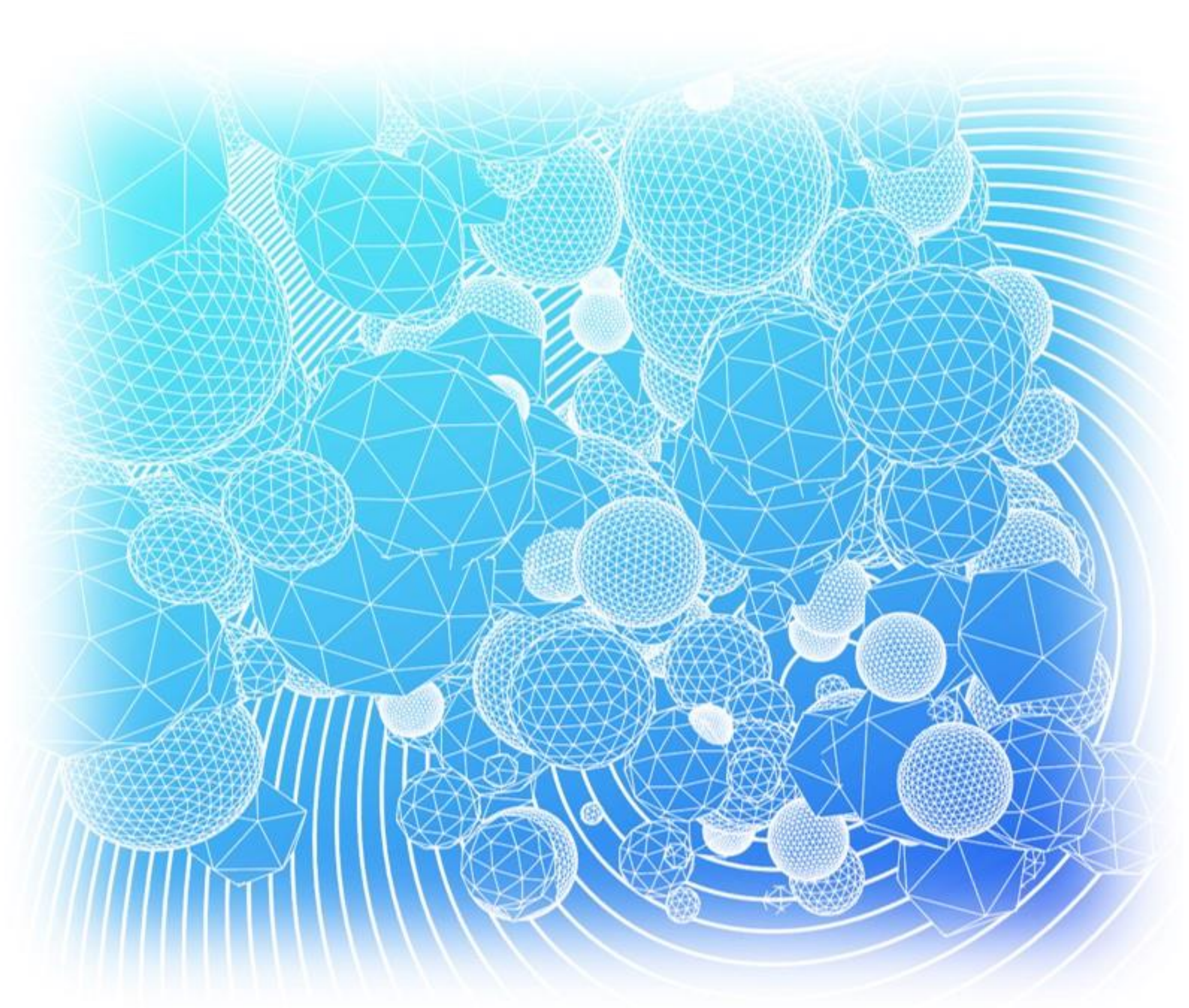


# Human Health Risk Assessment for Respirable Crystalline Silica: Expansion of Dowe's Quarry

*Prepared for: R. W. Corkery & Co. PTY Limited*

4 March 2020

## Document History and Status

| | |
|---|---|
| **Report Reference** | RWC/20/DOWR001 |
| **Revision** | B – Final |
| **Date** | 4 March 2020 |
| **Previous Revisions** | A – Draft issued on 3 March 2020 |

## Limitations

Environmental Risk Sciences Pty Ltd has prepared this report for the use of R. W. Corkery & Co. Pty Limited (RWC) in accordance with the usual care and thoroughness of the consulting profession. It is based on generally accepted practices and standards at the time it was prepared. No other warranty, expressed or implied, is made as to the professional advice included in this report.

It is prepared in accordance with the scope of work and for the purpose outlined in the **Section 1** of this report.

The methodology adopted, and sources of information used are outlined in this report. Environmental Risk Sciences Pty Ltd has made no independent verification of this information beyond the agreed scope of works and assumes no responsibility for any inaccuracies or omissions. No indications were found that information contained in the reports provided for use in this assessment was false.

This report was prepared from December 2019 to March 2020 and is based on the information provided and reviewed at that time. Environmental Risk Sciences Pty Ltd disclaims responsibility for any changes that may have occurred after this time.

This report should be read in full. No responsibility is accepted for use of any part of this report in any other context or for any other purpose or by third parties. This report does not purport to give legal advice. Legal advice can only be given by qualified legal practitioners.

# Table of Contents

# Glossary of Terms

| | |
|---|---|
| ADI | Acceptable Daily Intake |
| ACGIH | American Conference of Governmental Industrial Hygienists. |
| AIOH | Australian Institute of Occupational Hygienists Inc |
| ANZECC | Australia and New Zealand Environment and Conservation Council |
| AQIA | Air Quality Impact Assessment |
| ATSDR | US Agency for Toxic Substances and Disease Registry |
| COPD | Chronic Obstructive Pulmonary Disease |
| EIS | Environmental Impact Statement |
| ESL | Effects Screening Levels |
| HHRA | Human Health Risk Assessment |
| HI | Hazard Index |
| HQ | Hazard Quotient |
| IARC | International Agency for Research on Cancer |
| MDH | Minnesota Department of Health |
| NEPC | National Environment Protection Council |
| NEPM | National Environment Protection Measure |
| NHMRC | National Health and Medical Research Council |
| NIOSH | National Institute for Occupational Safety and Health |
| NOAEL | No Observable Adverse Effect Level |
| OEHHA | California EPA Office for Environmental Health Hazard Assessment |
| PEL | Permissible Exposure Limit |
| $PM_{2.5}$ | Particulate matter below 2.5 µm in diameter |
| $PM_{10}$ | Particulate matter below 10 microns in diameter |
| REL | Recommended Exposure Limit |
| ReV | Chronic Reference Value |
| RCS | Respirable Crystalline Silica |
| RfC | Reference Concentration |
| RfD | Reference Dose |
| TC | Tolerable Concentration |
| TCEQ | Texas Commission on Environmental Quality |
| TDI | Tolerable Daily Intake |
| TLV | Threshold Limit Value |
| TRV | Toxicity Reference Value |
| TSP | Total Suspended Particulates |
| TWA | Time-weighted Average |
| UR | Unit Risk |
| USEPA | United States Environmental Protection Agency, |
| WHO | World Health Organisation |

# Executive Summary

### *Introduction*

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by R. W. Corkery & Co. Pty Limited (RWC) to review available data and undertake a human health risk assessment (HHRA) in relation to the potential presence of respirable crystalline silica (RCS) in dust emitted during the continued operation and extension of Dowe's Quarry (the "Quarry"). Rural residential properties are located adjacent to the Quarry and some members of the community are concerned that dust containing RCS emitted from the Quarry may migrate onto the residential properties and be inhaled.

The Quarry is located on Rural Land owned by Mr. Rod Dowe and leased to Darryl McCarthy Constructions Pty Ltd (Darryl McCarthy Constructions). The Quarry is located approximately 8 km north-east of Tenterfield in NSW and has been operating at its current location since 1987. The current destination of raw materials extracted from the Quarry is the Sunnyside Crushing and Screening Plant (the "Sunnyside Plant"), located to the north-west of the Quarry and Tenterfield. Material extracted from the Quarry is processed and dispatched to their destination at the Sunnyside Plant.

Darryl McCarthy Constructions is seeking development consent for the continued operation and expansion of extraction activities within the Quarry. The proposed activities comprise:

- Ongoing extraction of quartzose material within the existing extraction area and an additional 4.4 hectares (ha) of area, producing up to 230,000 tonnes per annum (tpa) of stone products;
- Crushing and screening of extracted material at the Quarry using mobile processing equipment. All on-site materials processing (including crushing and screening) is proposed to be performed within the extraction area (the pit);
- Ongoing transportation of fragmented and crushed rock on the New England highway to the Sunnyside Plan and other destinations (including locally within Tenterfield);
- Ongoing transport of stone material directly to the destination, where further processing at the Sunnyside Plant is not required; and
- Transport of clay fines and crusher fines from the Sunnyside Plant to the Quarry for progressive emplacement within and adjacent to the extraction area.
- The Quarry will then be progressively rehabilitated for native vegetation conservation.

It is understood that the key changes to the operation of the Quarry outlined in the development application (DA) of relevance to this HHRA include the expansion of the extraction area and the crushing and screening of extracted material at the Quarry, instead of at the Sunnyside Plant as per current operations. As noted above, all crushing and screening activities will be undertaken within the quarry pit. It is understood that this is with the aim of reducing the potential for dispersion of dust emissions and create a barrier to noise propagation from the Quarry.

An Environmental Impact Statement (EIS; R. W. Corkery 2019) has been submitted to Tenterfield Council in support of the DA to continue and expand activities at the Quarry. The Air Quality Impact Assessment (AQIA) undertaken as part of the EIS provides some consideration that dust emitted from the Quarry may contain RCS. This report provides a more detailed assessment of the potential risks to human health posed by the potential presence of RCS in dust emitted from the Quarry, to residents utilising the existing residential properties adjacent to the Quarry.

### *Objectives*

The objectives of the assessment presented in this report are:

- To undertake an evaluation of the potential risks to human health associated with RCS in dust that may be emitted from the quarry and may migrate onto residential properties adjacent to the Quarry; and
- Based on the HHRA, and if required, identify any additional data that may be necessary to assist in refining the assessment of risk or in considering additional risk management measures that may be needed.

This assessment has been undertaken to evaluate potential risks to human health at residential properties adjacent to the Quarry based on the data and information available up to the end of February 2020 and as described in **Section 2.1**. The HHRA has addressed human health risk issues relevant to RCS that may be present in dust sourced from the Quarry and the ongoing low-density rural/residential use of the existing properties adjacent to the Quarry

The assessment has not addressed any ecological/environmental risk issues, human health risk issues associated with other chemicals or human health risk issues at the Quarry or the Sunnyside Plant. No assessment has been undertaken of other non-site sourced contamination that may be present beneath off-site properties.

### *Approach*

The assessment of potential risks to community health has been undertaken in accordance with enHealth guidance (enHealth 2012a).

This assessment has relied on the air quality impact assessment (AQIA) to estimate the potential concentration of fine particles, as $PM_{2.5}$, the community may be exposed to as a result of the proposed Quarry operations. Due to the nature of the materials being quarried, it has then been assumed that 100% of the $PM_{2.5}$ dust generated from the Quarry is RCS. X-ray diffraction (XRD) analysis of the raw material at the Quarry was undertaken by the QUT Central Analytical Research Facility in November 2019 and identified that the raw materials produced at the Quarry are 99.5% quartz (crystalline silica) with trace impurities.

The potential risks associated with community inhalation exposures to RCS has also been evaluated on the basis of current information in relation to the adverse health effects. The assessment has also considered the levels of exposure at which such health effects may be of concern in both occupational environments and in the community.

### *Conclusions*

Based on the available data and the scope of this assessment, it has been concluded that health risks to residents in existing properties adjacent to the Quarry are low and acceptable.

Environmental Risk Sciences Pty Ltd has undertaken a human health risk assessment (HHRA) in relation to the potential presence of respirable crystalline silica (RCS) in dust emitted during the continued operation and extension of Dowe's Quarry (the "Quarry"). It is noted that limitations apply to the outcomes due to the focus of this assessment on RCS and the uncertainties identified and analysed in the report.

The HHRA has addressed human health risk issues relevant to RCS that may be present in dust sourced from the Quarry and the ongoing low-density rural/residential use of the existing properties adjacent to the Quarry.

No additional dust mitigation measures are recommended for operations assuming the proposed dust mitigation measures including the planned air monitoring program are implemented. It is recommended that $PM_{2.5}$ and $PM_{10}$ samples captured for monitoring are subject to laboratory analysis of for silica concentration. This is recommended to confirm the concentrations of silica in these PM fractions, that adjacent receptors may be exposed to.

Standard dust mitigation measures including dust suppression through chemical and water means, the tarping of loads, inspection of truck tyres and street sweeping should also continue for the operation. The proposed extension to the seal on the Quarry Access Road to a total length of 800m is supported..

# Section 1. Background

## 1.1 Introduction

Environmental Risk Sciences Pty Ltd (enRiskS) has been engaged by R. W. Corkery & Co. Pty Limited (RWC) to review available data and undertake a human health risk assessment (HHRA) in relation to the potential presence of respirable crystalline silica (RCS) in dust emitted during the continued operation and extension of Dowe's Quarry (the "Quarry"). Rural residential properties are located adjacent to the Quarry and some members of the community are concerned that dust containing RCS emitted from the Quarry may migrate onto and impact the residential properties and be inhaled.

The Quarry is located on Rural Land owned by Mr. Rod Dowe and leased to Darryl McCarthy Constructions Pty Ltd (Darryl McCarthy Constructions). The Quarry is located approximately 8 km north-east of Tenterfield in NSW and has been operating at its current location since 1987. The current destination of raw materials extracted from the Quarry is the Sunnyside Crushing and Screening Plant (the "Sunnyside Plant"), located to the north-west of the Quarry and Tenterfield. Material extracted from the Quarry is processed and dispatched to their destination at the Sunnyside Plant. **Figure 1.1** (RWC 2019) shows the location of the Quarry, the Sunnyside Plant and Tenterfield.

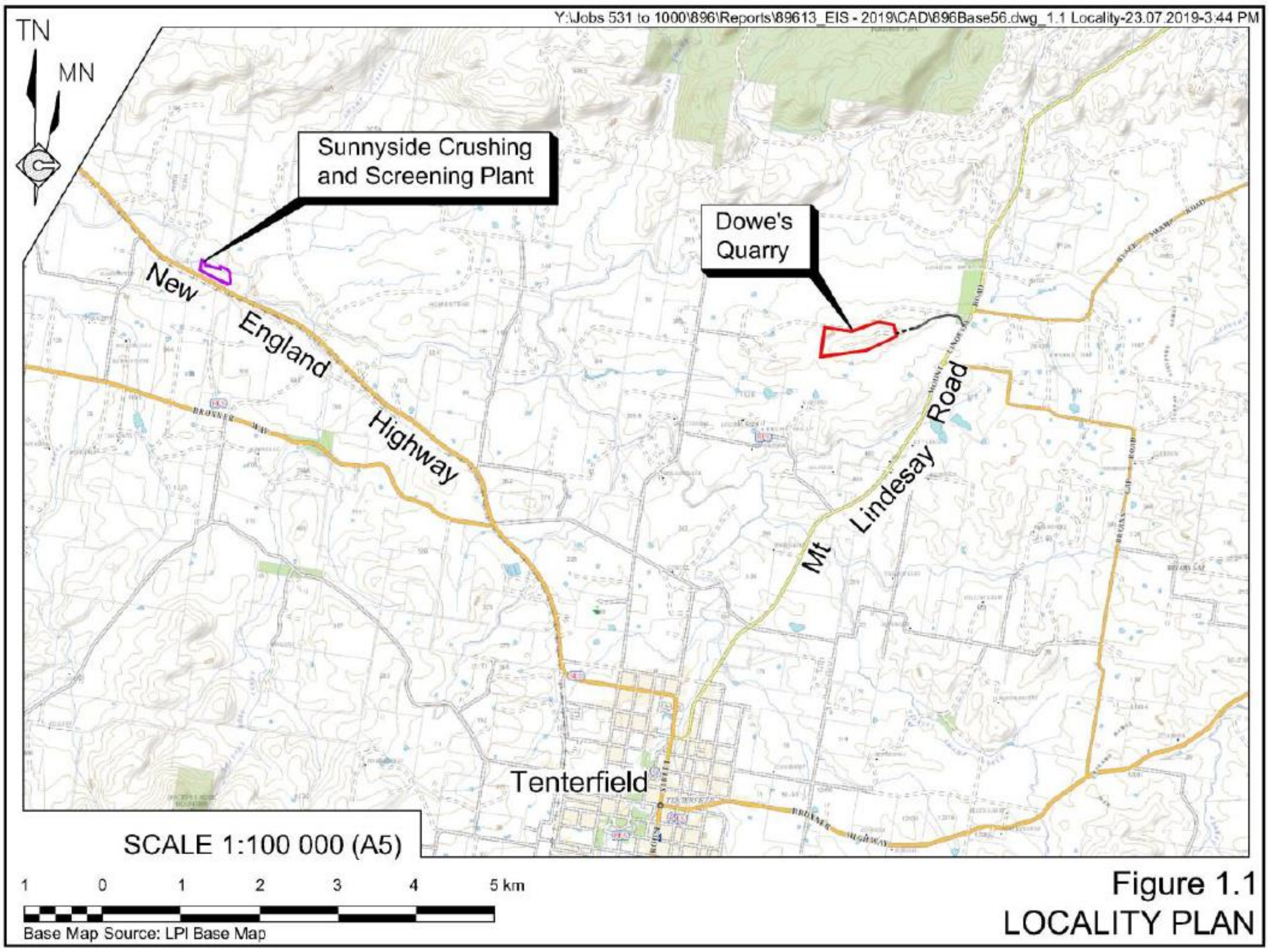


Figure 1.1
LOCALITY PLAN

Darryl McCarthy Constructions is seeking development consent for the continued operation and expansion of extraction activities within the Quarry. The proposed activities comprise:

- Ongoing extraction of quartzose material within the existing extraction area and an additional 4.4 hectares (ha) of area, producing up to 230,000 tonnes per annum (tpa) of stone products;
- Crushing and screening of extracted material at the Quarry using mobile processing equipment. All on-site materials processing (including crushing and screening) is proposed to be performed within the extraction area (the pit);
- Ongoing transportation of fragmented and crushed rock on the New England highway to the Sunnyside Plan and other destinations (including locally within Tenterfield);
- Ongoing transport of stone material directly to the destination, where further processing at the Sunnyside Plant is not required; and
- Transport of clay fines and crusher fines from the Sunnyside Plant to the Quarry for progressive emplacement within and adjacent to the extraction area.
- The Quarry will then be progressively rehabilitated for native vegetation conservation.

It is understood that the key changes to the operation of the Quarry outlined in the Development Application (DA) of relevance to this HHRA include the expansion of the extraction area and the crushing and screening of extracted material at the Quarry, instead of at the Sunnyside Plant as per current operations. As noted above, all crushing and screening activities will be undertaken within the quarry pit. It is understood that this has been designed with the aim of reducing the potential for dust emissions from the Quarry to impact on surrounding areas.

An Environmental Impact Statement (EIS; R. W. Corkery 2019) has been submitted to Tenterfield Council in support of the DA to continue and expand activities at the Quarry. The Air Quality Impact Assessment (AQIA) undertaken as part of the EIS provides some consideration that that dust emitted from the Quarry may contain RCS.

This report provides a more detailed assessment of the potential risks to human health posed by the potential presence of RCS in dust emitted from the Quarry, to residents at existing residential properties adjacent to the Quarry.

## 1.2 Objectives

The objectives of the assessment presented in this report are:

- To undertake an evaluation of the potential risks to human health associated with RCS in dust that may be emitted from the quarry and may migrate onto residential properties adjacent to the Quarry; and
- Based on the HHRA, and if required, identify any additional data that may be necessary to assist in refining the assessment of risk or in considering additional risk management measures that may be needed.

This assessment has been undertaken to evaluate potential risks to human health at residential properties adjacent to the Quarry based on the data and information available up to the end of February 2020 and as described in **Section 2.1**. The HHRA has addressed human health risk issues relevant to RCS that may be present in dust sourced from the Quarry and the ongoing low-density rural/residential use of the existing properties adjacent to the Quarry

The assessment has not addressed any ecological/environmental risk issues, human health risk issues associated with other chemicals or any occupational health and safety issues at the Quarry or the Sunnyside Plant. No assessment has been undertaken of other non-site sourced contamination that may be present beneath off-site properties.

## 1.3 Methodology

In general, the approach taken for the assessment of human health and environmental risks is in accordance with guidelines/protocols endorsed by Australian regulators, including:

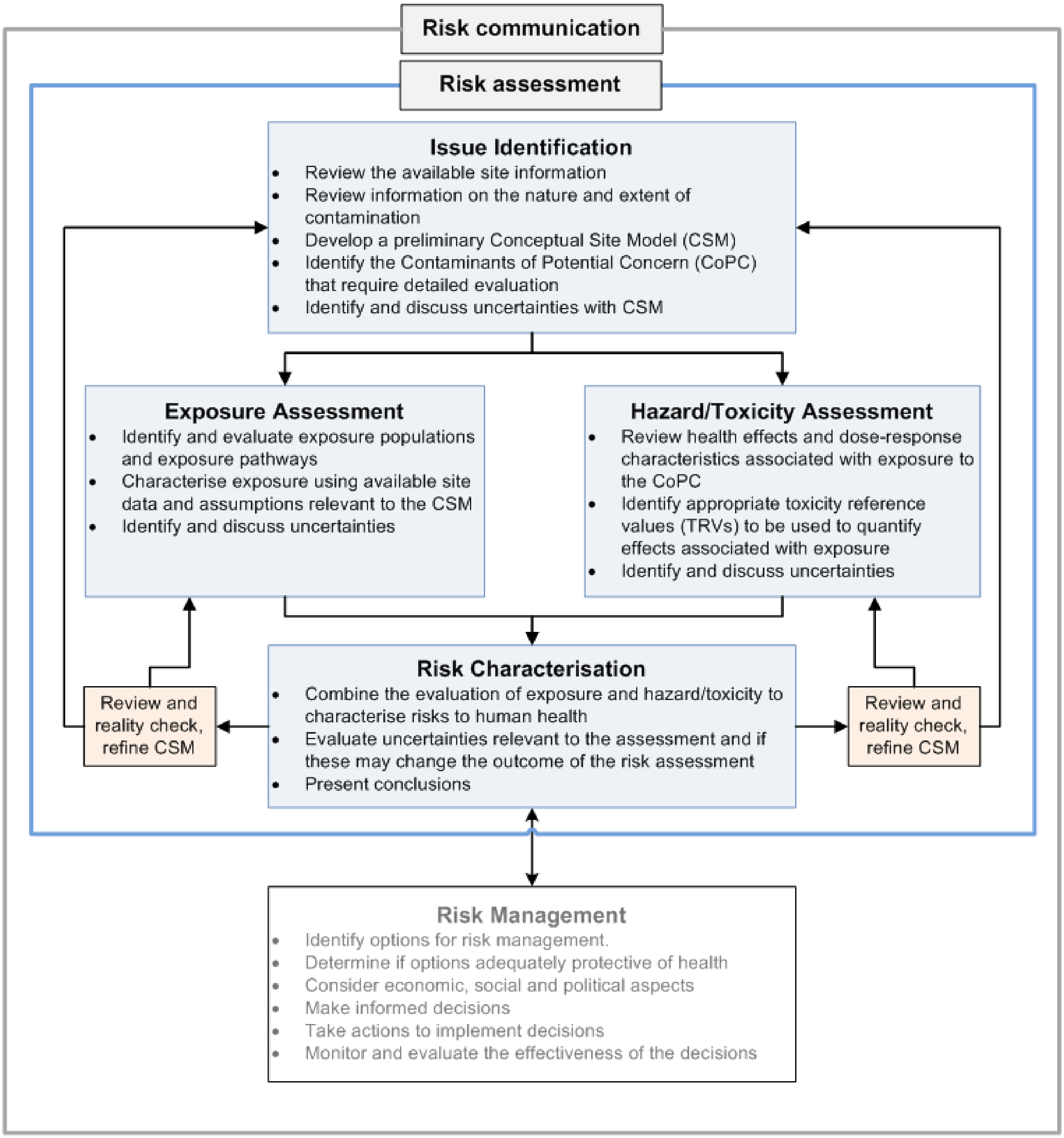
- enHealth Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012a);
- enHealth Australian Exposure Factor Guide (enHealth 2012b);
- National Environmental Protection Measure – Assessment of Site Contamination (ASC NEPM) including Schedule B1 Guideline on Investigation Levels of Soil and Groundwater (NEPC 1999 amended 2013a) and Schedule B4 Guideline on Health Risk Assessment Methodology (NEPC 1999 amended 2013b).

In addition, protocols and guidelines developed by international agencies such as the United States Environmental Protection Agency (USEPA) and the World Health Organisation (WHO) have been used (and referenced) to provide supplementary guidance where required. International guidance has not been adopted where it is inconsistent with the Australian regulatory or policy setting.

The overall approach adopted in this assessment is as follows:

- Issue identification comprising summary of relevant information and available data (**Section 2**);
- Review of the human toxicity of RCS, including the identification of appropriate screening level guidelines for the assessment of potential effects associated with exposures to RCS (**Section 3**) and;
- Assessment of human health risks based on the above. The assessment of risk will present conclusions in relation to risk with consideration of the uncertainties identified in the assessment and any requirements to undertake risk management measures (**Section 4**).

The overall approach for the HHRA is outlined in the following (modified from enHealth 2012):



# Section 2. Issue identification

## 2.1 General

This section provides a summary of the information relevant to the assessment and characterisation of the potential for RCS impacts in dust that may be emitted from the Quarry. This assessment is based on a review of the following information:

- RWC (2019), Environmental Impact Statement for the Expansion of the Dowe's Quarry, via Tenterfield, Report to Daryl McCarthy Constructions Pty Ltd, R. W. Corkery & Co Pty Limited, October 2019 specifically (of relevance to this HHRA):
  - Cover and Contents
  - Executive Summary
  - 1 - Introduction
  - 2 - Proposal Description
  - Appendix 6 – Air Quality Impact Assessment (AQIA)
- Northstar (2020), Dowe's Quarry, Air Quality Assessment, Northstar Air Quality, January 2020. This is an updated Draft of the AQIA included in the EIS that was provide to enRiskS by RWC on 6 February 2020;
- Group Submission, DA Application #2019.101 Designated development – Dowes Quarry, 12 November 2019 (the "Group Submission");
- Objection letter to Tenterfield Shire Council Re. Dowe's Quarry DA No. 2019.101, letter from B. and J. Morrow to the Chief Executive – Tenterfield Shire Council, 9 November 2019 (the "Morrow Submission"); and
- Additional information provided by RWC (as referenced).

Unless otherwise indicated, the information used to compile this section of the HHRA has been sourced from RWC (2019).

## 2.2 Description of the Quarry

RWC (2019) and Northstar (2020) indicate that the Quarry is situated on a small ridge to the south of Washpool Creek. The area to the north of the Quarry is relatively flat land that comprises patches of remnant vegetation and areas cleared for cropping and light grazing. A small valley is present to the south of the Quarry, created by a further ridge aligned generally parallel to the Quarry. The proposal would modify the existing topography through in part removal of the ridge to the east and west of the existing extraction area and development of the overburden and fines emplacement area.

The Quarry comprises an extraction area, processing area, bund, overburden and fines stockpile, overburden and fines emplacement area, sediment dams and an access road. The total area of the Quarry if 26.8 ha, with the disturbance area comprising a maximum of 16.4 ha. The layout of the Quarry is shown on **Figure 2.1**.

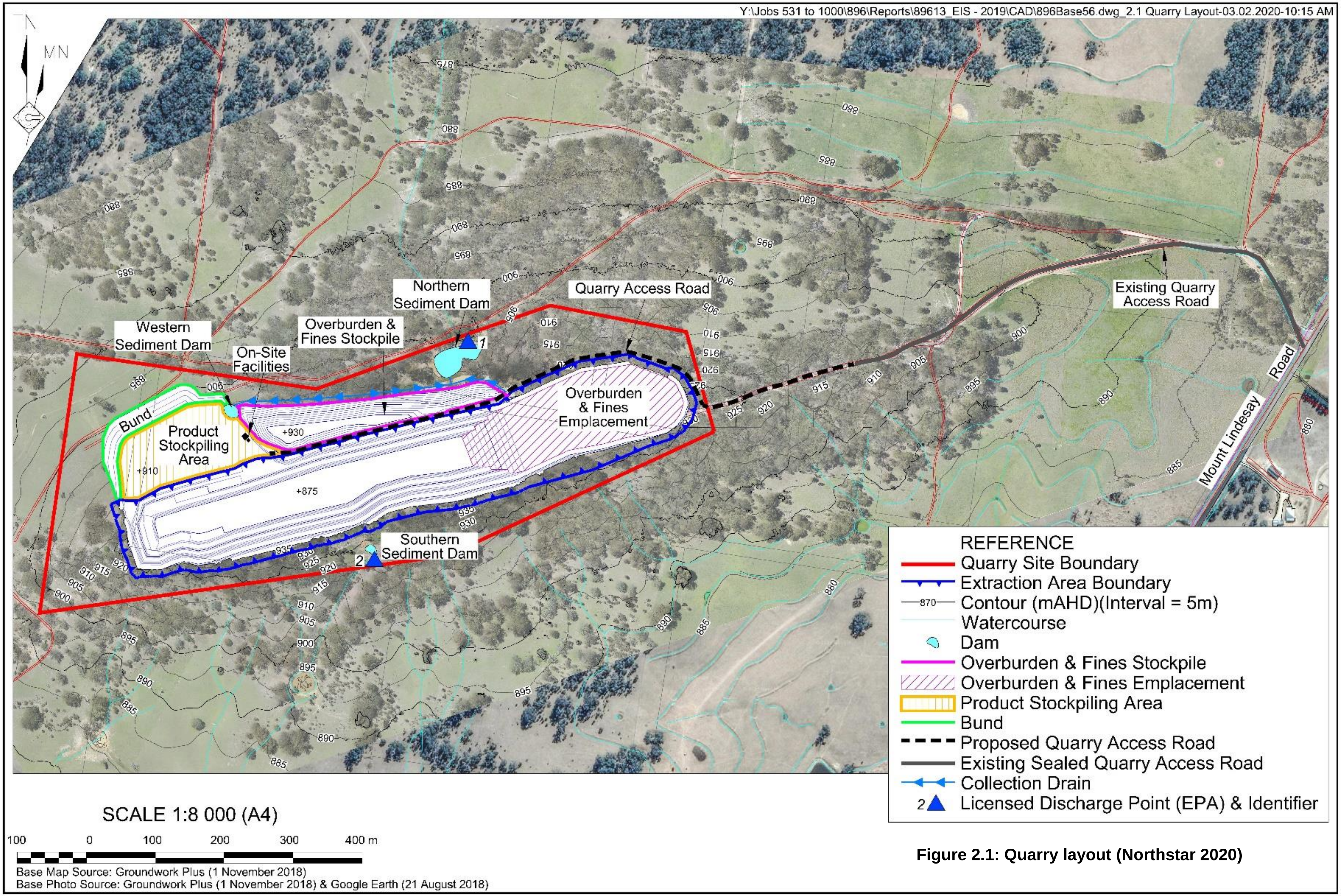



**Figure 2.1: Quarry layout (Northstar 2020)**

Rainfall is infrequent with few rain days each month resulting in rainfall greater than 1 mm. The mean annual rainfall is 848.5 mm with rainfall distributed unevenly throughout the year. Based on data from CSIRO for the last 5 years, the prevailing wind direction is to the east and west (likely to be the result of the topography of the Quarry).

The principal product currently produced at the Quarry is graded fractured quartoze rock blend with all fragments typically less than 400 mm. This product is produced by blasting and fragmenting oversize rock with a hydraulic hammer. RWC have indicated that analysis of the material proposed to be quarried indicates the material comprises 99.5% silica.

As indicated in **Section 1.1** (RWC, 2019 and Northstar, 2020), the key changes to the operation of the Quarry of relevance to this HHRA include the expansion of the extraction area and the production of a range of smaller products (5 to 24 mm) using a mobile crushing and screening plant. The crushing and screening of extracted material will also be undertaken at the Quarry, instead of at the Sunnyside Plant (as per current operations).

To facilitate this, the extraction area at the Quarry is proposed to be expanded to 11.4 ha across 3 stages. Extraction operations will be undertaken in a similar manner to existing operations i.e. using conventional drill and blast methods. Blasts would typically occur no more than once per month however the DA proposed blasting of no more than once per week excluding events required in the event of a misfire. The production rate will not exceed 230,000 tonnes per annum, which has been selected based on the inferred resource area, anticipated demand and allows for peaks in some years.

Excavated material will either be loaded directly onto highway trucks for transportation to the Sunnyside Plant, or hauled to the processing area at the Quarry for crushing using a mobile crushing plant. The rushing/screening rate at the Quarry will be up to 470 tonnes per hour. All crushing and screening works will be undertaken within the Quarry holes in the extraction area. Crushing equipment proposed to be used at the Quarry comprises a Jaw Crusher, Cone Crusher and Mobile Screen.

Following processing, products will be temporarily stored as stockpiles (5,000 to 10,000 tonnes) in a product stockpiling area, located immediately to the north-west of the extraction area. A bund would be constructed to the north and west of the product stockpiling area with the intent of mitigating any noise and visual impacts generated by operations. An overburden and fines stockpiling area will be located immediately north of the extraction area. As extraction operations continue, this material will be progressively backfilled within the generated voids to ground surface level. Two sediment dams will collect surface water runoff from the overburden and fines stockpile as well as other disturbed areas.

Dust emission to air that may occur during operation of the Quarry comprise:

- Clearing of vegetation;
- Emissions from product production and handling including those generated during blasting;
- Wheel generated emissions from product transportation product; and
- Wind erosion of exposed surfaces including stockpiled product.

## 2.3 Proposed dust management measures

The following mitigation measures are proposed at the Quarry to minimise any impacts from dust, as detailed in the air quality management plan (AQMP) for the Quarry:

- Use of a water truck;
- Regular servicing of the dust collection system on the drill rig;
- Misting water sprays on the mobile crushing and screening plant
- Rock boxes and dust covers on conveyor belts;
- Blasting and secondary rock breakage to be limited during periods of high wind or extremely dry weather (where practicable);
- All unsealed internal roads to be surfaced to minimise dust lift-off;
- Road watering on unsealed roads if dust becomes a nuisance during periods of westerly winds;
- All plant and equipment are washed down before any maintenance;
- Housekeeping on site including washing down only, with no blowing or sweeping;
- Use of appropriate care to avoid spillage during loading;
- Covering of trucks prior to leaving the Quarry;
- A speed limit of 30 km/hour on the Quarry access road, with a 10 km/hour limit on the unsealed internal roads;
- Maintenance staff wear personal protective equipment (PPE) including personally fitted masks (P2 type);
- All employees are inducted, and training is provided, which includes the minimisation of dust; and
- Continuation of the existing complaints system.

Darryl McCarthy Constructions has advised that the following dust management measures are currently implemented at the Sunnyside Plant during crushing activities:

- Use of a water truck;
- The crusher has in built dust sprays with a polo citrus addition that turns water into atomised water bubbles to maximise water particle size and maximise dust control;
- Use of airconditioned cabs;
- Maintenance staff wear personal protective equipment (PPE) including gloves and masks
- Plant is washed down prior to maintenance; and
- Crushing is not undertaken if winds exceed 30 kilometres per hour at the on-site weather station.

It has been indicated that the same management measures would be implemented during future crushing activities at the Quarry.

Darryl McCarthy Constructions has also committed to implementing continuous particulate matter monitoring at the Quarry at two locations (east and west of the Quarry). It is also expected that dust deposition monitoring would be undertaken at three locations, and a State-of-the-art Weather Station (Weathermation Live) will be installed so that operations can be proactively managed with wind speed and direction informing decisions for ongoing blasting / processing

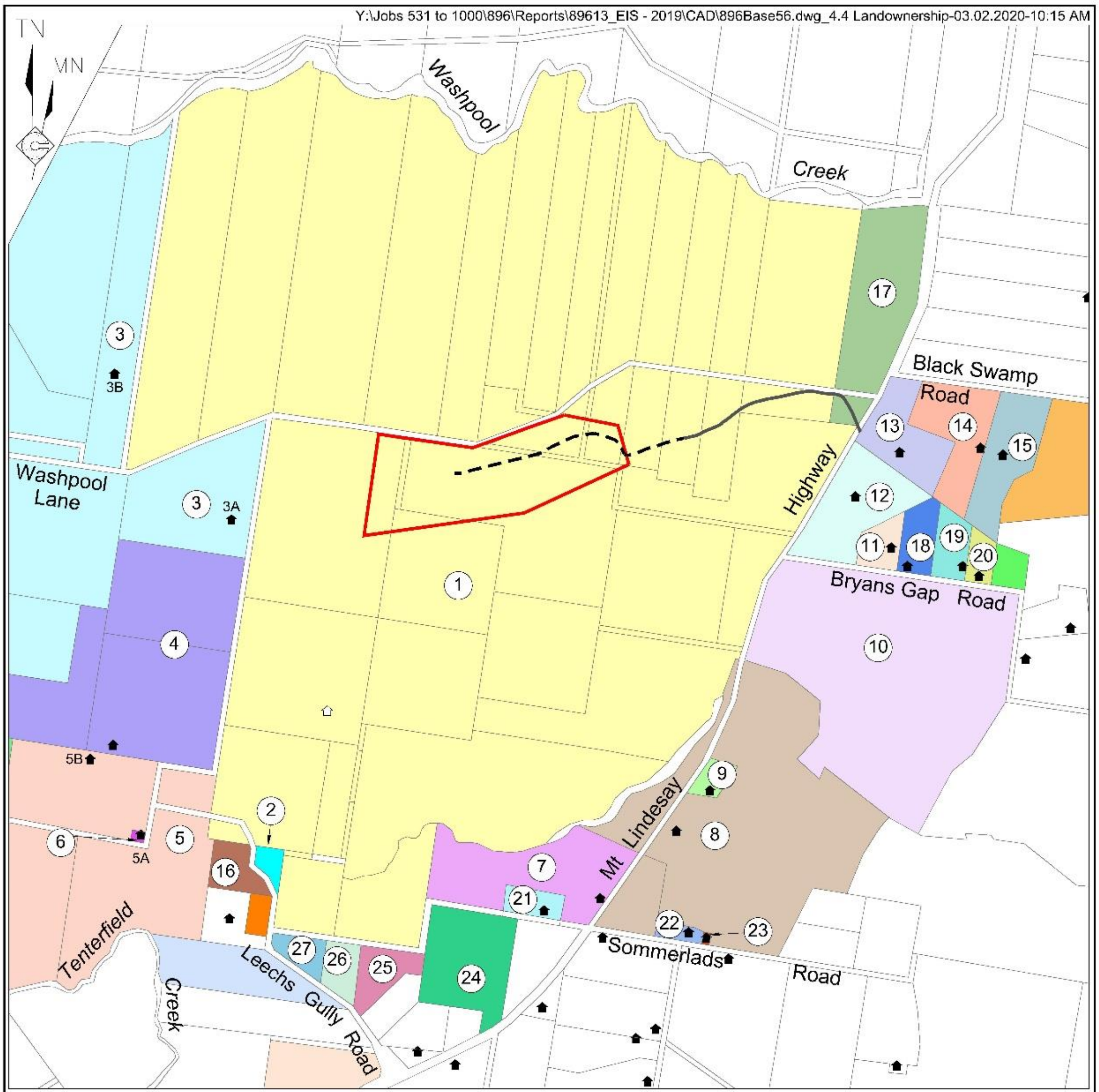
It is noted that operations at the Quarry would be undertaken in accordance with a Dust Control Plan, implemented under the Quarry Safety Management System.

## 2.4 Receptors and exposure pathways

The land surrounding the Quarry is agricultural with some residential properties.

Residents (adults and children) in residential properties adjacent to the Quarry are the receptors or population of concern for this HHRA. The relevant exposure pathway is the inhalation of dust sourced from the Quarry that may contain RCS.

The location and distances of the surrounding residences to the closest point of the existing and proposed extraction areas are shown on **Figure 2.2**. Residences are located to the east, west and south. There are no residences located to the north between the Quarry and Bald Rock National Park (approximately 2.5 km north of the Quarry).




REFERENCE
Quarry Site Boundary
Cadastral Boundary
Proposed Quarry Access Road
Existing Sealed Quarry Access Road
Residence (Project Related)
Residence (Non-Project Related)
Landowner Reference (See Table)

| Ref | Landowner | Ref | Landowner |
|---|---|---|---|
| 1 | RSH & MO Dowe | 15 | AJ & BW Lawrence |
| 2 | JP Jacquet, MJ Bielski | 16 | PJ Della & TM Curry |
| 3A,3B | RF & LL Tumbridge | 17 | The State of New South Wales |
| 4 | RL Caldwell | 18 | MN & DN Larsen |
| 5A,5B | GL & JM Smith | 19 | GB & DK Phillips |
| 6 | DB Weir, GR Smith, WF Marsden | 20 | CA Jackson, D Bunic |
| 7 | JM Dowe | 21 | DM & AJ Mullins |
| 8 | RB & CA Sewell | 22 | JP & SL Doyle |
| 9 | MJ & NJ Lewis, RB & CA Sewell | 23 | LD Merchant |
| 10 | KR & LA Willcocks | 24 | Harewood Investments Pty Limited |
| 11 | KH Baxman & CC Haynes | 25 | D Puglisi |
| 12 | BL & JA Morrow | 26 | BJ & RL Tom |
| 13 | RM Ibbett, S Ibbett | 27 | BJ Tom & Brad Tom Investments Pty Ltd |
| 14 | GM O'Reilly, MP Watt | | |

SCALE 1:25 000 (A4)

250 0 250 500 750 1000 1250 m

Cadastral Source: LPI (2014)
Landowner Source: Department of Lands Online Search - April 2019

**Figure 2.2: Location of adjacent residences (Northstar 2020)**

**Figure 2.2** shows that the closest non-mine owned residential properties to the Quarry are as follows (property owners are listed in parenthesis):

- East:
  - Property 10 (KR & LA Wilcocks)
  - Property 12 (BL & JA Morrow)
  - Property 13 (RM & S Ibbett)
- West:
  - Property 3A (RF & LL Tumbridge)

Based on this information, the quarrying activities will be moved to the west of the current location, which means activities will be closer to the properties to the west and further away from the properties to the east. Property 10 is currently unoccupied and is located the furthest away to the east. Properties 12 and 13 are located 1,300 to 1,470 m respectively to the east of the boundary of the proposed Quarry activities. This is an additional 150 m to the east for Property 12 and an additional 160 m to the east for Property 13 as compared to the distance to the boundary of the current Quarry activities. Property 3A is located 540 m from the boundary of the proposed Quarry activities. This is 510 m closer as compared to the current Quarry extent. Residences 10, 12 and 13 are located along the transport routes currently used to transport raw materials to the Sunnyside Plant. This is important as the Morrow Submission (Property 12) raises concerns in relation to dust emitted from truck tyres during the transportation of quarry materials.

The EIS was required to include an assessment of the likely air quality impacts of the development, with a particular focus on dust impacts on nearby private residences. This was provided in the form of the AQIA (Northstar 2020) which predicted concentrations of 4 types of particles in air at the adjacent residences, that were assumed to be sourced from the Quarry. Predicted concentrations were compared to guideline values endorsed by the NSW Government as applicable to the residential properties. The results of the AQIA are important to this HHRA as RCS may be transported in dust emitted from the Quarry to nearby residents. Hence, where dust emitted from the Quarry contains RCS, the predicted concentrations of particles in dust at the residential properties can be used to estimate potential health risks to residents from RCS. A general introduction to the 4 types of particles assessed in the AQIA is provided in **Section 2.5**. The methodology and results of the AQIA are summarised in **Section 2.6**.

## 2.5 Introduction to particles

As discussed above, the AQIA assessed 4 types of particles: $PM_{2.5}$, $PM_{10}$, total suspended particulates (TSP) and deposited dust. TSP refers to all particulates with an equivalent aerodynamic particle[1] size below 50 microns in diameter[2]. It is a fairly gross indicator of the presence of dust with a wide range of sizes:

- Larger particles (termed ‘inspirable’, comprise particles around 10 microns and larger) are more of a nuisance as they will deposit out of the air (measured as deposited dust) close to

[1] The term equivalent aerodynamic particle is used to reference the particle to a particle of spherical shape and particle of density one gram per cubic metre.

[2] The size, diameter, of dust particles is measured in micrometers (microns).

the source and, if inhaled, are mostly trapped in the upper respiratory system[3] and do not reach the lungs; and
- Finer particles (smaller than 10 microns, termed 'respirable') are transported further from the source and are of more concern with respect to human health as these particles can penetrate into the lungs (see discussion below).

Hence, not all of the dust characterised as TSP is relevant for this HHRA, and TSP has not been further evaluated in this assessment. Deposited dust has not been considered further in the HHRA for the same reason.

Instead, this HHRA has focused on particulates of a size that are respirable. These particulates comprise the following (as illustrated in **Figure 2.3**):

- $PM_{10}$ - particulate matter below 10 microns in diameter, µm;
- $PM_{2.5}$ - particulate matter below 2.5 µm in diameter;
- $PM_1$ - particulate matter below one µm in diameter, often termed very fine particles; and
- Ultrafines - particulate matter below 0.1 µm in diameter.

These particles are small and have the potential to penetrate beyond the body's natural clearance mechanisms of cilia and mucous in the nose and upper respiratory system, with smaller particles able to further penetrate into the lower respiratory tract[4] and lungs.

It is noted that the term 'respirable' is often used by various different groups and regulatory authorities (that include Safe Work Australia (Safe Work Australia 2013)) to refer to various ranges of particulate fractions that are smaller than 10 µm in diameter. This includes the above, as well as other groups such as $PM_4$ (particulate matter below 4 µm in diameter) and $PM_7$ (particulate matter below 7 µm in diameter). These other groupings of respirable particulates are not commonly measured in air, and hence many of the assessments utilise $PM_{2.5}$ or $PM_{10}$ as surrogates for $PM_4$ and $PM_7$.

[3] The upper respiratory tract comprises the mouth, nose, throat and trachea. Larger particles are mostly trapped by the cilia and mucosa and swept to the back of the throat and swallowed.

[4] The lower respiratory tract comprises the smaller bronchioles and alveoli, the area of the lungs where gaseous exchange takes place. The alveoli have a very large surface area and absorption of gases occurs rapidly with subsequent transport to the blood and the rest of the body. Small particles can reach these areas, be dissolved by fluids and absorbed.

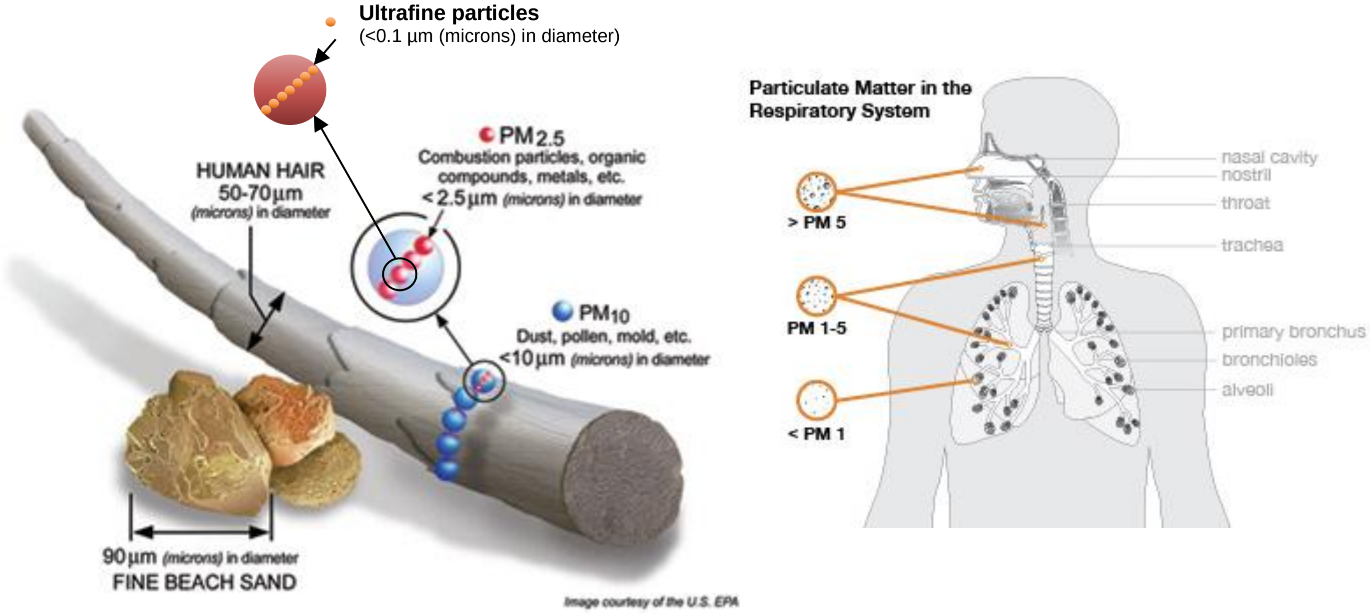



**Figure 2.3: Illustrative representation of particle sizes and penetration into the lungs**

In relation to measuring and assessing particulate matter, the following should be noted:

- The measurement of particulate matter in air most commonly reports $PM_{10}$. This is the concentration of particulate matter that less than or equal to 10 µm in diameter (and includes the smaller fractions of $PM_{2.5}$ and very fine particles). The measurement techniques for $PM_{10}$ are well established and provide stable, robust, verifiable data that is consistently reported across all regains and countries; and
- The measurement of $PM_{2.5}$ is becoming more common. This is the concentration of particulate matter that less than or equal to 2.5 µm in diameter (and includes the smaller fractions of very fine particles and ultrafines). The measurement techniques used for $PM_{2.5}$ are less well-established resulting in data that varies depending on the type of equipment used and how it is set-up and maintained. Data on this fraction is, however, of most relevance to the assessment of health impacts; and
- The measurement of very fine particles and ultrafine particles is difficult (using equipment that is less robust/stable and provides variable data) and has not been undertaken in most air environments. In addition, there are no health based guidelines established for these fine fractions of particles. Hence the assessment of these fractions is not undertaken where specific sources of particles is being considered.

**Figure 2.3** shows that $PM_{2.5}$ and smaller is the particle size that may reach the lower parts of the respiratory tract (the smaller bronchioles and alveoli). This is the area of the lungs where gaseous exchange takes place and the area that may be impacted by RCS (refer to **Section 4**). $PM_{2.5}$

includes a significant contribution from $PM_1$ (hence these fractions are included in the assessment of $PM_{2.5}$) Hence the further assessment of exposure to fine particulate matter has focused on particulates reported/evaluated as $PM_{2.5}$, with the consideration of $PM_{10}$ for completeness.

## 2.6 Summary of the air quality impact assessment (AQIA)

Northstar (2020) indicates that the AQIA has been undertaken in accordance with guidelines/protocols endorsed by Australian regulators including the National Environment Protection (Ambient Air Quality) Measure (Ambient Air Quality NEPM) (NEPC 2016) and NSW EPA Approved Methods for the Modelling and Assessment of Air Pollutants in NSW (NSW EPA 2016). These documents provide air quality standards and goals for particulate matter (i.e. dust), including smaller size particulate matter as $PM_{10}$ and $PM_{2.5}$, that may be inhaled by humans.

As noted above, the AQIA considered the following sources of dust emissions during operation of the Quarry, based on the proposed expansion of activities:

- Clearing of vegetation;
- Extraction, processing and storage of product including emissions from blasting;
- Wheel generated emissions from transporting product; and
- Wind erosion of exposed surfaces.

The modelling considered an activity rate of 230,000 tonnes per annum or 5,000 tonnes per day, which is noted to be significantly greater than those which are likely to be experienced as part of ongoing Quarry operations. Hence, the AQIA is stated to be conservative and likely to provide an overestimate of dust emissions that may occur. Potential impacts during construction were considered to be appropriately covered off by activities during ongoing operation and were not assessed separately.

The AQIA considered potential impacts to 25 privately owned residential properties surrounding the site including the 3 closest currently inhabited residences listed in **Section 2.4** (properties 3A, 12 and 13). It is however noted that the distances to properties 12 and 13 (located to the east) assumed in the AQIA was based on the distance to the Quarry boundary which is 900 m and 1,000 m respectively. This is 300 to 500 m closer than the distance from the part of the Quarry where activities are undertaken. This is a conservative assumption in the AQIA.

The dominant wind direction was assumed to be to the east and west (towards the above residences), and dispersion modelling (using the approved CALPUFF software) was undertaken. Two additional models (TAPM and CALMET) was used to predict the meteorological (weather) parameters required for CALPUFF. These models consider the local topography. The use of these models was required as no weather data was available for the Quarry. The closest location with weather data to the Quarry was the monitoring station in the nearby town of Tenterfield however only daily data (at 9 am) is recorded at this location which is not generally considered appropriate for modelling (hourly data is needed). The nearest full meteorological station with hourly data is >82 km away (which is too far away and not in an appropriate area – specifically the topography was very different).

The CALPUFF model was used to predict the concentrations of different types of particles, comprising $PM_{2.5}$, $PM_{10}$, TSP and deposited dust, at each nearby residential property. The predicted concentrations were compared to the adopted air quality guidelines.

Data on background particulate concentrations was obtained from the Rural Air Quality Monitoring Network, where the data from the closest station was adopted. The closest station that provided $PM_{10}$ data was Tamworth, located 258 km from the Quarry. Two stations are located closer to the Quarry (Armidale and Moree) however neither of these stations measure $PM_{10}$. It is also noted that the closest station (Armidale) is 171 km from the Quarry. No station within 300 km reported $PM_{2.5}$ concentrations, hence, $PM_{2.5}$ concentrations were inferred from $PM_{10}$ concentrations (noting that $PM_{2.5}$ is a subset of $PM_{10}$). The data from 2015 was adopted for the AQIA. The AQIA assessment indicates that data from 2015 best represents the general trend across the 5-year study period (2013 to 2017). The level of RCS in background $PM_{2.5}$ or $PM_{10}$ is not known as it is not measured, however it is expected to be low. Further discussion on background levels of RCS is presented in **Section 3.4**.

Cumulative impacts from other operations within the area that have the potential to generate RCS were assessed to be negligible as the closest industry with the potential to impact on air quality was the Sunnyside Plant, located 7.5 km to the west of the Quarry.

The concentrations of $PM_{2.5}$ and $PM_{10}$ predicted by the AQIA are summarised in **Table 2.1**. The results in the “incremental impact” column are the estimated concentrations at the residential properties as specifically sourced from Quarry activities. The results in the “cumulative concentration” column are the sum of the incidental impact and background concentrations. As noted above, RCS was assessed as unlikely to be present in background particulate matter.

As outlined in **Section 2.5**, $PM_{2.5}$ concentrations are most relevant to this HHRA, hence, concentrations of these particles have been presented. $PM_{10}$ concentrations have also been presented for completeness. Northstar (2020) indicates that the maximum modelled incremental concentrations are associated with a worst-case scenario where all material crushing occurs at the Quarry at the highest anticipated rate.

**Table 2.1: Predicted concentrations of $PM_{2.5}$ and $PM_{10}$ (Northstar 2020)**

| Residential property | Maximum predicted concentration (µg/m³) | | | | | |
|---|---|---|---|---|---|---|
| | $PM_{2.5}$ | | | $PM_{10}$ | | |
| | Incremental impact (from the Quarry) | Background | Cumulative concentration | Incremental impact (from the Quarry) | Background | Cumulative concentration |
| **Maximum annual average[1]** | | | | | | |
| Property 3A | 0.2 | 7.2 | 7.4 | 1.3 | 14.1 | 15.4 |
| Property 12 | 0.1 | 7.2 | 7.3 | 0.5 | 14.1 | 14.6 |
| Property 13 | 0.1 | 7.2 | 7.3 | 0.4 | 14.1 | 14.5 |
| Other properties (maximum) | 0.1 | 7.2 | 7.3 | 0.5 | 14.1 | 14.6 |
| **Adopted guideline value [N]** | -- | -- | **8** | -- | -- | **25** |
| **Maximum 24-hour Average Incremental Concentration[1]** | | | | | | |
| Property 3A | 2.9 | -- | -- | 19.9 | -- | -- |
| Property 12 | 0.9 | -- | -- | 5.4 | -- | -- |
| Property 13 | 0.8 | -- | -- | 7.5 | -- | -- |
| Other properties (maximum) | 0.7 | -- | -- | 7.0 | -- | -- |
| **Adopted Guideline Value [N]** | -- | -- | **25** | -- | -- | **50** |
| **Maximum Cumulative 24-hour Average, Property 3A[2]** | | | | | | |
| Existing Operations: Day with Maximum Background | 0.2 | 19.4 | 19.6 | 1.2 | 52.7 | 53.9 |
| Existing Operations: Day with Maximum Incremental Impact | 0.6 | 9.2 | 9.9 | 4.8 | 20.5 | 25.3 |
| Stage 1: Day with Maximum Background | 0.4 | 19.4 | 19.8 | 2.4 | 52.7 | 55.1 |
| Stage 1: Day with Maximum Incremental Impact | 1.7 | 9.2 | 10.9 | 12.1 | 20.5 | 32.6 |
| Stage 2: Day with Maximum Background | 0.5 | 19.4 | 19.9 | 3.3 | 52.7 | 56.0 |
| Stage 2: Day with Maximum Incremental Impact | 2.2 | 9.2 | 11.4 | 15.6 | 20.5 | 36.1 |
| Stage 3: Day with Maximum Background | 0.6 | 19.4 | 20.0 | 3.8 | 52.7 | 56.5 |
| Stage 3: Day with Maximum Incremental Impact | 2.9 | 9.2 | 12.2 | 19.9 | 20.5 | 40.4 |
| **Adopted Guideline Value [N]** | -- | -- | **25** | -- | -- | **50** |

**Notes for Table 2.1:**

1 = Modelling was undertaken for 3 stages of activities. The maximum predicted value from any stage has been presented in the table.

2 = The AQIA provides detailed results for property 3A as this property was predicted to have the highest impacts. The results from days when the incremental impact was predicted to be above 0.1 µg/m³ have been presented in the table.

N = Air guidelines adopted from the Air Quality NEPM (NEPC 2016) and NSW guidance (NSW EPA 2016)

Review of **Table 2.1** indicates an exceedance of the adopted 24-hour average guideline for $PM_{10}$, which occurred for modelling based on all 3 stages of Quarry expansion on 6 May 2015. Northstar (2020) notes that this exceedance is caused by the background air quality and not the incremental impacts from the Quarry. As noted above, background particulate matter is not expected to contain significant levels silica. For other days, the maximum incremental concentrations do not occur with sufficiently high background conditions to result in an exceedance of the air quality guidelines.

Many of the days where elevated levels are reported are likely to relate to bushfire smoke or dust storms (from drought conditions) where the dust generated relates to surface soil.

There were no exceedances of the adopted guidelines at any property for $PM_{2.5}$.

The guidelines adopted by Northstar (2020) as presented in **Table 2.1** are relevant for the assessment of $PM_{2.5}$ generally, and not for the assessment of RCS. Further information in relation to the human toxicity of RCS is provided in **Section 3**. Review of potential health risks from RCS in dust that may be generated from the Quarry and migrate to the adjacent residences is provided in **Section 4**.

This assessment has assumed that 100% of the predicted $PM_{2.5}$ concentration in RCS, which is appropriate based on the measured silica content in the material to be quarried (99.5%).

## 2.7 Summary

This HHRA provides an assessment of potential health risks associated with the potential presence of RCS in dust emitted during the continued operation and extension of the Quarry. The Quarry is located approximately 8 km north-east of Tenterfield in NSW and has been operating at its current location since 1987. The operator of the Quarry is seeking development consent for the continued operation and expansion of extraction activities within the Quarry, including the expansion of the extraction area and the crushing and screening of extracted material at the Quarry, instead of at the Sunnyside Plant (as per current operations). All crushing and screening activities will be undertaken within the Quarry pit. It is understood that this is with the aim of reducing the potential for dust emissions from the Quarry.

Dust emission to air that may occur during operation of the Quarry comprise:

- Clearing of vegetation;
- Emissions from product production and handling including those generated during blasting;
- Wheel generated emissions from product transportation product; and
- Wind erosion of exposed surfaces including stockpiled product.

The modelling undertaken has incorporated dust mitigation measures proposed to be implemented, and are detailed in the AQMP for the Quarry.

The land surrounding the Quarry is agricultural with some residential properties. The closest non-mine owned residential properties to the Quarry are:

- East: Property 10, Property 12 and Property 13; and
- West: Property 3A

Property 10 is currently unoccupied and is further away from the Quarry than the other properties.

An Air Quality Impact Assessment (Northstar 2020), which provides predicted concentrations of 4 types of particles in air at the residences adjacent to the quarry, that were assumed to be sourced from the Quarry, is available for review. Predicted concentrations of TSP, deposited dust, $PM_{10}$ and $PM_{2.5}$ were generated through a modelling exercise that is noted to be conservative based on expected Quarry operations. The AQIA then compared predicted concentrations of particulates in air to guideline values endorsed by the NSW Government as applicable to the residential properties. No exceedances of the guidelines were noted as a result of activities at the Quarry.

This HHRA has focused on particulates of a size that are respirable, as relevant to the assessment of potential health effects from RCS. These particulates comprise the $PM_{10}$ and $PM_{2.5}$ size fractions. $PM_{2.5}$ and smaller is the particle size that may reach the lower parts of the respiratory tract (the smaller bronchioles and alveoli). This is the area of the lungs where gaseous exchange takes place and the area that may be impacted by RCS. Hence the further assessment of exposure to fine particulate matter has focused on particulates reported/evaluated as $PM_{2.5}$, with the consideration of $PM_{10}$ for completeness.

The maximum predicted incremental impact concentrations of $PM_{10}$ and $PM_{2.5}$ generated by the AQIA are summarised in **Table 2.2**. These are the concentrations of particulates considered further in this HHRA, which has assumed that 100% of the predicted $PM_{2.5}$ concentration is RCS. It is noted that the annual average concentration is an average of all the 24-hour averages, and so considers any peaks in concentrations that may occur daily, over a year.

**Table 2.2: Summary of $PM_{2.5}$ and $PM_{10}$ Concentrations ($\mu g/m^3$) (Northstar 2020)**

| Value | Maximum Predicted Concentration | |
|---|---|---|
| | $PM_{2.5}$ | $PM_{10}$ |
| Maximum annual average | 0.2 | 1.3 |
| Maximum 24-hour | 2.9 | 19.9 |

# Section 3. Toxicity assessment

## 3.1 General

The quantitative assessment of potential risks to human health for any chemical requires the consideration of the health end-points and where carcinogenicity is identified; the mechanism of action needs to be understood.

For chemicals that are not carcinogenic, a threshold exists below which there are no adverse effects (for all relevant end-points). The threshold typically adopted in risk calculations (a tolerable daily intake [TDI] or tolerable concentration [TC]) is based on the lowest no observed adverse effect level (NOAEL), typically from animal or human (e.g. occupational) studies, and the application of a number of safety or uncertainty factors. Intakes/exposures lower than the TDI / TC is considered safe, or not associated with an adverse health risk (NHMRC 1999).

Where the chemical has the potential for carcinogenic effects the mechanism of action needs to be understood as this defines the way that the dose-response is assessed. Carcinogenic effects are associated with multi-step and multi-mechanism processes that may include genetic damage, altering gene expression and stimulating proliferation of transformed cells. Some carcinogens have the potential to result in genetic (DNA) damage (gene mutation, gene amplification, chromosomal rearrangement) and are termed genotoxic carcinogens. For these carcinogens it is assumed that any exposure may result in one mutation or one DNA damage event that is considered sufficient to initiate the process for the development of cancer sometime during a lifetime (NHMRC 1999). Hence no safe-dose or threshold is assumed, and assessment of exposure is based on a linear non-threshold approach using slope factors or unit risk values.

For other (non-genotoxic) carcinogens, while some form of genetic damage (or altered cell growth) is still necessary for cancer to develop, it is not the primary mode of action for these chemicals. For these chemicals, carcinogenic effects are associated with indirect mechanisms (that do not directly interact with genetic material) where a threshold is believed to exist.

Dose-response values (threshold or non-threshold) that are considered relevant to the characterisation of potential health effects associated with exposure to the CoPCs identified have been selected from credible peer-reviewed sources as outlined in enHealth (enHealth 2012a) and NEPM (NEPC 1999 amended 2013b).

## 3.2 Respirable crystalline silica

### 3.2.1 General

The US Agency for Toxic Substances and Disease Registry (ATSDR) released an updated Toxicological Profile for Silica in September 2019 (ATSDR 2019). This toxicity profile is based on the information presented in the ATSDR document, with support from other references where indicated.

Silica in the form of quartz is one of the most commonly occurring minerals on the Earth's surface, with over 95% of the earth's crust made of minerals containing silica. There are 2 forms of silica –

crystalline silica and amorphous silica. Amorphous silica lacks a crystalline structure. Two common forms of crystalline silica are quartz and cristobalite.

Silica from quartz is an odourless, white, black, purple or green solid and is generally considered to be insoluble in water and unreactive in the environment. RCS in dust is also considered stable. Amorphous silica is more soluble than crystalline silica, hence, the primary source of dissolve silica in water is amorphous silica. Any silica that does not dissolve settles as sediment.

Silica is naturally released into the environment through the weathering of rocks, volcanic activity and biogenic sources. Hence, background exposures may occur through air, indoor dust, food, water, soil and various consumer products. Crystalline silica has a wide variety of commercial and industrial uses including:

- To produce high-temperature or refractory silica brick, foundry moulds and cores for metal casings;
- To manufacture glass and pure silicon for computer chips;
- As a filler in asphalt, plastics, rubber and paint;
- As an abrasive (e.g. for blasting);
- In sand and gravel used for building roads and in concrete;
- In the water-sand mix used by the oil and gas industry to fracture rock;
- In bricks, mortar, plaster, calk, roofing granules and stone building materials (including benchtops);
- In art clay, glazes and gemstones in jewellery;
- In personal care products such as cleansers and talcum powder and cosmetics; and
- In pet litter and furniture foam.

### 3.2.2 Exposure, absorption and health effects

The exposure route of concern for RCS is inhalation. Exposure to RCS is known to occur in industrial and occupational settings, with RCS recognised as an important occupational inhalation hazard.

The mechanisms that contribute to the absorption of inhaled particles are the physical transformation of particles deposited in the lung (including any surface modification or fragmentation), the dissolution of particles and interactions of particles with macrophages. Macrophages are cells in the immune system that recognise, eat and destroy target cells. The activity of macrophages is the dominant mechanism by which RCS is absorbed from the pulmonary region (referred to as "the lungs" in this review).

After being inhaled, RCS is cleared from the lungs via lymph drainage, macrophage phagocytosis and migration, and upward mucociliary flow. However, the presence of RCS in the pulmonary region also triggers cytotoxicity (toxicity to cells in the lungs) and apoptosis (cell death) leading to impaired clearance of the inhaled RCS. Dissolution does not play a strong role in RCS clearance due to the low solubility of silica. Absorbed RCS is not metabolised but may be transported to the lymph nodes following inhalation and may be excreted in the urine. Hence, inhaled RCS is not easily removed from the lungs.

Health effects associated with inhaled RCS reported in the scientific literature are strictly associated with occupational exposures to particles that are of respirable size (i.e. <10 µm) in silica industries. These effects include acute as well as chronic health effects.

Acute silica exposure causes respiratory tract inflammation. It also stimulates a significant increase in alveolar macrophages, leading to elevated levels of reactive oxygen species (ROS), which plays an important part in inflammation and the production of antioxidant compounds.

When poorly soluble particles, such as RCS, are inhaled they are deposited in the lungs, where long term inflammation results in disease such as silicosis and fibrosis. The prolonged inflammation results in the formation of fibrotic scar tissue and degradation of the muco-ciliary escalator (lung clearance mechanism). The improper repair of damaged lung tissue is essential for the development of chronic disease.

Health effects associated with occupational exposures include silicosis, lung cancer, renal toxicity and autoimmune diseases. The health effects that are generally of greatest concern to humans are silicosis and lung cancer

Silicosis is a progressive and irreversible fibrotic lung disease that has been recognised since Roman and Greek times and is not caused by any substance other than RCS (including amorphous silica). A fibrotic lung disease is a disease where excess fibrous connective tissue is formed in an organ. This type of effect is also referred to as scarring when in response to an injury. Silicosis is caused by inhaling RCS, where the RCS is then deposited on the lungs. There is no known cure for silicosis. There are several types of silicosis:

- **Acute silicosis** is caused by intense exposure to fine RCS dust, such as those generated during blasting or tunnelling. With this disease, the alveolar (the tiny air sacks in the lungs which absorb oxygen) fill with a protein rich fluid containing damaged cells. Inflammation of the lung also occurs. Symptoms include laboured breathing, dry cough, decreased pulmonary function, fever and fatigue followed by cyanosis and respiratory failure;
- **Simple silicosis** is the most common type of silicosis and results from long periods (10 to >20 years) of continuous exposures to relatively low levels of RCS dust (i.e. low levels are those considered to be those above occupational exposure limits, but less than 10 times the occupational exposure limit, refer to **Table 3.1**). Primary function and general health is typically not compromised in the early stages, however, intensity of cough and mucous discharge increases as the disease progresses. Decreases in lung function are often observed (including non-reversible air flow obstruction);
- **Progressive massive fibrosis (PMF)** is a progression of simple silicosis where nodular lung lesions (injuries) grow and come together to form masses of connective tissue that ultimately destroys the lung structures including the blood vessels. This leads to restricted lung volume and poor gas exchange; and
- **Accelerated silicosis** is a progressive form of simple silicosis that develops 5 to 10 years after exposure and is typically associated with moderate exposures (as opposed to simple silicosis which is associated with lower level exposures). Symptoms are similar to those of simple silicosis.

Decreased lung function can also be observed in the absence of silicosis and may be caused by exposures to RCS. This is known as chronic obstructive pulmonary disease (COPD). COPC is characterised by limitation in airflow caused by chronic bronchitis, emphysema, asthma or peripheral airways disease (ATSDR 2019; NIOSH 2002). Cigarette smoking is the main cause of COPD however occupational exposures to dust and community air pollution can also contribute and there are limited studies that link RCS and COPD. No studies have investigated a potential link between RCS and asthma and RCS is not known to cause asthma occupationally.

The most important factor for the development of silicosis is cumulative exposure to RCS. Time from first exposure to onset of symptoms can vary from a few weeks (for acute silicosis) to 20 years or more (for simple silicosis). Disease severity may also slowly increase following cessation of exposure, where RCS is retained in the lungs.

Several studies have looked at whether exposure to RCS causes lung cancer and compared to other occupational lung carcinogens, the reported association is low. However, an increase risk to lung cancer in RCS workers has been reported, with risks dependant on cumulative (successive and ongoing) exposures over times. The available evidence indicates that RCS is genotoxic with the ability to cause mutagenicity and DNA damage.

The major biological processes thought to cause silicosis and lung cancer are shown in **Figure 3.1**, and there appears to be some evidence that silicosis is more prevalent in situations where the silica inhaled is freshly fractured (where the silica particles may generate free radicals).

Exposure to RCS can also cause adverse renal and autoimmune outcomes. However, these effects are not as well studied as silicosis and lung cancer and associations are not evident in all studies. It is considered that renal toxicity occurs at higher exposure levels than silicosis.

Data on health effects following oral exposures to RCS is also limited. However, the available studies do not identify adverse effects in animals following exposures via this route (no data is available for humans). Similarly, adverse effects in humans and animals are expected following dermal exposures.

No information is available in relation to the susceptibility of children to RCS as silicosis is generally considered to be an occupational disease that typically appears after prolonged exposures. The same adverse effects would be expected to appear in children where exposures were similar to adult workers. Individuals with underlying lung and health conditions such as asthma and emphysema may be more susceptible to adverse respiratory effects from inhaled RCS. The risk of silicosis in workers who smoke cigarettes is also higher than in workers who do not smoke.

The presence of silica in the urine indicates that exposure has occurred. However, the presence of silica in the urine does not provide any specific information in relation to exposure levels and/or the potential for adverse health effects.

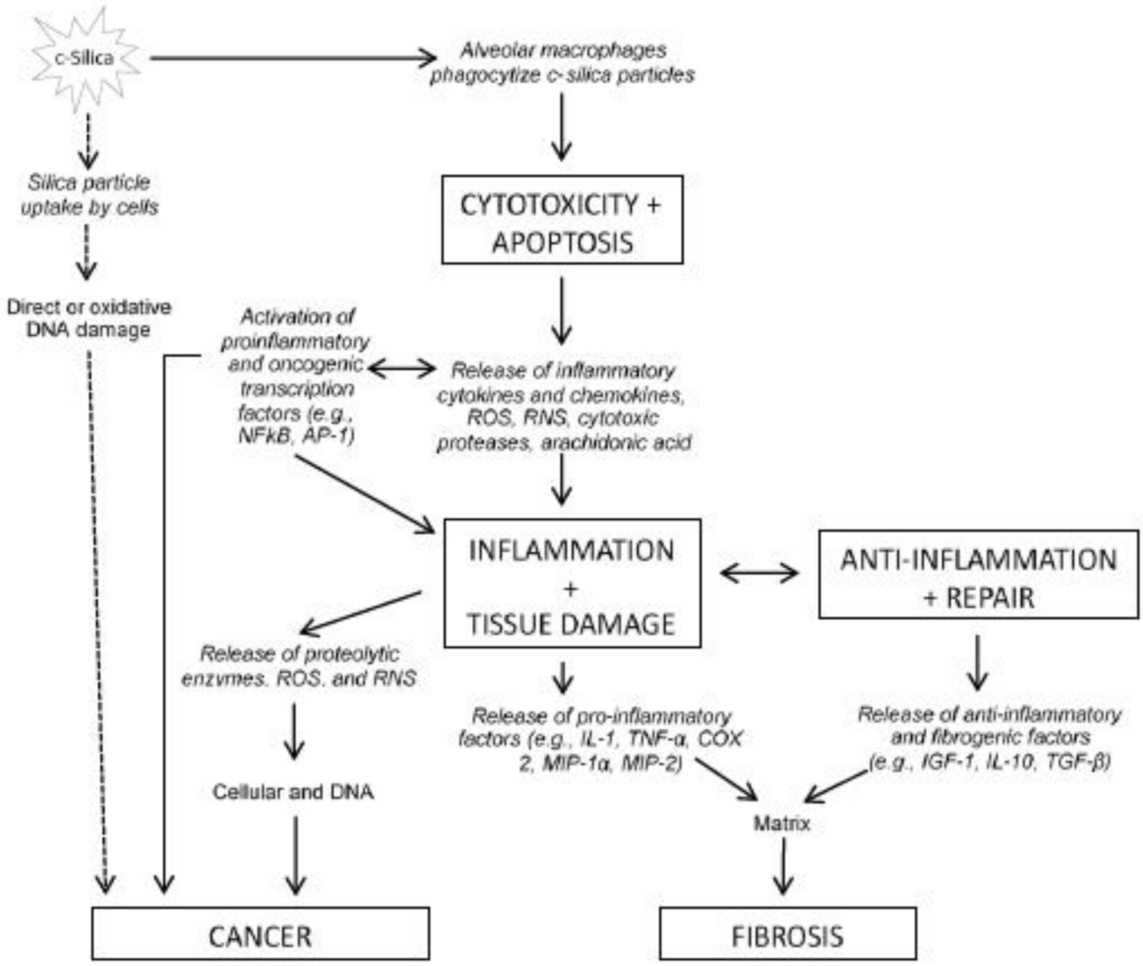



**Figure 3.1: Biological pathways for the formation of silicosis and lung cancer (ATSDR 2019)**

### 3.2.3 Classification

Inhaled crystalline silica dust in the form of quartz or cristobalite, is classified as Group 1 (carcinogenic to humans) by the International Agency for Research on Cancer (IARC) (IARC 2012).

The IARC classification is based on data from human workers in 5 main industrial settings comprising ceramics, diatomaceous earth facilities, ore mining, quarries, and sand and gravel operations. Of these settings, the data from diatomaceous earth facilities, quarries, and sand and gravel facilities was concluded to be least likely to be confounded (i.e. influenced by factors other than the presence of RCS). Most studies from these 3 industries reported associations between RCS exposure and lung cancer risk. Cancers other than lung cancer have not been as thoroughly researched. RCS has been demonstrated to be a lung carcinogen in experimental rats but not in mice and hamsters. It is noted that rats are generally considered more likely to get lung tumours than mice and hamsters. The mechanisms for carcinogenicity is likely to be inflammation. As noted above, RCS is thought to be genotoxic.

TCEQ (2009) notes that the carcinogenic potential of silica is controversial with statistically significant associations observed in some studies but not other studies. This may be due to the specific type of crystalline silica inhaled or on other external factors that affect biological activity and distribution (for example quartz is known to be variable where toxicity may be dependent on the surface characteristics and age of the particles, as well as other factors including confounding). There is epidemiological evidence that the risk of developing lung cancer is higher in workers with silicosis than those without silicosis, however it is not known if silicosis is necessary for the development of lung cancer.

TCEQ (2009) also emphasises that the identification of RCS as carcinogenic relates only to occupational exposures. This is because no epidemiological studies were available to IARC on environmental exposures at the time of the assessment.

The classification of RCS as an occupational carcinogen is supported by ACGIH (2010) which indicates that the consensus amount US and international agencies is that there is a positive association between silica exposures and lung cancer. Most agencies consider that silica does not directly act to initiate cancer, however, do agree that workers that have pulmonary fibrosis (following exposure to silica) are at risk of developing lung cancer (but does not prove that the fibrosis leads directly to lung cancer). However, ACGIG considers that a reduction in worker exposures such that risks from silicosis are eliminated will likely protect against the formation of lung cancer.

Silica is not currently identified by USEPA or TCEQ (TCEQ 2009) as having a mutagenic mode of action and data is not adequate to determine the mechanisms or key steps that are critical for lung cancer development, and hence the potential for increased susceptibility in children due to early life exposure.

### 3.2.4 Quantitative toxicity reference values

Toxicity reference values (TRVs) are quantitative values that are derived by key health authorities to be protective of the health effects that have been identified for a chemical. This involves an understanding of the different types of health effects that have been identified. It is often the case that different health effects occur at different levels of exposure. The detailed reviews that are undertaken by health authorities identify what the most sensitive health effect is and what would be the lowest, or most protective, quantitative value. This is the TRV, and it is established to be protective of all health effects.

For RCS, the information summarised above (and presented in the references noted) has been considered by a number of different health authorities. **Table 3.1** summarises the non-threshold and threshold chronic toxicity reference values (TRVs) that are available for RCS from Level 1 Australian and international sources. Two types of toxicity values are listed in this table:

- **Occupational air guidelines:** these guidelines are applicable to individuals who are exposed to chemicals in the workplace through use or handling, that does not present an unacceptable risk to worker health or cause undue discomfort. These guidelines relate exposures by healthy workers in the workplace, during work hours. The guidelines are higher than ambient or community air guidelines and may be at levels that are mildly irritating; and

- **Community air guidelines:** these guidelines represent the concentration of a chemical in air that, based on the current science, does not present an unacceptable risk to public or community health. These guidelines are based on a range of different studies conducted in animals and humans (from occupational studies or studies in large populations – epidemiological studies), with the application of an uncertainty factors to make sure that the guideline is relevant to the community who may have a range of sensitivities. The uncertainty factors may also take into account any limitations there are with the available studies.

The community air guidelines are the guidelines that are relevant for the assessment of potential health risks to residents that may be exposed to RCS in dust sourced from the Quarry. The occupational air guidelines have been provided for reference, as many of the health effects identified are of most significance for occupational exposures.

**Table 3.1: Summary of relevant TRVs for RCS**

| Source | Value | Basis/Comments |
|---|---|---|
| **Occupational Air Guidelines** | | |
| **Australian** | | |
| Work Safe Victoria[5] | 50 µg/m$^3$ | Time-weighted Average (TWA) for Quartz (respirable dust) and an 8-hour workday during a 40 hour workweek. WorkSafe Victoria recommends that employees are not exposed to levels above 0.02 mg/m$^3$ as a precautionary measure. |
| Safe Work Australia HCIS (Safe Work Australia) (Safe Work Australia 2019) | 50 µg/m$^3$ | TWA for an 8-hour workday during a 40 hour workweek. This TWA has been recently revised down (in December 2019) from 100 µg/m$^3$. The Draft document supporting the derivation of the revised TWA indicates that there is no clear or observable adverse effect concentration (NOAEC) in humans, however concentrations below 25 µg/m$^3$ are considered to be protective of the lungs by ACGIH and multiple data sources identify adverse effects in the lungs at 50 µg/m$^3$ and lung cancer at 65 µg/m$^3$. Concentrations of 20 µg/m$^3$ are considered protective against both silicosis and lung cancer, with lung cancer considered a secondary effect to silicosis. |
| AIOH (AIOH 2009) | 50 to 100 µg/m$^3$ | The Australian Institute of Occupational Hygienists Inc (AIOH) supports the previous Safe Work Australia TWA of 0.1 mg/m$^3$ however indicates that control strategies and health surveillance should be implemented where there is a likelihood of 50% of the TWA being exceeded (i.e. concentrations >0.05 mg/m$^3$). |
| **International** | | |
| WHO (WHO 2000) | None | No threshold or tolerable concentration identified. Recommends that occupational exposures to respirable quartz dust be reduced to the extent practicable. |
| NIOSH (NIOSH 2002) | 50 µg/m$^3$ (respirable fraction) | Recommended Exposure Limit (REL) for RCS and a 10-hour workday during a 40-hour workweek. A no observable adverse effect level (NOAEL) was unable to be determined. The REL recognises that the sampling and analytical methods used to evaluate occupational exposures to RCS are not accurate enough to quantify exposures at concentrations below the REL. The REL is aimed at reducing the risk of developing silicosis, lung cancer and other adverse health effects. Substitution of less hazardous materials is also recommended where feasible.<br><br>NIOSH defines the "respirable" fraction as "*the portion of airborne crystalline silica that is capable of entering the gas-exchange regions of the lungs if inhaled; by convention, a particle-size-selective fraction of the total airborne dust; includes particles with aerodynamic diameters less than approximately 10 µm and has a 50% deposition efficiency for particles with an aerodynamic diameter of approximately 4 µm.*"<br><br>This definition is generally consistent with that used by Safe Work Australia (Safe Work Australia 2013). |

[5] https://www.worksafe.vic.gov.au/dust-containing-crystalline-silica-construction-work

| Source | Value | Basis/Comments |
|---|---|---|
| ACGIH (ACGIH 2010) | 25 µg/m³ (respirable particulate matter) | Threshold Limit Value (TLV) for α-quartz and cristobalite and the protection against both silicosis and lung cancer. RCS classified as A2 – suspected human carcinogen. The TLV is based on the following:<br><u>α-quartz</u><br>Based on no change in longevity of lung function in workers exposed to 50 µg/m³, an increase in risk from silicosis in workers at 60 µg/m³, and an increase in risk from lung cancer in workers at 65 µg/m³. The TLV is based on the association of inflammation and fibrosis with lung cancer following silica exposures. The uncertainties associated with the epidemiological studies are noted and the industrial hygienist is advised to use every means available to keep exposures below the TLV.<br><u>Cristobalite</u><br>TVL for α-quartz recommended as the available human studies indicate a similar toxicity. |
| Cal/OSHA | 50 µg/m³ (respirable fraction) | Permissible Exposure Limit (PEL) enforced in workplaces under the jurisdiction of the California Division of Occupational Safety and Health.[6] The PEL applies to the respirable fraction as defined by NIOSH. |
| OSHA | -- | PEL not considered in HHRA as the PELs are noted by OSHA to be outdated and inadequate for ensuring protection of worker health.[7] |
| **Community Air Guidelines** | | |
| **Australian** | | |
| EPA Victoria (2007) | 3 µg/m³<br>($PM_{2.5}$ fraction) | Annual average assessment criteria for mining and extractive industries for RCS. This is the total concentration of background plus emissions arising from activities at a site. The assessment criteria are used to evaluate the impact of any residual emissions following appropriate controls. The REL from the California EPA Office for Environmental Health Hazard Assessment (OEHHA) has been adopted (refer below). |
| **International** | | |
| TCEQ (TCEQ 2009) | Non-cancer: = 2 µg/m³<br>($PM_4$ fraction)<br><br>Cancer: 0.27 µg/m³<br>($PM_4$ fraction) | Effects Screening Levels (ESLs) for quartz, cristobalite, tripoli and tridymite.<br><u>Non-cancer effects:</u><br>Chronic Reference Value (ReV) based on epidemiological data from 2 studies. The key study involved South African gold miners (Hnizdo and Sluie-Cremer 1993; 2,235 individuals following 24 years exposure mainly to RCS as quartz). The supporting study involved Californian diatomaceous earth workers (Hughes et. al. 1998; 2,342 individuals exposed for at least 1 year to cristobalite). Bench-mark dose modelling was undertaken at the 1% response rate for both studies. The adopted point of departure was in the range 4 to 6 µg/m³. The adopted uncertainty factor (UF) was 3 to account for susceptibility in the general population (including children and the elderly). An UF of 3 was assessed to be adequate as a $BMCL_{01}$ could be derived and the cohort examined was large and therefore assessed to cover sensitive sub-populations. However, the study only included male workers. The derived ReV was 2 µg/m³, based on the rounding of results from both studies. A chronic non-cancer ESL of 0.6 µg/m³ was also derived based on a Hazard Quotient (HQ) of 0.3 (this is not relevant to Australia where the applicable HQ is 1). |

[6] https://www.dir.ca.gov/title8/5155table_ac1.html#_blank
[7] https://www.osha.gov/dsg/annotated-pels/

| Source | Value | Basis/Comments |
|---|---|---|
| | | Cancer:<br>Unit Risk (UR) of $3.6x10^{-5}$ $(\mu g/m^3)^{-1}$ derived based on lung cancer mortality in silica-exposed workers (as pooled by Steenland etc. al. 2001; 65,980 workers from a range of industries) and RCS of ≤4 µm in diameter. The derived chronic ESL (cancer) was 0.00027 mg/m³ at a target risk level of $1x10^5$. |
| Minnesota Department of Health (MDH 2013) | 3 µg/m³<br>(PM fraction not stated) | Non-cancer effects:<br>Chronic Health Based Value (HBV) based on the same key epidemiological study evaluated by TCEQ (2009) (Hnizdo and Sluie-Cremer 1993), with a point of departure of 0.0098 mg/m³ and an UF of 3. The main difference in the TCEQ and MDH assessments was the assumed %RCS in dust inhaled by the workers (30% by MDH versus 54% by TCEQ; a difference of around 2-fold).<br>Cancer:<br>No cancer HBV was calculated. MDH concluded that if exposure to silica is maintained at levels below the Chronic HBV the likelihood of increased risk of developing lung cancer is minimal. |
| California OEHHA (OEHHA 2005) | 3 µg/m³<br>($PM_4$ fraction) | Non-cancer effects:<br>Inhalation Reference Exposure Level (REL) based on the same key epidemiological study evaluated by TCEQ (2009) (Hnizdo and Sluie-Cremer 1993), with a point of departure of 9.8 µg/m³ and an UF of 3. The assumed silica content in dust was 30%. Data from the Hughes et. al. (1998) study and 3 additional supporting studies (Chinese tin miners, Chen et. al., 2001; Dakota gold miners, Steenland and Brown 1995; South African gold miners, Churchyard etc. al. 2004) was also considered. Derived RELs were in the range 3 to 6 µg/m³. The REL applies to the respirable fraction as defined occupationally by ACGIH (2004)/ISO (1995) which has a 50% cut-off point at the 4 µm particle aerodynamic diameter.<br>Cancer:<br>OEHHA notes that RELs are not derived based on cancer endpoints and there are no approved cancer potency factors for silica. |
| Vermont Agency of Natural Resources (2018)[8] | 0.12 µg/m³<br>(PM fraction not stated) | Hazardous ambient air standard (annual average) for crystalline silica as listed in the 2018 Air Pollution Control Regulations. No information available in relation to the derivation of the air standard (information was requested on 7 February 2020, but no information had been provided at the time of this HHRA). This guideline has not been considered further in the HHRA as no information is available in relation to how the guideline has been derived. |

[8] https://dec.vermont.gov/sites/dec/files/aqc/laws-regs/documents/AQCD%20Regulations%20ADOPTED_Dec132018.pdf

As noted above, the community air guidelines presented in **Table 3.1** are the guidelines that are relevant for the assessment of potential health risks to off-site residents that may be exposed to RCS in dust sourced from the Quarry. The community air guidelines are lower than the occupational guidelines by around 10 to 30 times.

International community air guidelines for RCS are similar (2 to 3 µg/m$^3$) and are all based on data from occupational studies on protection against silicosis . The guideline of 3 µg/m$^3$ was first derived by OEHHA (2005), was confirmed by the most recent review undertaken by MDH (2013) and adopted by EPA Victoria (2007). Hence, this guideline has been adopted in this HHRA. This means that exposures to RCS concentrations of less than 3 µg/m$^3$ are considered safe, or not associated with adverse health risks from RCS. A slightly lower guideline of 2 µg/m$^3$ has been derived by TCEQ (2009) but is noted to be based on the same key studies and is not significantly different to 3 µg/m$^3$.

The OEHHA (2005) guideline specifically considered the protection of sensitive members of the population, especially children (as silica particles may penetrate further into the airways) and women (who may be more sensitive than men to the development of silicosis). For this reason, an UF of 3 (and not 1) was used for interspecies variation in the development of the air guideline, as the key studies primarily investigated effects in male workers. MDH (2013) notes that the derived guideline also considers general population exposures and is based on a benchmark concentration low$_{01}$ (BMCL$_{01}$; a value similar to a NOAEL) which is the 95% lower bound estimate of the concentration at which 1% of the population will develop silicosis.

Except for TCEQ (2009), national and international guidelines for cancer effects have not been derived, as silicosis was determined to be the most sensitive effect. i.e. cancer was deemed unlikely to occur at concentrations of RCS below the guideline for silicosis. The rationale for the inclusion of the cancer guideline by TCEQ (2009) appears to be based on the TCEQ policy position in relation to the lack of a clearly identified mode of action for silica toxicity, including the potential uncertainties in the epidemiology studies. In their response to comments on the Draft document outlining the derivation of the guidelines, TCEQ indicate that:[9]

- "*There is not a consensus among the scientific community on whether the carcinogenic mode of action for silica is non-linear or linear or whether silicosis is necessary for the development of lung cancer*".

The opinion of TCEQ (2009) is not supported by the more recent MDH (2013) review who indicate the following:

- *Silica has been classified as a known human carcinogen…because of an observed increase in lung cancers in occupationally exposed workers. There is, however, a large body of evidence that indicates that lung cancer attributed to silica occurs only after repeated insult leads to silicosis. While some controversy remains, MDH has determined that if exposure to silica is maintained at levels below those that result in silicosis the likelihood of increased*

[9] https://www.tceq.texas.gov/assets/public/implementation/tox/dsd/final/october09/comments/responses_silica.pdf

*risk of developing lung cancer is minimal. MDH will continue to monitor this issue and reconsider this decision as new information becomes available.*

In the absence of a definitive mode of action, TCEQ guidance indicates that where chronic adverse effects are determined to be associated with a linear dose-response relationship in the low-dose region, which is typically for chronic exposures to carcinogens, a cancer evaluation should be undertaken. This determination is based on data or science policy default assumptions (TCEQ 2006).

Irrespective of the above, IARC is clear that the determination that RCS is carcinogenic relates only to occupational exposures. For this reason, the TCEQ (2009) cancer guideline has not been adopted in this HHRA, however has been considered further in the uncertainty analysis (refer to **Section 4.3**).

In relation to the OEHHA (2005) community air guideline (REL), the background document notes that there is an absence of comprehensive data on the ability of different particle sizes to induce silicosis, hence, it is not possible to adjust the guideline for different size particle distributions (e.g. as might be measured at a particular site). Further, while silicosis is generally assumed to be induced by the fraction that reaches the alveoli (with the majority of particles around 4 µm), there is no data to confirm a lack of adverse effects for coarser particles of 4 to 10 µm. The guideline therefore applies to particles that are defined as "occupationally respirable". Given this:

- $PM_{2.5}$ and $PM_{10}$ concentrations ≤3 µg/m$^3$ would not be expected to be associated with adverse health effects;
- $PM_{10}$ concentrations >3 µg/m$^3$ require further investigation and/or risk management; and
- $PM_{2.5}$ >3 µg/m$^3$ < $PM_{10}$ concentrations may require further investigation, including a more precise determination of the respirable fraction.

It is noted that Victoria (EPA Victoria 2007) has adopted the OEHHA (2005) guideline for RCS as $PM_{2.5}$. This has also been adopted in this assessment, as modelling of particulates has focused on $PM_{2.5}$ and $PM_{10}$.

## 3.3 Environmental silicosis

As noted above, RCS is recognised as an important occupational inhalation hazard. However, information in relation to the potential for silicosis in the general population is less available.

ATSDR (2019) indicates that the primary route of exposure to RCS in the non-occupational population is through to be via the inhalation of RCS during the use of commercial products containing quartz. People who live near quarries, sand or gravel operations or hydraulic fracturing operations may be exposed to RCS in dust. However, to date adverse health effects associated with inhaled RCS have been strictly associated with occupational exposures to particles that are of respirable size (i.e. <10 µm). Adverse effects of RCS have not been reported for incidental exposure to low levels of RCS in the environment (e.g. in beach sand) or from exposures that exceed the respirable size fraction.

A USEPA report into ambient levels of RCS indicates that environmental silicosis is not a well-defined term (USEPA 1996). Although some studies have reported silicosis in the absence of occupational exposures, most studies reporting pulmonary aliments following ambient dust exposures are from underdeveloped arid regions of the world, and in general, the studies lack control patients and/or specific silica dust exposure measurements. These studies often do not clearly differentiate between occupational and environmental exposures. OEHHA (2005) confirms that several international studies have reported environmental silicosis, which is where the silicosis occurs in the absence of an industry usually associated with the disease. However, in the instances reviewed, the exposures were high and therefore considered to be the same as occupational exposures, or to express this another way, higher than exposures by most of the population.

The main example provided by OEHHA (2005) (and by other reviews in the scientific literature) is the instances of pneumoconiosis in Ladakh, India. Pneumoconiosis is a group of diseases of the lung caused by the inhalation of dust, which include silicosis. The Ladakh area is high in the western Himalayas where there are no mines or industries. In around 450 randomly selected inhabitants across three villages (Saboo, Shey and Chushot), the prevalence of pneumoconiosis was 2.0% (3/150) in Saboo, 20.1% (31/149) in Shey and 45.3% (68/150) in Chushot. The prevalence of pneumoconiosis was observed to correspond with the severity of dust storms and the presence or absence of chimneys in kitchens. Without chimneys (Chushot), dust concentrations in kitchens averaged 7,500 $\mu g/m^3$ during cooking periods. The free silica content of the dust storms was 60-70%. The authors suggested that the pneumoconiosis was due to exposure to free silica from dust storms and to soot from cooking with domestic fuels (with effects potentially affected by the interaction of silica and soot). Similar findings have been reported following studies with Bedouin women who undertake work including spinning wool, cooking and cleaning tents, in individuals involved in occupations with high exposures to silica dust such as farmers or woodworkers (USEPA 1996) and in other Himalayan villages that are exposed to frequent dust storms (Bhagia 2012). These situations could also be considered equivalent to exposures adjacent to industries in developing countries such as India and South Africa (refer to **Table 3.2**) where monitoring and/or risk mitigation measures are not routinely implemented.

There is evidence of silicosis among domesticated grazing animals (horses, camels and water buffalo). This indicates the potential for environmental silicosis however the specific relevance of these findings to humans is not clear. It is also noted that the utilised diagnostic techniques (e.g. chest X-rays) may have overlooked low levels of environmental silicosis in the general population, particularly in dusty/arid regions (USEPA 1996).

As noted above, some key limitations of the studies in the scientific literature relating to environmental silicosis is data on concentrations for RCS in air that the study population was exposed to, as well as the presence of confounding exposures (in particular particles from cooking and heating with no controls). However, data is available from 2 air monitoring studies undertaken in the USA and UK where RCS concentrations were reported. This data is summarised below.

Air monitoring for RCS was undertaken in Wisconsin USA between 2012 to 2014 in response to community concern in relation to ambient RCS concentrations adjacent to frac sand production facilities (Richards & Brozell 2015). Multi-year sampling programs were undertaken adjacent to 4 facilities, of which 3 were frac sand mines and 1 was a frac sand processing plant. Sampling locations were around 600 to 1,300 m from the facilities and considered the prevailing wind direction/s. A total of 2,128 24-hour average sample values were available, across the 8 sampling locations at the 4 facilities.

The RCS concentration in the $PM_4$ fraction was measured, with 88% of samples reporting RCS below the limit of reporting of 0.31 µg/m$^3$. Geometric means of 0.22 to 0.41 µg/m$^3$ were reported for the analysed yearly datasets, depending on the data analysis approach adopted. 99% concentrations were in the range 0.31 to 1.44 µg/m$^3$. The difference between upwind and downwind sampling locations was small at all 4 facilities, with no detectable change on 78% of days. Maximum background RCS concentrations were in the range 0.56 to 2.10 µg/m$^3$ (averages in the order of 0.02 to 0.3 µg/m$^3$). The study concluded that the measured RCS concentrations adjacent to the facilities is within the background range.

Air monitoring was undertaken at and in the vicinity of 7 construction sites in the UK to estimate inadvertent exposures to RCS as a result of the activities (Stacey, Thorpe & Roberts 2011). In total, 48 samples were collected from construction sites with 11 air samples collected from adjacent areas occupied by the community. The sites assessed included demolition, block cutting, road building and general construction activities. The sampling reported evidence of RCS transport from the construction sites to the adjacent public areas, with similar crystalline components reported in both types of samples. RCS concentrations were generally reported to be low for all sites with the exception of several samples from block cutting and demolition activities which reported maximum RCS concentrations of 11.9 µg/m$^3$. RCS concentrations in urban area air in the range 0.08 to 0.44 µg/m$^3$.

Information is also available from 3 sites in Australia (including 2 sites in Queensland) where monitoring for RCS has been undertaken in the vicinity of quarrying or tunnelling sites in response to community concern. These studies are discussed below.

***Darlington Range, Queensland***

Information is available from air sampling undertaken by the Queensland Government Department of Science, Information Technology and Innovation, to investigate air quality in the residential suburbs bordering the 6 large hard rock quarries in Ormeau and Yatala in South-East Queensland (DSITI 2017). At Yatala, monitoring was undertaken at a private residence approximately 1.6 km north of the nearest quarry and 150 m from the road used by trucks to transport quarry products. At Ormeau, monitoring was undertaken at a private residence approximately 500 m east of the nearest quarry. Weekly sampling for $PM_{2.5}$ samples for crystalline silica analysis was undertaken at both sites between September 2015 and November 2016.

The 7-day crystalline silica concentration reported in the $PM_{2.5}$ fraction was compared to the OEHHA (2005) Reference Exposure Level (REL; refer to **Table 4.1**) of 3 µg/m$^3$. Maximum 7-day crystalline silica concentrations at both sites were reported to be low, with concentrations of 0.07 µg/m$^3$ reported at Ormeau and concentrations of 0.13 µg/m$^3$ reported at Yatala. The average 7-day concentration was 0.03 to 0.04 µg/m$^3$, with crystalline silica above the limit of reporting only measured in 8 to 14% of samples. On this basis, it was concluded that dust emissions from local quarries contain very low concentrations of RCS that are not expected to result in adverse health impacts. This is noted in the report to be like another site investigated by the Department at Mount Cotton.

Continuous monitoring was also undertaken for $PM_{2.5}$ and $PM_{10}$, with the following average concentrations reported ($PM_{10}$ samples were not analysed for crystalline silica):

- Yatala: $PM_{2.5}$ of 4.5 to 5µg/m$^3$ and $PM_{10}$ of 12 µg/m$^3$; and
- Ormeau: $PM_{2.5}$ of 4.3 to 5 µg/m$^3$ and $PM_{10}$ of 18.3 µg/m$^3$.

***Brisbane, Queensland***

Monitoring for RCS was undertaken by the Queensland Government Air Quality Sciences Unit of the Department of Environment and Resource Management to investigate potential health effects from the inhalation of silica dust from the Airport Link/Northern Busway construction works at Lutwyche, Brisbane, Queensland (DERM undated). The monitoring was undertaken in response to community concerns in relation to dust emanating from the construction works. The report indicates that RCS is a potential component of airborne dust from the construction works due to the need to tunnel through granite, quartz and sandstone.

The monitoring measured concentrations of crystalline silica in the $PM_{10}$ and $PM_{2.5}$ fractions at 2 sites in Lutwyche, including at a private residence adjacent to the southern end of the construction works and a church to the east of the works area. Monitoring was undertaken over a 7-day period on 16 occasions between April and August 2011. The average overall 7-day crystalline silica concentration was 0.57 to 1.43 µg/m$^3$ in the $PM_{10}$ fraction and 0.57 to 1.21 µg/m$^3$ in the $PM_{2.5}$ fraction, with the following concentration range reported:

- 7-day $PM_{10}$ fraction site 1: 0.22 to 1 µg/m$^3$;
- 7-day $P_{2.5}$ fraction site 1: 0.21 to 0.97 µg/m$^3$;
- 7-day $PM_{10}$ fraction site 2: 0.5 to 3.72 µg/m$^3$; and
- 7-day $PM_{2.5}$ fraction site 2: 0.21 to 2.17 µg/m$^3$.

The difference in concentrations at site 1 and site was concluded to be due to wind, which favoured the migration of dust towards site 2. Measurements at site 2 were concluded likely to be representative of worst-case weather conditions. Significant effects due to rainfall were not noted.

Consistent with the DSITI (2017) assessment, RCS concentrations reported in dust were compared to the OEHHA (2005) REL of 3 µg/m$^3$. This guideline was adopted as there are no Queensland community air guidelines for RCS, however the report notes that the OEHHA guideline has been adopted by Victoria. The guideline was compared to the report $PM_{2.5}$ and $PM_{10}$ concentrations as sampling equipment is not available to measure RCS concentrations of 3 µg/m$^3$ or less. Given the similarity of reported $PM_{2.5}$ and $PM_{10}$ concentrations at both sites, and that overall average concentrations of both size fractions were below the adopted guideline, it was concluded that adverse health effects within the community from RCS from the works were unlikely.

***Hunter Valley, NSW***

An air quality study undertaken at 2 locations in the Hunter Valley airshed in NSW in the vicinity of operating open-cut coal mines (Morrison & Nelson 2011). This study reported RCS concentrations of 0.5 to 1.8 µg/m$^3$ for the $PM_4$ fraction and 0.2 to 1.4 µg/m$^3$ for the $PM_{2.5}$ fraction. Given that these concentrations were below the OEHHA (2005) guideline of 3 µg/m$^3$ it was concluded that adjacent populations were not at risk of silica induced disease.

## 3.4 Background intakes

ATSDR (2019) indicates that silica containing airborne dust is present in the environment as a result of the widespread natural occurrence and use of silica-containing products and materials. Local meteorological conditions can cause elevated concentrations of silica in dust, most notably in areas around recent volcanic eruptions and deserts (desert dust consists of fine particles, <10 µm, with a higher percentage of quartz). Monitoring has indicated that remote continental air contains a background dust concentration of 0.04 mg/m$^3$, of which ≥10% (i.e. ≥0.004 mg/m$^3$) may be crystalline silica. TCEQ (2009) indicates that the average ambient RCS is 1.9 µg/m$^3$, with a range of 0.3 to 5 µg/m$^3$. This is slightly lower than other estimates for the USA which indicate average quartz levels in metropolitan areas of 1.1 to 8 µg/m$^3$ (average of 3.2 µg/m$^3$) (Bhagia 2012).

ATSDR (2019) provides a summary of studies that have measured ambient RCS concentrations in urban environments, including those adjacent to silica industries. The available data is summarised in **Table 3.2**.

**Table 3.2: Summary of measured RCS or quartz concentrations in urban environments[1]**

| Location | Concentration (µg/m$^3$) | Comments |
|---|---|---|
| **Background Locations** | | |
| USA | 0.9 to 8 | 24-hour ambient concentration of RCS sourced from 2.5 to 5 µm quartz in urban areas, as measured at 22 sites in several different states. |
| California, USA (WDNR 2010) | 1.2 to 3.5 | Silica concentration in $PM_{10}$ fraction from 12 samples collected in urban areas. |
| | 0 to 1.4 | Silica concentration in $PM_{10}$ fraction from 16 samples collected in rural areas. |
| | 0 to 1.2 | Silica concentration in $PM_{10}$ fraction from 18 samples collected in remote background areas. |
| California, USA (Bhagia 2012) | 1.1 to 1.3 | Based on reported $PM_{10}$ concentrations of 18.2 and 18.9 µg/m$^3$ with a 6-7% silica content. |
| Rome, Italy | 0.25 to 2.9 | As total $PM_{10}$ with a mean diameter range of 0.3 to 10.5 µm where >87% of particles had a diameter of <2.5 µm. Silica concentrations in dust thought to be from the Sahara Desert as carried to Mediterranean Europe via the Southern Winds. |
| Tokyo, Japan | ≤34 | Concentration of quartz in air samples (no information on silica concentration or potential sources). |
| **Locations Adjacent to Silica Industries** | | |
| California, USA | 26 to 97 | Airborne quartz concentration up to 750 m downwind a sand and gravel facility. $PM_{10}$ concentrations were in the range 26 to 1,026 µg/m$^3$. |
| | 4 to 16 | Background (upwind) quartz readings. |
| California, USA | <0.3 to 2.8 | RCS (as $PM_4$) concentrations up and downwind of a quarry and processing plant. The 8-hour working shift $PM_{10}$ RCS concentration was 1 to 19 µg/m$^3$. This study was sponsored by the US National Stone, Sand & Gravel Association with samples collected down wind of 4 crushing plants processing high-quartz-context rock. |
| Minnesota, USA | <1 to 7 | RCS (as $PM_4$) concentrations in ambient air near industrial sand mining, processing and transport sites. |
| Minnesota, USA (Richards & Brozell 2015) | 0.4 to 1.3 | Maximum RCS concentrations adjacent to 2 frac sand operations. |
| Gansu Province, China | ≤5,720 | Dust, comprising fine particles of <5µm, from sandy areas during the windy season. Dust concentration was 8,350 to 22,000 µg/m$^3$ of which 15 to 26% was free silica. |
| India | 41 to 57 | $PM_{10}$ quartz concentration near an industrial slate pencil site. |
| | 3.5 | $PM_{10}$ quartz concentration at a control site for the industrial slate pencil site (5 km away) |

| Location | Concentration (µg/m³) | Comments |
|---|---|---|
| India | 31 to 67 | Based on average ambient air $PM_{2.5}$ at two villages near stone crushing sites and a silica content of up to 24%. |
| | 120 to 156 | Based on average ambient air $PM_4$ at two villages near stone crushing sites and a silica content of up to 24%. |
| | 110 to 185 | Based on average ambient air $PM_{10}$ at two villages near stone crushing sites and a silica content of up to 24%. |
| | 1,082 to 1,956 | Based on ambient air $PM_4$ at stone crushing site and a silica content of up to 24%. |
| India (Bhagia 2012) | 15.3 | Average concentrations of crystalline silica (quartz) at 4 sites in the vicinity of agate industry. Control locations reported a concentration of 3 µg/m³. |
| South Africa (Andraos, Utembe & Gulumian 2018) | 17.4 to 34.9 | $PM_4$ via personal monitoring approximately 0.2 to 7 km away from a tailing storage facility (8 sampling locations). |

**Notes:**

1 = Ref. ATSDR (2019) unless otherwise noted.

Review of the above data indicates that where there are specific industries that generated RCS, and these are unmanaged (in terms of dust), levels of RCS in air adjacent to these facilities is significantly elevated (reference data for China and India). Levels adjacent to such industries are lower where dust generation is better managed (such as a number of sites in the US).

Where there are no specific RCS industries present background levels are lower. The average ambient RCS value of 1.9 µg/m³ from TCEQ (2009) is considered a reasonable average that reflects an annual average exposure. This value is higher than the background levels reported in the Darlington Range in Queensland and similar to average values reported in Brisbane and the Hunter Valley (refer to **Section 3.3**), noting that all these sites are near RCS generating industries. Hence adopting a background of 1.9 µg/m³, which is assumed to be as $PM_{2.5}$, in this assessment is expected to be conservative.

# Section 4. Assessment of health risks

## 4.1 General

This section presents a screening level assessment of potential health risks relevant to residents in properties adjacent to the Quarry who may inhale dust containing RCS.

## 4.2 Screening level assessment of health risks

The assessment of potential risks to residents has been undertaken via a screening level assessment. This has involved comparison of the predicted level of RCS in the air within the community with the health-based guideline identified in **Section 3**.

The health based guideline adopted for this assessment is 3 µg/m$^3$ of RCS (OEHHA 2005) (EPA Victoria 2007). This guideline relates to an annual average concentration of RCS as $PM_{2.5}$ in air, where the community may be exposed. This guideline relates to total exposures to RCS.

In relation to exposures that may occur within the community, the following has been considered:

- Existing or background exposures to RCS – no data is available for the area near the Quarry, hence expected background level of RCS in air as discussed in **Section 3.4**, of 1.9 µg/m$^3$ has been adopted in this assessment. It is assumed that this background relates to RCS as $PM_{2.5}$.
- Impacts from the proposed Quarry operations – this has been modelled for the project, with the maximum incremental increase in annual average $PM_{2.5}$ predicted to be 0.2 µg/m$^3$ (refer to **Table 2.1**). It is assumed that 100% of the $PM_{2.5}$ is RCS.
- Total maximum annual average RCS exposures as $PM_{2.5}$ are therefore 2.1 µg/m$^3$, noting that the Quarry is contributing only 9.5% of the cumulative exposure, with the remainder being assumed natural background exposure.
- This is less than the adopted guideline of 3 µg/m$^3$.

On this basis, there are no health risk issues of concern in relation to community exposures to RCS in dust that may be sourced from the Quarry.

## 4.3 Uncertainties

### 4.3.1 General

This HHRA comprises a screening level assessment where it has been assumed that predicted concentrations of $PM_{2.5}$ in air at residential properties adjacent to the Quarry comprise 100% silica. The predicted $PM_{2.5}$ concentrations have been sourced from the AQIA (Northstar 2020) which has been undertaken in accordance with National and State requirements and has undergone review by NSW EPA. The predicted $PM_{2.5}$ concentrations are based on a modelling exercise, where there is some uncertainty, however it is noted that incremental annual average $PM_{2.5}$ concentrations are at least 15 times below the adopted screening level guideline. As discussed in **Section 3**, this screening level guideline has been derived using a conservative process and is protective of all members of the community including sensitive individuals and children. The adopted screening level guideline is also supported by other international reviews.

However, as there are uncertainties throughout all stages of any risk assessment, it is important to consider how these uncertainties impact on the assessment presented. This uncertainty analysis has considered:

- The slightly lower screening guideline derived by TCEQ (2009) for the protection of silicosis;
- The TCEQ (2009) screening level guideline for the protection of lung cancer;
- The predicted maximum 24-hour average $PM_{2.5}$ concentrations;
- The predicted $PM_{10}$ concentrations; and
- The assumed silica content in dust.

Further discussion is provided below.

### 4.3.2 TCEQ (2009) TRVs

TCEQ (2009) has derived a slightly lower screening level guideline, 2 µg/m$^3$ versus the 3 µg/m$^3$ adopted in the HHRA. This guideline is based on the same key toxicity studies but a different assumed silica content in dust that workers in the original study (e.g. the South African gold miners) were exposed to. From the differing views of the international organisations, it appears that the silica content that these workers were exposed to was not well documented/explained. Hence the assumptions adopted by TCEQ (2009) were more conservative.

For the assessment of potential risk, TCEQ provided a guideline relevant to the protection of silicosis of 2 µg/m$^3$. This guideline relates to a threshold assessment of total exposure to RCS. The maximum predicted concentrations of RCS in the community (including background) is essentially equal to this guideline. Where only the impact form the Quarry is considered the maximum incremental exposure 0.2 µg/m$^3$ is 10 times below this guideline.

For the assessment of lung cancer effects, TCEQ (2009) adopted a non-threshold approach (which is different from other health agencies). This calculation relates to an incremental lifetime cancer risk and can only be compared with the incremental change in RCS predicted as a result of the project. The maximum increased in RCS predicted in the community from Quarry operations is 0.2 µg/m$^3$, which is below the incremental guideline of 0.29 µg/m$^3$ established by TCEQ.

On the basis of the above review, consideration of the TRVs established by TCEQ (2009) does not change the outcome of the assessment presented in this report – that there are no risk issues of concern in relation to community exposure to RCS derived from the proposed Quarry operations.

In addition, the following can also be noted:

- A predicted incremental annual average $PM_{2.5}$ concentration of 0.1 µg/m$^3$, which is 20 times below the guideline for silicosis and 2 to 3 times below the guideline for lung cancer, were predicted at all adjacent residential properties except Property 3A (refer to **Table 2.1**);
- As noted above, IARC is clear that the determination that RCS is carcinogenic relates only to occupational exposures. Hence, the comparison of $PM_{2.5}$ concentrations with the screening level guideline derived by TCEQ (2009) for protection against cancer is conservative and expected to overestimate these risks in the community; and
- The AQIA indicates that the assessment undertaken is designed to be protective of worst-case activities at the Quarry.

### 4.3.3 Maximum 24-hour average $PM_{2.5}$ concentrations

The AQIA also predicts a maximum incremental 24-hour average $PM_{2.5}$ concentration of 2.9 µg/m$^3$ at the adjacent residences (specifically Property 3A). The screening level guideline adopted in the HHRA is for chronic (long-term) exposures, not for short-term peaks such as a 24-hour average.

The daily peaks in the concentrations are all considered in the calculation of an annual average concentration. Hence, it is not appropriate to compare the chronic screening level guideline adopted in the HHRA with the maximum 24-hour average concentration.

TCEQ (2009) derived a screening level guideline for acute exposures (a ReV) of 47 µg/m$^3$. Maximum incremental 24-hour average $PM_{2.5}$ concentrations at Property 3A are 16 times below this acute guideline. In addition all cumulative concentrations of $PM_{2.5}$ (assuming 100% of all $PM_{2.5}$ is RCS, which is not the case for background $PM_{2.5}$) are below this guideline.

It is also noted that maximum 24-hour average $PM_{2.5}$ concentrations are well below the workplace exposure guidelines (which range from 25 to 100 µg/m$^3$; with a quoted safe level in the order of 20 µg/m$^3$) (ACGIH 2010). The workplace exposures guidelines are not relevant to acute exposures, they cover longer duration exposures for 8 hours per day over a 40-hour workweek.

On this basis, there are no acute (short-term) health risk issues of concern for the off-site community in relation to concentrations of RCS in dust that may be sourced from the Quarry.

### 4.3.4 $PM_{10}$ concentrations

In this uncertainty analysis, $PM_{10}$ concentrations have also been reviewed against the adopted screening level guideline given the recommendations of OEHHA (2005) which indicates that where $PM_{2.5}$ < 3 µg/m$^3$ but $PM_{10}$ > 3 µg/m$^3$ concentrations may require further investigation, including a more precise determination of the respirable fraction (including the silica concentration in this fraction). As noted above, Victoria (and subsequently other states including NSW and Queensland) has adopted the OEHHA (2005) guideline for RCS as $PM_{2.5}$, and do not compare $PM_{10}$ concentrations to the guideline. Hence, the approach adopted is conservative. There is no information on background levels of RCS as $PM_{10}$, hence it is not possible to consider total exposures.

The maximum modelled incremental increase in annual average $PM_{10}$ associated with Quarry activities presented in the AQIA was 1.3 µg/m$^3$. If this was assumed to be 100% RCS, then this is below the adopted guideline of 3 µg/m$^3$.

This assumes that all the $PM_{10}$ can be inhaled and would penetrate deep into the lungs, which is conservative, as only particles smaller than $PM_5$ are sufficiently small to penetrate deep enough into the lungs to be of concern. $PM_{2.5}$ comprises a proportion of $PM_{10}$.

A maximum incremental 24-hour average $PM_{10}$ concentration of 19.9 µg/m$^3$ was reported by the AQIA for Property 3A. As discussed above, comparison of this concentration to the adopted screening level guideline for long-term (chronic) health effects is not appropriate, even assuming that all the $PM_{10}$ is respirable. Maximum 24-hour average concentrations are however noted to be below the TCEQ (2009) acute guideline by around 2 times, which is an appropriate comparison, and below workplace exposure guidelines (ACGIH 2010).

On the basis of the above, consideration of the potential impact of the modelled concentrations of $PM_{10}$, and assuming these are 100% RCS, does not change the outcome of the assessment presented in this report – that there are no risk issues of concern in relation to community exposure to RCS derived from the proposed Quarry operations.

### 4.3.5 Assumed silica content in dust

One difference in the way the community air guidelines have been derived for RCS by international agencies is the assumed concentration of silica in dust that the workers in the key studies evaluated were exposed to. For example, for the same key study identified by 2 agencies, the proportion of silica in dust that workers were exposed to was assumed to be 30% by MDH (2013) and 54% by TCEQ (2009). The actual silica content in the dust the workers were exposed to is not known as it was not measured in the workplace.

This HHRA has assumed that the silica content in dust generated from the Quarry is 100%.

Unfortunately, a straightforward adjustment of air guidelines is problematic due to the different modelling methodologies adopted by the agencies and because the silica content that the workers in the study were initially exposed to is unclear. However, if a guideline of 3 µg/m$^3$ is derived for a silica content of 30% and a guideline of 2 µg/m$^3$ is derived for a silica content of 54%, a guideline for a silica content of 100% could be 2 to 3 times lower than the available guidelines. This may mean a guideline of around 0.7 to 1.5 µg/m$^3$. Predicted concentrations of $PM_{2.5}$ in air derived from the quarry where 100% RCS is assumed (maximum of 0.2 µg/m$^3$) are still below these alternative guidelines.

# Section 5. Conclusions

Based on the available data and the scope of this assessment, it has been concluded that health risks to residents in existing properties adjacent to the Quarry are low and acceptable.

Environmental Risk Sciences Pty Ltd has undertaken a human health risk assessment (HHRA) in relation to the potential presence of respirable crystalline silica (RCS) in dust emitted during the continued operation and extension of Dowe's Quarry. It is noted that limitations apply to the outcomes due to the focus of this assessment on RCS and the uncertainties identified and analysed in the report.

The HHRA has addressed human health risk issues relevant to RCS that may be present in dust sourced from the Quarry and the ongoing low-density rural/residential use of the existing properties adjacent to the Quarry.

No additional dust mitigation measures are recommended for operations assuming the proposed dust mitigation measures including the planned air monitoring program are implemented. It is recommended that PM2.5 and PM10 samples captured for monitoring are subject to laboratory analysis for silica concentration. This is recommended to confirm the concentrations of silica in these PM fractions, that adjacent receptors may be exposed to.

Standard dust mitigation measures including dust suppression through chemical and water means, the tarping of loads, inspection of truck tyres and street sweeping should also continue for the operation. The proposed extension to the seal on the Quarry Access Road to a total length of 800m is supported.

# Section 6. References


ACGIH 2010, *Silica, Crystalline - a-Quartz and Cristobalite*, American Conference of Governmental Industrial Hygienists.

AIOH 2009, *AIOH Position Paper: Respirable Crystalline Silica and Occupational Health Issues*, Australian Institute of Occupational Hygienists Inc, February 2009.

Andraos, C, Utembe, W & Gulumian, M 2018, 'Exceedance of environmental exposure limits to crystalline silica in communities surrounding gold mine tailings storage facilities in South Africa', *Science of The Total Environment,* vol. 619-620, 2018/04/01/, pp. 504-16.

ATSDR 2019, *Toxicological Profile for Silica*, U.S. Department of Health and Human Services, Agency for Toxic Substances and Disease Registry.

Bhagia, LJ 2012, *Non-occupation exposure to silica dust*, Indian J Occup Environ Med. 2012 Sep-Dec; 16(3): 95–100.

DERM undated, *Health Risk Assessment of Community Exposure to Silica from Airport Link / Northern Busway Construction Activities*, Environmental Health Science and Regulation Unit, Environmental Health Branch, Queensland Health.

DSITI 2017, *Ormeau/Yatala air quality investigation*, Queensland Government Department of Science, Information Technology and Innovation.

enHealth 2012a, *Environmental Health Risk Assessment, Guidelines for assessing human health risks from environmental hazards*, Commonwealth of Australia, Canberra. <http://www.health.gov.au/internet/main/publishing.nsf/content/804F8795BABFB1C7CA256F1900045479/$File/DoHA-EHRA-120910.pdf >.

enHealth 2012b, *Australian Exposure Factors Guide*, Commonwealth of Australia, Canberra. <http://www.health.gov.au/internet/main/publishing.nsf/Content/health-pubhlth-publicat-environ.htm>.

IARC 2012, *Arsenic, Metals, Fibres, and Dusts, IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 100C*, Arsenic, Metals, Fibres, and Dusts

IARC Monographs on the Evaluation of Carcinogenic Risks to Humans Volume 100C.

MDH 2013, *Chemical Name: Silica, Crystalline (respirable PM4), 2013 Health Based Value for Ambient Air*, Minnesota Department of Health.

Morrison, A & Nelson, P 2011, *Quantification, speciation and morphology of respirable silica in the vicinity of open-cut coal mines in the Hunter Valley, NSW*, Macquarie University Graduate School of the Environment.

NEPC 1999 amended 2013a, *Schedule B1, Guideline on Investigation Levels For Soil and Groundwater, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

NEPC 1999 amended 2013b, *Schedule B4, Guideline on Health Risk Assessment Methodology, National Environment Protection (Assessment of Site Contamination) Measure*, National Environment Protection Council. <https://www.legislation.gov.au/Details/F2013L00768/Download>.

NEPC 2016, *National Environment Protection (Ambient Air Quality) Measure*, Federal Register of Legislative Instruments F2016C00215.

NHMRC 1999, *Toxicity Assessment for Carcinogenic Soil Contaminants*, National Health and Medical Research Council.

NIOSH 2002, *Health Effects of Occupational Exposure to Respirable Crystalline Silica*, DEPARTMENT OF HEALTH AND HUMAN SERVICES Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, April 2002.

NSW EPA 2016, *NSW EPA Approved Methods for the Modelling and Assessment of Air Pollutants in NSW*, NSW Environment Protection Authority, 2016.

OEHHA 2005, *Adoption of Chronic Reference Exposure Levels for Silica (crystalline, respirable)*, Office of Environmental Health Hazard Assessment, Califironia.

Richards, J & Brozell, T 2015, *Assessment of Community Exposure to Ambient Respirable Crystalline Silica near Frac Sand Processing Facilities*, Atmosphere 2015, 6, 960-982; doi:10.3390/atmos6080960.

Safe Work Australia, *Hazardous Substances Information System*, Safe Work Australia. <http://www.hsis.safeworkaustralia.gov.au/HazardousSubstance>.

Safe Work Australia 2013, *Guidance on the Interpretation of Workplace Exposure Standards for Airborne Contaminants*, Safe Work Australia.

Safe Work Australia 2019, *Silica, Crystalline (Respirable Dust)*, Draft Evaluation Report for the Revision of the Workplace Exposure Standards.

Stacey, P, Thorpe, A & Roberts, P 2011, *Levels of respirable dust and respirable crystalline silica at construction sites*, UK Health and Safety Executive (HSE).

TCEQ 2006, *Guidelines to develop effects screening levels, reference values and unit risk factors.*, Texas Commission on Environmental Quality.

TCEQ 2009, *Silica, Crystalline Forms, Development Support Document*, Texas Commission on Environmental Quality.

USEPA 1996, *Ambient Levels and Noncancer Health Effects of Inhaled Crystalline and Amorphous Silica: Health Issue Assessment*, United States Environmental Protection Agency, Office of Research and Development Washington, DC 20460, EPA/600/R-95/115 November 1996.

WDNR 2010, *Status Report to the Natural Resources Board: Silica Study, DRAFT for Public Comment*, Wisconsin Department of Natural Resources, December 2010.

WHO 2000, *Concise International Chemical Assessment Document 24, Crystalline Silica, Quartz*, World Health Organization, Geneva.