Benchmark Toxicology Services
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Empowering Through Knowledge

Undertake a human health risk assessment for modelled particulate dust emissions from the proposed extraction of limestone quarry

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ABBREVIATIONS

AA	Accendo Australia Pty Ltd
AAQA	Air Quality Assessment (AA Report December 2020)
AAQG	Ambient Air Quality Guideline(s)
AAQS/C	Ambient Air Quality Standard(s)/Criteria
ACHAPS	Australian Child Health and Air Pollution Study
ACS	American Cancer society
MAED	Median aerodynamic equivalent diameter
BTS	Benchmark Toxicology Services Pty Ltd
CAAQS	Canadian Ambient Air Quality Standards
Cal EPA	California Environmental Protection Agency
CCME	Canadian Council of Ministers of the Environment
CEM	Conceptual Exposure Model
cf	*Confer* (Latin compare)
COPC	Chemicals of Potential Concern (Potential Toxicity Data Concern)
COPD	Chronic obstructive pulmonary disease
d	Day(s)
EA	Exposure Assessment
EI	Extractive Industry
enHealth	National Environmental Health Standing Committee
DEC	WA Department of Environment and Conservation
DoH	Department of Health WA
DRA	Dose Response Assessment
g	Gramme(s)
GPRS	Greater Bunbury Region Scheme
h	Hour(s)
ha	Hectare
II	Issue Identification
HA	Hazard Assessment
HA	Hazard Identification
HEPA	Filter - high-efficiency particulate air
HHRA	Human Health Risk Assessment
HHIA	Human Health Impact Assessment
HQ	Hazard Quotient
Kg	Kilogramme(s)
km	kilometre
L	Litre(s)

mg	Milligramme(s); one thousandth of a gram
NPO	Non-Profit Organisation
OEHHA	Office of Environmental Health and Hazard Assessment (California)
PM	Particulate Matter
PM_{10}	Particulate Matter of Median Aerodynamic Equivalent Diameter of 10 µm
$PM_{10-2.5}$	*Coarse* Particulate Matter (CPM)
$PM_{2.5}$	Particulate Matter of Median Aerodynamic Equivalent Diameter of 2.5 µm, Fine PM (FPM)
$PM_{0.1}$	Ultra-fine PM (UFMP)
POD	Point of Departure
RA	Risk Assessment
RC	Risk Characterisation
RM	Risk Management
RfC	Reference Concentration(s) (mg/m^3) US EPA
SES	Low socioeconomic status
SF	Safety Factor(s)
SCEW	Standing Council on Environment and Wate
TC	Tolerable Concentration (mg/m^3)
TRV	Toxicity Reference Value – Generic
TSP	Total Suspended Particulate(s) of Median Aerodynamic Diameter of 90 µm
GLC	Ground Level Concentration
US EPA	United States Environmental Protection Authority
WHO	World Health Organisation
µg	Microgrammme(s); one thousandth of a mg (10^{-3} mg); one millionth of a gram (10^{-6} g)
yr	Year(s)

Executive Summary

Benchmark Toxicology Services Pty Ltd (BTS) have been engaged by Accendo Australia (AA) Pty Ltd to undertake an independent Human Health Risk Assessment (HHRA) and toxicology report on ambient particulate matter (*particularly in relation to PM_{10}*), from the proposed limestone quarry on Lot 4 Binningup Road, Binningup, Western Australia ((Site).

Background

MGM Bulk Pty Ltd (the applicant) is proposing to extract limestone from a 26-hectare (ha) area located the Site. The proposed quarry operations will extract approximately 120,000 m^3 of limestone in seven stages.

The site is in the municipality of the Shire of Harvey, Western Australia, approximately 1 kilometre (km) south-east of Binningup and approximately 1 km west of the Forrest Highway. The site is positioned within 2 km of the coastline on land that has been previously cleared of native vegetation.

Particulate Matter

PM can be described by its "*median aerodynamic equivalent diameter*" (MAED). PM of the same MAED will tend to have the same settling velocity and thus most authors subdivide particles into MAED fractions based on how the particles are generated and where they deposit in human airways. These include:

- < 90 µm – Total suspended particulates (TSP)
- < 10 µm (referred to as PM_{10}) – Particulate matter
- < 10 and > 2.5 ($PM_{2.5–10}$) - *Coarse* particulate matter (CPM)
- < 2.5 µm ($PM_{2.5}$) - *Fine* particulate matter (FPM)
- < 0.1 µm ($PM_{0.1}$) - *Ultrafine* particulate matter (UFPM)

Particles with a diameter greater than 10 µm have a relatively small suspension half-life and are largely filtered out by the nose and upper airway. Therefore, TSP data is not used in health risk assessment. However, TSP contains also < PM_{10} concentrations and is associated with deposited dust which causes nuisance effects.

Objective

The scope of works provided by the client in the request for quote is as follows:

- Undertake a human health risk assessment for modelled particulate dust emissions from the proposed extraction of limestone
- Provide a toxicological assessment about Ambient Air Quality Criteria/Standards (AAQC/S); particularly PM_{10}.

Methodology

An HHRA is a systematic scientific assessment that estimates the likelihood of population level adverse health effects from air emissions and if so, discover the likely causative agents. The HHRA is intended to help address concerns for people who might be exposed to air emissions and answers questions such as:

- Is it possible that residents (of neighbouring suburbs), workers or visitors of the area might be exposed to particulate matter at levels higher than those determined to be accepted as safe (by the WA Air Quality Guidelines that are the same as the National Air Quality Guidelines)?
- What are the health effects if the levels of any chemical or particle are higher than regulatory standards?

The method adopted in this study for characterising possible health risks is to compare the predicted ground level concentrations (GLC) for individual emission components from the proposed quarry to an air guideline value established by a reputable regulatory agency for protection of public health. Predicted ground level concentrations of pollutants are outdoor air concentrations for different in this risk assessment the maximum GLC for each emission component is used and compared to regulatory guidelines for the protection of health.

Risk Characterisation

The metrics used to characterise human health risks in this assessment are summarised below in Table 0-2.

Analysis from each metric is ranked as one of five '*Levels of Concern*' (LoC), as described below in Plate 1. The LoC is not a health assessment for an individual, but a tool to help health professionals understand health risk at a population level. Plate 1 provides an overview of the LoC based on understanding of toxicological and health based regulatory categories of concern. Each metric was assessed by:

- Stage of project. Stage 2 and 7 involve quarry activities in different locations resulting in different emission estimates for sensitive receptors. The air quality assessment considered potential impacts associated with Stage 2 and Stage 7 operations of the quarry. These stages are expected to have the worst-case effect, as emissions sources are located closest to the receptors during these stages.
- Level of control. Two scenarios were modelled: without dust control and with dust control, and,
- Geographic location – the distance and geographical location has a bearing on the risk characterisation; thus a matrix is provided by geographical location. The sensitive receptors were grouped by geographical location into 4 zones.

Table 0-1 Metrics used to characterise human health risks

Pathway	Metric	What does this metric tell us?
Primary Pathway (Inhalation)	**Metric 1: Acute Risk**	**Are there any emission components and/or is the emission in total present at air concentrations that are potentially harmful to health over a short time duration?** This is assessed by direct comparison to the health action levels.
	Metric 2: Chronic Risk	**Are there any emission components and/or is the emission in total present in air that are potentially harmful to health over an extended duration?** This is assessed by direct comparison to the health action levels.

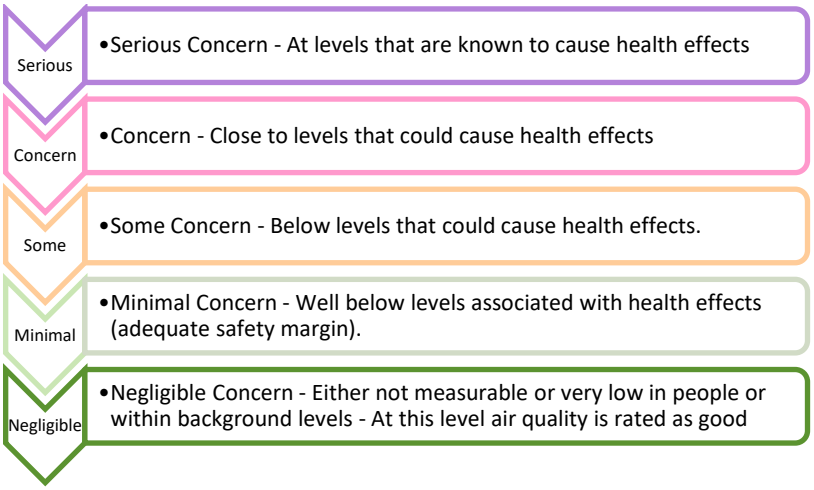


Plate 1 Level of Concern Rankings

Table 0-2 and **Table 0-3** provides a summary of the outcomes for both 24 h and annual average concentrations and with ranking for each metric for the LoC for adverse health effects to the general population and sensitive subpopulations for each exposure scenario assessed. In considering health risk both the toxicity of individual emission components and the emission has been considered together.

Table 0-2 Risk Characterisation Results Stage 2 with background by Level of Dust Control and Geographical Location

Metric	What does this metric tell us?	No dust control				With dust control			
		Area 1 R4, R2, R3, R5, R6, R7	Area 2 R9, R10, R8 North	Area 3 R11, R12, R13 South – Southeast	Area 4 R1 Adjacent to plant	Area 1 R4, R2, R3, R5, R6, R7	Area 2 R9, R10, R8 North	Area 3 R11, R12, R13 South – Southeast	Area 4 R1 Adjacent to plant
Metric 1: Acute Risk	**Are there any emission components and/or is the emission in total present at air concentrations that are potentially harmful to health over a short time duration?** This is assessed by comparing PM concentration estimates to the LoC category concentrations.	**Low concern**			**Some Concern**	**Low concern**			**Low concern**
Metric 2: Chronic Risk	**Are there any emission components and/or is the emission in total present in air that are potentially harmful to health over an extended duration?** Assessed as above	**Low concern**			**Low concern**	**Low concern**			**Low concern**

Table 0-3 Risk Characterisation Results Stage 7

Metric	What does this metric tell us?	No dust control				With dust control			
		Area 1 **R4, R2, R3, R5, R6, R7**	**Area 2** **R9, R10, R8** **North**	**Area 3** **R11, R12, R13** **South – Southeast**	**Area 4** **R1** **Adjacent to plant**	**Area 1** **R4, R2, R3, R5, R6, R7**	**Area 2** **R9, R10, R8** **North**	**Area 3** **R11, R12, R13** **South – Southeast**	**Area 4** **R1** **Adjacent to plant**
Metric 1: Acute Risk	**Are there any emission components and/or is the emission in total present at air concentrations that are potentially harmful to health over a short time duration?** This is assessed by comparing PM estimates with concentration described within the LoC Categories (very low to high).	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**
Metric 2: Chronic Risk	**Are there any emission components and/or is the emission in total present in air that are potentially harmful to health over an extended duration?** Assessed as above	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**	**Low concern**

$PM_{2.5}$ Annual Average

The incremental annual average $PM_{2.5}$ concentrations due to Binningup Quarry (Stage 2 or 7) is between 0.00 and 0.57 µg/m^3 across all receptors and all stages and with or without dust controls (i.e., 0% to 7% of the standard and less than 6.1% of BG: BG). On this basis the quarry contributes a negligible health risk due to the key metric for health (annual average $PM_{2.5}$). However, the BG annual average is 9.3 µg/m^3 (recorded in 2015). This average is greater than the NEPM AAQC of 8 µg/m^3 (16.3 µg/m^3). This is due to inclusion of prescribed burn and bushfire data (i.e., extraordinary short-term events) in the annual average dataset.

PM_{10} Short Term Risk at R1

PM_{10} – particles smaller than 10 µg MAED. These particles tend to be produced by mechanical processes such as wind erosion and can irritate the eyes, throat and lungs but are too large to enter the bloodstream. There is an increasing body of evidence suggesting there is an association between PM_{10} exposure and adverse health effect, including respiratory and cardiovascular diseases.

Without dust control, the Stage 2 PM_{10} concentrations (24 h; max 63.48 and 99th Percentile 53.49 µg/m^3) are greater than both the ambient standard (50 µg/m^3) and BC (20.9 µg/m^3).

With dust control the Stage 2 PM_{10} concentrations (24 h; max 45.05 µg/m^3 and 99th Percentile 39.67 µg/m^3) are elevated compared to BG (20.9 µg/m^3). At all other sensitive receptors, the 24 h PM_{10} concentration is < 0.5 of the PM_{10} standard (21.04-22.06 µg/m^3) and with 2 µg/m^3 of BG (20.9 µg/m^3).

The result for R1 (Rodgers' residence) reflects the close distance to the quarry. On approximately 37 d (i.e., 10% d/yr), the result would be greater than 0.5 of the PM_{10} standard. However, the model does not differentiate wind direction. The two highest emission sources for the project (with dust control) are wind erosion of exposed area and the active pit including stockpiles. Thus, one of the two source contributions are operational (wind erosion in active pit). The pit will be active for about 11 h/d for 5 d/wk. The air quality model estimated a wind speed threshold of 6 m/s for particulate matter lift off. Thus, there are operational controls during Stage 2 that can be implemented to reduce the number of days with exceedances of PM_{10} concentrations. For example, these include:

- On days with a predicted wind speed of greater 8 m/s (i.e., 28 km/h) do not operate in the active pit and increase dust suppression controls on stockpiles. On practically all occasions (Figure 5-2-page 17 ETA 2020 model) the wind direction when the wind speed was > 8 m/s was a westerly (from the west) thus the wind direction may also be an important consideration for this control measure.
- On days with a predicted wind speed of greater than 6 m/s (i.e., 19 km/h) increase dust suppression controls on stockpiles and consider whether active pit operations can be shortened from 11 h to 8 h.
- In addition to operational controls. it is important that the R1 residence can reduce ambient dust indoors. Mitigations to reduce exposure to PM at R1 are undertaken in the risk management, which is not included in the HHRA undertaken by BTS.

Section 1 Introduction

Ms Kirsten Muir-Thompson, Principal Consultant, Accendo Australia (AA) Pty Ltd (The client) contacted Dr Peter Di Marco, Principal Consultant of Benchmark Toxicology Services Pty Ltd (BTS), by email on 30 July 2021 for an expression of interest to undertake a "*human health risk assessment [HHRA] for dust emissions including a toxicologist report (particularly in relation to PM_{10})*", from the proposed limestone quarry on the Site.

BTS provided a draft Proposal to AA dated 17 August 2021, including BG (paragraph below), Scope of Works, proposed approach for assessment, estimated cost and conditions to be met, with a request of written authorisation from the Client for BTS to proceed on the Scope of Works.

1.1 Background

MGM Bulk Pty Ltd (the applicant) is proposing to extract limestone from a 26-hectare (ha) area located on the Site. The proposed quarry operations will extract approximately 120,000 m^3 of limestone in seven stages.

The site is in the municipality of the Shire of Harvey, Western Australia, approximately 1 km) southeast of Binningup and approximately 1 km west of the Forrest Highway. The Site is within 2 km of the coastline on land that has been previously cleared of native vegetation. It is zoned "*Rura*l" under the Greater Bunbury Region Scheme and "*General Farming*" pursuant to the Shire of Harvey Local Planning Scheme No. 1 (Accendo Australia, 2020a).

1.2 Material Provided

The Client provided:

- A report attached to an email dated by Ms Deanna Tuxford, Principal Air Quality Specialist/Director, Environmental Technologies & Analytics entitled "*Lot 4 Binningup Road, Binningup Ambient Air Quality Assessment*" dated Tue 15/12/2020, was included in the email to BTS by the client on 30 July 2021. This report provides the Ground Level Concentration (GLC) of the Ambient Air Quality (AAQ) assessment for the HHRA.
- A *Works and Excavation Plan* (dated November 2020) by AA regarding the Extractive Industry (EI) proposed to be undertaken on Lot 4 Binningup Road, Binningup.

On acceptance of the BTS Proposal, BTS requested a site visit to complement the information on the two documents provided. BTS also requested a written acceptance of, and the start of the scope of works.

1.3 Scope of Works

The scope of works provided by the client in the request for quote is as follows:

- Undertake a human health risk assessment for modelled particulate dust emissions from the proposed extraction of limestone
- Provide a toxicological assessment about Ambient Air Quality Criteria/Standards (AAQC/S); particularly PM_{10}

1.4 Methodology

The overall methodology employed in this risk assessment is consistent with that of the Department of Health in Western Australia (DoH, 2006 and 2010), the Australian enHealth Council (enHealth 2012) and the US Environmental Protection Agency (2009).

The following is an outline of the approach used in this HHRA:

- Issue identification involves a data review with the aim to identify key emission components of potential concern (in this case particulate matter PM) and describe the links between PM and receptors (who is exposed?)
- Toxicity assessment determines the relationship between the exposure concentration and the probability of adverse effects. Although direct health effects from air emissions are assessed quantitatively, there are aspects that are primarily of a screening nature since air emission health risk assessment deals with risks for people who are hypothetically exposed to the highest atmospheric emission concentrations that are reasonably expected to occur (within the modelled areas). This step identifies screening criteria and provides a brief overview toxicological information for PM.
- Exposure Assessment aims to determine the amount of a contaminant (dose) to which receptors may be exposed. This step involves the estimation of exposure which relies upon:
  - Assessment of what is in the emissions,
  - Assessment of PM at point of release to atmosphere, and
  - Dispersion modelling to predict the '*ground level concentration*' (GLC) of contaminant at locations where people may live or spend appreciable time.
- Risk characterisation provides an assessment of the risks posed by exposure to PM emissions and whether the risk is considered acceptable.

Section 2 Issue Identification

2.1 What is a Human Health Risk Assessment?

An HHRA is a systematic scientific assessment that estimates the likelihood of population level adverse health effects from air emissions and if so, discover the likely causative agents. The HHRA is intended to help address concerns of people who might be exposed to air emissions. For example:

- Is it possible that residents (neighbouring suburbs, villages, or isolated residences), workers or visitors of the area might be exposed to chemicals at levels higher than those determined to be of low concern? (Determined by categorisation by LoC).
- If the levels of any chemical are higher than regulatory standards, what are the health effects that might occur?
- Even if individual chemicals are below their specific standard, what is the risk from exposure to a mixture of chemicals?

2.2 Where are the exposure pathways complete?

Structured decision making is used to organise HI and decision analysis and has been used to address complex decision making in environmental management. Risk based frameworks are commonly used by regulators across various environmental disciplines (US EPA 2009). Risk management in governance and risk frameworks provide a structured and accepted practice for complex decision making, by accounting for uncertainty with qualitative and quantitative approaches. Environmental risk frameworks emerged from the 1970s onwards, beginning with the US EPA (US EPA 1998, 2009) with origins in regulatory risk-based decision making. risk frameworks follow a structured process (e.g., ISO31000:2018), however today many variations and customised approaches exist.

Undertaking an HHRA requires the consideration of three elements: source, pathway, and receptor. These three elements need to be overlapped for an exposure to be realised. Once realised, the next step is to assess exposure and characterise the risk posed to identified receptors.

Risk assessments provide a structured and familiar framework for regulators to examine scenarios with complex environmental interactions. A Conceptual Exposure Model (CEM) is commonly used to describe the pathways by which exposure to any contamination from source may occur. A CEM is typically developed as a preliminary screening tool and revised and improved as more information about issues becomes available and issues better understood. For exposure to occur, a complete pathway must exist between a source of contamination and a receptor. Where the exposure pathway is incomplete, there is no exposure and hence no risk via that pathway, i.e., risk is a function of hazard and exposure.

The CEM (Figure 1) below (summarises the exposure pathways and assessment endpoints used in this assessment.

– Issue Identification

Local resident of Binningup, about 1 km NW from the proposed quarry operations of extracting limestone are concerned about adverse health effects from fugitive dust. An additional resident, south of the proposed quarry about 100 m from the quarry (precise measure not stated by ETA; refer to Figure ES 1: Discrete sensitive receptor locations, page iii in ETA report) numbered Rogers' Residence: R1. The quarry is divided by seven cells undertaken as 7 operation stages, with Stages 1 and 2 closest to R1 (Rogers' residence) and stage 7 the closest distance to R2 south Binningup.

ETA has undertaken

- *a dispersion modelling study, which incorporated site-specific*
- *meteorological data, emissions information, source characteristics, and*
- *the location of model receptors indicative of neighbouring residents*.

Emission rates were estimated by using appropriate methods of emissions estimation, including published emission factors from the National Pollutant Inventory (NPI) standards. TSP, PM_{10} and $PM_{2.5}$ in air concentrations.

– Conceptual exposure model

A CEM describes the possible pathways by which exposure to potential contamination from a source may occur. As more information becomes available, the CEM can be revised, and the HI becomes better understood and communicated. For exposure to occur, a complete pathway must exist between the source of contamination and the "*receptor*" (i.e., the person or ecosystem components potentially affected by the contamination). Where the exposure pathway is incomplete, exposure cannot occur, leaving no risk present via that pathway (DEC, 2006). An exposure pathway will typically consist of the following elements (DEC, 2006):

- A source of air pollutants (i.e., natural and anthropogenic sources)
- A release mechanism and risk event (e.g., exceedance in ambient air PM concentration)
- Retention in the transport medium (e.g., ambient air)
- An exposure source/location, and
- An exposure route (e.g., inhalation, oral).

Figure 1 shows the CEM for PM in Binningup. This assessment focuses solely on the sensitive receptors in Binningup and the primary route of exposure of inhalation of particulate matter.

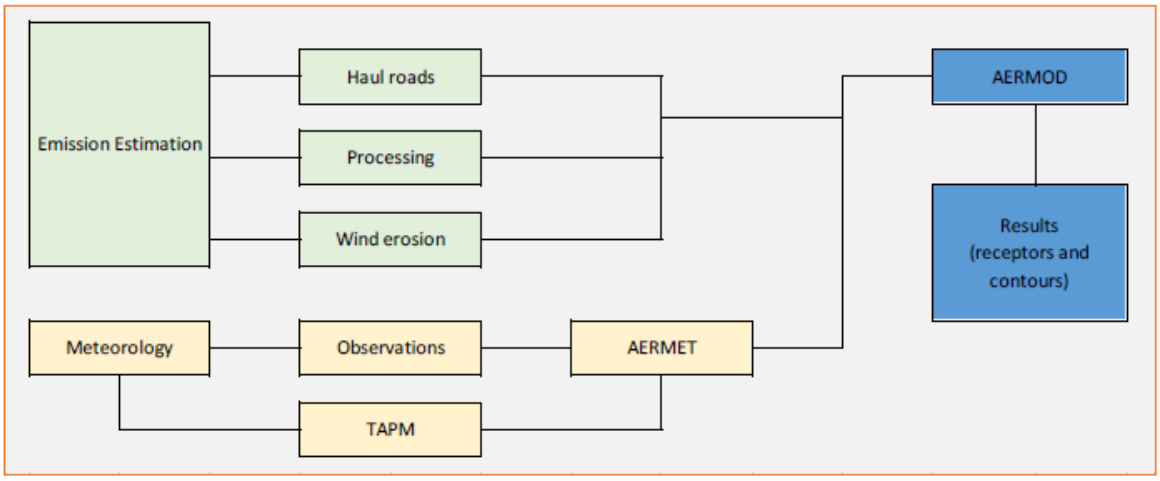


Figure 1 Conceptual Exposure Model (ET&A, 2020)

Section 3 Toxicity Assessment

The toxicity section is largely based on US EPA 2019 as it the latest systematic review and synthesis of the health effects (human, animal toxicity and other studies). The summary also relies on WHO (2013, 2021).

There is an increasing body of evidence (mainly population-based epidemiological studies) reporting an association between particle matter and adverse health effect (US EPA 2019). These studies suggested that daily changes in particulate matter (PM) level and exposure have been linked to:

- Morbidity outcomes such as:
  - Respiratory (small transient changes in the respiratory tract and impaired lung function, exacerbation of asthma); and
  - Cardiovascular outcomes, restricted activity/reduced performance, emergency department attendances and hospital admission, and
- Mortality (short-term and long-term).

Epidemiological and clinical studies reviewed by international and national agencies suggest that there are short-term and long-term impacts of changes in CPM in air. The respirable fraction of PM is considered responsible for health effects. TSP is not used to characterise health impact potential as it includes both respirable and non-respirable PM.

Historically respirable particulate matter was measured as:

- PM can be described by its MAED. PM of the same MAED will tend to have the same settling velocity and thus most authors subdivide particles into MAED fractions based on how the particles are generated and where they deposit in human airways. These include:
  - < 100 µm –TSP
  - < 10 µm (PM_{10}) PM
  - < 10 and > 2.5 ($PM_{2.5–10}$) CPM
  - < 2.5 µm ($PM_{2.5}$) FPM
  - < 0.1 µm ($PM_{0.1}$) UFPM

Particles with a MAED greater than 10 µm have a relatively small suspension half-life and are largely filtered out by the nose and upper airway. Therefore, TSP data is not used in health risk assessment.

Any discussion of PM_{10} and health effects is a discussion of coarse, fine, and ultrafine particles. All health authorities agree that the major burden associated with PM health effects is attributable to fine and ultrafine fractions. This is not to say that the coarse fraction does not contribute at all.

For this reason, the order within the hazard description and risk characterisation in this report first focusses on $PM_{2.5}$ and then PM_{10}.

In this section, the health effect descriptions associated with short-term and long-term exposure to PM are summarised from:

- NEPC – AAQ 2016
- US EPA – AAQ 2019
- WHO – Health effects of Particulate Matter 2013, a literature review update in 2016 and publications (2021)
- California Environmental Protection Agency (Cal EPA), Office of Environmental Health Hazard Assessment (OEHHA) – Staff Report on Ambient Air Quality, 2000

3.1 Health endpoints

Based on the reviewed studies focusing on PM-related health impacts including increase in mortality and morbidity outcomes, PM have been suggested to exert adverse health effects. The findings of epidemiological studies are supported by the results of toxicological studies.

The results of epidemiological studies have shown that a wide range of health effects are associated with exposure to PM. Australian studies (NEPC, 2016; EPHC 2006) have found associations between PM levels currently experienced in Australian cities and the following health outcomes consistent with regulators and NGO:

- Increases in daily mortality
- Hospital Admissions for:
  - Respiratory disease
  - Cardiovascular disease
  - Cardiac disease
  - Pneumonia and bronchitis
  - Emergency room attendances asthma

The body of literature for the adverse health effects from exposure to particulate matter have shown the strong relation with the respiratory and cardiovascular system effects for both long term and short-term exposure. Based on the current scientific literature, coarse particles, i.e., particles between $PM_{2.5}$ and PM_{10} have effects independent of the $PM_{2.5}$ fraction. Coarse ($PM_{2.5-10}$) and fine ($PM_{\leq 2.5}$) particles deposit at different locations in the respiratory tract, have different sources and composition, act through partly different biological mechanisms, and result in different health outcomes.

The latest review of the health impacts of PM has been published by US EPA (2019) and WHO (2021). The expert evaluation of each health endpoint (both morbidity and mortality endpoints) and the causal association with the endpoint for both $PM_{2.5}$ and PM_{10} are described in the figure below. The causality assessment is consistent with the conclusion that the clearest health impact is associated with fine particulate matter ($PM_{2.5}$) and the relationship between coarse ($PM_{10-2.5}$) is not as clear.

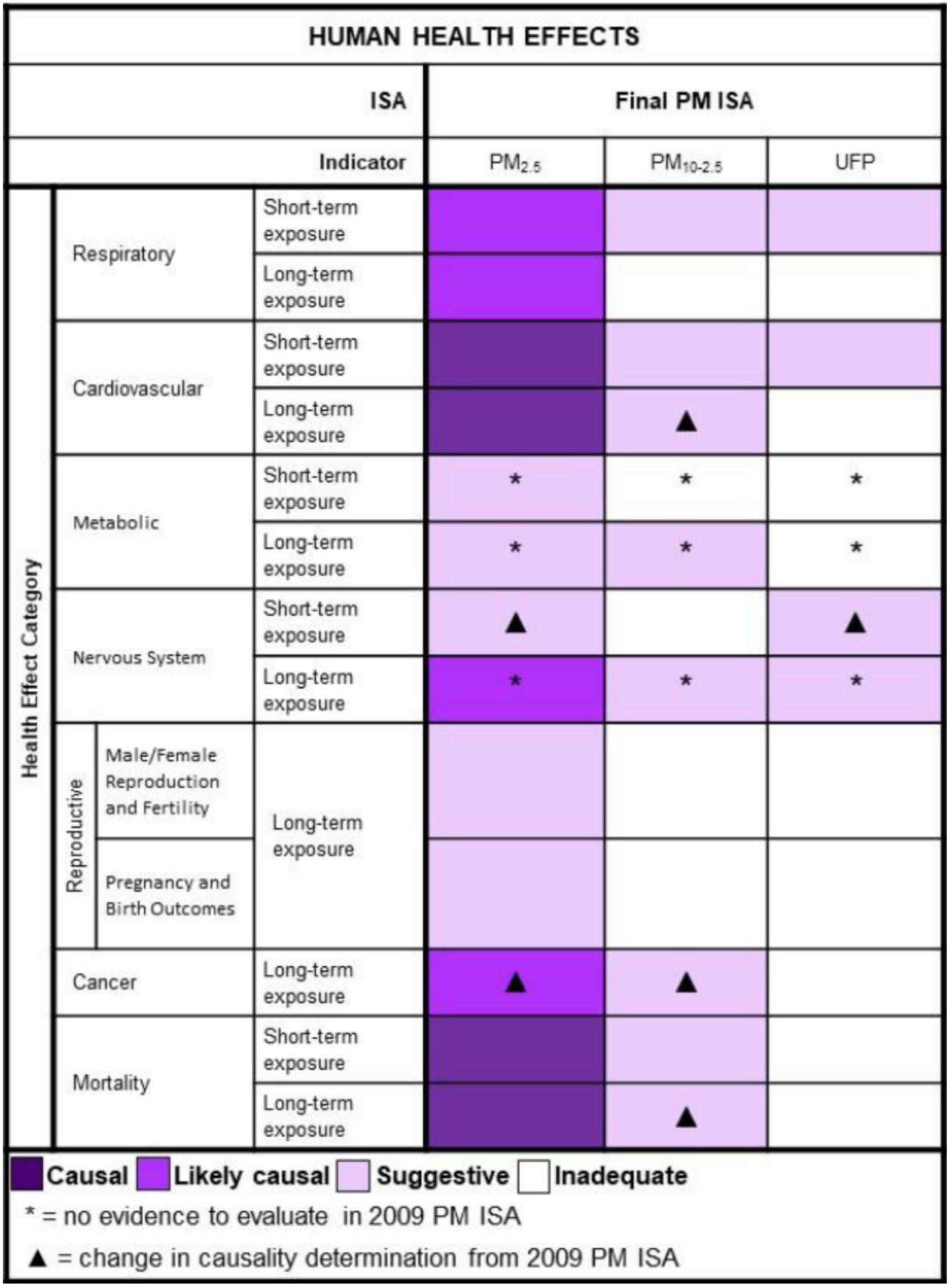


Figure 3-1 **Summary of causality determinations for health effect categories (US EPA ISA, 2019) (UFP = Ultra Fine Particle)**

$PM_{2.5}$ Health Effects

The toxicity section is largely based on US EPA (2019-2021) as it the latest systematic review and synthesis of the health effects (human, animal tox and other studies). The summary also relies on WHO (2013-2022).

There is a large database that supports a causal association between exposure to $PM_{2.5}$ and a range of both short-term and long-term mortality and morbidity outcomes.

Short Term Effects – Mortality

An evaluation of the epidemiological literature indicates consistent positive associations between short-term exposure to $PM_{2.5}$ and all-cause, cardiovascular- and respiratory-related mortality.

A study conducted in four Australian cities (Brisbane, Melbourne, Perth and Sydney), found statistically significant associations between particles and all-cause mortality. Meta-analyses carried out for three cities yielded estimates for the increase in the daily total number of deaths of 0.9% (-0.7% to 2.5%) for a 10 µg/m^3 increase in $PM_{2.5}$ concentration. A study conducted in Melbourne found statistically significant positive associations between the particle measures considered and all cause and respiratory mortality in the warmer seasons (November-March).

A study of ambient levels of air pollution in Melbourne and daily mortality due to all causes, respiratory and cardiovascular disease found that after controlling for the effects of weather and other confounding factors, air pollution in Melbourne is associated with increases in daily mortality. Associations were found between mortality and O_3, NO_2, CO and $PM_{2.5}$ with the strongest and most robust relationships being observed for ozone and nitrogen dioxide with smaller increases in mortality being noted with $PM_{2.5}$ (EPA Victoria, 2000).

Multicity studies examined the association between $PM_{2.5}$ and respiratory and/or cardiovascular mortality. Rodriguez et al. (2007) and Zanobetti and Schwartz (2009), found the consistent, positive associations between short-term exposure to $PM_{2.5}$ and respiratory mortality ranging from 1.67 to 2.20% at lag 0–1 d as well as cardiovascular mortality ranging from 0.47 to 0.85% for mean 24-h $PM_{2.5}$ average concentrations above 13 µg/m^3. Although examinations of potential confounders of the $PM_{2.5}$-cardiovascular mortality relationship are limited, the observed associations are supported by PM_{10}-mortality studies, which found that particle risk estimates remained robust to the inclusion of co-pollutants in models.

Although the overall effect estimates reported in the multicity studies are consistently positive, it should be noted that a large degree of variability exists between cities when examining city-specific effect estimates potentially due to differences between cities and regional differences in $PM_{2.5}$ composition.

Long Term Effects – Mortality

Long-term studies and analyses showed a consistent, statistically significant association between long-term exposure to $PM_{2.5}$ and the risk of mortality (WHO, 2013). Using the 51 cities from the ACS study Pope et al., (1995) reported that reductions in $PM_{2.5}$ across the metropolitan regions between 1980 and 2000 were strongly associated with increases in life expectancy after controlling for other risk factors.

The evidence for a biological mechanism, derived from both epidemiological and toxicological studies, has increased substantively in recent years, and indicates that exposure to $PM_{2.5}$ is associated with systemic inflammation, oxidative stress, and alteration of the electrical processes in the heart (Brooks et al., 2013). Epidemiological studies show variations in cardiovascular biomarkers such as C-reactive protein and fibrinogen. These biomarkers have been consistently linked to subsequent cardiovascular disease and death (WHO, 2013; 2021).

Short Term Effects – Morbidity

A large body of evidence supports the effect of $PM_{2.5}$ on hospital admissions and emergency department visits for respiratory and cardiovascular diseases. $PM_{2.5}$ is consistently correlated with effect estimate in the range of 0.5 to 3.4% for cardiovascular disease and ~1–4% for respiratory diseases per 10 µg/m^3 increase in $PM_{2.5}$.

Many of the studies that examined the association between $PM_{2.5}$ and respiratory symptoms and medication use found a consistent increase in asthmatic children (effect estimates ranging from ~1.0–1.3) with less consistent

evidence for an association in asthmatic adults in cities with mean 24-h average $PM_{2.5}$ concentrations ranging from 6.1 to 19.2 µg/m^3. An evaluation of epidemiological studies that examined specific physiologic alterations in the respiratory health of asthmatic children (i.e., pulmonary function and pulmonary inflammation) found a decrease in forced expiratory volume (FEV1) ranging from 1-3.4% per 10 µg/m^3 increase in $PM_{2.5}$.

Long Term effects – Morbidity

Recent studies have also shown the effects of long-term exposure to $PM_{2.5}$ on diseases other than cardiovascular and respiratory diseases (WHO, 2013). Evidence suggests effects on diabetes, neurological development in children and neurological disorders in adults (Ruckerl et al., 2011). Epidemiological studies in Germany (Herder et al., 2010) and Denmark (Anderson et al., 2012; Raaschou-Nielsen et al., 2013) have all found strong associations between exposure to $PM_{2.5}$ and diabetes. These findings have been supported by mechanistic studies (WHO, 2013, 2021).

Epidemiological and toxicological evidence is suggestive of a causal relationship between long-term exposures to $PM_{2.5}$ and reproductive and developmental outcomes (US EPA 2019). However, the epidemiological literature report of associations between long-term exposure to particles and preterm birth, growth restriction, birth defects or decreased sperm quality are not consistent (US EPA, 2019).

Long Term Effects – Cancer

A large European cohort study found that long-term exposure to $PM_{2.5}$ is linked to increases in cancer deaths (Cesaroni et al., 2013).

IARC (2013) conducted an evaluation of the literature on PM and cancer and concluded that there is *sufficient evidence in humans for the carcinogenicity of particulate matter in outdoor air pollution, Particulate matter in outdoor air pollution causes cancer of the lung.* The epidemiology studies predominantly used to make this conclusion include multicity studies in Europe and the USA. IARC's evaluation did not distinguish between coarse and fine particulate matter.

The IARC review suggests that in some instances (but not all, see page 390) CPM was found to be inflammogenic and that there is both temporal and spatial variability in the potency of PM (for example see page 389). IARC states that this is likely to be related to the endotoxin content in CMP (page 391, IARC, 2013).

Endotoxins are made up of organic matter predominantly linked to human activities but also geographical density of animal and natural plant matter. Sources of endotoxins in rural environments include animal confinements, grain storage facilities, and row crop harvesting. Lipids, proteins, and lipopolysaccharides and are capable of remaining airborne for long periods of time due to their small size. However, endotoxins are often attached onto PM, and consequently the majority of endotoxin is found in the coarse fraction as opposed to the fine fraction of particulate samples.

WHO (2018) conducted a literature review to update its understanding of particulate matter and health effects. WHO noted (page 11) that the relationship between air pollution and lung cancer may be related to motor vehicle emissions and in particular diesel exhaust. WHO concluded that "*These findings indicate that black smoke, which is closely-related in the modern urban setting with diesel engine exhaust, could serve as a useful marker in epidemiological studies, perhaps even retrospective analyses using the historic data available in many European urban areas".*

Thus, IARC and WHO observations regarding coarse particulate matter are important in considering the causality of PM and cancer.

US EPA (2019) concluded that there is sufficient evidence in humans for the carcinogenicity of $PM_{2.5}$ and that evidence for $PM_{10-2.5}$ is suggestive but not sufficient to infer a causal relationship. In our view there is no discrepancy between the IARC and US EPA conclusions. All authorities consider that the major contributor to health impact (including cancer) is PM with higher organic inputs (either due to traffic or other human related activities). This is not to suggest that coarse mineral particulate matter is innocuous, however, it does suggest that the link between PM and cancer is stronger for $PM_{2.5}$ and for PM in areas with accompanying air pollution issues.

3.2 PM_{10} Health Effects

Particles with a diameter < 10 µm are referred to as respirable PM. Any discussion of PM_{10} and health effects includes coarse, fine, and ultrafine particles.

Short Term Effects – Mortality

Time-series epidemiological studies of mortality and hospital admissions suggest an association between short-term exposure to PM_{10} and adverse health effects.

The epidemiological literature indicates consistent positive associations between short-term exposure to PM_{10} and all-cause mortality. The results of multicity studies report an approximate 0.12–0.81% increase in all-cause mortality per 10 µg/m^3 increase in PM_{10} with 24-h average PM_{10} concentrations ranging from 13 µg/m^3 to 53.2 µg/m^3. Moreover, consistent positive associations have also been found between PM_{10} and respiratory and cardiovascular-related mortality (Katsouyanni et al., 2003). Studies conducted in Australia have found similar results with a 0.2% (-0.8–1.2%) increase in all-cause mortality per 10 µg/m^3 increase in 24-h average PM_{10} (Simpson et al. 2005). It is noted that heterogeneity and seasonality in PM_{10} mortality risk estimates is observed between cities and studies, including Australian studies. A study conducted in Melbourne found statistically significant positive associations between PM_{10} and all cause and respiratory mortality in the warmer seasons (November-March). Statistically significant associations were also found in the 65+ age group in the warmer seasons (Simpson et al. 2000). In recent years, there has been a substantial increase in studies showing associations between particles and cardiovascular effects (US EPA, 2012; WHO, 2013), 2021. PM_{10} risk estimates per 10µg/m^3 of 0.76% (95% CI: 0.47–1.05) for cardiovascular deaths and 0.71% (95% CI: 0.22–1.20) for respiratory deaths were reported for 29 European cities for the average of 0- and 1-d lags (Analitis et al., 2006).

Long Term Effects – Mortality

There are some studies that have investigated the effects of long-term exposure to PM_{10}.

A positive association with coronary heart disease mortality was reported for PM_{10} among females (RR = 1.22 [95% CI: 1.01–1.47] per 10 µg/m^3 PM_{10}), but not for males (RR 0.94 [95% I:0.82–1.08] per 10 µg/m^3 PM_{10}); (Chen et al., 2005). The results of this study are suggestive that females may be more sensitive to air pollution-related effects, on differences between males and females in dosimetry and exposure (US EPA, 2009, 2016?). An ongoing prospective cohort study examining the relation of chronic PM_{10} exposures with all-cause mortality and incident and fatal coronary heart disease consisting of 66,250 female nurses in the north-eastern region of the US. The association with fatal coronary heart disease occurred with the greatest magnitude when compared with other specified causes of death (HR 1.42 [95% CI: 1.11–1.81]) (Puett et al., 2008). The North Rhine-Westphalia State Environment Agency (LUA NRW) initiated a cohort of approximately 4,800 women and assessed whether long-term exposure to air pollution originating from traffic and industrial sources was associated with total and cause-specific mortality (Gehring et al., 2006). They found that cardiopulmonary mortality was associated with PM_{10} (RR = 1.52 [95% CI: 1.09-2.15] per 10µg/m^3 PM_{10}).

Short Term Effects – Morbidity

The majority of recent evidence for an association between short-term exposure to PM_{10} and cardiovascular health effects is derived from epidemiological studies of hospital admissions and emergency department visits. A detailed examination of specific cardiovascular health outcomes has suggested that ischemic heart disease and chronic heart failure are responsible for particle-related cardiovascular disease hospital admissions, however, one large multicity study provides evidence of an association between PM_{10} and ischemic stroke (US EPA, 2019). Overall, the literature provides consistent evidence for associations between short-term exposure to PM_{10} and increased risk of cardiovascular hospital admissions and emergency department visits in cities with mean 24-h average concentrations ranging from 16.8 to 48 µg/m^3. The association between particles and hospital admissions for cardiovascular disease and ischemic heart disease appear to be greater in Europe and Australia/New Zealand than in the US (NEPC, 2010; US EPA, 2019; WHO, 2013; 2021).

Many of the studies that examined the association between PM_{10} and respiratory symptoms and medication use found an increased risk ranging from ~1.0 to 1.75 for cough, phlegm, difficulty breathing, and bronchodilator use in asthmatic children in cities with mean 24-h average concentrations ranging from 16.8 µg/m^3 to 64.5 µg/m^3. Positive, but less consistent effects for respiratory symptoms and medication use were observed in asthmatic adults. An evaluation of respiratory emergency department visits and hospital admission studies found consistent positive associations at ambient PM_{10} concentrations ranging from 13.3 to 60.8 µg/m^3, among asthmatic children (~ 2% increase) and older adults with chronic obstructive pulmonary disease (COPD)(~ 0 to 3% increase). It has been concluded that a causal relationship is likely to exist between short-term exposure to ambient concentrations of PM_{10} and respiratory morbidity (US EPA, 2019).

Long Term Effects – Morbidity

The evidence of particle effects in these studies of morbidity in relation to chronic exposures is not as consistent as for mortality. There is evidence of a particle-related effect on chronic morbidity, as measured by chronic respiratory symptoms and lung function. However, it is not possible, based on current evidence, to identify which size fractions or specific constituents are likely to be most influential (OEHHA, 2000).

Among the total cohort (ever or current asthma, bronchitis, cough or wheeze) assessed by questionnaire, neither PM_{10} nor $PM_{2.5}$ were associated with respiratory illness (Peters et al., 1999 cited in US EPA, 2019). In contrast, among children with asthma, respiratory symptoms increased with increasing particle levels (McConnell et al., 1999 cited in US EPA, 2019). Specifically, there was about a 40% increase in the odds of bronchitis among asthmatics per 19 µg/m^3 change in PM_{10} measured over 2-week intervals (OR=1.4, 95% C.I. = 1.1-1.8). Therefore, children may be at greater risk from long-term exposures to particles or other air pollutants because the growth and development of the respiratory system may be permanently affected by early environmental insults (US EPA, 2019, WHO 2013).

The Swiss study on Air Pollution and Lung Disease in Adults (SAPALDIA) showed that although an increase of 10 µg/m^3 PM_{10} might correspond to increase in respiratory risk among non-smokers, the roles of PM_{10} versus NO_2 in the observed associations could not be ascertained, as NO_2 concentrations were strongly correlated with PM_{10} levels.

The Australian Child Health and Air Pollution Study (ACHAPS, (SCEW, 2011)) used a similar study design as that used in the Southern Californian Children's Health Study (McConnell et al., 1999; Peters et al., 1999). The results of a cross-sectional study of approximately 4,000 Australian school children aged 7-11 years showed varied results for the particulate matter exposures used in ACHAPS. PM_{10} was associated with decline in FEV1 post-bronchodilator and increase in exhaled NO, but no overall increase in current symptoms.

3.3 Sensitive populations

Based on the available studies and health impacts associated with PM, specific groups of people in the general population are identified as being more vulnerable to the adverse effect of air pollution associated with PM. These sensitive populations include:

- The elderly
- People with existing cardiovascular and respiratory disease
- People with asthma
- Low socioeconomic groups
- Children

Compared to healthy adults, children are generally more sensitive to air pollutants as their exposure is generally higher. The reasons for this are that children inhale more air per minute and have a larger contact lung surface area relative to their size compared to adults. Other factors that increase the potential for exposure in children are that children generally spend more time outdoors and more time exercising.

People who have a low socioeconomic status (SES) also form a group within the population that is particularly vulnerable to the effects of air pollution (US EPA, 2012). This is largely because people within these groups usually have poorer health status than people within higher SES groups. They may also have poorer access to medical care. In addition, they usually live within areas that are more polluted (e.g., near major roads or near industry) as property is generally cheaper in these areas.

Moreover, comparison of the health risk factors between indigenous and non-indigenous Queenslanders suggests that death rate (due to coronary heart disease, chronic lower respiratory disease, and lung cancer) is significantly higher among Indigenous Queenslanders compared to non-indigenous Queenslanders. As such, Indigenous population can be considered as sensitive population. Based on 2016 Census data, indigenous population in Moranbah is comparable to Queensland (4%).

3.4 Limestone Health Effects

Limestone quarrying includes a range of practices that results in the emission of airborne dust. Most of the dust (TSP) will be representative of the local lithosphere. This is because most of the emission of dust is due to wheel generated dust, and wind erosion of exposed area. Limestone itself is unlikely to be a major emission factor and is expected to be only a small proportion 1-5% of emissions based on the estimates of particulate emissions from the crusher screen and loader. That is, it is unlikely that people will be exposed to limestone dust, rather, limestone dust is likely to be a minor component of the particulate matter from the limestone quarry.

No studies on the health effects of limestone quarry dust was found in the literature. As is the convention the dust from this quarry has been assessed in this HHRA as particulate matter (PM_{10} and $PM_{2.5}$).

One study did investigate the constituents of TSP matter from a limestone quarry in Israel. The authors concluded that the mineralogical analysis and major elements present showed significant contribution of the local lithosphere (in that region carbonate rock). An elemental analysis of the TSP did not identify any hazardous metals as enriched. The only two elements found to be enriched in the TSP were calcium (component of local regional carbonate rock) and phosphorus (thought to be a consequence of organic matter).

Limestone (Calcium carbonate, chalk, anti-ckaking agent, surface colourant, stabiliser in food grade plastics) in its pure form can cause skin, eye and respiratory irritation. Exposure to large amounts of limestone dust can cause coughing sneezing and nasal irritation. Chronic exposure to pure calcium carbonate does not cause pneumoconiosis, exposure to dust containing a high content (3-20%) quartz can lead to occupational silicosis risk. (UC CDC, 1995)

3.5 Conclusions on Health Effects

The body of literature for the adverse health effects from exposure to particulate matter have shown the strong relation with the respiratory and cardiovascular system effects for both long term and short-term exposure. Scientific literature has shown that coarse particles, that is particles between $PM_{2.5}$ and PM_{10} have effects independent of the $PM_{2.5}$ fraction. Coarse ($PM_{2.5-10}$) and fine ($\leq PM_{2.5}$) particles deposit at different locations in the respiratory tract, have different sources and composition, act through partly different biological mechanisms, and result in different health outcomes.

3.6 Health Based Guideline Levels

The Ambient Air Quality Assessment Report uses the National Environmental Protection Measure (NEPM) for Ambient Air Quality standards for particulate matter. The adopted criteria are summarised in Table 3-1.

Table 3-1 Adopted Human Health Assessment Criteria

Parameter	Criteria (Average)	Reference
PM_{10}	50 µg/m^3 (24-h)	Ambient Air NEPM
PM_{10}	25 µg/m^3 (annual)	Ambient Air NEPM
$PM_{2.5}$	25 µg/m^3 (24-h)	Ambient Air NEPM
$PM_{2.5}$	8 µg/m^3 (annual)	Ambient Air NEPM

3.6.1 Other Jurisdictions

Guidelines from other jurisdictions

Table 3-2 Comparison of Australian Criteria with WHO criteria

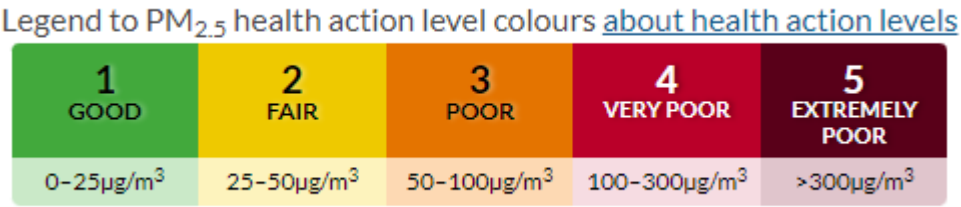
		Australia	NSW#	WHO (2005)	WHO (2021)***
Fraction	Exposure Time	Guidelines (µg/m^3)			
TSP	24 h	90*	90#		
PM_{10}	24 h	50	50	50	45
PM_{10}	Annual	25	30	20	15
$PM_{2.5}$	24 h	20		25	15
$PM_{2.5}$	Annual	8		10	5
DR		2 g/m²/m	2 g/m²/m		
#: Annual. Government of NSW (2019)					
*: EPA WA (1999).					
**: Deposition Rate (2 g/m2/month)					
***: WHO (22 Sep 2021) Objectives - Refer references					

3.7 Level of Concern (Dose Response)

3.7.1 $PM_{2.5}$ – Short Term Exposure (24 h Averages)

Health action levels are recommendations that have been developed by Queensland Health to support and inform the community on what actions to take to protect their health during a smoke event. The health action levels are based on hourly $PM_{2.5}$ measurements and provide separate advice on preventative actions for the public and for individuals who are potentially more sensitive.

A health action level is only provided for monitoring stations where $PM_{2.5}$ is measured. The health action levels categories described below are based on extrapolation from health advisories from Australian health authorities and consideration of background levels. It is noted that the categories described below are more conservative that those used for health guidance by regulatory authorities. For instance, the QLD government uses the following legend for $PM_{2.5}$ health action levels[1].



[1] https://apps.des.qld.gov.au/air-quality/health/ Colours may be slightly different

Table 3-3 Health action level categories and sensitive receptors

Level of Concern	Potential Impact	Sensitive receptors	Advice	$PM_{2.5}$ 24 h (µg/m³)
Negligible	Everyone can go about their normal activities.	– Older people over the age of 65 – Infants and children (e.g., students) – Pregnant women – People with respiratory and cardiovascular disease – People with type 2 diabetes – Indigenous community	Undertake normal activities	0-8.99
Minimal	Most people can go about their normal activities.	– Older people over the age of 65 – Infants and children (e.g., students) – Pregnant women – -People with respiratory and cardiovascular disease – People with type 2 diabetes – Indigenous community	Undertake normal activities. Sensitive groups should be aware for changing conditions	9-16.99
Some concern	The air is probably dusty and/or smoky. Sensitive groups may experience symptoms like coughing or shortness of breath.	– Older people over the age of 65 – Infants and children ((e.g., students) – Pregnant women – People with respiratory and cardiovascular disease – People with type 2 diabetes – Indigenous community	Sensitive groups should closely monitor the situation and take appropriate action if conditions worsen. If outdoor conditions have noticeably improved, open windows and doors to get fresh air into the home.	17-25
Concern	The air is probably very dusty and/or smoky. Everyone may experience symptoms like coughing or shortness of breath.	Everyone	Everyone should minimise prolonged or strenuous physical activities outdoors and close windows and doors. Sensitive groups should avoid being outside to minimise exposure, reduce prolonged or strenuous physical activity, close windows and doors and follow their treatment plans.	26-38
Serious Concern	The air is probably extremely dusty or smoky. Everyone may experience symptoms like coughing or shortness of breath.	Everyone	Everyone should stay indoors to minimise exposure and avoid prolonged and/or strenuous physical activity and close windows and doors. Sensitive groups should reduce physical activity, actively monitor their symptoms, and follow their treatment plans. If you feel that the air in your home is uncomfortable, consider going to an air-conditioned building like a library or shopping centre for a break if it is safe to do so.	>38

3.7.2 $PM_{2.5}$ Long Term (Chronic – Annual Average)

The long term NEPM guideline values for PM are based on epidemiological studies that use $PM_{2.5}$ as an indicator. These are largely based on avoiding PM related mortality however health effects (morbidity) endpoints have also been considered during the guideline development. These are used in the present assessment to characterise health risk.

Level of Concern	Concentration	Averaging time
Negligible	Below background and below 8 µg/m^3 Incremental contribution less than 1 µg/m^3	Annual
Minimal	**At background** Incremental + Background below 8 µg/m^3 Incremental contribution less than 1 µg/m^3	Annual
Some Concern	**Above background** Incremental contribution less than 2 µg/m^3	Annual
Concern	Incremental + Background above 10 µg/m^3 Incremental contribution above 2.5 µg/m^3	Annual
Serious Concern	Incremental + Background above 12 µg/m^3 Incremental contribution above 2.5 µg/m^3	Annual

Table 3-4 Level of Concern Categories PM_{10} (24 h)

Category	Concentration Range (µg/m^3)
Negligible concern	**0-16.99**
Minimal	**17-33**
Some Concern	**34-49.99**
Concern	**50-75**
Serious Concern	**>75**

3.7.3 PM_{10} Long Term (Chronic – Annual Average)

The long term NEPM guideline values for PM are based on epidemiological studies that use $PM_{2.5}$ as an indicator. These are largely based on avoiding PM related mortality however health effects (morbidity) endpoints have also been considered during the guideline development. These are used in the present assessment to characterise health risk.

Level of Concern	Concentration	Averaging time
Negligible	**At background and below** 25 µg/m^3 Incremental contribution less than 3 µg/m^3	Annual
Minimal	Incremental + Background below 25 µg/m^3 Incremental contribution less than 5 µg/m^3	Annual
Some Concern	**Above background** Incremental contribution less than 7 µg/m^3	Annual
Concern	Incremental + Background above 25-30 µg/m^3 Incremental contribution above 10 µg/m^3	Annual
Serious Concern	Incremental + Background above 30 µgbm^3 Incremental contribution above 10 µg/m^3	Annual

Section 4 Exposure Assessment

4.1 Population Description

Binningup is a coastal township 31 km north of Bunbury. In the 2016 Census Binningup (Code SSC50129) had a population of 1259 with a median age of 39. The proportion of male to female residents is slightly different to the State of Western Australia with 51.4 % male and 48.6% female (WA is 50% for each sex). The proposed quarry is in the municipality of the Shire of Harvey, approximately 1 km from the buffer southeast of Binningup and approximately 1 km West of the Forrest Highway

4.2 Sensitive Receptors

Sensitive receptors were selected by the AQA team. These were the residences identified as being closest to the site, or in the case of the Binningup, centrally located as to cover most of the town.

Table 4-1 and Figure 3-1 summarise the sensitive receptors.

Area 1 North west R4, R2, R3, R5, R6, R7	Area 2 North R9, R10, R8	Area 3 South – Southeast R11, R12, R13	Area 4 Adjacent to plant R1

Table 4-1 Sensitive Receptor descriptions and groupings

ID	Description
Area 1	**(Main town) to the north west of the quarry**
2	Nearest Binningup Residence
3	Binningup Country Club
4	Southerly Binningup Residence
5	Binningup Residential Area 1
6	Binningup Residential Area 2
7	Binningup Residential Area 3
Area 2	**Isolated rural residences North of the quarry**
8	Binningup Rd Residence 1
9	Binningup Rd Residence 2
10	Noble St Residence
Area 3	**Rural residences (far apart) south and southeast of quarry**
11	Old Coast Rd Residence 1
12	Old Coast Rd Residence 2
13	Springhill Rd Residence
Area 4	**Single residence known as Rodgers's residence in very close proximity to the quarry and in particular closest to Stage 2 of the operational plan.**
1	Rodgers's Residence

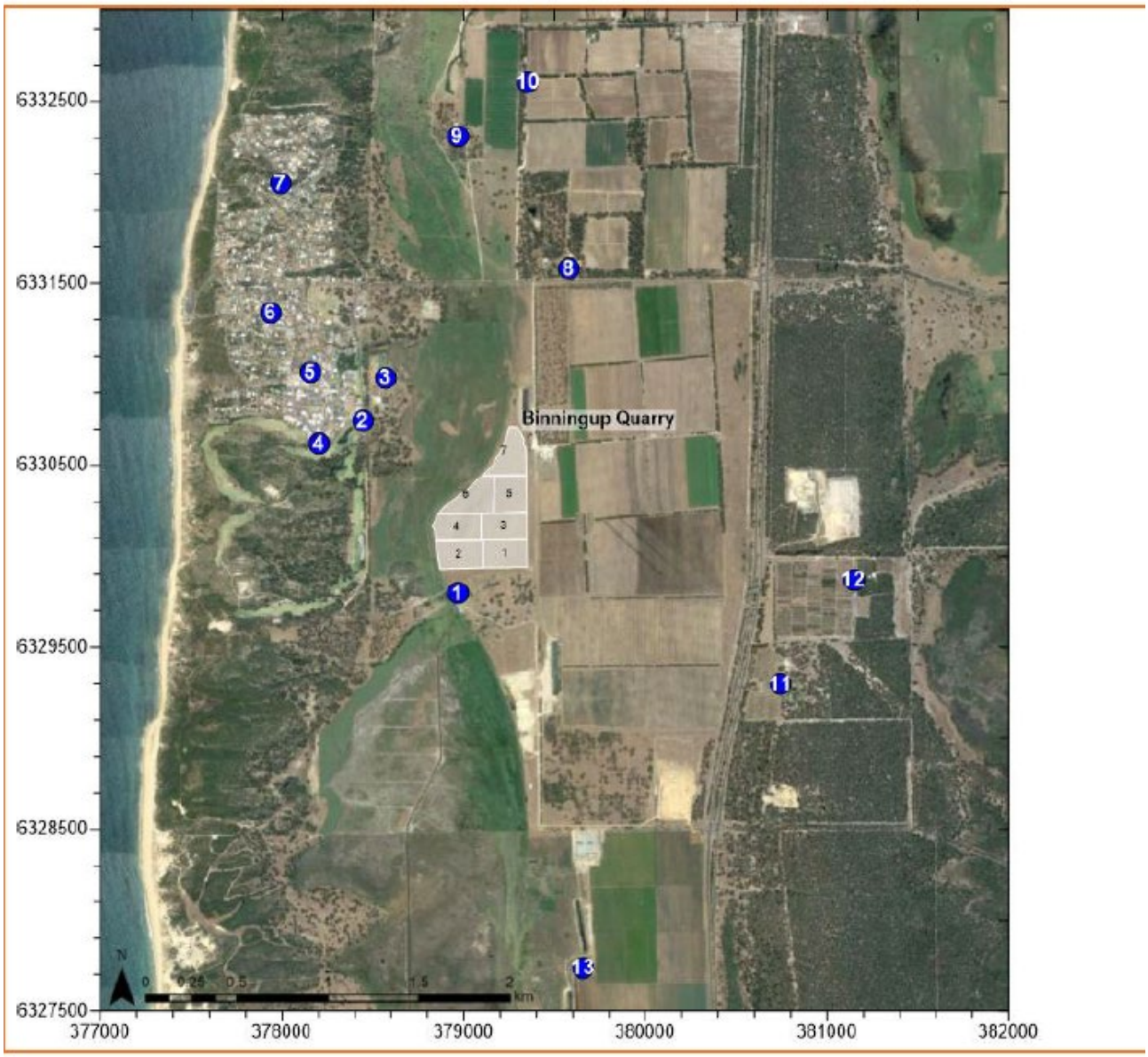


Figure 2 Sensitive Receptor Map (AT&A 2020)

4.3 Exposure Estimates

Estimated particulate matter ground level concentrations were provided within an air quality assessment report (AE&T 2020). The AQ assessment conducted a dispersion modelling study. Emission rates for the proposed quarry were based on recognised and accepted methods and published emission factors.

A site-specific meteorological dataset was generated using the AERMET meteorological processor, which used a combination of observations at the Bureau of Meteorology (BoM) automated weather station (AWS) at Bunbury (Station ID 009965) and meteorological data produced by the prognostic model TAPM. These were then used to drive the AERMOD dispersion model to predict ground-level concentrations of pollutants at identified sensitive receptors and the surrounding environment. BG AAQ monitoring data is not available for the immediate area so data from the Bunbury air monitoring station was used.

The maximum predicted modelling results for PM_{10}, and $PM_{2.5}$ with the inclusion of assumed existing BGC were used within the HHRA. Two scenarios are presented for the quarry operating with and without the proposed dust

management controls. The HHRA uses the following GLC; maximum, 99th, 95th, and 90th percentile GLC. The assessment focussed on two operational stages – Stage 2 and Stage 7.

- Stage 2 – when quarry activities are occurring across Stage 1 and Stage 2 cells are furthest from the community of Binningup, but closest to the Rodgers residence.
- Stage 7 – when quarry activities are occurring across Stage 6 and Stage 7 cells and are closest to the community of Binningup

The predicted modelling results for PM_{10}, and $PM_{2.5}$ with the inclusion of assumed existing BG concentrations are presented within Section 5, Tables 5-1 to 5-4.

Section 5 Risk Characterisation

Table 5-1 summarises the health endpoints assessed. Analysis from each metric is ranked as one of five 'LoC', as described below in Plate 1. The LoC is not a health assessment for an individual but a tool to help health professionals understand health risk at a population level. Plate 1 provides an overview of the levels of concern based on understanding of toxicological and health based regulatory categories of concern. Each metric was assessed by:

- Stage of project. Stage 2 and 7 involve quarry activities in different locations resulting in different emission estimates for sensitive receptors. The air quality assessment considered potential impacts associated with Stage 2 and Stage 7 operations of the quarry. These stages are expected to have the worst-case impacts, as emissions sources are located closest to the receptors during these stages.
- Level of control. Two scenarios were modelled: without dust control and with dust control, and,
- Geographic location – the distance and geographical location has a bearing on the risk characterisation; thus, a matrix is provided by geographical location. The sensitive receptors were grouped by geographical location into 4 zones.

Table 5-1 Metrics used to characterise human health risks

Pathway	Metric	What does this metric tell us?
Primary Pathway (Inhalation)	**Metric 1: Acute Risk**	**Are there any emission components and/or is the emission in total present at air concentrations that are potentially harmful to health over a short time duration?** This is assessed by direct comparison to the health action levels .
	Metric 2: Chronic Risk	**Are there any emission components and/or is the emission in total present in air that are potentially harmful to health over an extended duration?** This is assessed by direct comparison to the health action levels.

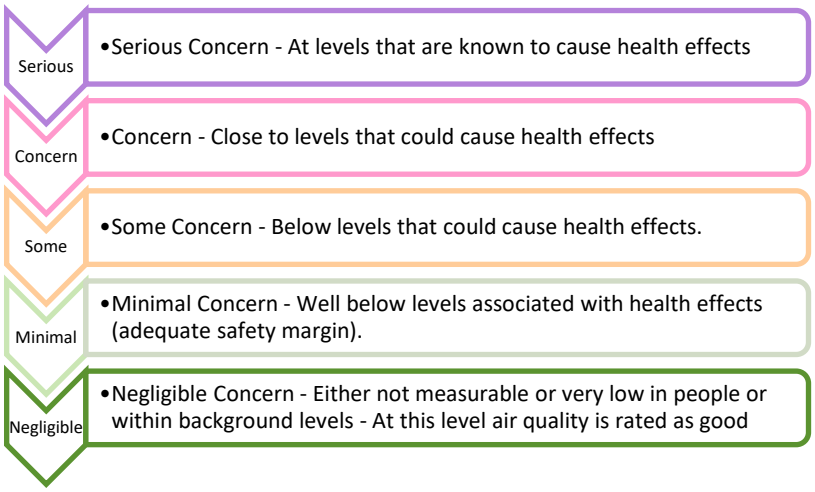


Plate 2 Level of Concern Rankings

The $PM_{2.5}$ and PM_{10} short term and long-term LoC categorisations are provided in Section 3.7.

5.1 Stage 2

The incremental annual average $PM_{2.5}$ concentrations due to Binningup Quarry (Stage 2 or 7) is between 0.00 and 0.57 µg/m³ across all receptors and all stages and with or without dust controls (i.e.,0% to 7% of the standard and less than 6.1% of BG). On this basis the quarry contributes a negligible health risk due to the key metric for health (annual average $PM_{2.5}$). However, the annual BG average is 9.3 µg/m³ (recorded in 2015) which is greater than the NEPM value of AAQ of 8 µg/m³. This is due to inclusion of prescribed burn and bushfire data (i.e., extraordinary short term events) in the annual average dataset.

Table 5-2 Stage 2 Modelled $PM_{2.5}$ concentration (µg/m³ including background[a]) at each Receptor

Receptor	Without dust control					With dust control				
	Max	Percentile				Max	Percentile			
		99th	95th	90th	Ann Av		99th	95th	90th	Ann Av
R1	17.81	15.88	11.88	11.28	9.87	14.41	13.39	11.08	10.66	9.61
R2	10.42	10.20	9.99	9.97	9.33	10.19	10.08	9.96	9.95	9.32
R3	10.30	10.00	9.96	9.95	9.32	10.12	9.96	9.94	9.93	9.31
R4	10.33	10.14	9.99	9.96	9.32	10.14	10.04	9.96	9.94	9.32
R5	10.19	10.08	9.95	9.93	9.31	10.06	10.01	9.93	9.92	9.31
R6	10.07	10.01	9.93	9.92	9.31	9.99	9.96	9.92	9.91	9.31
R7	10.01	9.93	9.91	9.91	9.30	9.96	9.92	9.91	9.91	9.30
R8	10.06	9.98	9.95	9.93	9.31	9.98	9.95	9.93	9.92	9.31
R9	9.99	9.96	9.92	9.92	9.31	9.96	9.94	9.92	9.91	9.30
R10	10.01	9.98	9.93	9.91	9.31	9.96	9.95	9.92	9.91	9.30
R11	10.50	10.26	9.97	9.92	9.32	10.22	10.09	9.94	9.91	9.31
R12	10.90	10.33	9.94	9.92	9.32	10.43	10.13	9.92	9.91	9.31
R13	10.12	10.09	9.92	9.91	9.31	10.02	10.00	9.91	9.91	9.30

Note a: BG concentration of 9.9 µg/m³ (24 h) and 9.3 µg/m³ (Annual Average) for Binningup Quarry operations (ET&A 2020).

Without dust control the Stage 2 24 h PM_{10} concentrations (max 63.48 and 99th Percentile 53.49 µg/m³) are greater than both the ambient standard (50 µg/m³) and BG concentration (20.9 µg/m³).

With dust control the Stage 2 24 h PM_{10} concentrations (max 45.05 µg/m³ and 99th Percentile 39.67 µg/m³) are elevated against BG (20.9 µg/m³). At all other sensitive receptors. the 24 h PM_{10} concentration is less than 50% of the standard (21.04-22.06 µg/m³) and with 2 µg/m³ of BG (20.9 µg/m³).

Table 5-3 Stage 2 Modelled PM_{10} concentration (µg/m³ including background[a]) at each Receptor

Receptor	Without dust control					With dust control				
	Max	Percentile				Max	Percentile			
		99th	95th	90th	Ann Av		99th	95th	90th	Ann Av
R1	**63.48**	**53.49**	33.57	29.23	20.92	45.05	39.67	27.51	25.54	19.32
R2	23.70	22.54	21.42	21.26	17.66	22.45	21.86	21.29	21.17	17.61
R3	22.98	21.46	21.25	21.17	17.60	22.02	21.28	21.17	21.10	17.57
R4	23.22	22.23	21.40	21.24	17.65	22.23	21.67	21.30	21.15	17.60
R5	22.48	21.88	21.19	21.09	17.58	21.77	21.47	21.11	21.04	17.56
R6	21.81	21.49	21.07	21.02	17.55	21.40	21.24	21.03	20.98	17.53
R7	21.45	21.07	20.98	20.96	17.52	21.20	21.04	20.96	20.94	17.52
R8	21.85	21.41	21.18	21.06	17.56	21.39	21.22	21.09	21.01	17.54
R9	21.43	21.28	21.05	20.99	17.53	21.27	21.14	21.01	20.96	17.52
R10	21.55	21.39	21.08	20.98	17.54	21.26	21.19	21.03	20.95	17.52
R11	24.05	22.72	21.27	21.01	17.59	22.56	21.86	21.12	20.98	17.55
R12	26.14	23.10	21.14	21.01	17.59	23.67	22.06	21.04	20.98	17.55
R13	22.04	21.94	21.02	20.97	17.54	21.51	21.45	20.99	20.95	17.52

Note a: Background concentration of 20.9 µg/m³ (24 h) and 17.5 µg/m³ (Annual Average) for Binningup Quarry operations (ET&A 2020).

5.2 Stage 7

The incremental annual average $PM_{2.5}$ concentrations due to Binningup Quarry (Stage 2 or 7) is between 0.00 and 0.57 µg/m³ across all receptors and all stages and with or without dust controls (i.e., 0% to 7% of the standard and less than 6.1% of BG. On this basis the quarry contributes a negligible health risk due to the key metric for health (annual average $PM_{2.5}$). However, the BG annual average is 9.3 µg/m³ (recorded in 2015) which is greater than the NEPM value of AAQ of 8 µg/m³. This is due to inclusion of prescribed burn and bushfire data (i.e., extraordinary short-term events) in the annual average dataset.

Table 5-4 Stage 7 Modelled $PM_{2.5}$ concentration (µg/m³ including background[a]) at each Receptor

Receptor	Without dust control					With dust control				
	Max	Percentile				Max	Percentile			
		99th	95th	90th	Ann Av		99th	95th	90th	Ann Av
R1	12.22	11.57	10.99	10.66	9.59	10.93	10.58	10.24	10.12	9.39
R2	10.72	10.39	10.09	10.02	9.35	10.33	10.17	10.01	9.97	9.33
R3	10.63	10.37	10.06	10.00	9.35	10.28	10.17	10.00	9.97	9.33
R4	10.64	10.37	10.01	9.98	9.33	10.32	10.14	9.96	9.95	9.32
R5	10.29	10.17	9.99	9.96	9.32	10.12	10.04	9.95	9.93	9.31
R6	10.14	10.03	9.95	9.93	9.31	10.02	9.98	9.93	9.92	9.31
R7	10.06	9.98	9.93	9.92	9.31	9.99	9.95	9.92	9.91	9.30
R8	10.21	10.06	10.02	9.96	9.32	10.07	10.02	9.97	9.94	9.32
R9	10.01	9.97	9.94	9.93	9.31	9.96	9.94	9.92	9.92	9.31
R10	10.08	10.04	9.95	9.92	9.31	10.00	9.98	9.93	9.92	9.31
R11	10.45	10.31	9.97	9.92	9.32	10.18	10.12	9.94	9.91	9.31
R12	10.63	10.36	9.95	9.92	9.32	10.28	10.14	9.93	9.91	9.31
R13	10.09	10.06	9.92	9.91	9.31	10.00	9.98	9.91	9.91	9.30

Note a: Background concentration of 9.9 µg/m³ (24 h) and 9.3 µg/m³ (Annual Average) for Binningup Quarry operations (ET&A 2020).

Without dust control the Stage 7 24 h PM_{10} concentrations (max 34.21) is greater than BG concentration (20.9 µg/m³) and categorised as Some Concern. All other scenarios with or without dust controls are Low Concern (i.e., less than 0.5 of the standard (21.04-22.06 µg/m³) and with 2 µg/m³ of BG (20.9 µg/m³)).

Table 5-5 Stage 7 Modelled PM10 concentration (µg/m³ -including background[a]) at each Receptor

Receptor	Without dust control					With dust control				
	Max	Percentile				Max	Percentile			
		99th	95th	90th	Ann Av		99th	95th	90th	Ann Av
R1	34.21	31.29	27.84	25.82	19.34	26.73	24.72	23.1	22.31	18.06
R2	25.69	23.73	21.94	21.58	17.8	23.41	22.56	21.5	21.32	17.68
R3	24.87	23.54	21.81	21.51	17.78	22.97	22.36	21.51	21.31	17.68
R4	25.27	23.76	21.52	21.35	17.7	23.38	22.41	21.28	21.17	17.62
R5	23.14	22.42	21.41	21.22	17.64	22.17	21.7	21.2	21.1	17.59
R6	22.2	21.66	21.18	21.08	17.58	21.57	21.39	21.09	21.02	17.55
R7	21.75	21.34	21.06	21.01	17.54	21.35	21.16	21	20.97	17.53
R8	22.74	21.91	21.61	21.28	17.65	21.89	21.68	21.35	21.14	17.6
R9	21.58	21.34	21.13	21.05	17.56	21.27	21.15	21.05	21	17.54
R10	22.04	21.77	21.22	21.04	17.56	21.53	21.42	21.09	21	17.54
R11	23.72	23.04	21.28	21.05	17.59	22.36	22.04	21.12	20.99	17.55
R12	24.68	23.26	21.16	21.03	17.59	22.87	22.12	21.04	20.98	17.55
R13	21.92	21.73	21.02	20.97	17.53	21.44	21.33	20.97	20.94	17.52

Note a: Background concentration of 20.9 µg/m³ (24 h) and 17.5 µg/m³ (Annual Average) for Binningup Quarry operations (ET&A 2020).

5.3 Comparison to other regions

De Jesus et al (2020) described the PM concentrations in Australia cities using the entire dataset available for each population monitoring station. The dates and number of samples for each station varies, the minimum number of years is 3 and maximum 12 yr. Across the 23 monitoring stations in Australian capital cities the PM concentrations were relatively low. The daily concentrations are within the country's daily standards at least 95% of the time. Mean concentrations are within the annual standards. This is also the case for the local airshed for the Binningup Quarry. The mean daily values are well within the BG concentrations for Bunbury.

5.4 Risk Characterisation Conclusions

The overall conclusion is that the proposed quarry has a low and acceptable health impact to practically all receptors.

The result for R1 (Rodgers's residence) reflects the close distance to the quarry. On approximately 37 d (i.e., 10% d/yr) the result would be greater than 0.5 of the standard. However, the model does not differentiate wind direction. The two highest emission sources for the project (with dust control) are wind erosion of exposed area and the active pit including stockpiles. Thus, one of the two source contributions are operational (wind erosion in active pit). The pit will be active for about 11 h/d for 5 d/wk. The air quality model estimated a wind speed threshold of 6 m/s for particulate matter lift off. Thus, there are operational controls during Stage 2 that can be implemented to reduce the number of days with exceedances of PM_{10} concentrations. For example, these include:

- On days with a predicted wind speed of greater 8 m/s (i.e., 28 km/h) do not operate in the active pit and increase dust suppression controls on stockpiles. On practically all occasions (Figure 5-2-page 17 ETA, 2020) the wind direction when the wind speed was > 8 m/s was a westerly (from the west) thus the wind direction may also be an important consideration for this control measure.
- On days with a predicted wind speed of greater than 6 m/s (i.e., 19 km/h) increase dust suppression controls on stockpiles and consider whether active pit operations can be shortened from 11 h to 8 h.
- In addition, to operational controls it is important that the R1 residence can reduce ambient dust indoors. Mitigations to reduce exposure to PM is at R1 are undertaken in the risk management, which is not included in the HHRA undertaken by BTS.

Section 6 Confidence, Conservatism and Uncertainty

Variability and uncertainty will exist in any assessment. When variability is not characterized, and uncertainty is high there is less confidence in the exposure and risk estimates; characterizing variability and reducing uncertainty increases the confidence in the estimates and increase transparency and understanding of the assessment. By definition:

- **Variability** refers to the inherent heterogeneity or diversity of data in an assessment and provides a quantitative description of the range or spread of a set of values, often expressed through statistical metrics. While variability cannot be reduced, but it can be better characterized.
- **Uncertainty** refers to a lack of data or an incomplete understanding of the context of the risk assessment decision, and can be either qualitative or quantitative

Not all exposure evaluations are of the same complexity, and thus the level of complexity in evaluating uncertainty and variability can vary from one assessment to another. A tiered approach, starting with a simple assessment, is sometimes used to determine whether additional evaluation is required to further address uncertainty and variability.

This study includes assumptions and data analysis decisions where there are gaps in available information. With these assumption and decisions there come uncertainties and limitations in the conclusions. Table 7-11 summarises the potential sources of variability and uncertainty identified in this study.

Table 6-1 Potential sources of uncertainty and variability in this assessment

Potential source	Comment
Uncertainty in Hazard Assessment	The following needs to be considered when selecting and LoC categories for PM: - The applicability of the dose response functions derived from studies conducted elsewhere to conditions in Australia given our unique geology and climate compared with areas where the epidemiological studies were undertaken. - Source of air pollutants in epidemiological studies are another determinant. Location of the epidemiology studies determines the source and composition of air pollutants. Epidemiological studies were primarily based in urban centres with significantly more traffic, combustion, and industrial sources, compared to crustal and mining conditions. - The effects of multiple exposure on the dose response (e.g., the combined effects of PM_{10} and ozone).
Uncertainty in Exposure Assessment	- Location of sensitive receptors was chosen by the Air Quality Assessment team. - Number of individuals, groups or communities who may be at risk of exposure - Estimates of exposure for the individuals, groups or communities who may be at risk of exposure - Difficulties in estimating variability dispersion modelling estimates
selection of BG level of exposure to $PM_{2.5}$	Background concentrations for PM used in the Air Quality assessment are based on a State Government air quality station in Bunbury. It is assumed that this data is relevant to Binningup given its geographical proximity to Bunbury: - BG levels at Bunbury are influenced by prescribed burns and bushfires (i.e., smoke) and sea spray. Different sources of ambient particulate matter influence health outcomes in different ways. It is likely that the non-smoke PM BG for Binningup is overestimated. - Daily and seasonally variations are not considered with this estimation method.
Dust deposition monitoring and speciation were not assessed in this report	Dust deposition modelling is well within the regulatory guide for all receptors other than R1. Risk mitigation suggestions have been provided for this location. .

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[2] This interactive tool provides a snapshot – in the form of a map – of current national air quality standards for classical pollutants (particulate matter, nitrogen dioxide, ozone, carbon monoxide and sulphur dioxide) for various averaging times, The data was compiled by the Swiss Tropical and Public Health Institute and shall be updated regularly.

Appendix A Disclaimer

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