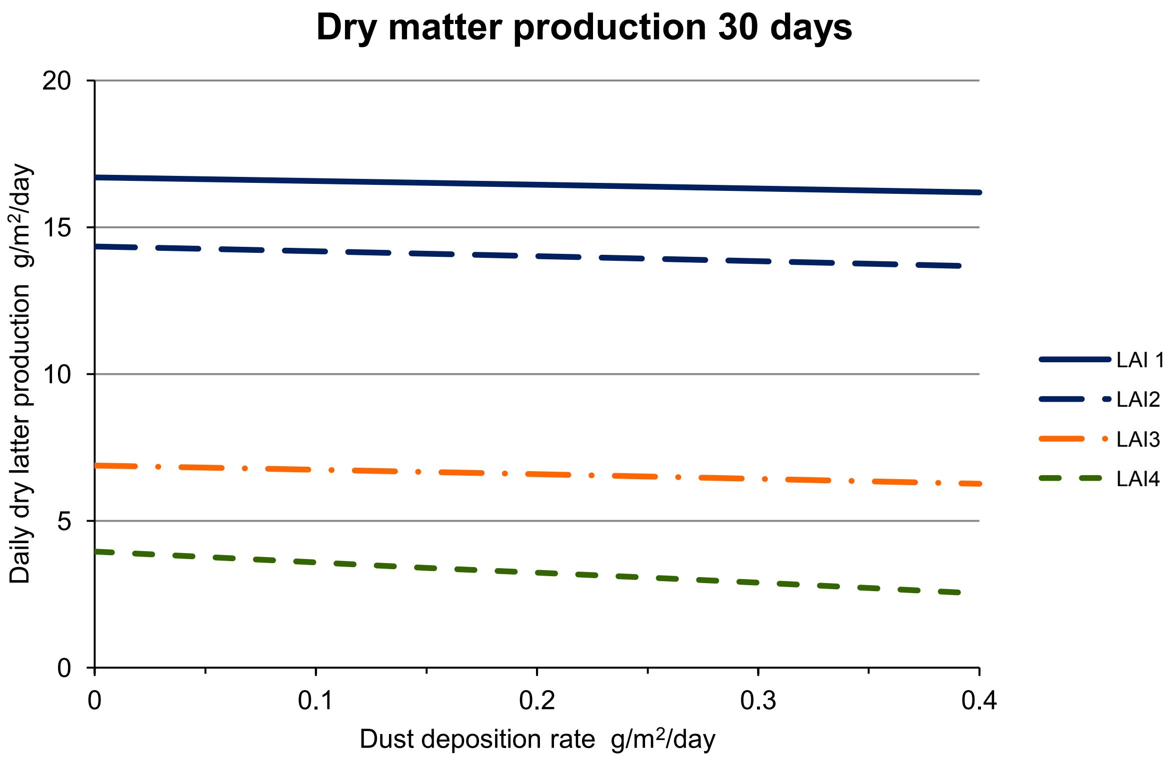

Figure 8 Model calculations of relative dry matter production in different leaf area index (LAI) layers from the top of a remnant RE 12.11.23 vegetation canopy with the characteristics described in Table 5 under different dust deposition rates as recorded in a dust deposit gauge.

The proportional effects of dust accumulation on leaves at different positions in a remnant RE 12.11.23 mixed-species canopy can be demonstrated more clearly by expressing the rate of daily dry matter production as a percentage of the dust-free rate after different periods of dust accumulation (Figure 9).

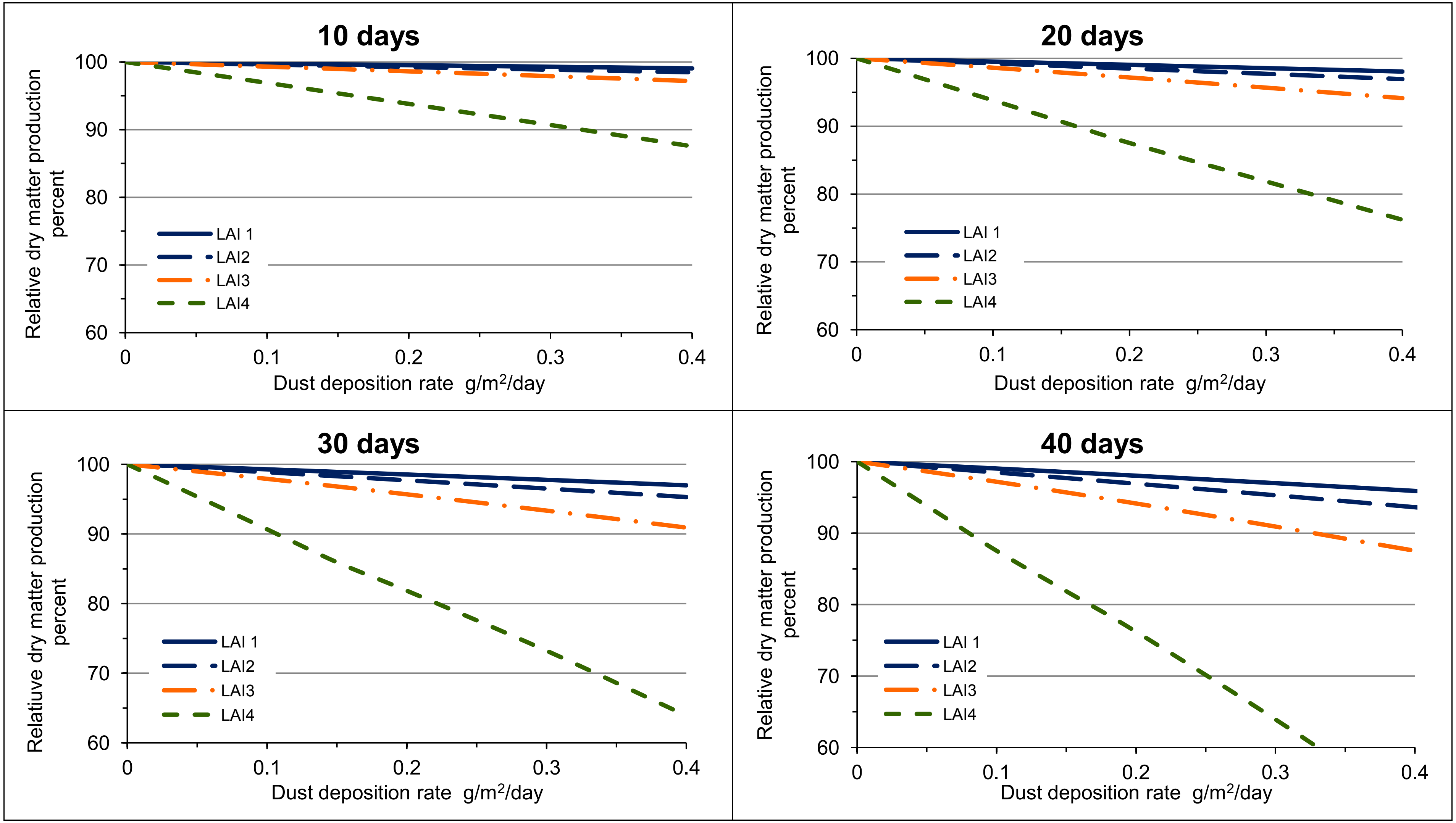

Figure 9. Simulations of relative effect of dust accumulation on dry matter production in four strata of a remnant *Eucalyptus pilularis* forest (RE 12.11.23) with the characteristics described in Table 5 and subjected to dust deposition for 10, 20, 30 or 40 days.

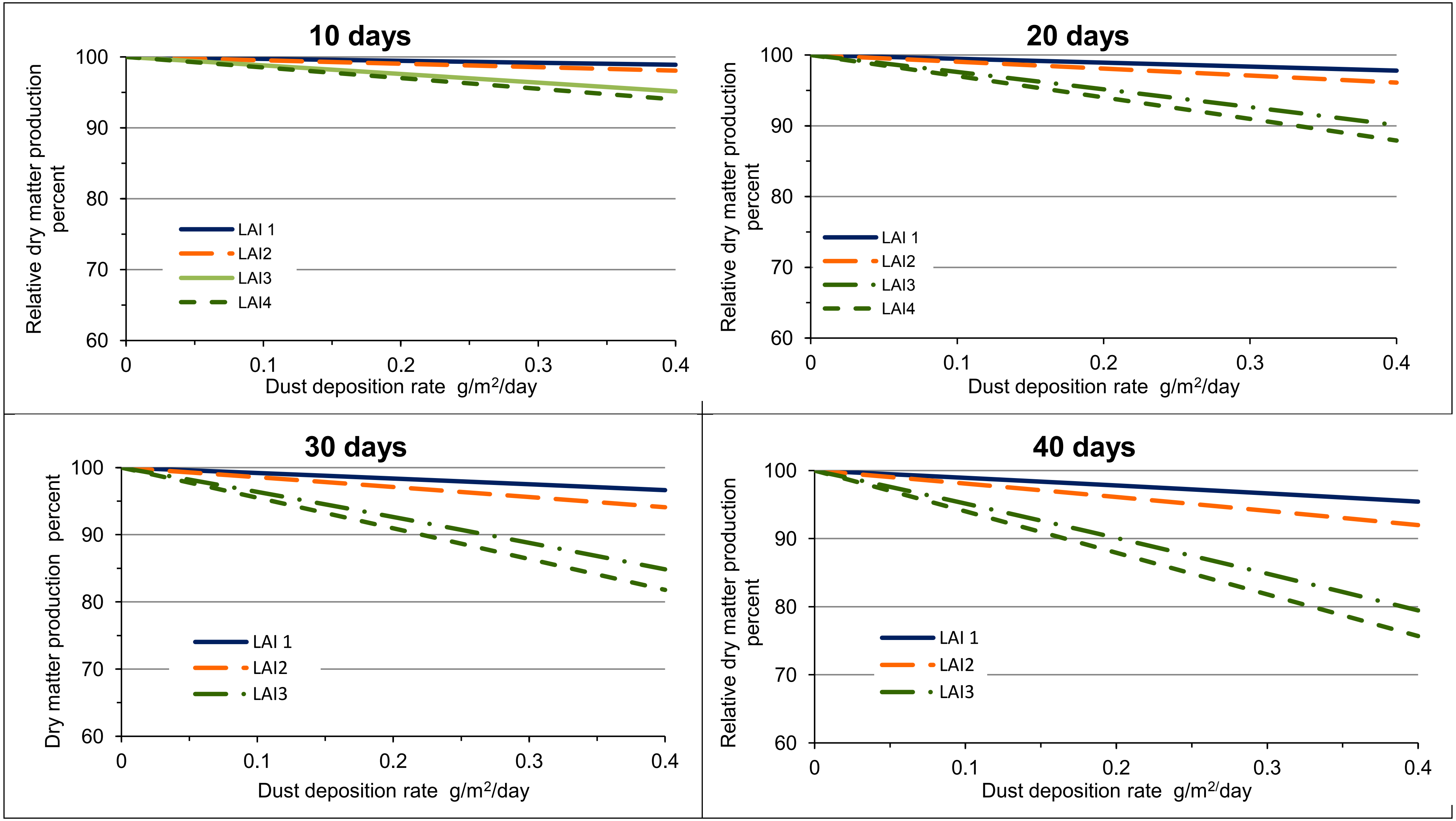

Figure 10. Simulations of relative effect of dust accumulation on dry matter production in four strata of an ecological offset portion of *Eucalyptus pilularis* forest (RE 12.11.23), with the characteristics described in Table 65 and subjected to dust deposition for 10, 20, 30 or 40 days.

The calculations in Figures 9 and 10 cover the predicted monthly maximum dust deposition rate at Site L (vegetation buffer zone within the quarry property) and are consistent with the predicted dust deposition contours for the portion of RE 12.11.23 closest to the quarry footprint (Figure 5). These estimates are considered to be appropriate for sunny rain-free days in spring. Extended periods of cloud cover would reduce the absolute productivity values, and may also increase the e\differential effects on the various canopy layers. These possibilities were not examined in the present case.

Relative dry matter production for different leaf area index layers of the remnant and ecological offset variants of RE 12.11.23 are summarised in Table 7 for 30-day exposure to dust deposition at the 0.4 g/m^2/day (greater than the maximum predicted value of 0.339 g/m^2/day (Katestone Environmental 2013).

Table 7. Comparison of predicted dust effects on selected layers within the canopies of RE 12.11.23 (blackbutt-dominated forest) within the Boral property and subjected to a mean monthly dust deposition rate of 300 or 400 mg/m^2/day for 40 days.

LAI layer from top	RE 12.11.23 Remnant			RE 12.11.23 Ecological Offset		
	Dust deposition rate (mg/m^2/day)	300	400	Dust deposition rate (mg/m^2/day)	300	400
	Species	DMP %	DMP %	Species	DMP %	DMP %
1	*Eucalyptus pilularis*	97	96	*Eucalyptus pilularis*	97	95
2	*Eucalyptus pilularis*	95	94	Understorey	94	92
3	Understorey	91	88	Ground species	85	79
4	Ground species	64	51	Ground species	82	76

Abbreviations: LAI Leaf area index; DMP Dry matter production rate (percent of dust-free).

4. DISCUSSION AND CONCLUSIONS

4.1 Effects of dust on vegetation

A light interception and dry matter production model has been modified to allow for variation in the structural and physiological characteristics of individual leaf area index layers within a vegetation canopy. Because detailed structural and physiological data are available for only a very few Australian native plant species, assumptions have been made in Tables 5 and 6 that are considered to provide practical guidance for the assessment of dust effects on vegetation.

Two conditions of the regional ecosystem of major concern (RE 12.11.23, blackbutt-dominated remnant forest and an ecological offset area) were examined. For the remnant vegetation, it was assumed that the overstorey canopy was well developed, while in the ecological offset area it was sparser. This difference in overstorey structure has an influence on the light penetrating to the understorey layer, and the characteristics of this layer influence conditions close to the ground. In both situations, it was assumed that the total foliage area carried above unit ground area was the same, at 4 m^2/m^2.

Assumptions concerning leaf disposition and the retention of dust on leaf surfaces have a large influence on the shading of individual leaf layers, and hence on dry matter production. The assumptions used are considered to be conservative, that is, they are more likely to overestimate than underestimate dust retention of leaves. The period for which dust accumulation occurs has been selected to range from 10 to 40 days. In the Gold Coast hinterland, a 40-day period without rain might be expected to occur during a major drought, but under such conditions, it is possible that periods with higher speeds might dislodge dust from foliage. On balance, the parameters selected are considered to give conservative estimate of dust effects.

In both forest conditions of RE 12.11.23 (remnant and ecological offset area), the overstorey *Eucalyptus pilularis* layer is relatively unaffected by dust deposition at the maximum mean monthly rate predicted by Katestone Environmental (2013) (Figures 9 and 10, Table 7). The understorey (small tree and large shrub) layers in both situations lose approximately 10 % of their dry matter production potential. This reduction is not likely to be deleterious for the species within this vegetation layer.

The effect on the ground species is predicted to be greater, with a possible loss of about one-quarter of dry matter production potential in the *Imperata cylindrica*-dominated cover in the offset area, and about half of the potential in the remnant forest. While the loss of production potential in the ground layer of the ecological offset area may not cause major changes in its structure, there may be a reduction in grass density. In the remnant forest, a reduction of dry matter production potential by 50% could be detrimental for small ground cover species with horizontally displayed leaves.

An important factor that would alter the outcome of such predictions include the interception of dust my taller vegetation strata, and the consequent reduction in dust deposition rate at ground level. While it is possible to estimate dust interception by vegetation using the procedures described by Raupach et al. (2001), providing an adequate description of the physical structure of a mixed-species understorey is beyond the scope of the present work. However, if it is assumed that foliage elements have a width of 10 mm, the relationship shown in Figure 2 suggests that about 20% of the dust may be intercepted by a unit leaf area index layer of vegetation. This is not sufficient to make a substantial difference to light interception in the lowest layer of the remnant vegetation. It must be assumed that the ground layer of RE 12.11.23 could be at risk from prolonged exposure to dust deposition at a rate of 400 $mg/m^2/day$, or even 300 $mg/m^2/day$.

In areas of interest beyond the Boral site, Site A (Kingsmore Estate) and Site B (Old Burleigh Town), the annual mean dust deposition rate is in the vicinity of 50 mg/m^2 per day. Figure 4 shows that this rate of dust deposition is predicted to reduce dry matter production in the tree canopy layer (uppermost two leaf area index layers) by less than 1% and in the ground layer by less than 5%. These losses in potential dry matter production are considered to be insignificant.

4.2 Possible mitigation measures

The calculation made here assume that dust transport to the areas of RE 12.11.23 is unimpeded by physical properties of the landscape or other mitigation measures. The quarry wall adjacent to the more sensitive ecological area is planned to be more than 15 m tall (Cardno information). In addition, Boral plan to establish a windbreak of *Casuarina* species at the edge of the native vegetation area immediately to the south of the quarry margin. Observations of the writer in New Zealand indicate that windbreaks of *C. cunninghamiana* are very effective in preventing damage to sensitive orchard species from salt-laden winds, especially if the windbreaks are hedged to a thickness of about 2 m and a higher of 10 m. This trimming requires vehicle access on both sides of the windbreak, but if it is carried out regularly, a very uniform barrier of fine foliage can be maintained from ground level to 10 m height. This would satisfy the requirements specified by Raupach et al. (2001) for an efficient structure for the interception of dust particles less than 10 μm diameter (cf. Figure 2).

If ground level dust concentrations were reduced by 80 %, the rates of deposition might be expected to be reduced by a similar amount. If that were the case, a rate of dust deposition of 60 to 80 mg/m^2/day would have very little effect on most layers of vegetation, and would reduce potential dry matter production in the ground layer of remnant RE 12.11.23 by less than 10 % (Figure 9).

4.3 Conclusions

In each vegetation type considered in this report, the overstorey species in the vicinity of the proposed Boral quarry are very unlikely to be affected adversely by dust deposition. Predicted maximum dust deposition rates could impact on vegetation layers within plant communities that have a deeply shaded understorey. One such community is the blackbutt-dominated forest described as Regional Ecosystem 12.11.23. If the maximum rate of dust deposition predicted to be recorded in a deposit gauge applies uniformly throughout a vegetation profile, there could be sufficient additional shading by dust on leaves of ground cover species that their integrity could be threatened.

However, the ground layer of RE 12.11.23, occurs at a distance of more than 100 m and at least 20 m below the crest of a hill between the proposed quarry surface and the site in question. In addition, there is likely to be progressive interception of dust as it moves through vegetation (both laterally and vertically). Therefore, the maximum dust deposition rate predicted by a general dispersion model is likely to be an overestimate of the rate occurring at a potential sensitive site.

Practical mitigation measures, especially the establishment and maintenance of a *Casuarina* windbreak at the quarry edge is likely to reduce the concentration of dust in air moving laterally into the native vegetation by up to 80%.

The combination of these factors suggests that, at the locations likely to be most impacted by dust deposition, the risk to the health and integrity of vegetation communities is likely to be very low.

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APPENDIX B - Supplementary information for the response to the key matters relating to air quality

Table 1 Dust control reduction efficiency (Table 12 in Appendix GG) with literature references and justifications included

Dust control measure	Reduction efficiency	Source
Operation in daylight hours only (0600 - 1800)	No reduction efficiency applied in model, but good practice to only operate in daylight hours	n/a
Use of water truck/s to wet down working roads and pads	50 %	Mining & Processing of Non-Metallic Minerals v2.0 – Table 3 (level 1 watering)
Drill rig has integral dust collector	70 %	see comment 1 below
Use of water truck/s to wet down blast surface prior to firing	No reduction efficiency applied in model, but will be adopted because good practice measure	n/a
Install and use dust suppression systems on the plant and equipment	90 % (91%)	Mining & Processing of Non-Metallic Minerals v2.0 – Table 3 (70% enclosure, 70% watering)
Internal access road from intersection to car park will be sealed (concrete / asphalt / bitumen sealed)	No reduction efficiency applied in model but effective in reducing potential emissions by reducing the amount of unsealed roads	n/a
Use of water truck/s to wet down working roads and pads - including application of polymer additives for efficient use of water, and longer retention time	75%	Mining & Processing of Non-Metallic Minerals v2.0 – Table 3 (level 2 watering)
Plant enclosures and hi-pressure dust suppression systems	90 % (91%)	Mining & Processing of Non-Metallic Minerals v2.0 – Table 3 (70% enclosure, 70% watering)
All external conveyors to be covered and fitted with rain/wind barriers	75%	Sources have 3 sides and/or a roof which has been assumed to have a reduction efficiency of 75%
Contained storage in "toast-rack" bunkers. Dust bunkers to be fitted with retractable covers.	75%	
Majority of high turnover aggregate products will be despatched into trucks from overhead load out bins with automated weigh-feeders to control product discharge.	No reduction efficiency applied in model, but will be adopted because good practice measure	n/a
Diligent use of water truck/s to wet down aggregate product stockpiles located at the northern area of the facilities pad	75%	see comment 2 below
The main quarry access road (including weighbridge area) will be sealed. All product despatch trucks will pass through wheel wash units. A street sweeper will be employed to periodically sweep the internal roads and turnout areas to Old Coach Rd.	No reduction efficiency applied in model, but will be adopted because good practice measure	n/a

Comment 1 :Drill rig
While there is no reported control efficiency for an integral dust collector, there is a 70% control efficiency reported for water sprays and a 99% control efficiency reported for fabric filters. The integral dust collector is expected to be more effective in reducing dust than water sprays and so 70% represents a conservative estimate of control efficiency.

Comment 2: Aggregate Product Stockpiles
The NPI manual reports a 50% control for watering of stockpiles. Diligent use of water trucks and the potential use of suppressants if required will ensure that Boral can meet a higher level of control, akin to the level 2 control efficiency used for haul roads. Therefore a 75% control efficiency has been applied to this source.

APPENDIX C - Supplementary information for the response to the key matters relating to air quality

Table 2 Detailed dust inventory for each stage of the Gold Coast Quarry

Activity	Description	Emission calculation basis		Modelled emission rate (g/s)		
				TSP	PM_{10}	$PM_{2.5}$
Establishment Phase 1						
FEL - overburden	Establishment stage - cut by excavator	21,900	tonnes	0.011	0.005	0.001
	Establishment stage - fill dump to truck	1,850	tonnes	0.001	0.000	0.000
	Establishment stage - fill truck dump to placement area	1,850	tonnes	0.001	0.000	0.000
	Establishment stage - overburden dump to truck	20,050	tonnes	0.010	0.005	0.001
Dozer	Establishment stage - dozer	12	hrs/day	0.499	0.094	0.008
			Establishment Phase 1 Total:	**0.523**	**0.105**	**0.010**
Establishment Phase 2						
FEL - overburden	Establishment stage - cut by excavator	422,240	tonnes	0.184	0.087	0.013
	Establishment stage - fill dump to truck	213,510	tonnes	0.111	0.053	0.008
	Establishment stage - fill truck dump to placement area	213,510	tonnes	0.111	0.053	0.008
	Establishment stage - overburden dump to truck	326,480	tonnes	0.170	0.081	0.012
Dozer	Establishment stage - dozer	12	hrs/day	0.499	0.094	0.008
Haulage - overburden	E2 - haul of overburden	7,682	km	1.879	0.530	0.053
	E2 - haul of fill	4,864	km	1.190	0.336	0.034
			Establishment Phase 2 Total:	**4.145**	**1.233**	**0.136**
Establishment Phase 3						
FEL - overburden	Establishment stage - cut by excavator	453,180	tonnes	0.237	0.112	0.017
	Establishment stage - fill dump to truck	115,900	tonnes	0.060	0.029	0.004
	Establishment stage - fill truck dump to placement area	115,900	tonnes	0.060	0.029	0.004
	Establishment stage - overburden dump to truck	337,280	tonnes	0.176	0.083	0.013
	Establishment stage - product to truck	337,280	tonnes	0.003	0.001	0.000
Dozer	Establishment stage - dozer	12	hours	0.499	0.094	0.008
Haulage - overburden	E3- haul of overburden	15,452	km	3.779	1.067	0.107
	E3 - haul of fill	5,887	km	1.440	0.406	0.041
Establishment Phase 3 Total:				**6.255**	**1.821**	**0.194**
Development Phase D1/D2						
FEL - overburden	Development stage - cut by excavator	2,330,075	tonnes	1.216	0.575	0.087
	Development stage - fill dump to truck	0	tonnes	0.000	0.000	0.000
	Development stage - fill truck dump to placement area	0	tonnes	0.000	0.000	0.000

Activity	Description	Emission calculation basis		Modelled emission rate (g/s)		
				TSP	PM_{10}	$PM_{2.5}$
	Development stage - overburden dump to truck	1,621,277	tonnes	0.846	0.400	0.061
Crushing - tertiary	Primary Scalper number 1	450	tph	0.084	0.038	0.007
	Primary Scalper number 2	450	tph	0.084	0.038	0.007
Transfers	Transfers from scalper number 1	450	tph	0.059	0.028	0.004
	Transfers from scalper number 2	450	tph	0.059	0.028	0.004
FEL - raw material	Development Stage Product loading	708,797	tonnes	0.197	0.093	0.014
Truck dumping to primary crusher	Development stage - prod dump to crusher	708,797	tonnes	0.197	0.093	0.014
Crushing - tertiary	Primary crusher 1	350	tph	0.0656	0.0292	0.0054
	Secondary crusher 1	291	tph	0.0546	0.0243	0.0045
	Tertiary crusher 1	124	tph	0.0233	0.0103	0.0019
Screening	Screen 1	415	tph	0.3602	0.1239	0.0084
Transfers	Transfer to scalp stock 1	59	tph	0.0077	0.0036	0.0005
	Transfer to roadbase stock 1	290	tph	0.0377	0.0178	0.0027
Dozer	D1/D2 - dozer	12	hours	0.4993	0.0941	0.0085
Haulage - overburden	D1/D2 - overburden and product offiste - unselaed	53,376	km	3.755	1.060	0.106
Haulage - product, sealed	D1/D2 - overburden and product offiste - sealed	53,376	km	0.896	0.172	0.042
Haulage - raw material	D1/D2 - haul of fill	0	km	0.000	0.000	0.000
			Development Phase D1/D2 Total:	**8.442**	**2.827**	**0.378**
Development Phase D3/D4						
FEL - overburden	Development stage - cut by excavator	2,771,385	tonnes	1.446	0.684	0.104
	Development stage - fill dump to truck	24,890	tonnes	0.013	0.006	0.001
	Development stage - fill truck dump to placement area	24,890	tonnes	0.013	0.006	0.001
	Development stage - overburden dump to truck	1,572,113	tonnes	0.821	0.388	0.059
Crushing - tertiary	Primary Scalper number 1	450	tph	0.084	0.038	0.007
	Primary Scalper number 2	450	tph	0.084	0.038	0.007
Transfers	Transfers from scalper number 1	450	tph	0.059	0.028	0.004
	Transfers from scalper number 2	450	tph	0.059	0.028	0.004
FEL - raw material	Development Stage Product loading	1,174,383	tonnes	0.326	0.154	0.023
Truck dumping to primary crusher	Development stage - prod dump to crusher	1,174,383	tonnes	0.326	0.154	0.023
Crushing - tertiary	Primary crusher 1	350	tph	0.0656	0.0292	0.0054
	Secondary crusher 1	291	tph	0.0546	0.0243	0.0045
	Tertiray crusher 1	124	tph	0.0233	0.0103	0.0019
Screening	Screen 1	415	tph	0.3602	0.1239	0.0084
Transfers	Transfer to scalp stock 1	59	tph	0.0077	0.0036	0.0005
	Transfer to roadbase stock 1	290	tph	0.0377	0.0178	0.0027
Dozer	D3/D4 - dozer	12	hours	0.4993	0.0941	0.0085

Activity	Description	Emission calculation basis		Modelled emission rate (g/s)		
				TSP	PM_{10}	$PM_{2.5}$
Haulage - overburden	D3/D4 - overburden and product offiste - unsealed	85,118	km	5.989	1.690	0.169
Haulage - product, sealed	D3/D4 - overburden and product offiste - sealed	85,118	km	1.429	0.274	0.066
Haulage - raw material	D3/D4 - haul of fill	676	km	0.048	0.027	0.003
Development Phase D3/D4 Total:				**11.745**	**3.818**	**0.503**