APPENDIX N

DUNGOWAN DAM AND PIPELINE EIS

Health Impact Assessment

NSW GOVERNMENT | EMM creating opportunities

Health Impact Assessment - Dungowan Dam and pipeline project

Prepared for: EMM

28 September 2022

Document History and Status

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Limitations

Environmental Risk Sciences has prepared this report for the use of EMM 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 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 between May and July 2022 and is based on the information provided and reviewed at that time. Environmental Risk Sciences disclaims responsibility for any changes that may have occurred after this time.

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Glossary of Terms and Abbreviations

Term	Definition
AAQ	Ambient air quality.
ABS	Australian Bureau of Statistics.
Acute exposure	Contact with a substance that occurs once or for only a short time (up to 14 days).
Absorption	The process of taking in. For a person or an animal, absorption is the process of a substance getting into the body through the eyes, skin, stomach, intestines, or lungs.
Adverse health effect	A change in body function or cell structure that might lead to disease or health problems.
Aerodynamic diameter	Airborne particles have irregular shapes, their aerodynamic behaviour is expressed in terms of the diameter of an idealised spherical particle.
AIHW	Australian Institute of Health and Welfare.
ANZECC	Australia and New Zealand Environment and Conservation Council.
AQGGA	Air Quality and Greenhouse Gas Assessment.
ATSDR	Agency for Toxic Substances and Disease Register.
Background level	An average or expected amount of a substance or material in a specific environment, or typical amounts of substances that occur naturally in an environment.
Biodegradation	Decomposition or breakdown of a substance through the action of micro-organisms (such as bacteria or fungi) or other natural physical processes (such as sunlight).
Body burden	The total amount of a substance in the body. Some substances build up in the body because they are stored in fat or bone or because they leave the body very slowly.
Carcinogen	A substance that causes cancer.
CCME	Canadian Council of Ministers of the Environment.
Chronic exposure	Contact with a substance or stressor that occurs over a long time (more than one year) [compare with acute exposure and intermediate duration exposure].
dB	Decibels.
DEC	NSW Department of Environment and Conservation.
DECC	NSW Department of Environment and Climate Change.
DECCW	NSW Department of Environment, Climate Change and Water.
Detection limit	The lowest concentration of a substance that can reliably be distinguished from a zero concentration.
Dose	The amount of a substance to which a person is exposed over some time period. Dose is a measurement of exposure. Dose is often expressed as milligram (amount) per kilogram (a measure of body weight) per day (a measure of time) when people eat or drink contaminated water, food, or soil. In general, the greater the dose, the greater the likelihood of an effect. An ‘exposure dose’ is how much of a substance is encountered in the environment. An ‘absorbed dose’ is the amount of a substance that actually got into the body through the eyes, skin, stomach, intestines, or lungs.
EIS	Environmental Impact Statement.
EPHC	Environment Protection and Heritage Council.
EU	European Union.
Exposure	Contact with a substance by swallowing, breathing, or touching the skin or eyes. Also includes contact with a stressor such as noise or vibration. Exposure may be short term [acute exposure], of intermediate duration, or long term [chronic exposure].
Exposure assessment	The process of finding out how people come into contact with a hazardous substance, how often and for how long they are in contact with the substance, and how much of the substance they are in contact with.

Term	Definition
Exposure pathway	The route a substance takes from its source (where it began) to its endpoint (where it ends), and how people can come into contact with (or get exposed) to it. An exposure pathway has five parts: a source of contamination (such as chemical substance leakage into the subsurface); an environmental media and transport mechanism (such as movement through groundwater); a point of exposure (such as a private well); a route of exposure (eating, drinking, breathing, or touching), and a receptor population (people potentially or actually exposed). When all five parts are present, the exposure pathway is termed a completed exposure pathway.
Genotoxic carcinogen	These are carcinogens that have the potential to result in genetic (DNA) damage (gene mutation, gene amplification, chromosomal rearrangement). Where this occurs, the damage may be sufficient to result in the initiation of cancer at some time during a lifetime.
Guideline value	Guideline value is a concentration in soil, sediment, water, biota or air (established by relevant regulatory authorities such as the NSW Department of Environment and Conservation (DEC) or institutions such as the National Health and Medical Research Council (NHMRC), Australia and New Zealand Environment and Conservation Council (ANZECC) and World Health Organization (WHO)), that is used to identify conditions below which no adverse effects, nuisance or indirect health effects are expected. The derivation of a guideline value utilises relevant studies on animals or humans and relevant factors to account for inter and intra-species variations and uncertainty factors. Separate guidelines may be identified for protection of human health and the environment. Dependent on the source, guidelines would have different names, such as investigation level, trigger value and ambient guideline.
HHRA	Human health risk assessment.
HI	Hazard Index.
IARC	International Agency for Research on Cancer.
ICNG	Interim Construction Noise Guideline.
I-INCE	International Institute of Noise Control Engineering.
Inhalation	The act of breathing.
Intermediate exposure	Contact with a substance that occurs for more than 14 days and less than a year [compared with acute exposure and chronic exposure].
LGA	Local Government Area.
LOAEL	Lowest-observed-adverse-effect level.
LOR	Limit of Reporting.
Metabolism	The conversion or breakdown of a substance from one form to another by a living organism.
Morbidity	This is the condition of being ill, diseased or unhealthy. This can include acute illness (which has a sudden onset and may improve or worsen over a short period of time) as well as chronic illness (which can present and progress slowly over a long period of time).
Mortality	This is the condition of being dead. It may be presented as the number of deaths in a population over time, either in general or due to a specific cause.
NCAs	Noise catchment areas.
NEPC	National Environment Protection Council.
NEPM	National Environment Protection Measure.
NHMRC	National Health and Medical Research Council.
NSW	New South Wales.
NSW EPA	NSW Environment Protection Authority.
OEHHA	Office of Environmental Health Hazard Assessment, California Environment Protection Agency (Cal EPA).
PM	Particulate matter.

Term	Definition
$PM_{0.1}$	Particulate matter of aerodynamic diameter 0.1 micrometre (µm) and less (termed ultrafine particles).
PM_1	Particulate matter of aerodynamic diameter 1 micrometre (µm) and less (termed ultrafine particles).
$PM_{2.5}$	Particulate matter of aerodynamic diameter 2.5 micrometres (µm) and less.
PM_{10}	Particulate matter of aerodynamic diameter 10 micrometres (µm) and less.
Point of exposure	The place where someone can come into contact with a substance present in the environment [see exposure pathway].
Population	A group or number of people living within a specified area or sharing similar characteristics (such as occupation or age).
RBL	Rating Background Level.
Receptor	An assessed location for potential air, noise or blasting impacts. Typically, receptors are residences, however can include commercial and industrial premises, places of worship, schools, etc. Also known as receivers.
Receptor population	People who could come into contact with hazardous substances [see exposure pathway].
Risk	The probability that something would cause injury or harm.
Route of exposure	The way people come into contact with a hazardous substance. Three routes of exposure are breathing [inhalation], eating or drinking [ingestion], or contact with the skin [dermal contact].
SEARs	Secretary's Environmental Assessment Requirements.
SEIFA	Socio-Economic Index for Areas.
SIA	Social Impact Assessment.
TCEQ	Texas Commission on Environmental Quality.
Toxicity	The degree of danger posed by a substance to human, animal or plant life.
Toxicity data	Characterisation or quantitative value estimated (by recognised authorities) for each individual chemical substance for relevant exposure pathway (inhalation, oral or dermal), with special emphasis on dose-response characteristics. The data are based on based on available toxicity studies relevant to humans and/or animals and relevant safety factors.
Toxicological profile	An assessment that examines, summarises, and interprets information about a hazardous substance to determine harmful levels of exposure and associated health effects. A toxicological profile also identifies significant gaps in knowledge on the substance and describes areas where further research is needed.
Toxicology	The study of the harmful effects of substances on humans or animals.
TSP	Total suspended particulates.
UK	United Kingdom.
US	United States of America.
USEPA	United States Environmental Protection Agency.
WHO	World Health Organization.
$\mu g/m^3$	Micrograms per cubic metre.
µm	Micrometre.

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Section 1. Introduction

1.1 The project

The Peel River, part of the Namoi River catchment, provides water for irrigation as well as being the primary water supply for the city of Tamworth. Prompted by the millennium drought, investigations into the future water supply and demand for bulk water were undertaken for the regional city of Tamworth and the Peel Valley water users. The Dungowan Dam and pipeline project (the project) is a critical project to improving long-term water security for the region. The project includes a new dam at Dungowan (new Dungowan Dam) approximately 3.5 km downstream of the existing Dungowan Dam and a new section of pipeline about 32km long between the proposed Dam outlet and the tie in point to an existing pipeline from Dungowan Showground to the Calala Water Treatment Plant (WTP).

In September 2022, the Minister for Planning and Homes declared the project to be Critical State Significant Infrastructure (CSSI) as it is a development that is essential for the State for economic and social reasons. This requires Schedule 5 of the *State Environmental Planning Policy (Planning Systems) 2021* to be updated to reflect the CSSI status of the project. As CSSI, the project is subject to Part 5, Division 5.2 of the *Environmental Planning and Assessment Act 1979* (EP&A Act), which requires the preparation of an environmental impact statement (EIS) and the approval of the NSW Minister for Planning and Homes. The EIS has been prepared for the planning approval application for the project. This health impact assessment (HIA) has been prepared to support the EIS.

In addition to requiring approval from the NSW Minister for Planning and Homes, the project has been deemed a controlled action under the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and requires approval from the Commonwealth Minister for the Environment and Water. The Minister for the Environment and Water has accredited the NSW planning process for the assessment of the project. Therefore, a single EIS has been prepared to address the requirements set out by the NSW Department of Planning and Environment (DPE) and the Commonwealth Department of Climate Change, Energy, the Environment and Water.

1.2 Project location

1.2.1 General

The project is located in the Tamworth Regional local government area (LGA), the New England Tablelands bioregion and part of the New England and North West region of NSW, west of the Great Dividing Range (DPE 2017). The New England and North West region is home to approximately 186,900 people and has a total area of around 99,100 km^2 (ABS 2018).

The city of Tamworth is the nearest (and largest) town to the project with over 40,000 residents. Other nearby regional towns include Quirindi (70 km west), Manilla (90 km north-west), Gloucester (90 km south-east), Armidale (100 km north) and Gunnedah (110 km west of the project).

The existing Dungowan Dam is in the Namoi River catchment approximately 50 km south-east of Tamworth in NSW. The Namoi catchment covers 4,700 km^2 and borders the Gwydir and Castlereagh catchments and is bounded by the Great Dividing Range in the east, the Liverpool

Ranges and Warrumbungle Ranges in the south, and the Nandewar Ranges and Mount Kaputar to the north.

The existing Dungowan Dam is on Dungowan Creek, which is a minor tributary of the Peel River. Dungowan Creek is confined by the existing Dungowan Dam, while the Peel River system is regulated by Chaffey Dam, located in the upper catchment near the town of Woolomin, approximately 45 km from Tamworth.

The project's regional setting is shown in **Figure 1.1**.

1.2.2 Project impact areas

In outlining the project, a project footprint has been defined to facilitate the assessment of direct impacts from the project:

- Project footprint: all areas where direct impacts may be experienced during construction and/or operation.

The project footprint has an area of 315 ha and is comprised of the construction and operational footprints, of which there is some overlap:

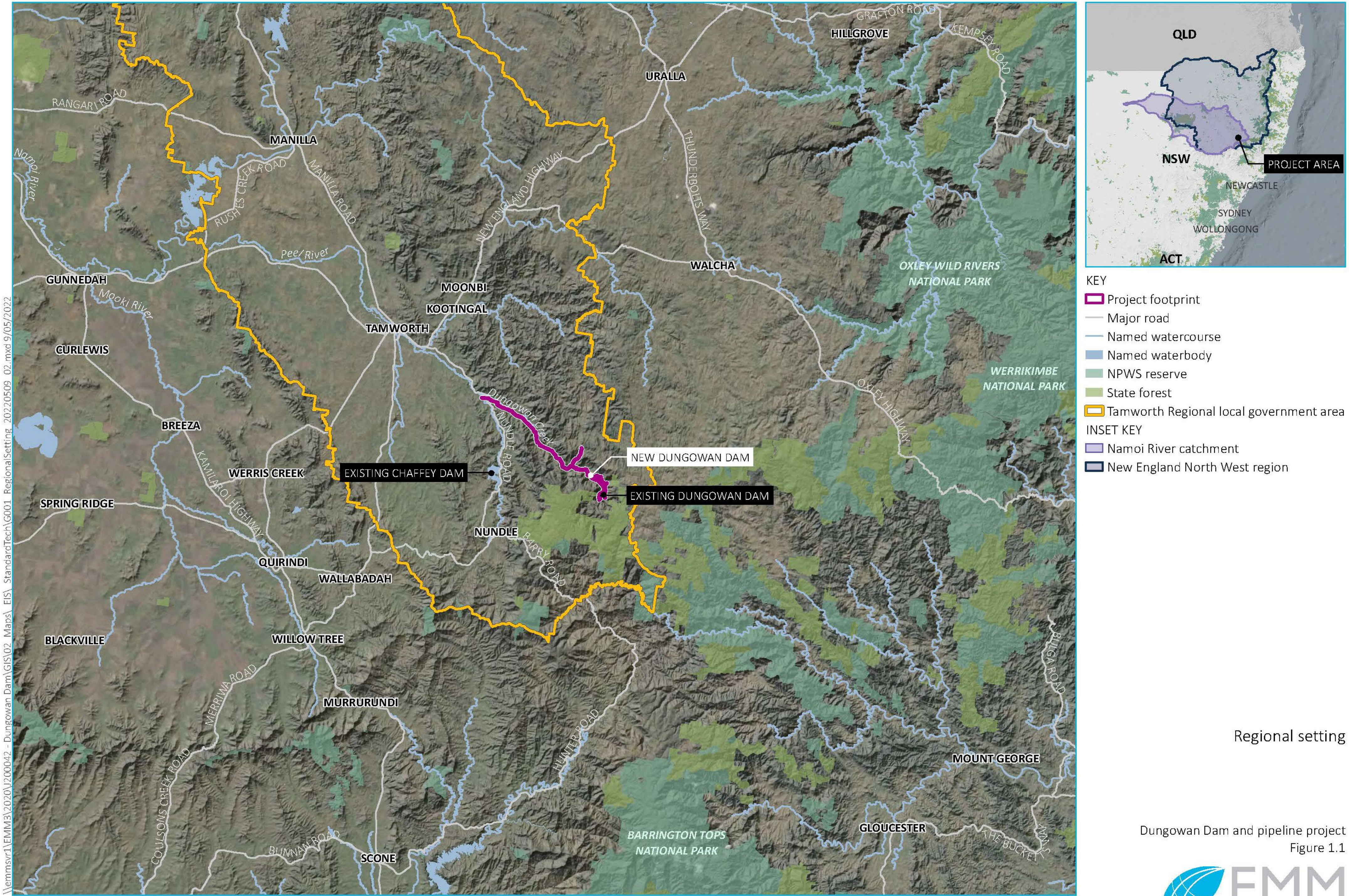
- Construction footprint: areas where vegetation clearing and/or ground disturbance is required for construction of the dam, pipeline and ancillary facilities, including the area needed to decommission and rehabilitate the existing dam.
- Operational footprint: areas where there will be permanent operational elements or easements, including infrastructure needed to operate the new Dungowan Dam and pipeline. The operation footprint includes the inundation area, being the area defined by the proposed full supply level (FSL) for the project.

Additional areas outside the project footprint have also been considered where relevant to the assessment of project impacts and include:

- Upstream flood extent: An area above the FSL to the level of a probable maximum flood (PMF) event that would be inundated for relatively short periods during operation associated with extreme rainfall events.
- Project area: A 10 km buffer around the project footprint defined to allow for assessment of potential indirect impacts.
- Downstream impact area: the area where hydrological changes may occur due to the project. This area is discussed in detail in the Surface Water Assessment (EMM 2022f) as well as other technical reports subject to changed flow regimes as a result of the new Dungowan Dam operation. The downstream impact area includes Dungowan Creek and also the Peel River downstream of Chaffey Dam.

1.2.3 HIA study area

The HIA evaluates potential impacts on community health, associated with a range of different aspects relating to construction and operation of the project. In relation to the spatial extent of impacts evaluated, these are defined by the project construction and operational footprints shown in **Figure 1.2**. In relation to characterising the community, data relevant to the broader community for the Tamworth LGA and the Hunter New England Health District has been evaluated and considered representative for the population in the project area.

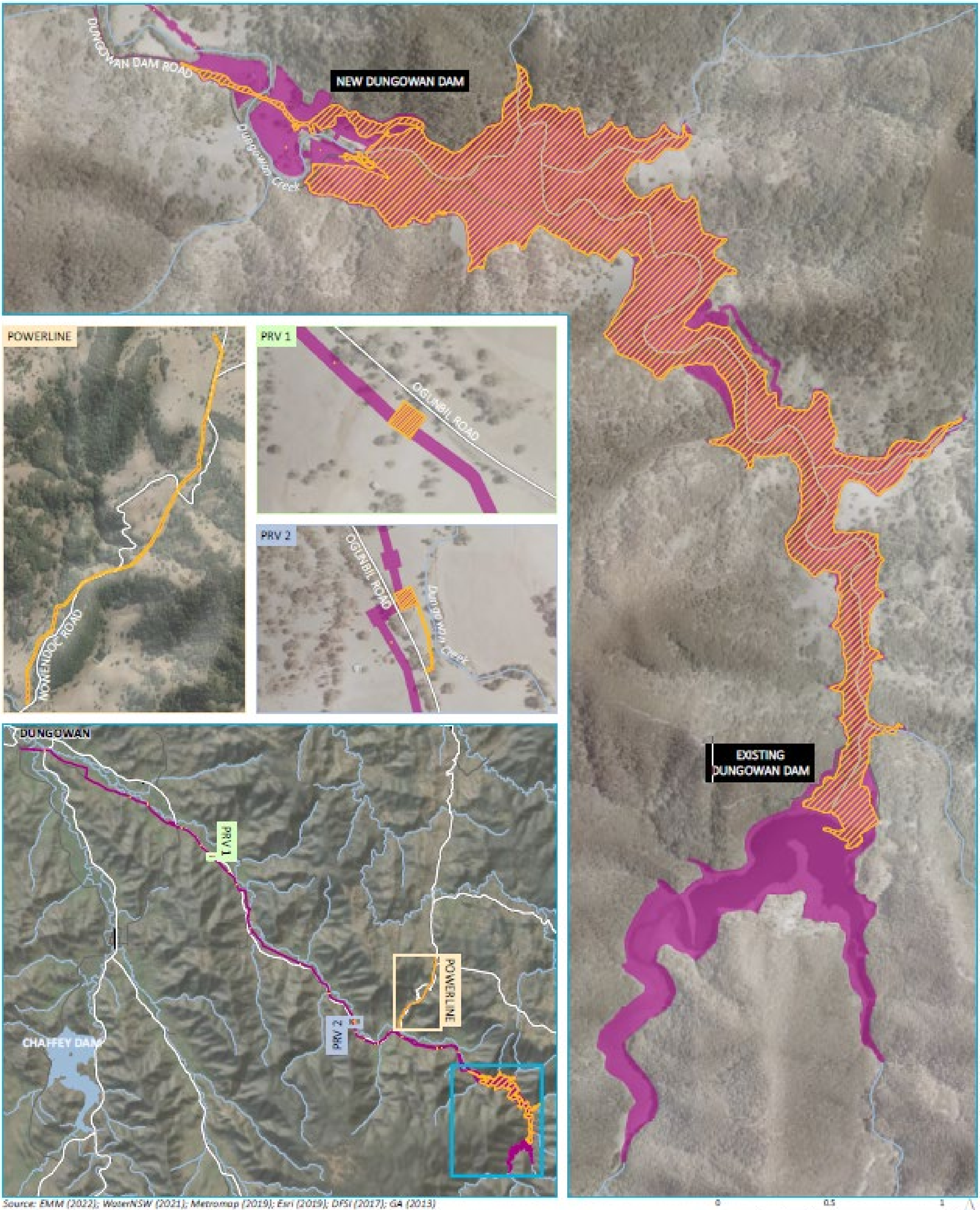


Source: EMM (2022); WaterNSW (2021); DFSI (2017); GA (2013)

Regional setting

Dungowan Dam and pipeline project
Figure 1.1

creating opportunities



Source: EMM (2022); WaterNSW (2021); Metromap (2019); Esri (2019); DFSI (2017); GA (2013)

0 0.5 1 km
GDA 1994 MGA Zone 56 N

KEY
- Construction footprint
- Operational footprint

Existing environment
- Major road
- Minor road
- Named watercourse
- Named waterbody

Project footprint

Dungowan Dam and pipeline project
Figure 1.2

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1.3 Purpose of this report

This health impact assessment (HIA) supports the EIS for the project. The Secretary's Environmental Assessment Requirements (SEARs) for the project requires that a health impact assessment is conducted in accordance with the current guidelines.

The overall objective of the HIA presented in this report is to provide an assessment of project related impacts (positive and negative) on the health of the community surrounding the project and identify any additional measures that may enhance benefits or mitigate impacts to community health.

This report addresses impacts relevant to community health, specifically in relation to impacts on air quality, noise and vibration, water (surface water and groundwater), contamination, traffic and transport and hazards. The report does not provide a detailed assessment of impacts to on-site workers or construction workers. Workplace health and safety is expected to be managed separately through application of the NSW Work Health and Safety Act 2011 and associated regulations. This approach is consistent with the Health Impact Assessment Guidelines (enHealth 2017) which states that their aim and scope is to focus on the application of HIA during the planning stages of a development and that they do not address occupational health and safety issues, as separate agencies are specifically charged with this responsibility in most jurisdictions (refer to Section 1.3 enHealth 2017).

While workplace health and safety of workers carrying out construction activities is not addressed here, a conservative approach was taken to air quality emissions and consideration has been given to potential health effects of exposure to fine particulates at the construction accommodation camp (see Section 4.4.2). Other technical assessments that are part of the EIS including the Preliminary Site Contamination Investigation (EMM 2022d) and the Bushfire Risk Assessment (BlackAsh 2022) provide consideration of relevant safety aspects for the construction workforce, however the focus of the HIA is on the health of the community.

1.4 Assessment requirements

1.4.1 SEARs

This HIA has been prepared in accordance with the Secretary's Environmental Assessment Requirements (SEARs) for the Dungowan Dam and pipeline project, as well as relevant government assessment requirements, guidelines and policies, and in consultation with the responsible government agencies.

The SEARs must be addressed in the EIS. **Table 1.1** lists the matters relevant to this assessment and where they are addressed in this report.

Table 1.1: Relevant matters raised in SEARs

Requirement	Section addressed
Public safety – including: 50. A Health Impact Assessment of the project in accordance with the current guidelines	Whole report

To inform preparation of the SEARs, DPE invited relevant government agencies to advise on matters to be addressed in the EIS. These matters were taken into account by the Secretary for DPE when preparing the SEARs.

1.4.2 Assessment guidelines

An HIA is an assessment of potential health impacts related to a project. An HIA addresses impacts to both health and wellbeing of a community and considers both positive and negative impacts of a project on community health. As is often the case, the EIS process typically focuses on the negative impacts, and, as the HIA relies on the EIS assessments, it is expected that the HIA will only be able to focus on negative health impacts. Where positive impacts can be addressed, they will be included in the HIA.

The HIA has been undertaken in accordance with the following guidance (and associated references as relevant, which includes all guidelines on Health Impact Assessment as detailed in the SEARs):

- enHealth Environmental Health Risk Assessment, Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012)
- enHealth, Health Impact Assessment Guidelines (enHealth 2017)
- Harris, P., Harris-Roxas, B., Harris, E. & Kemp, L., Health Impact Assessment: A Practical Guide, Centre for Health Equity Training, Research and Evaluation (CHETRE). Part of the UNSW Research Centre for Primary Health Care and Equity. University of New South Wales, Sydney, 2007 (Harris 2007) – also referred to as (NSW Health 2007)
- *State Environmental Planning Policy* (SEPP) *(Resilience and Hazards) 2021* {NSW Government, 2021 #15515}
- NEPC National Environment Protection (Ambient Air Quality) Measure (NEPC 2021)
- NSW EPA Methodology for valuing health impacts of changes in particle emissions (EPA 2013)
- National Environmental Protection Measure – Assessment of Site Contamination including:
    - Schedule B1 Investigation Levels for Soil and Groundwater (NEPC 1999 amended 2013a)
    - Schedule B4 Guideline on Health Risk Assessment Methodology (NEPC 1999 amended 2013b)
    - Schedule B6 Guideline on Risk Based Assessment of Groundwater Contamination (NEPC 1999 amended 2013e)
    - Schedule B7 Guideline on Health-Based Investigation Levels (NEPC 1999 amended 2013c)
    - Schedule B8 Guideline on Community Consultation and Risk Communication (NEPC 1999 amended 2013d)
- NSW Approved Methods for the Modelling and Assessment of Air Pollutants (NSW EPA 2017a)
- NSW Industrial Noise Policy (NSW EPA 2000)
- NHMRC Australian Drinking Water Guidelines (NHMRC 2011 updated 2022) and recreational guidelines (NHMRC 2008).

Where relevant, additional guidance has been obtained from relevant Australian and International policy, such as that available from the United States Environmental Protection Agency (USEPA) and the World Health Organization (WHO), consistent with current industry best practice.

1.5 Other relevant reports

This HIA has been prepared with reference to other technical reports that were compiled as part of the EIS. The other relevant reports referenced in the HIA are listed below.

- Air Quality and Greenhouse Gas Impact Assessment (EMM 2022a) – Appended to the EIS
- Bushfire Risk Assessment (BlackAsh 2022) – Appended to the EIS
- Groundwater Impact Assessment (EMM 2022b) – Appended to the EIS
- Noise and Vibration Impact Assessment (EMM 2022c) – Appended to the EIS
- Preliminary Site Contamination Investigation (EMM 2022d) – Appended to the EIS
- Traffic Impact Assessment (EMM 2022e) – Appended to the EIS
- Surface Water Assessment (EMM 2022f) – Appended to the EIS.

Section 2. Project description

2.1 General

This section provides a summary of the Dungowan Dam and pipeline project. It outlines the permanent infrastructure required to operate the project, as well as the key construction elements and activities required to construct the project. A comprehensive and detailed description of the project is provided as Appendix B1 of the EIS, which has been relied upon for the basis of this technical assessment.

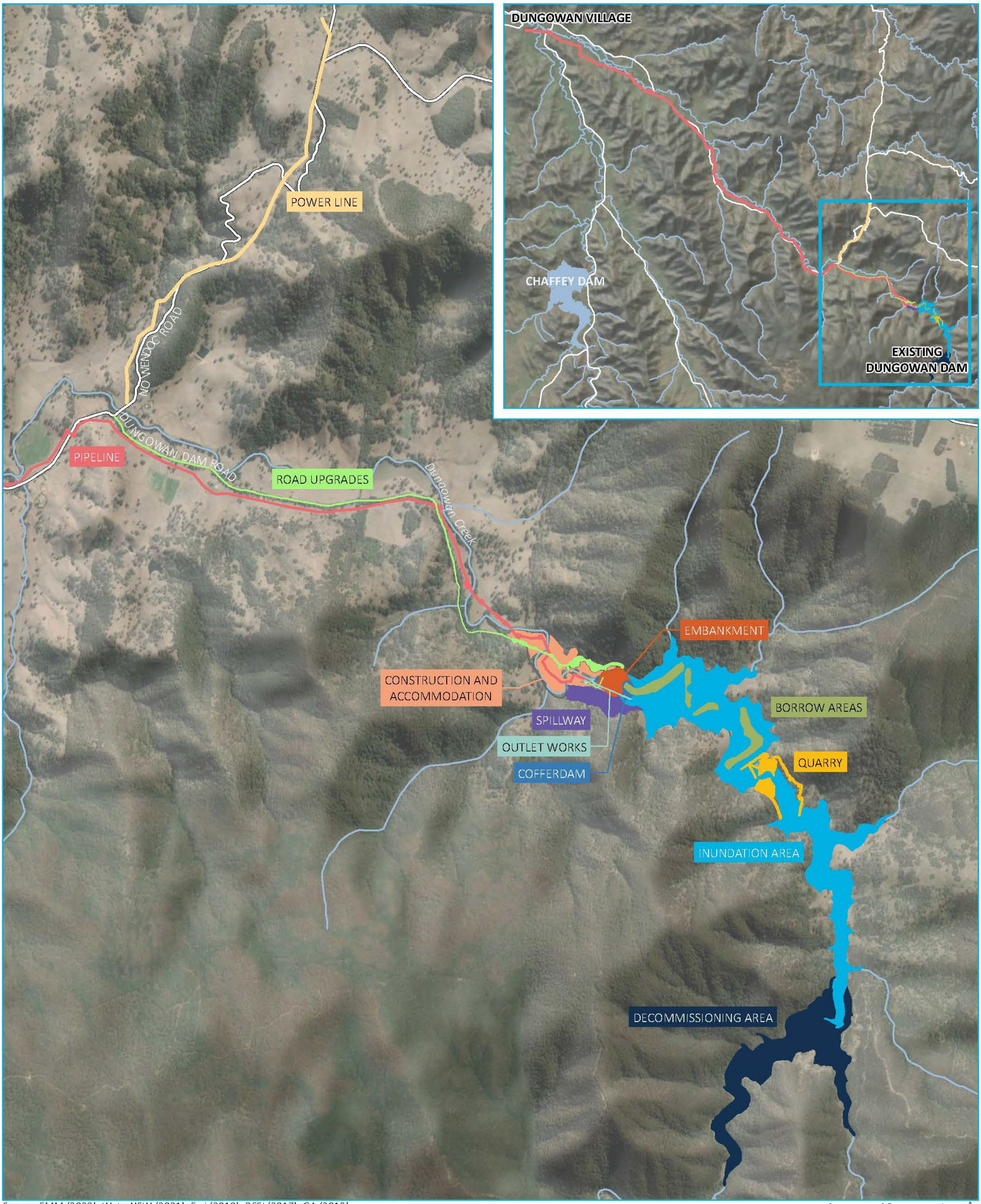
2.2 Project overview

Water Infrastructure NSW proposes to build a new dam at Dungowan (new Dungowan Dam) about 3.5 km downstream of the existing Dungowan Dam and an enlarged delivery pipeline from the new Dungowan Dam outlet to the tie in point to the existing pipeline from Dungowan Showground to the Calala WTP. The existing pipeline from Dungowan Showground to the Calala WTP is not part of the Dungowan Dam and pipeline project. A summary of project elements is provided in **Table 2.1** and **Figure 2.1**.

Table 2.1: Overview of the project

Project element	Summary of the project
New Dungowan Dam infrastructure	Earth and rockfill embankment dam with height of ~58 m and a dam crest length of ~270 m.
	Storage capacity of 22.5 GL at full supply level (FSL) of RL 660.2 m AHD.
	The new Dungowan Dam on Dungowan Creek has a catchment size of 175 km^2 and is part of the Peel Valley and Namoi River catchment.
	Inundation extent (to FSL) of 130 ha (1.3 km^2)
	Spillway to the south of the dam wall including an approach channel, uncontrolled concrete ogee crest, chute and stilling basin. Free standing multiple-level intake tower connected with a bridge to the embankment, diversion tunnel with outlet conduit, valve house and associated pipework and valves.
	A permanent access road over the Dam crest to the valve house for operation and maintenance.
	Water diversion works including a diversion tunnel and temporary pipeline and upstream and downstream cofferdams to facilitate construction of the dam wall embankment.
Pipeline infrastructure	31.6 km of buried high density polyethylene (HDPE) pipe between 710 mm to 900 mm nominal diameter.
	Maximum 71 ML/day from the proposed dam to the junction with the pipeline from Chaffey Dam to the Calala Water Treatment Plant, to replace the existing 22 ML/day pipeline. The pipeline would connect to the valve house on the left abutment of the embankment. Valve infrastructure would include control valves installed in two above ground buildings along the pipeline.
	10 m wide easement for the 31.6 km length of the pipeline. The replacement pipeline extends from the new Dungowan Dam to a connection point with the existing pipeline between Dungowan Showground and Calala WTP.
Ancillary infrastructure and works	Road works to improve existing roads to provide construction access, temporary establishment and use of a construction compound, an accommodation camp, two upstream quarries and four borrow areas within the inundation area.
	A new 4.2 km long 11 kV overhead powerline (including a new easement and access track) connecting to an existing overhead line approximately 6 km north west of the dam. The existing overhead line that extends approximately 13.2 km to the Niangala area would also require minor upgrades, including re-stringing of new overhead wiring and replacement of some poles.
Decommissioning of existing Dungowan Dam	Dewatering of existing dam, removal of existing Dungowan Dam infrastructure and full height breach of the existing Dungowan Dam wall. Rehabilitation of inundation area of the existing Dungowan Dam.

Project element	Summary of the project
Disturbance	Areas of disturbance have been identified based on the direct impacts of the project. There is some overlap in the areas disturbed during construction and operation, with a resulting total disturbance area proposed for the project of 315 ha (project footprint). Disturbance would occur in a staged manner, with construction requiring disturbance of approximately 315 ha (construction footprint). Following construction and once rehabilitation is completed, there would be a permanent disturbance of approximately 158 ha comprising the inundation area and permanent infrastructure (operational footprint).
Construction	Construction duration of approximately 6 years.
	Construction workforce of approximately 125 workers at construction peak.
Operation	WaterNSW will be responsible for management, operation and general maintenance of the new dam. Tamworth Regional Council will be responsible for the management, operation and general maintenance of the pipeline. Public use and access to the dam would not be permitted and there would be no public facilities available during operation.
	One to two new full time workers plus part time work for existing WaterNSW operations team. Due to the new Dungowan Dam being prioritised over Chaffey Dam for Tamworth's future water supply, the water reserved for town water in Chaffey Dam would increase from 14.3 GL to 30 GL to ensure that water is set aside to meet Tamworth's town water supply water demand in years when rainfall is low.
Design life	100 years for zoned earthen embankment, structural concrete elements of the dam and the pipeline. 15 to 50 years for other non-structural project elements and pavements.
Assessment period (operational)	The assessment end point is when the water system performance reaches a level when an additional water supply option or change to the Water Sharing Plan is required. This has been estimated to be when the mean average annual water demand from Tamworth increases to 11 GL/year.



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Source: EMM (2022); WaterNSW (2021); Esri (2019); DFSI (2017); GA (2013)

0 0.5 1 km
GDA 1994 MGA Zone 56
N

KEY

- Inundation area
- Borrow areas
- Construction and accommodation camp
- Outlet works
- Cofferdams
- Embankment
- Quarries
- Spillway
- Road upgrade
- Decommissioning area
- Power line footprint
- Pipeline construction footprint

Existing environment

- Major road
- Minor road
- Named watercourse
- Named waterbody

Project overview

Dungowan Dam and pipeline project
Figure 2.1

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Section 3. Local community

3.1 General

This section provides an overview of the community potentially impacted by the project during construction and operation. In particular this section provides an overview of the demographics and existing health within the community.

3.2 Local setting

The project is in the Tamworth Regional local government area (LGA) and the New England Tablelands bioregion. The project is in the south of the New England and North West region of NSW, which is west of the Great Dividing Range.

The city of Tamworth, located approximately 50 km north-west of the project, is the nearest (and largest) town to the project with over 40,000 residents. Other nearby regional towns include Quirindi (70 km west), Manilla (90 km north-west), Gloucester (90 km south-east), Armidale (100 km north) and Gunnedah (110 km west of the project).

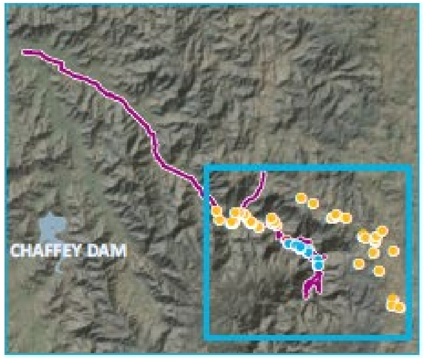
The existing Dungowan Dam is on Dungowan Creek, which is a tributary of the Peel River, in northern NSW. Dungowan Creek is regulated by the existing Dungowan Dam and pipeline, while the Peel River system is regulated by Chaffey Dam, which is in the upper catchment near the town of Woolomin, approximately 45 km from Tamworth.

The existing Dungowan Dam provides water to Tamworth via an existing pipeline that delivers raw water from Dungowan Dam to the Calala water treatment plant (WTP) before delivery to Tamworth.

Recently, a new pipeline was also constructed from the existing Chaffey Dam to a connection point with the existing Dungowan Dam pipeline at Back Woolomin Road in Dungowan (the Chaffey Dam pipeline). This pipeline enables water to be delivered from Chaffey Dam to the Calala WTP, via the existing Dungowan Dam pipeline. It is noted that approval to operate the Chaffey Dam pipeline expired in 2021, and therefore approval is currently being sought by WaterNSW for the future operation of the pipeline.

The main construction works, and infrastructure, are located within the Peel Valley. Downstream of the new Dungowan Dam wall, the land use of the Peel Valley is predominantly agricultural, however within and upstream of the new Dungowan Dam wall, ie within the operational footprint for the project, the land has been purchased by Tamworth Regional Council and is not currently used for agriculture.

To enable an assessment of potential impacts on the community surrounding the project, rural properties adjacent to the project and within 10 km of the project (project area) have been considered in the assessment of air quality impacts as shown in **Figures 3.1** and listed in **Table 3.1**. Additional community locations have also been evaluated in relation to noise and vibration impacts adjacent to the pipeline, as shown in **Figure 3.2**. Due to the number of residential noise assessment locations, noise catchment areas (NCAs) were used to provide a logical grouping of receivers affected by the same construction works. The closest properties to the dam infrastructure construction activities are located within the inundation footprint and are now vacant. These properties are labelled 1 to 13 in **Table 3.1** and have not been further assessed as no one can live in these properties during construction and there would be no access following completion as the properties would be inundated with dam water.



Source: EMM (2022); WaterNSW (2021); Esri (2019); DFSI (2017); GA (2013)

KEY
- Project footprint
- Assessment location
  - Vacant
  - Accommodation camp
  - Occupied
- Existing environment
  - Major road
  - Minor road
  - Named watercourse
  - State forest
  - Named waterbody

Air quality assessment locations for modelling

Dungowan Dam and pipeline project
Health impact assessment
Figure 3.1

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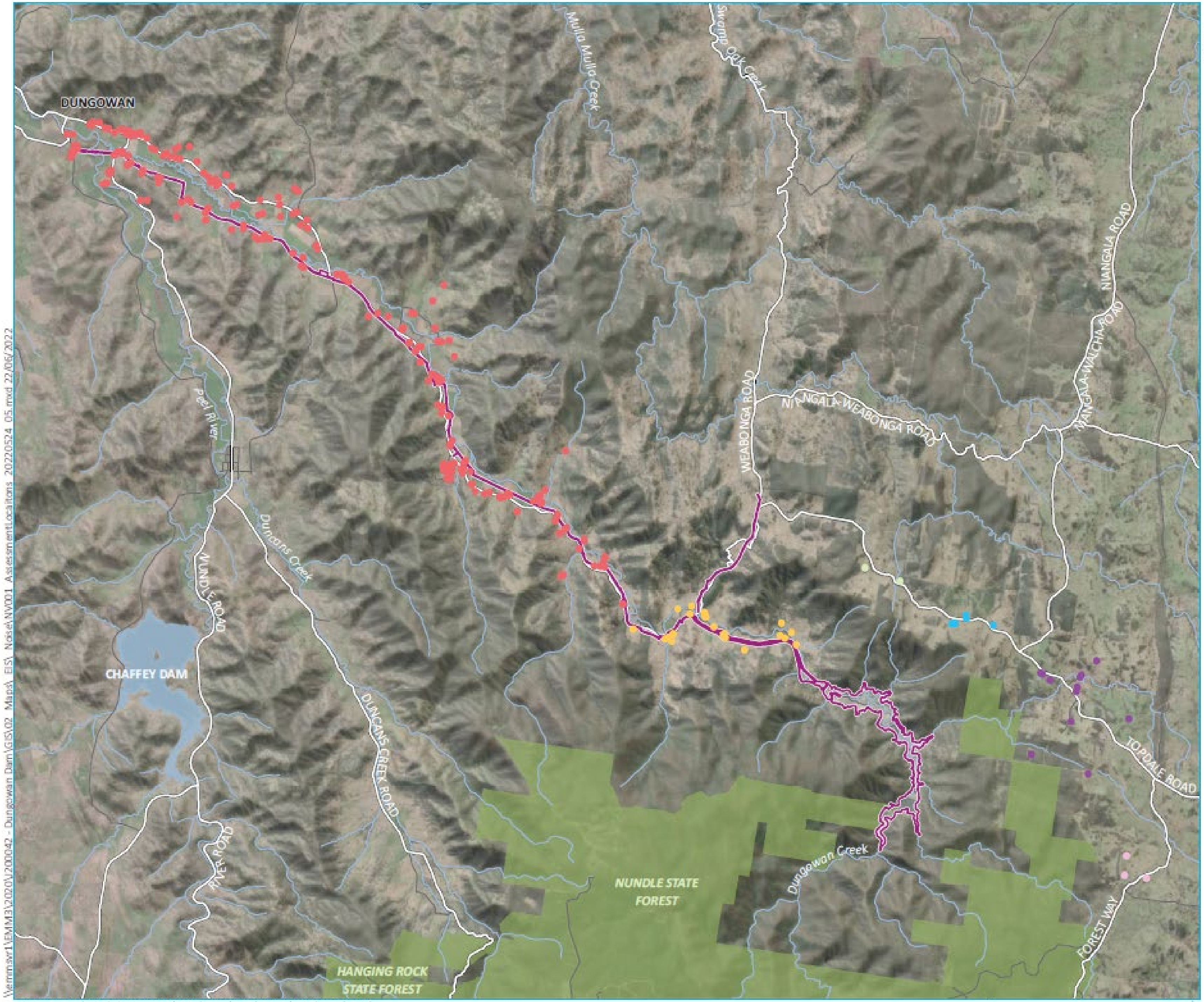


Source: EMM (2022); WaterNSW (2021); Esri (2019); DFSI (2017); GA (2013)

KEY
- Project footprint
- Major road
- Minor road
- Named watercourse
- State forest
- Named waterbody

Assessment locations
- NCA 1
- NCA 2
- NCA 3
- NCA 4
- NCA 5
- NCA 6

Noise assessment locations

Dungowan Dam and pipeline project
Health impact assessment
Figure 3.2

EMM
creating opportunities

Table 3.1: Surrounding rural residential properties and construction camp considered in assessment of air quality modelling

ID	Type/use	ID	Type/use	ID	Type/use
C1	Construction Camp	20	Unknown	40	Shed
1	Vacant	21	Unknown	41	House
2	Vacant	22	Unknown	42	Shed
3	Vacant	23	Unknown	43	Shed
4	Vacant	24	Unknown	44	House
5	Vacant	25	Unknown	45	Shed
6	Vacant	26	Unknown	46	Shed
7	Vacant	27	Unknown	47	House
8	Vacant	28	Unknown	48	House
9	Vacant	29	House	49	Shed
10	Vacant	30	Unknown	50	Shed
11	Vacant	31	House	51	House
12	Vacant	32	House	52	Dwelling
13	Vacant	33	House	53	Shed
14	Unknown	34	House	54	House
15	Unknown	35	House	55	House
16	Unknown	36	House	56	House
17	Unknown	37	Shed	57	House
18	Unknown	38	Shed	58	Shed
19	Unknown	39	House	59	House

Vacant = properties located in the inundation zone, which have not been further assessed as the community cannot live or access these areas during construction or once completed

The location for the construction camp is approximately 500 m from the new Dungowan Dam wall embankment and provides accommodation for workers involved in the construction works. Construction exposures are required to be monitored and managed in accordance with Work Health and Safety (WHS) regulations and guidance. However, exposures outside of construction activities are possible where workers reside at the camp outside of their working hours. A conservative approach was taken and project related impacts at this location have been further considered in this assessment.

3.3 Community profile

The project is situated in an area that includes existing agricultural and rural residential properties.

The boundary of the community evaluated in this assessment has been determined based on modelling completed to evaluate key potential health impacts, specifically air quality and noise.

These assessments have focused on individual properties within 10 km of the project with potential to experience impacts. The individual properties assessed in the Noise and Vibration Impact Assessment (EMM 2022c) and the modelling completed for the Air Quality Greenhouse Gas Assessment (EMM 2022a) are shown in **Figure 3.1** and **Figure 3.2** with the individual properties evaluated in the air quality modelling detailed in **Table 3.1**. All these areas are located within the Tamworth LGA.

Table 3.2 presents a summary of the populations within the Tamworth LGA (based on 2016 Census and 2016 Socio-Economic data from the Australian Bureau of Statistics [ABS]) with comparison to NSW and Australia.

Table 3.2: Summary of populations surrounding the Project

Indicator	Tamworth LGA	NSW	Australia
Total population	59,663	7,480,228	23,401,892
Population 0 - 4 years	6.5%	6.2%	6.3%
Population 5 - 19 years	20.0%	18.3%	18.5%
Population 20 - 64 years	54.7%	59.2%	59.6%
Population 65 years and over	18.8%	16.3%	15.7%
Median age	40	38	38
Average household size	2.5	2.6	2.6
Unemployment (December 2021)	4.3%	4.0%	4.2%
Tertiary or technical institution	12.2%	22.4%	22%
SEIFA IRSD	962	--	--
SEIFA IRSD rank	3	--	--
Indigenous	10.1%	2.9%	2.8%
Born overseas	15.4%	34.5%	26.3%

Most data presented in the table derived from the ABS 2016 Census (ABS 2016).
* Data presented for unemployment is based on available data (Australian Government 2018) to December 2021: https://www.nationalskillscommission.gov.au/topics/small-area-labour-markets#Downloads
SEIFA IRSD = index of socioeconomic disadvantage, rank relates to rank in Australia that ranges from 1 = most disadvantaged to 5 = least disadvantaged. Ranks lower than 2 are more disadvantaged than Australia on average.
Shading relates to comparison against NSW:
- statistic/data suggestive of a potential higher vulnerability within the population to health stressors.
- statistic/data suggestive of a potential lower vulnerability within the population to health stressors.
- statistics/data materially different to that of NSW and Australia, however this indicator is not a clear determinant of higher or lower vulnerability to health stressors.

Based on the population data available and presented in **Table 3.2**, the community of Tamworth has a similar age distribution as NSW and Australia, noting that Tamworth has a slightly older population, lower levels of tertiary and technical institution education and a lower percentage of people born overseas. The rate of unemployment is consistent with that for NSW and Australia, with the data indicating the LGA is no more socioeconomically disadvantaged than the average person in NSW.

The indicators outlined in **Table 3.2** reflect the vulnerability of the population and its ability to adapt to environmental stresses. While it is not possible to provide more refined data for smaller pockets of these LGAs (in particular the properties evaluated in this assessment), in general the Tamworth population is not considered more vulnerable, however there are a few aspects such as a slightly higher proportion of older people and a higher proportion of indigenous people that may suggest some increased vulnerability[1].

The health of the community is influenced by a complex range of interactive factors including age, socio-economic status, social capital, behaviours, beliefs and lifestyle, life experiences, country of

[1] Health statistics for aboriginal people in NSW (NSW Health Stats: http://www.healthstats.nsw.gov.au/) indicate higher levels of pre-existing health conditions and a higher rate of mortality (i.e. shorter life span) which may make this group more vulnerable to stressors that impact on key health outcomes such as cardiovascular and respiratory health.

origin, genetic predisposition and access to health and social care. The health indicators available and reviewed in this report (**Table 3.3**) generally reflect a wide range of these factors.

The population of the project area is relatively small and health data is not available that specifically relates to this population.

The project is located within the Hunter New England Health District. This district covers a region of 131,785 square kilometres from Newcastle in the south to Tenterfield in the north, and past Narrabri in the west. There are approximately 920,000 people residing in the district, including residents of a major metropolitan centre (Newcastle) and regional communities. The population of Tamworth LGA represent approximately 6% of the total population in the Hunter New England Health District, with the population of the properties surrounding the project (and considered in this assessment) an even smaller proportion.

Table 3.3 presents a summary of the general population health relevant to the area, based on currently available data. The table presents available information on health-related behaviours (i.e. key lifestyle and behaviours factors known to be important to health) and indicators for the burden of disease within the Tamworth Regional LGA (where data is available), the Hunter New England Health District and NSW.

Table 3.3: Summary of health indicators/data

Health indicator/data	Hunter New England	NSW
Health behaviours		
Adults - compliance with fruit consumption guidelines (2020)[1]	40.2%	40.3%
Adults - compliance with vegetable consumption guidelines (2020)[1]	8.3%	5.9%
Children - compliance with fruit consumption guidelines (2019-2020) [1]	63.8%	64.2%
Children - compliance with vegetable consumption guidelines (2019-2020) [1]	4.5%	5.2%
Adults - increased lifetime risk of alcohol related harm (2020) [1]	43.6%	32.5%
Adults - body weight (overweight) (2020) [1]	38.6%	34.3%
Adults - body weight (obese) (2020) [1]	29.2%	22.5%
Adults – sufficient physical activity (2020) [1]	59.6%	61.7%
Children – adequate physical activity (2019-2020) [1]	27.3%	18.1%
Current smoker (2021) [1]	12.8%	12%
Burden of disease		
Morbidity - cardiovascular disease hospitalisations (all ages, 2018-2020)[1]	Tamworth Regional LGA = 1,583.3*	1,628.4*
Morbidity – respiratory disease hospitalisations (all ages, 2019-2020)[1]	1,462.7*	1,462.5*
Mortality – all causes, all ages (2019)[1,2]	608.5* Tamworth Regional LGA = 707.4*	513.8*
Mortality - cardiovascular *all ages) (2018-2019)[1]	158.2	127.3
Mortality – respiratory (all ages) (2017-2019)[1]	55.6*	48.7*
Emergency department presentations for asthma like illness (all ages, annual) (2020-2021)[1]	385.1*	200.1*
Adult asthma – prevalence (2019)[1]	8.5%	10.5%
Children – prevalence of current asthma (2017 – 2019)[1]	12.1%	11.8%

* Rate per 100,000 population.

1 Data from NSW Health Statistics: http://www.healthstats.nsw.gov.au/.

2 Mortality data for LGAs available from the Australian Institute of Health and Welfare (MORT books): https://www.aihw.gov.au/reports/life-expectancy-death/mort-books/contents/mort-books

Shading relates to comparison against NSW:

- statistic/data suggestive of a potential higher vulnerability within the population to health stressors.
- statistic/data suggestive of a potential lower vulnerability within the population to health stressors.

As described above, the Hunter New England Health District covers a large area. Hence it has been assumed that the data presented in **Table 3.3** also applies to smaller population groups that are located in the area surrounding the project.

Data presented in **Table 3.3**, suggest some of the population in the areas surrounding the project may be more vulnerable to health-related impacts associated with the project, than the general population of NSW. The underlying reasons for this increased vulnerability are expected to be complex, and may include a broad range of lifestyle, behaviour and environmental factors.

Section 4. Health impact assessment: Air emissions

4.1 Approach

This section presents a review of impacts on health associated with predicted air emissions, relevant to the project. The assessment presented has relied on the following:

- EMM 2022a, Air Quality and Greenhouse Gas Assessment, Dungowan Dam and pipeline project. This report is referred to as the AQGHGA.

The estimation of risk follows the general principles outlined in the enHealth document Environmental Health Risk Assessment: Guidelines for Assessing Human Health Risks from Environmental Hazards (enHealth 2012).

4.2 Background on particulate matter

The focus of the AQGHGA and this assessment of potential health impacts is the emissions to air of dust or particulate matter.

Dust or Particulate Matter (PM) is a widespread air pollutant (that has and will always be present in air) with a mixture of physical and chemical characteristics that vary by location (and source). Unlike many other pollutants, particulates comprise a broad class of diverse materials and substances, with varying morphological, chemical, physical and thermodynamic properties, with sizes that vary from <0.005 micrometres (μm) to >100 μm. Particulates can be derived from natural sources such as crustal dust (soil), pollen and moulds, and other sources that include combustion and industrial processes. Secondary particulate matter is formed via atmospheric reactions of primary gaseous emissions. The gases that are the most significant contributors to formation of secondary particulates include: nitrogen oxides, ammonia, sulfur oxides, and certain organic gases (derived from vehicle exhaust; combustion sources; and agricultural, industrial and biogenic emissions).

The potential for particulate matter to result in adverse health effects is dependent on the size and composition of the particulate matter.

The size of particulates is important as it determines how far from an emission source the particulates may be present in air (with larger particulates settling out close to the source and smaller particles remaining airborne for greater distances) and also the potential for adverse effects to occur as a result of exposure (how far the particles can infiltrate into the human respiratory system).

Only particulates that are small enough can penetrate into the lungs where there is the potential for effects to occur. If the particles are too large, they will be captured high up in the respiratory tract, trapped and flushed out and eventually swallowed.

Dust is commonly assessed on the basis of four types (or groups) of particles: $PM_{2.5}$, PM_{10}, total suspended particulates (TSP) and deposited dust.

Deposited dust includes particles of any size, but it generally comprises large size dust particles; that is, greater than 20 microns in diameter[2]. These particles are too large to reach the lungs and are not considered to be of concern in relation to exposure. These particles have enough mass that they easily fall out of the air and deposit or accumulate on surfaces. These larger particles fall out and deposit onto surfaces close to specific sources, such as quarry activities. Sometimes sufficient dust can deposit so that it results in a visible layer of dust, which is often considered to be a nuisance.

TSP refers to all particulates with an equivalent aerodynamic particle[3] size below 50 microns in diameter. 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 the source and, if inhaled, are mostly trapped in the upper respiratory system[4] and do not reach the lungs. This is the same with the even larger particles in deposited dust.
- 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).

The deposition of dust based on the different particle sizes is illustrated in **Figure 4.1**.

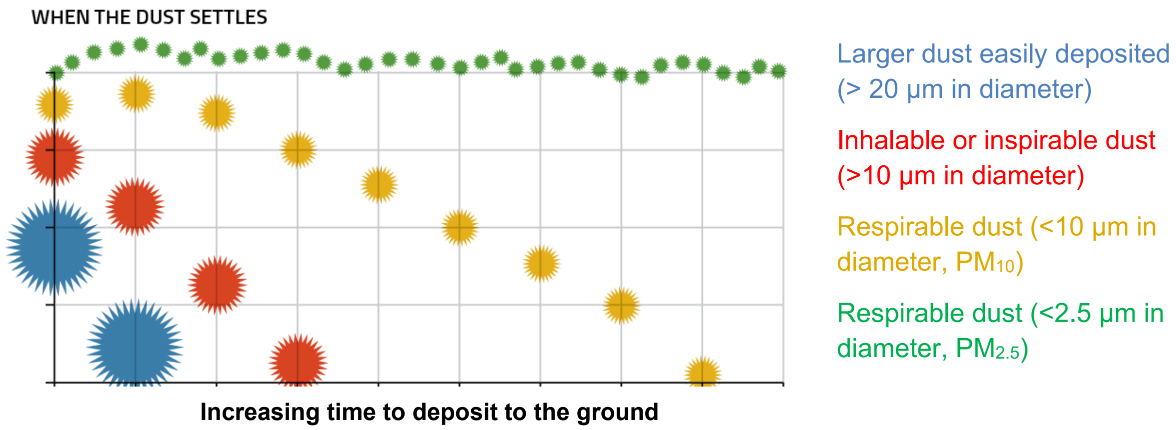


Figure 4.1: Deposition of dust particles

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

[3] 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.

[4] 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.

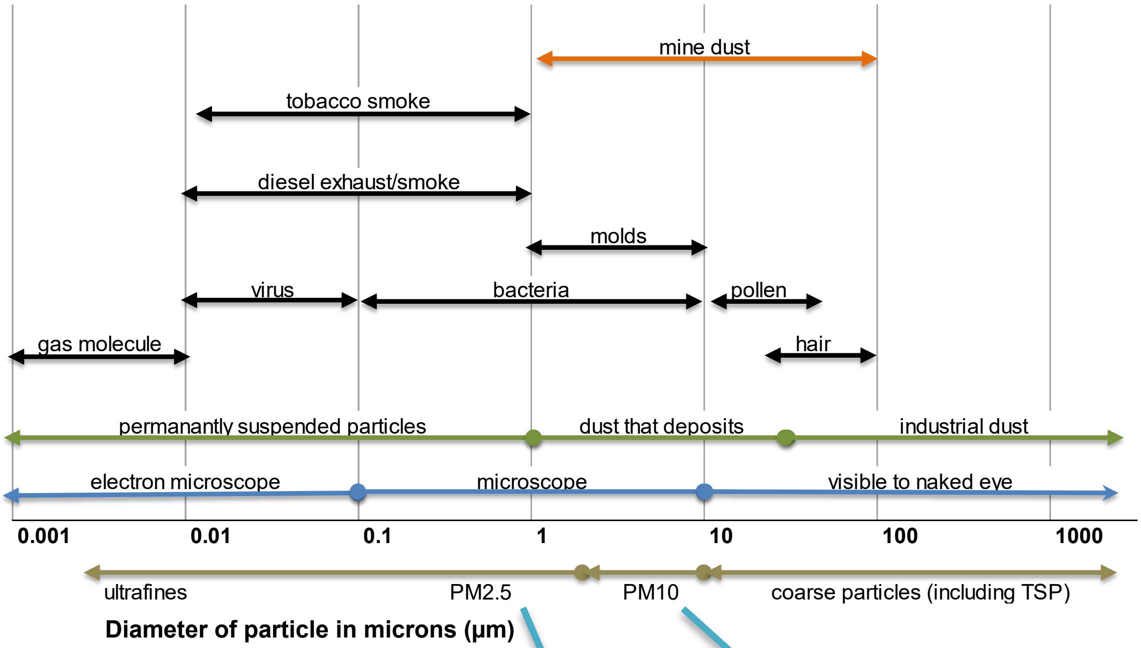
The focus of any assessment addressing potential health effects relates to particulates of a size that are respirable. These particulates comprise the following (as illustrated in **Figure 4.2**):

- 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
- Ultrafine particles - 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[5] and lungs. Once in the lungs, adverse health effects may occur that include mortality and morbidity, which have been causally linked with a range of adverse cardiovascular and respiratory effects (USEPA 2019).

Figure 4.2 shows a general illustration to provide some context in relation to the size of different particles (discussed above) and their relevance and importance for the assessment of inhalation exposures.

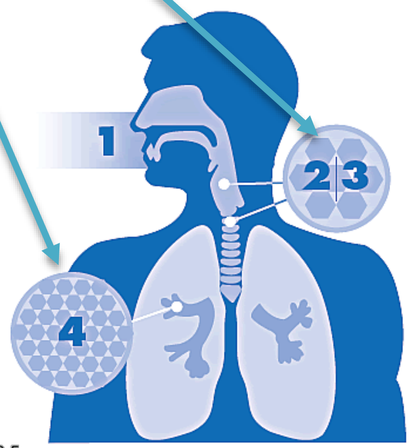
[5] The lower respiratory tract comprises the smaller bronchioles and alveoli, the area of the lungs where gaseous exchange takes place. The alveoli have a very large surface area and absorption of gases occurs rapidly with subsequent transport to the blood and the rest of the body. Small particles can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



1 Particulate matter enters our respiratory (lung) system through the nose and throat.

2|3 The larger particulate matter (PM_{10}) is eliminated from the respiratory system through coughing, sneezing and swallowing.

4 $PM_{2.5}$ can penetrate deep into the lungs. It can travel all the way to the alveoli, causing lung and heart problems, and delivering harmful chemicals (where present) to the blood system.



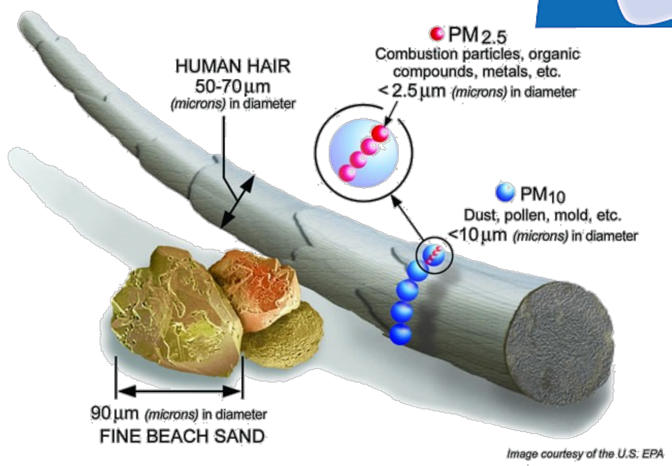


Figure 4.2: Illustrative comparison of relative particle sizes and importance for health

Figure 4.2 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 fine particles that have specific characteristics including respirable crystalline silica (RCS) (refer to **Section 4.5**).

Figure 4.2 also illustrates that particle sizes generated during excavation and other similar construction activities such as mining operations principally comprise sizes between 1 and 100 µm in diameter, with most of the dust considered coarse particles (comprising deposited dust and TSP), PM_{10} and some $PM_{2.5}$. For this reason, the focus of most dust assessments for construction activities relates to deposited dust and PM_{10}. This is in contrast to combustion sources where particulate matter is dominated by vehicle emissions and smoke (from woodfired heaters), which are dominated by $PM_{2.5}$ and smaller particles.

4.3 Summary of air quality assessment

4.3.1 Existing air quality

The main sources of particulate matter in the area surrounding the project includes local traffic using unsealed roads, fugitive dust generated during dry conditions such as agricultural activities and wind erosion from exposed ground, seasonal emissions from household wood heaters, episodic emissions from bushfires, seasonal pollen from grass and trees and long-range transport of fine particulates into the region.

The existing air quality has been evaluated in the AQGHGA based on data available from a regional air quality monitoring station located in Tamworth. Data from Tamworth indicates the following:

- In relation to existing levels of PM_{10} and $PM_{2.5}$, existing air quality is described as good, with the available data complying with annual air quality standards for most years
- Like many regions in NSW, there have been periods of time (such as during 2019) where PM_{10} and $PM_{2.5}$ concentrations have been significantly influenced by bushfires/hazard reduction burns or regional dust storms.

The AQGHGA has utilised background data for PM_{10} and $PM_{2.5}$ based on data reported from 2018, which was considered to provide a conservatively high background year of data (as it related to dry conditions following extended drought conditions and presence of dust storms), and does not include influences from bushfires and hazard reduction burns.

4.3.2 Modelling impacts from the project

The assessment of impacts on air quality has focused on key emissions sources and pollutants (specifically dust) applicable to the construction of the project, including fugitive dust from material extraction, handling, processing and movement, and wind erosion of exposed surfaces. The key pollutants evaluated are dust as TSP, PM_{10} and $PM_{2.5}$. The operation of construction equipment is also expected to result in air emissions associated with diesel exhaust. These diesel emissions were not considered to result in significant concentrations and hence all emissions, except particulate emissions have not been further assessed.

Once construction has been completed there are no emissions to air applicable to the operation of the new Dungowan Dam.

Modelling of air quality impacts requires consideration of the local area, specifically the local terrain and meteorological conditions, as well as emissions to air from the various construction activities relevant to the project.

The local meteorological conditions have been evaluated on the basis of data available from the Tamworth meteorological station. Data from this location is noted to be approximately 50 km from the project and hence the data has been used within the modelling package, along with local terrain, to generate meteorological data relevant to the project area.

Dust emissions from the various construction activities have been estimated on the basis of emission factors for all the relevant activities, volumes to be handled and equipment proposed to be used. The emissions evaluated also included wind erosion from exposed areas. The emission factors have incorporated the following dust mitigation measures, which would be implemented during the project:

- watering of haul roads
- use of water sprays on drilling, screening/sizing and crushing activities.

Modelling was undertaken using CALPUFF for the worst-case construction year.

The construction schedule occurs over a period of approximately six years. The main embankment construction would occur during years two to four of the construction schedule, with the most significant dust generating activities occurring during construction of the main embankment dam and spillway (plus associated quarrying). The emissions scenario therefore focuses on this period of construction and includes the following activities and assumptions:

- excavation of spillway, including:
  - stripping of soil and overburden and temporary stockpiling
  - excavation and hauling to main dam embankment for emplacement
- rock quarrying, including:
  - extraction and processing of material (crushing and screening/sizing)
  - hauling of material to main dam embankment and concrete batch plant
- borrow area, including:
  - excavation and hauling to main dam embankment for emplacement
- construction of main dam embankment including:
  - placement and shaping of material from spillway, quarry, borrow area and external commercial source
- operation of concrete batch plant, including:
  - import of material from quarry and external source
  - handling of material, including cement
  - hauling to spillway and main dam embankment
- realignment of the existing Dungowan Dam Road.

Air emissions during other years of construction would be lower than evaluated in the AQGHGA.

The AQGHGA has also evaluated potential emissions to air that may occur during vegetation removal and disposal, which includes the controlled burning of vegetation stockpiles. The emissions evaluated during these activities include $PM_{2.5}$, carbon monoxide and oxides of nitrogen.

Assessment of other construction activities including the pipeline construction and decommissioning of the existing dam was undertaken using a qualitative approach. This involves the qualitative assessment of potential impacts on community health, including consideration of the implementation of dust mitigation measures.

4.3.3 Outcome of air quality impact assessment

The AQGHGA concluded the following in relation to the modelling and assessment of impacts of the project on air quality:

- The highest predicted impacts occur at the receptors within the inundation zone (R1- R13), all of which are vacant and not relevant to the assessment of exposure to impacts from the project.
- There are no exceedances of the guidelines applicable to the assessment of 24-hour average PM_{10} and $PM_{2.5}$ at any receptor outside of the inundation zone, including the accommodation camp.
- Similarly, there are no exceedances of the annual average impact assessment criteria for PM_{10}, TSP and dust deposition. The existing annual average background $PM_{2.5}$ concentration is already above the impact assessment criterion; therefore it is difficult to assess compliance based on cumulative predictions. The annual average $PM_{2.5}$ concentration at the accommodation camp is 1.8% of the impact assessment criterion, which is slightly above screening criteria used to assess significance. For all other receptors (not within the inundation zone), the annual average $PM_{2.5}$ concentration is 0.3% of the impact assessment criterion and can be considered insignificant.
- Vegetation waste disposal may require controlled burning under suitable conditions. A screening level modelling assessment found that open burning has the potential to add additional days over the impact assessment criteria for 24-hour average PM_{10} and $PM_{2.5}$. Therefore, in addition to selecting a location that is as far as possible from the accommodation camp and occupied residences, periods of poor dispersion should be avoided, such as stable atmospheric conditions. To achieve this, open burning should be planned for daytime hours only with avoidance of smouldering overnight where possible.

  It is noted that the modelling of other emissions, specifically oxides of nitrogen (which can be conservatively assumed to comprise 100% nitrogen dioxide) and carbon monoxide indicate that the maximum predicted impacts are significantly below the assessment criteria adopted (which are based on the protection of health) and hence no further assessment of these emissions has been presented in this assessment.

- To assess the air quality impact from the construction phase of the pipeline and powerline, a qualitative impact assessment was undertaken. A low to medium risk rating was identified for dust soiling impacts, human health impacts and ecological impacts from uncontrolled emissions. With the successful implementation of recommended dust mitigation measures, the risk of dust soiling or human health and ecological impacts would be further reduced.

4.4 Assessment of health impacts – particulates

4.4.1 Health effects

Evaluation of size alone as a single factor in determining the potential for particulate toxicity is difficult since the potential health effects are not independent of chemical composition. There are certain particle size fractions that tend to contain certain chemical components, such as metals or other organic compounds.

There is strong evidence to conclude (USEPA 2012; WHO 2003, 2013) that fine particles (<2.5 µm, $PM_{2.5}$) are more hazardous than larger ones (coarse particles), primarily on the basis of studies conducted in urban air environments where there is a higher proportion (as a percentage of all particulates) of fine particles and other gaseous pollutants present from fuel combustion sources, as compared to particles derived from crustal origins. It should be noted that recent detailed review of the available studies in relation to the health effects of particulates (Hime, Marks & Cowie 2018) concluded that while there is some evidence that particulate matter from traffic and coal-fired power station emissions may elicit greater health effects compared to particulate matter from other sources (diesel exhaust, domestic wood combustion heaters and crustal materials), overall the evidence to date does not indicate a clear 'hierarchy' of harmfulness for particulate matter from different emission sources. Hime et al (2018) identified that making such conclusions is limited by studies, many of which are not comparable. For this assessment, the health effects of exposure to particulate matter has been evaluated as being the same from all sources.

When undertaking any quantitative assessment of health impacts, it is important that the assessment considers health effects where there is sufficient evidence to demonstrate a causal link between exposure to particulates and the health outcome identified. There are numerous studies where statistical associations have been identified. Association does not mean causation; hence it is important that robust reviews are considered where the strength of the available data is fully evaluated and only health effects where there is strong causal evidence is evaluated. Such robust reviews are undertaken by key organisations such as the USEPA, WHO and Australian authorities (as noted below). Assessing health impacts based on associations only (not causation) would be misleading and inappropriate.

A significant amount of research, primarily from large epidemiology studies, has been conducted on the health effects of particulates with causal effects relationships identified for exposure to $PM_{2.5}$ (acting alone or in conjunction with other pollutants) (USEPA 2012, 2019). A more limited body of evidence suggests an association between exposure to larger particles, PM_{10} and adverse health effects (USEPA 2009, 2019; WHO 2003).

Adverse health effects associated with exposure to particulate matter have been well studied and reviewed by Australian and International agencies. Most of the studies and reviews have focused on population-based epidemiological studies in large urban areas in North America, Europe and Australia, where there have been clear associations determined between health effects and exposure to $PM_{2.5}$ and, to a lesser extent, PM_{10}. These studies are complemented by findings from other key investigations conducted in relation to the characteristics of inhaled particles; deposition and clearance of particles in the respiratory tract; animal and cellular toxicity studies; and studies on inhalation toxicity by human volunteers (NEPC 2010).

Particulate matter has been strongly linked to adverse health effects after both short term exposure (days to weeks) and long term exposure (months to years). The health effects vary widely (with the respiratory and cardiovascular systems most affected) and include mortality and morbidity effects.

In relation to mortality, for short term exposures in a population, this relates to the increase in the number of deaths due to pre-existing (underlying) respiratory or cardiovascular disease. For long term exposures in a population, this relates to mortality rates over a lifetime (i.e. shortening the lifespan), where long term exposure is considered to accelerate the progression of disease or even initiate disease.

In relation to morbidity effects, this refers to a wide range of health indicators used to define illness that have been associated with (or caused by) exposure to particulate matter. In relation to exposure to particulate matter, effects are primarily related to the respiratory and cardiovascular system and include (Morawska, Moore & Ristovski 2004; USEPA 2009, 2019):

- aggravation of existing respiratory and cardiovascular disease (as indicated by increased hospital admissions and emergency room visits)
- changes in cardiovascular risk factors such as blood pressure
- changes in lung function and increased respiratory symptoms (including asthma)
- changes to lung tissues and structure
- altered respiratory defence mechanisms.

These effects are commonly used as measures of population exposure to particulate matter in community epidemiological studies (from which most of the available data in relation to health effects is derived) and are more often grouped (through the use of hospital codes) into the general categories of cardiovascular morbidity/effects and respiratory morbidity/effects. The available studies provide evidence for increased susceptibility for various populations, particularly older populations, children and those with underlying health conditions (USEPA 2009, 2019).

There is consensus in the available studies and detailed reviews that exposure to fine particulates, $PM_{2.5}$, is associated with, and causal to, cardiovascular and respiratory effects and mortality (all causes) (USEPA 2012). Similar relationships have also been determined for PM_{10}, however, the supporting studies do not show causal relationships as clear as those shown with $PM_{2.5}$ (USEPA 2012).

There are a number of studies that have been undertaken where other health effects have been evaluated. These studies have a large degree of uncertainty or a limited examination of the relationship and are generally only considered to be suggestive or inadequate (in some cases) of an association with exposure to $PM_{2.5}$ (USEPA 2018). A causal relationship has not been established for these health effects. This includes long term exposures and metabolic effects, male and female reproduction and fertility, pregnancy and birth outcomes; and short term exposures and nervous system effects (USEPA 2018).

In relation to the key health endpoints relevant to evaluating exposures to $PM_{2.5}$, there are some associated health measures or endpoints where the exposure-response relationships are not as strong or robust as those for the key health endpoints and are considered to be a subset of the key health endpoints. This includes mortality (for different age groups), chronic bronchitis, medication use by adults and children with asthma, respiratory symptoms (including cough), restricted work days, work days lost, school absence and restricted activity days (Anderson et al. 2004; EC 2011; Ostro 2004; WHO 2006). While these relationships/associations have identified exposure-response relationships, these relationships are not as strong or as robust as those discussed above and use of these in quantitative assessments is problematic. In addition, the baseline population health data is not available for theses health endpoints, limiting the ability of any assessment to utilise these relationships.

4.4.2 Assessment of fine particulate exposures

In relation to the assessment of exposures to particulate matter, there is sufficient evidence to demonstrate an association between exposure to $PM_{2.5}$ (and to a lesser extent PM_{10}) and effects on health that are causal.

The available evidence does not suggest a threshold below which health effects do not occur. Accordingly, there are likely to be health effects associated with background levels of $PM_{2.5}$ and PM_{10}, even where the concentrations are below the current guidelines. Standards and goals are currently available for the assessment of $PM_{2.5}$ and PM_{10} in Australia (NEPC 2021). These standards and goals are not based on a defined level of risk that has been determined to be acceptable. Rather, they are based on balancing the potential risks due to background and urban sources to lower impacts on health in a practical way.

The air quality standards and goals relate to average or regional exposures by populations from all sources, not to localised ‘hot-spot’ areas such as locations near industry, busy roads or mining. They are intended to be compared against ambient air monitoring data collected from appropriately sited regional monitoring stations. In some cases, there may be local sources (including busy roadways and industry) that result in background levels of PM_{10} and $PM_{2.5}$ that are close to, equal to, or in exceedance of, the air quality standards and goals.

For very localised impacts from a specific project, such as construction works for the project, it is not valid to undertake a detailed assessment of particulate exposures and risks using population exposure-response relationships. The use of population exposure-response relationships do not apply to individuals or even small populations. In addition, the relevance of such methods for the assessment of exposure to crustal dust (rather than urban particulates principally from combustion sources) is not known.

For the assessment of dust generated during construction works, most of the dust comprises larger particle sizes (as characterised by TSP or PM_{10}). However, these larger particle sizes are of less relevance to human health. $PM_{2.5}$ is the particle size fraction that is of most relevance and importance for assessment impacts on human health. It is noted that $PM_{2.5}$ includes all particles that are 2.5 microns in diameter and smaller, which would include ultrafine particles.

For this assessment, review of dust emissions relating to the air standards provided for $PM_{2.5}$ (the key size fraction of concern for human health) from NEPM (2021) is considered to be adequately protective of health for exposures that may occur during construction. The guidelines adopted for the project are as follows:

- 24-hour average = 25 micrograms per cubic metre ($\mu g/m^3$), and 20 $\mu g/m^3$ adopted as goal from 2025

- Annual average = 8 µg/m³ (with no exceedances), and 7 µg/m³ adopted as goal from 2025.

It should be noted the guidelines noted above relate to regional air quality, for comparison with data from regional air quality monitoring in the community, not air quality directly adjacent to a source. Application of these guidelines to the assessment of localised dust emissions during construction is undertaken for the purpose of identifying any significant issues in terms of localised impacts.

Table 4.1 presents a summary of the $PM_{2.5}$ exposure concentrations modelled in the AQGHGA, with consideration against the relevant health based guidelines.

Table 4.1: Summary and review of $PM_{2.5}$ impacts – construction activities

Source and location	Concentration of $PM_{2.5}$ (µg/m³)		Comments
	24-hour average	Annual average	
Background (existing sources)	Varying	8.3	PM2.5 annual average concentrations
Worst-case construction works			
Construction camp			
- incremental	1.6	0.1	Annual average noted to be 1.8% of the guideline
- total (incremental plus background)	24.3	8.4	Small change in total concentrations
Closest community location (outside of inundation area)			
- incremental	0.4	<0.1	Annual average noted to be 0.3% of guideline
- total (incremental plus background)	24.2	8.3	No change in existing background
Burning of biomass			
- construction camp	33.2	NA	Short term impacts only, when burning occurs Impacts greatest during early morning, evenings and overnight – management measures identified to minimise impacts
- closest community location	14.8	NA	
Guideline	**25** **20 (goal for 2025)**	**8** **7 (goal for 2025)**	

Review of **Table 4.1** indicates the following:

- Background exposures:
  - In all areas the background annual average $PM_{2.5}$ concentrations exceeds the adopted guideline. This is due to a range of sources in the rural area. Where this occurs (in relation to an annual average concentration), it is important to assess the potential for impacts on health based on the incremental impacts predicted.
- Community exposures:
  - For the community outside of the project area (and construction camp), $PM_{2.5}$ impacts are considered negligible, and would not change existing air quality (either short-term as 24-hour average or long-term as annual average).
  - This outcome is dependent on implementation of the dust management measures outlined in the AQGHGA.

- Exposures in the construction camp:
  - Data relevant to exposures that may occur in the construction camp have been considered, even though this assessment does not address occupational exposure issues relating to the construction works. Workers in this area may not be monitored and managed in relation to workplace exposures, hence the expectation of air quality that does not pose a risk to health applies to this area.
  - There are no exceedances of the relevant 24-hour average guideline (for the project plus background).
  - The incremental impacts of annual average $PM_{2.5}$ as a result of the worst-case construction workers are low at 0.1 µg/m^3 for an annual average (which comprises 1.8% of the guideline). Reference is often made in some air quality guidance as to what sort of increment would be considered to be negligible:
    - EPV Victoria (EPA Victoria 2022) indicate that an incremental change of up to 4% of the guideline would not be measurable (based on the operation of ambient monitoring equipment). The annual average increment predicted at the construction camp is 1.8% of the guideline and would not be measurable.
    - Draft guidance in Western Australia (WA DWER 2019) suggests an annual average incremental impact that is less than 1% of the guideline is considered insignificant. The basis for determining what is insignificant is not stated in the WA guidelines, and such a change would not be considered measurable.

In relation to assessing impacts on health, it is important to understand if the impacts being evaluated are measurable where people may be exposed. In relation to the construction camp, the increase in annual average $PM_{2.5}$ concentration would not be measurable. Further, the following should be noted:

- Workers in the construction compound are adults who are generally healthy (as they are involved in construction activities).
- Exposures during construction activities would be expected to be managed to comply with WHS regulations and guidelines.
- Exposures outside of construction activities, in the construction camp, would not occur all day, every day for a whole year. Exposures would be variable depending on the work activities undertaken and the amount of time spent on site in the camp (rather than at home/on leave).
- An incremental increase of annual average $PM_{2.5}$ of 0.1 µg/m^3 would not result in an increased risk of premature mortality that would be considered significant[6] (Capon & Wright 2019; NEPC 2011), noting that such a calculation relates to lifetime continuous exposures by all members of the community, with the risk expected to be dominated/driven by sensitive individuals rather than healthy adult workers.

Based on the above there are no health impacts of concern in relation to emissions to air of PM2.5 as a result of the construction works, where proposed dust mitigation measures are implemented.

[6] An increased risk of 1 in 100,000 is considered to be of potential significance in relation to changes in air quality for small groups, rather than whole populations (NEPC 2011 and enHealth 2012)

In relation to peak exposures that may occur as a result of biomass burning, which occurs only on occasion, assessment of public health responses relating to smoke events (NSW Health 2017) places the predicted concentrations at the construction camp and in the off-site community in a level determined to represent low level risk and health response. Such exposures would be lower where further managed to prevent smouldering of such burned materials overnight.

4.5 Composition of particulates

4.5.1 General

This relates to whether the make-up (chemical composition) and/or shape of the dust particle has the potential to result in health effects, if inhaled and the particle is small enough to penetrate the lungs.

This is particularly important when discussing exposures to respirable crystalline silica (RCS) as the health effects specific to these particles is linked to the crystalline nature, specifically the hardness of the particles and the crystal fragmentation (that is, their shape), which ultimately results in an inflammatory response (Turci et al. 2016). Where other chemicals are bound to the dust particle when inhaled these chemicals may move off the dust particle and be absorbed into the body.

When assessing impacts relating to the composition of the particle, the faction that can penetrate into the lungs as $PM_{2.5}$ is of most relevance.

4.5.2 Silica

The toxicity of RCS has been evaluated following guidance provided by enHealth (enHealth 2012) and NEPM (NEPC 1999 amended 2013b). This requires consideration of the health end-points and where carcinogenicity is identified; the mechanism of action needs to be understood. A detailed review of the available information and data is provided in Appendix A. This section provides an overview of the key aspects relating to the toxicity of RCS and the approach adopted for the assessment of community exposures.

Silica in the form of quartz is one of the most commonly occurring minerals on the Earth's surface, with over 95 per cent of the earth's crust made of minerals containing silica. There are two forms of silica – crystalline silica, and amorphous silica. Amorphous silica lacks a crystalline structure and is not further assessed. 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.

Silica is naturally released into the environment through the weathering of rocks, volcanic activity and biogenic sources. This means that background exposures (naturally occurring exposures outdoors or indoors – where there are no specific silica sources) 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 (such as 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
- in pet litter and furniture foam.

Given the wide range of sources of silica in the environment it is expected there would be RCS in urban and rural environments. Review of information related to background or ambient levels of RCS in air from the available Australian and international sources is provided in Appendix A. Based on the available data, existing air quality in the project area (which is an urban air environment away from sources of RCS) is expected to have a low level of RCS.

4.5.3 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.

When RCS is inhaled it is the fine fractions that are of importance as these are small enough to penetrate into the lungs (see **Figure 4.2**) where they can be deposited. RCS particles are not soluble so they are not easily absorbed by the body and remain as solid particles once deposited in the lungs.

The presence of these particles in the lungs damages cells in the lungs, which impairs the ability of the lungs to clear or flush out the particles (which would normally occur through mucous or coughing). This means these particles can become 'stuck' or embedded in the lungs. As these particles can remain in the lungs for a long time, the shape of the particles becomes important as this leads to inflammation which results in disease such as silicosis or fibrosis. The prolonged inflammation results in the formation of fibrotic scar tissue and degradation of the lung clearance mechanism. The improper repair of damaged lung tissue is essential for the development of chronic disease.

Acute exposures can also result in respiratory inflammation, which 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.

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

Silicosis is a progressive and irreversible fibrotic lung disease 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. While primary function and general health is typically not compromised in the early stages, 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.
- **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). COPD 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 but 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.

Carcinogenicity

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 increased risk to lung cancer in RCS workers has been reported, with risks dependant on cumulative (successive and ongoing) exposures over times. RCS workers are workers who are frequently exposed to crystalline silica at high levels as part of their occupation/work. This relates to workers being in frequent close proximity to or undertaking activities such as the crushing, cutting, drilling, grinding, sawing and polishing of stone or manufactured products that contain silica[7].

Inhaled crystalline silica dust in the former of quartz or cristobalite, is classified as Group 1 (carcinogenic to humans) by the International Agency for Research on Cancer (IARC) (IARC 2012), based on occupational data. TCEQ (TCEQ 2009) also emphasises that identification of RCS as carcinogenic relates only to occupational exposures. The mechanism for carcinogenicity is likely to be inflammation.

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

The available evidence indicates that RCS is genotoxic with the ability to cause mutagenicity and DNA damage (ATSDR 2019).

No information is available about 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.

4.5.4 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 two types of toxicity values are available (see **Appendix A**):

- **Occupational air guidelines** – these guidelines are applicable to individuals who are exposed to chemicals in the workplace through use or handling, and represent exposure concentrations that do not result in adverse health effects or cause undue discomfort for workers. These guidelines relate exposures by healthy workers in the workplace, during

[7] Refer to additional information available from SafeWork Australia in relation to work activities that represent a high risk exposure https://www.safeworkaustralia.gov.au/silica

work hours. The guidelines are higher than ambient or community air guidelines and may be at levels that are mildly irritating.

- **Community air guidelines** – these guidelines represent the concentration of a chemical in air that, based on the current science, do not result in adverse health effects for the public or community. 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 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.

This assessment has only further considered community air guidelines.

Based on the available guidelines and information related to the development of these guidelines (see **Appendix A**), the following TRV or guideline has been adopted for the assessment of community exposures to RCS:

- RCS in air as $PM_{2.5}$ (based on an annual average concentration) = 3 µg/m^3

This guideline is consistent with evaluations undertaken in California (OEHHA 2005), Texas (TCEQ 2009) and Minnesota (MDH 2013), and adopted by the Victorian EPA (EPA Victoria 2007) for the assessment of RCS exposures in the community surrounding mining and extractive industries (which includes quarry activities). The guideline is protective of all health effects for exposures by all members of the community.

As the construction works of the project involve variable dust emissions, peak exposures to RCS within the community have also been evaluated using an acute guideline as follows (TCEQ 2020):

- RCS in air as $PM_{2.5}$ (based on a 24-hour average concentration) = 24 µg/m^3

4.5.5 Assessment of potential RCS impacts from project

The toxicity reference values, or health based guidelines, relate to all inhalation exposures to RCS. No background RCS data is available for the project area, and given the rural nature of the area, some level of background RCS is expected to be present. Hence conservative background estimates of RCS have been adopted for the purpose of this assessment (refer to **Appendix A** for additional detail on background levels of RCS).

In relation to potential RCS emissions as a result of the construction works, it has been conservatively assumed that 100% of $PM_{2.5}$ derived from construction works is RCS. This would not be the case as the $PM_{2.5}$ comprises particulate emissions from diesel equipment as well as dust generated during various activities. The rock and soil in the area would not comprises 100% silica materials. Hence the proportion of $PM_{2.5}$ that is RCS would be significantly lower.

Based on the above assumptions, and the health based guidelines adopted for the assessment of community exposures to RCS, the following is relevant:

- When evaluating long-term exposures on the basis of an annual average:
  - background levels of RCS can be conservatively assumed to be 1.9 µg/m^3

- modelling of $PM_{2.5}$ impacts associated with the project indicated the maximum incremental impact was between <0.1 to 0.1 µg/m^3 (range for community areas and construction camp)
- assuming 100% of PM2.5 was RCS, the total RCS concentration is in the range <2 to 2 µg/m^3
- these total RCS exposure concentrations are lower than the health based guideline of 3 µg/m^3.

- When evaluating short-term exposures on the basis of a 24-hour average:
  - background levels of RCS (as 24-hour average) can be conservatively assumed to be 8 µg/m^3
  - modelling of $PM_{2.5}$ impacts associated with the project indicated the maximum incremental impact was between 0.4 to 1.6 µg/m^3 (range for community areas and construction camp)
  - assuming 100% of PM2.5 was RCS, the total RCS concentration is in the range 8.4 to 9.6 µg/m^3
  - these total RCS exposure concentrations are lower than the acute health based guideline of 24 µg/m^3.

Based on the above potential exposures to RCS in air during construction, in the construction camp, and in all off-site areas where the community may be exposed, are low and there are no health risk issues of concern.

4.6 Uncertainties

The assessment of potential health impacts as a result of emissions to air during construction works has relied on the modelling of air quality impacts. The modelling has incorporated a number of conservative assumptions, which include the following:

- use of background particulate concentrations from a year where background levels were typically higher as a result of a prolonged drought and presence of dust storms
- burning of biomass has made a conservative estimation of the volume of waste and assumes that material expected to be burned over a week, is combusted over a single 24 hour period
- all emission scenarios evaluated during the worst-case construction year, are assumed to occur continuously at the same time.

In addition, the assessment of potential health impacts has assumed that workers in the construction camp and the off-site community remains at home (or on their property) all day, every day for a lifetime. This approach overestimates actual exposures where residents spend time away from the home, and the changes in air quality evaluated in this assessment remain the same for a lifetime.

The assessment of potential exposures to RCS has adopted a number of conservative assumptions that will overestimate RCS exposures in all areas evaluated.

As a result of the above, the risk calculations presented are considered to be conservative.

4.7 Outcomes of assessment of health impacts – air quality

Table 4.2 presents a summary of the outcomes of the assessment undertaken in relation to the impacts of changes in air quality, associated with the project, on community health.

Table 4.2: Summary of health risks – air quality

Air emissions	
Impacts	The focus of the assessment of air emissions relates to construction activities. There are no impacts to air quality during project operation. Where all proposed dust mitigation measures are implemented, there are no risk issues of concern in relation to community exposure to particulate matter, specifically $PM_{2.5}$, and respirable crystalline silica that may be generated during construction activities.
Mitigation	All mitigation measures as detailed in the AQGHGA are required to be implemented. This include the development and implementation of an Air Quality Management Plan (AQMP) that provides detail on the methods to be used to minimise the generation of dust during all works, and from exposed materials.

Section 5. Health impact assessment: Noise and vibration

5.1 Background

This section presents a review and further assessment of impacts on health associated with noise and vibration, relevant to the project. The assessment presented has relied on the information provided in the following report:

- EMM 2022c, Noise and Vibration Impact Assessment, Dungowan Dam and pipeline project. Report dated May 2022 and referred to as the NVIA.

The noise impact assessment has considered impacts that may occur in the off-site community as a result of construction and operation of the project. The NVIA has evaluated noise impacts within six noise catchment areas (NCAs), which incorporate residential areas located outside of the inundation area and adjacent to the pipeline alignment. These NCAs and receptors are illustrated in **Figure 3.2** It is noted that these receptors are generally consistent with those evaluated in the AQGHGA (refer to **Figure 3.1** and **Section 4**), however the NVIA also includes a number of receptors located adjacent to the pipeline.

5.2 Health impacts associated with noise

Environmental noise has been identified (I-INCE 2011; WHO 2011, 2018)[8] as a growing concern because it has negative effects on quality of life and wellbeing and has the potential for causing harmful physiological health effects. With increasingly urbanised or developed societies, impacts of noise on communities have the potential to increase over time.

Sound is a natural phenomenon that only becomes noise when it has some undesirable effect on people or animals. Unlike chemical pollution, noise energy does not accumulate either in the body or in the environment, but it can have both short-term and long-term adverse effects on people. These health effects include (WHO 1999, 2011, 2018):

- Sleep disturbance (sleep fragmentation that can affect psychomotor performance, memory consolidation, creativity, promote risk-taking behaviour and increase risk of accidents).
- Annoyance.
- Cardiovascular health.
- Hearing impairment and tinnitus.
- Cognitive impairment (effects on reading and oral comprehension, short and long-term memory deficits, attention deficit).

Other effects for which evidence of health impacts exists, and are considered to be important, but for which the evidence is weaker, include:

- Effects on quality of life, well-being and mental health (usually in the form of exacerbation of existing issues for vulnerable populations rather than direct effects).
- Adverse birth outcomes (pre-term delivery, low birth weight and congenital abnormalities).

[8] I-INCE – International Institute of Noise Control Engineering.

- Metabolic outcomes (type 2 diabetes and obesity).

Within a community the severity of the health effects of exposure to noise and the number of people who may be affected are schematically illustrated in **Figure 5.1**.

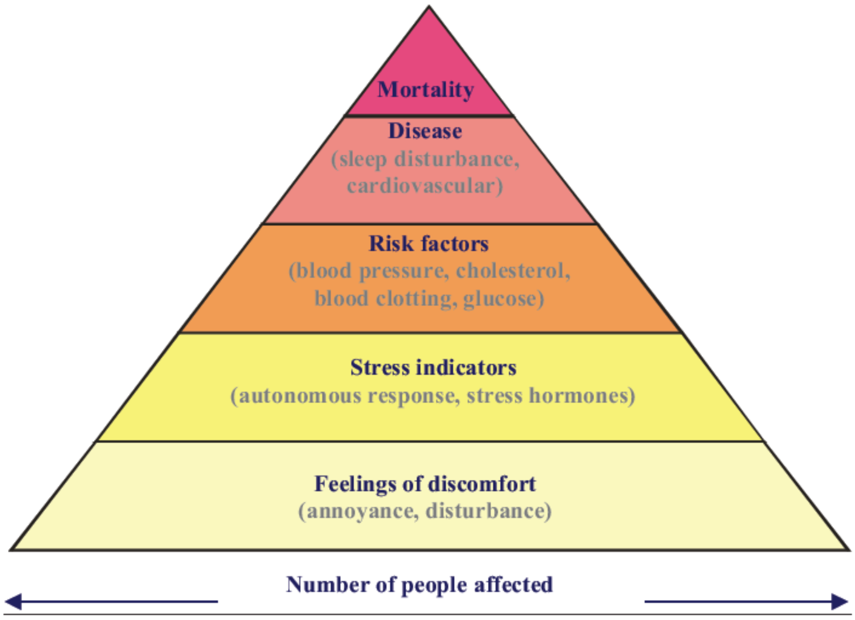


Figure 5.1: Schematic of severity of health effects of exposure to noise and the number of people affected (WHO 2011)

Often, annoyance is the major consideration because it reflects the community's dislike of noise and their concerns about the full range of potential negative effects, and it affects the greatest number of people in the population (I-INCE 2011; WHO 2011, 2018).

There are many possible reasons for noise annoyance in different situations. Noise can interfere with speech communication or other desired activities. Noise can contribute to sleep disturbance, which has the potential to lead to other long-term health effects. Sometimes noise is just perceived as being inappropriate in a particular setting without there being any objectively measurable effect at all. In this respect, the context in which sound becomes noise can be more important than the sound level itself (I-INCE 2011; WHO 2011, 2018).

Different individuals have different sensitivities to types of noise and this reflects differences in expectations and attitudes more than it reflects any differences in underlying auditory physiology. A noise level that is perceived as reasonable by one person in one context (e.g. in their kitchen when preparing a meal) may be considered completely unacceptable by that same person in another context (e.g. in their bedroom when they are trying to sleep). In this case the annoyance relates, in part, to the intrusion from the noise. Similarly, a noise level considered to be completely unacceptable by one person, may be of little consequence to another even if they are in the same room. In this case, the annoyance depends almost entirely on the personal preferences, lifestyles and attitudes of the listeners concerned (I-INCE 2011; WHO 2011, 2018).

Perceptible vibration (e.g. from construction activities) also has the potential to cause annoyance or sleep disturbance and adverse health outcomes in the same way as airborne noise. However, the health evidence available relates to occupational exposures or the use of vibration in medical treatments. No data is available to evaluate health effects associated with community exposures to perceptible vibrations (I-INCE 2011; WHO 2011, 2018).

It is against this background that an assessment of potential noise impacts of the Project on health was undertaken.

In relation to the available noise guidelines, the most recent review of noise by the WHO (WHO 2018) provided an update in relation to environmental noise guidelines (and targets) that more specifically relate to transportation (road, rail and air), wind turbines and leisure noise sources. The more comprehensive guideline levels for noise (related to all sources) remain the older WHO guidelines (WHO 1999) and night noise guidelines (WHO 2009).

5.3 Existing noise environment

The project area comprises existing rural residential areas, where existing ambient noise is dominated by natural sounds and local traffic with noise from human activity and domestic pets also present.

Long-term unattended noise monitoring was completed in the localities of Calala and Loomberah between 12 and 25 June 2020, as part of a Review of Environmental Factors for the replacement pipeline between Dungowan Village and Calala (completed in February 2022). The results of the noise monitoring showed that background noise in the rural residential areas surveyed was below the minimum background noise levels outlined in NSW Environment Protection Authority (EPA) 2017, *NSW Noise Policy for Industry* (NPfI).

5.4 Review of the noise guidelines adopted

5.4.1 General

The assessment of noise impacts of the project has been informed by the use of guidelines. The first step in evaluating potential impacts of noise in community health is to determine if the noise guidelines adopted are adequately protective of community health. Where the guidelines are protective of community health, and where predicted levels of noise exposure comply with, or can comply with these guidelines following implementation of mitigation/management measures, the potential for health impacts in the community is considered to be negligible (where there would be compliance with no additional mitigation) to low (where mitigation measures are required to ensure compliance).

5.4.2 Adopted noise and vibration guidelines

Construction noise

Construction noise has been assessed on the basis of the NSW Department of Environment and Climate Change, Interim Construction Noise Guideline (ICNG) (NSW DECC 2009). These guidelines identify noise limits that are applicable to different working hours. These noise limits are termed construction noise management levels (NMLs). The NMLs are based on background levels and an additional noise level, which varies depending on the hours of work. The NMLs adopted for the project are as follows (applied as $L_{Aeq,\ 15\text{-minute}}$):

- Day (standard construction hours) = 45 dB, with noise impacts of 75 dB and over defined as highly noise affected
- Day (outside of standard hours) = 40 dB
- Evening = 35 dB
- Night = 35 dB.

Construction vibration

Vibration has been evaluated based on the *Environmental Noise Management – Assessing Vibration: a technical guideline* (DEC 2006) (the guideline), which is based on advice contained within the British Standard BS 6472 – 2008, *Evaluation of human exposure to vibration in buildings* (1-80 Hz) (British Standard 2008).

The guideline presents preferred and maximum vibration values for use in assessing human responses to vibration and provides recommendations for measurement and evaluation techniques. At vibration values below the preferred values, there is a low probability of adverse comment or disturbance to building occupants.

The criteria adopted relate to intermittent vibration (applicable for the construction activities), with different values adopted for day and night time periods.

Guidelines are also adopted for assessing potential impacts on buildings and structures (cosmetic damage).

Construction blasting

Blasting has been assessed on the basis of ANZEC (ANZEC 1990) criteria for the minimisation of human annoyance, which apply to impacts at privately-owned and other sensitive receptors. These criteria are:

- maximum overpressure due to blasting should not exceed 115 dB for more than 5% of blasts in any year, and should not exceed 120 dB for any blast; and
- maximum peak particle ground velocity should not exceed 5 millimetres per second (mm/s) for more than 5% of blasts in any year, and should not exceed 10 mm/s for any blast.

The guidelines also indicate that blasting should generally only be permitted during the hours of 9am and 5pm Monday to Saturday, and not take place on Sundays or Public Holidays.

Operational noise

Operation noise impacts are assessed on the basis of noise criteria established accordance with the NSW Industrial Noise Policy (NPfI) (NSW EPA 2017b). These criteria are protective of intrusive noise and noise amenity, with project noise levels established to protect both these aspects. For this project the following noise criteria have been adopted (applied as $L_{Aeq,\ 15\text{-minute}}$):

- Day = 40 dB
- Evening = 35 dB
- Night = 35 dB.

Maximum noise criteria, that related to protecting sleep disturbance, adopted are as follows (applicable to night time noise):

- $L_{Aeq,15min}$ 40 dB
- L_{AFmax} 52 dB.

Road traffic noise

Road traffic noise was assessed on the basis of the NSW Road Noise Policy (NSW DECCW 2011)[9], as it applies to existing residences on main roads (freeway/arterial and sub-arterial roads) as well as local roads affected by additional traffic. This guidance provides the following (as external noise):

- main roads: guideline of 60 dB as $L_{Aeq,15\ hour}$ (day and evening) and 55 dB as $L_{Aeq,9\ hour}$ (night)
- local roads: guideline of 55 dB as $L_{Aeq,1\ hour}$ (day and evening) and 50 dB as $L_{Aeq,1\ hour}$ (night).

Additionally, the NSW Road Noise Policy states where existing road traffic noise criteria are already exceeded, any additional increase in total traffic noise level should be limited to 2 dB where all feasible and reasonable noise mitigation is considered.

Noise levels where mitigation needs to be considered are also identified (essentially based on existing noise levels + 12 dB for $L_{Aeq,15\ hour}$ (day and evening) and $L_{Aeq,9\ hour}$ (night).

5.4.3 Review of criteria

Noise criteria adopted in the NVIA are consistent with the relevant guidance referenced. In relation to noise impacts during construction and operation, the noise criteria adopted are sufficiently low during the day and night to be protective of health, based on available guidance from the WHO (WHO 1999, 2011).

The maximum noise criteria for operations are set to protect residence from sleep disturbance and for this project, an L_{AFmax} of 52 dBA is relevant to the night-time period. This maximum noise level is sufficiently low to be protective of health, based on available guidance from the WHO (WHO 1999).

The road traffic noise criteria adopted are higher than the health based goals relevant to road noise traffic from the WHO (WHO 2018) but consistent with the upper end of noise criteria established in previous WHO guidelines for outdoor noise predictions (WHO 1999, 2009). In addition, the NSW

[9] DECCW – NSW Department of Environment, Climate Change and Water.

Road Noise Policy also indicates that "*an increase of up to 2 dB represents a minor impact that is considered barely perceptible to the average person*".

Blasting and vibration impacts have been evaluated in accordance with criteria established to protect human annoyance and structural damage. Provided the human comfort criteria are met, there would be no concern in relation to health impacts.

5.5 Review and assessment of health impacts from noise

5.5.1 Noise modelling

Noise impacts have been assessed in the NVIA using a model, the iNoise software package. This incorporates information on the location of the plant and equipment, distances to receptor locations, ground effects, atmospheric absorption, topography and meteorological conditions. The modelling has utilised sound power levels for the plant and equipment to be used, and the following assumptions:

- all construction plant is conservatively assumed to operate continuously in any 15 minute period
- all on-site vehicle movements are 20 km/hr or less.

Road noise has been assessed on the basis of the US Environmental Protection Agency Federal Highway Administration (FHWA) traffic noise model (TNM), based on estimated daily traffic movements (and traffic composition in terms of trucks and passenger vehicles).

5.5.2 Construction noise

Construction noise has been assessed for static construction areas (activities at locations that remain unchanged throughout construction, such as quarrying, dam demolition) and dynamic construction (activities that are transient as works change location such as pipeline and road construction works).

Based on the modelling undertaken the following has been determined:

- Static construction: Noise emissions from static construction works are predicted to comply with NMLs at all residential assessment locations both during and outside standard construction hours, where relevant. This is due to the intervening topography and large separation distances between the construction areas and assessment locations.
- Pipeline construction: Residential receptors within approximately 30 m of pipeline construction activities may experience levels above the 'highly affected' noise management level of 75 dB $L_{Aeq,15\ minute}$. It is not expected that this would occur for more than five days. A number of residences are within 30 m of the pipeline construction area. Residential receptors within approximately 730 m of pipeline construction activities may experience levels above the standard hours construction noise management level of 45 dB $L_{Aeq,15\ minute}$ prior to any mitigation or management measures being implemented. The level of exceedance is not stated, however, during standard work hours noise levels just above the adopted criteria would not be expected to result in health impacts.
- Dungowan Dam Road: Residential receptors within approximately 90 m of the Dungowan Dam Road upgrade works may experience levels above the "highly affected" noise

management level of 75 dB $L_{Aeq,15 minute}$ prior to any mitigation or management measures being implemented. A number of residences are within 90 m of the road upgrade works area. Residential receptors within approximately 1,300 m of the Dungowan Dam Road upgrade works may experience levels above the standard hours construction noise management level of 45 dB $L_{Aeq,15 minute}$. The level of exceedance is not stated, however, during standard work hours noise levels just above the adopted criteria would not be expected to result in health impacts.

Construction noise levels are predicted to exceed the NMLs at the nearest residential assessment locations at some stage during the pipeline construction and Dungowan Dam Road upgrade, both during and outside standard construction hours (where out of hours works is necessary). This is not an uncommon finding for construction projects in close proximity to rural residential areas with low background noise levels and indicates that feasible and reasonable mitigation practices should be considered and applied to minimise the impacts of noise on the community.

Noise mitigation measures are detailed in the NVIA, to minimise potential impacts of the project on the surrounding community. These measures would be detailed in a Noise and Vibration Management Plan (NVMP). This would require location and activity specific assessments undertaken prior to activities that have the potential to result in exceedance of the adopted guidelines (including works associated with the pipeline construction and Dungowan Dam Road upgrade). An out of hours protocol would be developed for the construction of the project. In addition, the community is to be notified (ahead of time) of information relating to activities that may result in noise impacts. Noise monitoring is also required to determine the effectiveness of the noise mitigation measures.

A range of noise management measures and practices relevant to a range of work practices, plant and equipment, work scheduling and the use of noise controls would be outlined in the NVIA. The noise controls (screening, enclosures and silencing) have the potential to reduce noise impacts by 5 to 50 dB, depending on the control measure implemented.

Where the above measures are implemented, the potential for health impacts associated with construction noise is expected to be further reduced. It is important that the noise mitigation measures detailed in the NVIA are implemented to ensure the potential for impacts on health are minimised.

It is noted, however, that even where noise mitigation measures are implemented, it is expected that noise from activities will be discernible by the community, at times.

5.5.3 Operational noise

Operational noise is expected to be derived from operational maintenance and pipeline control valves.

The operational maintenance noise levels are predicted to be below the relevant NPfI noise trigger levels at all assessment locations for noise enhancing meteorological conditions.

In relation to the operation of pipeline control valves, these would be within an enclosure and the noise assessment identified maximum noise levels that can be emitted from the enclosure to ensure the noise criteria at the closest residential areas is met.

Based on the assessment presented, there are no community health impacts of concern in relation to operation noise associated with the project.

5.5.4 Road traffic noise

Construction

Construction traffic noise would not exceed the adopted noise criteria on the New England Highway, Duri-Dungowan Road, hence there would be no health impacts of concern for these areas.

However, for other roadways in the project area there is the potential for some impacts during construction:

- There is the potential for exceedance of the criteria at the closest residences along Tamworth-Nundle Road and Ogunbil Road, in particularly during the night time period. Mitigation measures are therefore required to minimise night-time noise along these roadways.
- In addition, mitigation measures need to be implemented to minimise night-time noise on Dungowan Dam Road, Dungowan Creek Road and Back Woolomin Road, noting that the construction traffic evaluated on these roads is expected to result in a significant change in road traffic from existing traffic (as these are currently low use local roads).

Road noise impacts are required to be mitigated, as detailed in the NVIA. In relation to road noise, these mitigation measures include

- developing routes for the delivery of materials and parking of vehicles to minimise noise
- minimising truck movements
- scheduling activities to minimise impacts by undertaking all possible work during hours that will least adversely affect sensitive receivers and by avoiding conflicts with other scheduled events
- optimising the number of deliveries to the site by amalgamating loads where possible and scheduling arrivals within designated hours
- designating, designing and maintaining access routes to the site to minimise impacts
- include contract conditions that include penalties for non-compliance with reasonable instructions by the principal to minimise noise or arrange suitable scheduling.

In particular, minimising the movement of trucks during the night-time period along Tamworth-Nundle Road, Ogunbil Road, Dungowan Dam Road, Dungowan Creek Road and Back Woolomin

Road would be of key importance to minimise health impacts, particularly impacts relating to sleep disturbance. A number of these existing roads are infrequently used with low background noise. Hence changes in traffic volumes on these roads is expected to be noticeable by the community, and may result in increased levels of annoyance and sleep disturbance, where mitigation measures are not implemented.

Operations

Operational road traffic noise levels are predicted to be low, with increases in road traffic volumes expected to be less than 2% of existing traffic. Hence no exceedances of road noise guidelines would be expected during operations.

5.5.5 Blasting and vibration impacts

The assessment undertaken identified that there are no exceedances of the adopted criteria protective of human comfort for blasting in the spillway area, the quarrying areas, the diversion tunnel or the existing Dungowan dam to be decommissioned.

Assessment of vibration impacts during construction determined that the risk of cosmetic damage is low with all operations outside of the working distances established to be protective of human comfort.

Hence there are no community health impacts of concern in relation to blasting and vibration.

5.6 Uncertainties

The assessment presented in relation to potential noise and vibration impacts, and the potential for impacts on community health as a result of changes in noise or vibration as a result of the project, is considered to be conservative. There are a number of areas within the NVIA where conservative assumptions and approaches have been adopted. This includes the consideration of the worst-case meteorological conditions, assuming these occur on a regular basis and assumptions in relation to the concurrent use of plant and equipment.

On the basis of the above, conclusions in relation to potential impacts on community health are expected to be conservative.

5.7 Outcomes of health risk assessment: noise and vibration

Table 5.1 presents a summary of the outcomes of the assessment undertaken in relation to the impacts of changes in noise and vibration, associated with the project, on community health.

Table 5.1: Summary of health risks – noise and vibration

Noise and vibration emissions	
Impacts	Based on the predicted noise levels, there are no health impacts of concern for noise generated during construction from static locations or during operations. However, during the construction of the pipeline, Dungowan Dam Road upgrade works there is the potential for elevated levels of noise that require mitigation to ensure health is protected. These measures are of most importance during the night-time period. In relation to road noise impacts, there is the potential for construction traffic to result in impacts to the community located adjacent to some local roads. In particular, minimising the movement of trucks during the night-time period along Tamworth-Nundle Road, Ogunbil Road, Dungowan Dam Road, Dungowan Creek Road and Back Woolomin Road would be of key importance to minimise health impacts, particularly impacts relating to sleep disturbance. A number of these existing roads are infrequently used with low background noise. Hence changes in traffic volumes on these roads are expected to be noticeable by the community and may result in increased levels of annoyance and sleep disturbance, where mitigation measures are not implemented. The potential for adverse health impacts within the off-site community associated with construction vibration or blasting is considered to be negligible.
Mitigation	The NVIA describes a range of mitigation measure that would be adopted for the project to minimise noise impacts within the community. It is important that these mitigation measures are implemented to mitigate impacts identified and minimise the potential for health impacts in the community.

Section 6. Health impact assessment: Water

6.1 Approach

Health impacts associated with project related changes in flood risks, water access and water quality relevant to the local community have been evaluated on the basis of information provided in the following reports:

- SMEC 2021, Hydrology & Consequence Assessment, Dungowan Dam Design. Report dated 8 January 2021.
- EMM 2022f, Streamflow analysis, Surface Water Assessment – Annexure A. Report dated April 2022.
- EMM 2022f, Flooding technical report, Surface Water Assessment – Annexure G. Report dated May 2022.
- Royal HaskoningDHV 2021, Reservoir Limnology Assessment Report, Dungowan Dam and Pipeline Project. Report dated 30 June 2021.
- EMM 2022g, Groundwater Impact Assessment, Dungowan Dam and pipeline project. Report dated June 2022.

The assessment undertaken in relation to water has involved a qualitative review of the available information to determine if there is the potential for the project to result in changes to surface water or groundwater quality or quantity, and where such changes may occur, if these may adversely affect the health of the community who may access and use these water resources.

6.2 Catchment

The Dungowan Dam catchment is located on the western side of the Great Dividing Range approximately 50 km southeast of Tamworth. The catchment contains the existing Dungowan Dam with a catchment area of approximately 126 km^2. The existing dam is proposed to be decommissioned.

The new reservoir will have a total catchment area of approximately 175 km^2. The catchment lies on Dungowan Creek, which feeds into the Peel River upstream of Tamworth.

Dungowan Creek is ephemeral but can flow for extended periods. Dungowan Creek can also be dry for extended periods (i.e. months at a time).

6.3 Dam access and water uses

The primary purpose of the new Dungowan Dam is for potable water supply. Public use and access to the new Dungowan Dam would not be permitted and there would be no public facilities available at the site. Access to the new Dungowan Dam would be restricted to WaterNSW staff and their contractors by a fence at all access points.

A boat ramp would provide operational and maintenance staff access to the new Dungowan Dam and would consist of a single lane concrete access ramp located on the upstream face of the embankment adjacent the spillway approach channel.

The new Dungowan Dam and replacement pipeline would be operated by WaterNSW and Tamworth Regional Council respectively. This infrastructure would be managed as part of an integrated water supply system with Chaffey Dam. The management and operation of the new Dungowan Dam and associated infrastructure would be consistent with the management and operation of other water storage facilities across NSW. This includes all necessary activities such as monitoring, surveillance and maintenance.

The new Dungowan Dam's primary operational function is the supply of raw water to Calala WTP via the replacement pipeline.

Calala WTP is owned and operated by Tamworth Regional Council. Once the water is treated at Calala WTP, it would be distributed via Tamworth Regional Council's water reticulation system. The operation of Calala WTP and the Tamworth water reticulation system is subject to separate approvals and is not addressed in this EIS. Hence water quality as supplied by Calala WTP has not been further considered in this assessment.

The project would also:

- supply raw water to customers that have connections to the existing pipeline and to additional new customers along the route of the replacement pipeline where it traverses their property
- provide water via run of the river discharges to any stock and domestic water licence holders along Dungowan Creek
- provide environmental flows through translucency releases and a new Environmental Contingency Allowance (ECA).

The new Dungowan Dam and pipeline would operate in parallel with the existing Chaffey Dam to supply raw water to Tamworth.

Water supply

Water for supply to Tamworth would be drawn from the reservoir at the optimal depth for water quality and temperature. Water quality in the reservoir would be consistent with WaterNSW's water quality monitoring program and would include monitoring for:

- water level in the storage
- temperature
- dissolved oxygen (DO)
- pH and turbidity
- chlorophyll-a of the water at surface (an increase in the concentration of chlorophyll-a is an indication of active algae growth)
- algal enumeration and speciation, and if required testing for specific algal toxins.

Monitoring equipment would be located in the outlet tower and would be able to be remotely accessed for analysis and setting of gate positions for draw off.

No water treatment would be undertaken at the new Dungowan Dam site. A spool pipe would be placed in the pipeline immediately downstream of the valve house to allow the addition of treatment facilities if required at a later date. Raw water from the new Dungowan Dam would be transferred via the replacement pipeline to the Calala WTP for supply to Tamworth and surrounds.

Pipeline customer supply

The raw water pipeline from the existing Dungowan Dam supplies water to around 65 customers (in addition to the Calala WTP) through a series of connections teeing off the main raw water pipeline.

Existing customers would continue to be supplied raw water through the replacement pipeline, either through tapping into existing customer connections (ie where the replacement raw water pipeline is in close proximity to the existing raw water pipeline) or through the provision of new customer connection points. The existing raw water pipeline would remain in situ but would not be utilised to supply raw water once the replacement pipeline is commissioned.

There would be negligible disruption to the supply of raw water to existing customers during the pipeline construction and commissioning. Around three planned interruption periods are proposed that are expected to be between 24-48 hours in duration, with advanced notice provided to customers.

Approximately 52 new customers would also be supplied raw water from the replacement raw water pipeline where it traverses their property.

Raw water supplied from the pipeline is not suitable for drinking or showering (as indicated by Tamworth Regional Council), however the water may be used for flushing toilets, irrigation, stock/pet watering.

6.4 Review of Project impacts on surface water and groundwater

6.4.1 Flood risk

The new Dungowan Dam would be operated in accordance with the ANCOLD and Dam Safety NSW Guidelines. The new Dungowan Dam has no dedicated flood storage capacity and has an uncontrolled spillway, which does not allow the management of flood waters. When the reservoir water level is below the full supply level (FSL), the new Dungowan Dam would have a greater capacity to capture flood waters than the existing dam, however, the magnitude of flood mitigation is dependent upon the size of the flood event and the reservoir water level when the flood event begins.

In the rare situation when the dam is at FSL when a major inflow event occurs, there would be a minor increase in flooding downstream of the dam as the dam would not have capacity to capture flood waters, and the new dam has a larger catchment area and spillway than the existing dam.

During high rainfall events, inflows into the new Dungowan Dam may exceed the capacity of the spillway and water levels in the dam may exceed the FSL for short periods of time and areas of land above the FSL would experience temporary inundation.

Assessment of flood events relevant to the project (EMM 2022f) indicate that where dam storage levels were at FSL prior to rainfall, the existing and new dams both attenuate flood flows compared with the unregulated scenario.

In addition, changes in flood impacts associated with the new Dungowan Dam are small and not considered to be significant in terms of flood risk to properties.

6.4.2 Surface water

The new Dungowan Dam is designed to capture water flows in the Dungowan Creek catchment, which would result in changes in surface water flows in this area. The new Dungowan Dam would result in the inundation of 130 ha of land (at FSL). The spillway is uncontrolled, and water would spill from the new Dungowan Dam where inflows into the dam exceed the capacity of the spillway and water levels in the dam.

Land that will be inundated for the construction of the project would be vacated prior to construction works occurring, hence there are no safety risks relevant to former occupants of land impacted by the new Dungowan Dam.

Review of water quality relevant to the new Dungowan Dam has been undertaken by Royal HaskoningDHV (2021). This review indicated the following:

- water quality of reservoirs varies on a seasonal and interannual basis in response to runoff from local catchments and biogeochemical processes occurring within the reservoirs themselves
- the existing Dungowan Dam is likely the most representative site of the potential operational water quality at the new Dungowan Dam due to its proximity to the new site and largely similar environment, catchment, relatively similar infrastructure and size, and due to the expected similarities of each dam's operational strategy
- reduced and/or more variable water quality surface water may be expected during the first few years after the commissioning of the new Dungowan Dam due to the breakdown of organic matter such as tree stumps and other organic material in the new inundation area, which may affect raw water quality during the first few years after commissioning, but not treated water quality
- the potential for algal blooms to impact on water quality is expected to be managed through the implementation of mitigation measures including regular monitoring and drawing water from algal free areas of the dam and use of a multi-level intake, to minimise impacts on raw water quality (in particular).

In addition to the above the new pipeline would reduce the potential for leakage, and so the minor risk of pathogens getting into the pipe via a leak would be removed.

Based on the above, town water quality provided by the Calala WTP is not expected to change as a result of the project. In the few years after commissioning there may be the potential for reduced water quality for raw water, however where raw water is not used for drinking water, these impacts are not expected to be significant in terms of health. It remains relevant to manage algal blooms to ensure raw water quality remains safe for the intended (non-potable) uses.

6.4.3 Groundwater

The hydrogeological unit intersecting the project footprint is fractured or fissured, with extensive aquifers of low to moderate productivity. There are over 100 registered groundwater bores within 1 km of the project footprint mostly within the western portion, with the following characteristics (EMM 2022g):

- the authorised purposes of the groundwater bores are predominately for domestic, stock and irrigation use
- one groundwater bore was identified within the site boundary
- the final installed depth of the groundwater bores ranged from 3 to 83 m
- the standing water level within the groundwater bores ranged from 0.5 to 26 m.

Assessment of the impact of the new Dungowan Dam on groundwater in the project area (EMM 2022g) indicates the following:

- there are no groundwater users in the vicinity of the new Dungowan Dam and spillway excavation areas and hence there is no potential for impacts on water quantity and water quality during construction
- during pipeline construction works no impacts on groundwater users (availability or water quality) are expected where management and engineering measures are implemented to reduce groundwater take during these works
- operation of the dam would have a negligible impact on groundwater availability and water quality

Based on the above, no impacts on groundwater access or quality is expected in relation to the construction and operation of the project.

6.5 Outcomes of health risk assessment: water

Table 6.1 presents a summary of the outcomes of the assessment undertaken in relation to the impacts of changes in surface water and groundwater, associated with the project, on community health.

Table 6.1: Summary of health risks - water

Water	
Impacts	A range of assessments have been undertaken in relation to changes in surface water and groundwater, associated with the new Dungowan Dam. In relation to changes that have the potential to impact on community health, the assessments completed indicate the following: ■ the project would not result in any significant changes to flood risks for properties surrounding the project ■ water quality, as raw water and treated water, from the dam would not be expected to change with the operation of the project ■ the project would not change water availability or water quality within groundwater, where extracted and use in the surrounding community.
Mitigation	The above outcomes are dependent on a range of mitigation measures proposed to be implemented during construction and operation, specifically: ■ mitigation measures identified to minimise the potential for algal blooms to impact on raw water quality (Royal HaskoningDHV 2021) ■ mitigation measures detailed in the Groundwater Impact Assessment (EMM 2022g), particularly during pipeline construction.

Section 7. Contamination

Health impacts associated with the presence and management of contamination in the project area relevant to the local community have been evaluated on the basis of information provided in the following report:

- EMM 2022d, Contamination Preliminary Site Investigation, Dungowan Dam and pipeline project. Report dated May 2022.

The Contamination Preliminary Site Investigation completed by EMM provides a review of available information to determine if there is the potential for contamination to be present in the project area that may be disturbed during construction.

The project area is predominantly rural (agricultural) land, with the exception of the easternmost portion, which includes land utilised as part of the existing Dungowan Dam and associated catchment area.

The Contamination Preliminary Site Investigation did not identify any significant history of contaminating activities, with the exception of historical mining activities and past/present agricultural uses of the area (including a known sheep dip site where elevated levels of arsenic has been identified). In addition, the assessment identified a low potential for construction activities to encounter naturally occurring asbestos (NOA) near the far western end of the project footprint and the central portion of the project footprint. The central portion of the project area, however is noted to be within 2 km of an area of high probability for NOA. In addition, there is a low probability of encountering potential or actual acid sulfate soil or acid mine drainage (both of which, if present, may result in mobilisation of metals to impact on waterways).

Management measures were recommended for the construction/operation of the project, including (refer to EMM 2022d for additional detail):

- undertake further investigations at identified low-medium risk areas of potential contamination, which have not been adequately characterised and will be disturbed by construction activities
- development of appropriate project documentation (eg Construction Environmental Management Plan (CEMP), Contaminated Land Management Plan (CLMP), Construction Soil and Water Management Plan (CSWMP), Asbestos Management Plan (AMP), Operational Environmental Management Plan (OEMP)) to manage contamination during the construction and operation of the project.

For the community to be exposed to any contaminants present in the project footprint, which may be disturbed by construction works, there needs to be a mechanism for these contaminants to be able to migrate away from the sources and into the community. This can occur where contamination is present in soil or rock, and this material is placed near the community where significant amounts of dust or inhalable fibres may be generated (from contaminated materials or NOA), or contamination may leach from the material and runoff into local surface water bodies which may be accessed by the community.

The available information indicates a limited potential for contamination to be present. In addition, where the above management measures are implemented, the potential for construction works to disturb and mobilise contamination in the project footprint, such that the offsite community may be exposed to contaminants from these activities is considered negligible.

Section 8. Bushfire risks

Health impacts associated with changes in bushfire risks relevant to the local community associated with the project have been evaluated on the basis of information provided in the following reports:

- Blackash 2022, Bushfire Risk Assessment, Dungowan Dam and pipeline project. Report dated May 2022.

In relation to assessing community health, the key issue related to bushfires risk, is whether the project has the potential to result in changes that increase the risk of bushfires in the local community, where public safety can be impacted.

The Dungowan Dam and pipeline project is in a relatively isolated Bushfire Prone Area that is in rugged, heavily timbered country. All new development on bushfire prone land must comply with the NSW Rural Fire Service (RFS) document *Planning for Bushfire Protection 2019* (PBP 2019). The work completed by Blackash (2022) complies with the PBP guidance.

Vulnerability to bushfire risk is a combination of the physical location of the person under threat and the understanding and ability that person has that enables them to deal with the risk. Bushfire risk can be reduced by good emergency management and planning. Radiant heat is the primary cause of death or serious injury in a bushfire. Any action that exposes people to radiant heat should be avoided. Also, wind conditions can cause branches and trees to fall and block access roads making driving hazardous. Smoke and embers will make driving even more hazardous.

The site and surrounds have a history of bushfire and the existing dam and catchment is identified in the Tamworth Zone Bush Fire Management Committee Bushfire Risk Management Plan 2011 as having the potential for high bushfire risk requiring the management of fuel and impacts on dam infrastructure to be considered over the life of the dam.

Based on the assessment presented, the infrastructure associated with the project will not increase the bushfire risk to the surrounding areas. Suitable measures would be put in place as part of a Bushfire Management Plan during construction to manage ignition potential on or from the project site.

The Bushfire Risk Assessment provided recommendations to minimise impacts on infrastructure as a result of a bushfire. This includes the design of critical infrastructure to minimise the impact of bushfires and incorporation of bushfire protection measures. The construction phase of the development will require large numbers of workers to be in a relatively remote area that is susceptible to bushfire. Detailed emergency management planning should be completed prior to construction to ensure the safety of workers. The operational phase of the new Dungowan Dam will have ongoing management requirements to reduce the bushfire attack level on key assets.

Overall, based on the available information, the project does not change the existing bushfire risk to the surrounding community. Hence there are no health impacts of concern in relation to bushfire risk.

Section 9. Traffic

Health impacts associated with changes in traffic relevant to the local community have been evaluated on the basis of information provided in the following report:

- EMM 2022e, Traffic Impact Assessment (TIA), Dungowan Dam and pipeline project. Report dated May 2022.

The TIA relates to the impact of project related traffic on local and major roads in the project area.

In relation to the assessment of impacts on community health the aspects of concern relate to changes in road safety (for pedestrians, cyclists and motorists), changes in active transport options or changes in access by or to essential services. Based on the TIA , the following is noted in relation to these aspects:

- there were no potential impacts identified to traffic flow on major roads
- all key intersections currently operate Level of Service (LOS) A in the peak hours, except for the New England Highway/Nundle Road/Railway Street intersection where LOS B and LOS C is experienced in the AM and PM peak respectively. With construction traffic, all the key intersections will remain at the same LOS
- the project does not change existing public transport, pedestrian or cycling infrastructure (noting these are currently not present due to the remote location of the project)
- along the pipeline construction route, the potential traffic impacts would primarily be limited to locations where the project construction activities or access points would interact with existing roads. At these locations there may be temporary disruptions to traffic flows through lane or road closures or other access impacts. On all the identified local roads which are potentially affected by the pipeline construction access (Duri-Dungowan Road, Back Woolomin Road and Dungowan Creek Road) the forecast pipeline construction generated traffic increases would be generally noticeable in comparison to the existing daily traffic flows using these roads, but would have minimal impact in relation to any existing traffic flow conditions or safety standards. The access agreements, which are to be negotiated with rural property landowners impacted by the pipeline construction activity would need to address any restrictions to access (to tracks, paddocks etc by workers and livestock).

The TIA identified a range of mitigation measures which would minimise changes in safety and access (including pedestrian and cyclist access). These measures would be detailed in a Construction Traffic Management Plan (CTMP) that would also require any changes in roads or paths to emergency services to be communicated. The key mitigations proposed include:

- a large part of the primary transport route will be affected by a reduced speed limit for the majority of the construction period
- detailed traffic management measures would be required to minimise traffic safety conflicts with school buses along the primary transport routes
- a number of road safety actions including road upgrades have been identified for the Dungowan Dam Road section of the primary transport route

Where the proposed mitigation measures are implemented, the potential impacts of changes in traffic in the project area on community health is considered low.

Section 10. Conclusions

The HIA has considered potential impacts on community health in relation to project related changes in air quality, noise and vibration, water, contamination, bushfire risk and traffic.

Based on the available information, and with consideration of the uncertainties identified, no health risk issues of concern have been identified for the community. More specifically, **Table 10.1** presents a summary of the health impact assessment and mitigation measures relevant to ensuring impacts are suitably mitigated and/or managed.

Table 10.1: Summary of health risks

Air emissions	
Impacts	The focus of the assessment of air emissions relates to construction activities. There are no impacts to air quality during project operation. Where all proposed dust mitigation measures are implemented, there are no risk issues of concern in relation to community exposure to particulate matter, specifically $PM_{2.5}$, and respirable crystalline silica that may be generated during construction activities.
Mitigation	All mitigation measures as detailed in the Air Quality and Greenhous Gas Assessment are required to be implemented. This include the development and implementation of an Air Quality Management Plan (AQMP) that provides detail on the methods to be used to minimise the generation of dust during all works, and from exposed materials.
Noise and vibration	
Impacts	Based on the predicted noise levels, there are no health impacts of concern for noise generated during construction from static locations or during operations. However, during the construction of the pipeline, Dungowan Dam Road upgrade works there is the potential for elevated levels of noise that require mitigation to ensure health is protected. These measures are of most importance during the night-time period. In relation to road noise impacts, there is the potential for construction traffic to result in impacts to the community located adjacent to some local roads. In particular, minimising the movement of trucks during the night-time period along Tamworth-Nundle Road, Ogunbil Road, Dungowan Dam Road, Dungowan Creek Road and Back Woolomin Road would be of key importance to minimise health impacts, particularly impacts relating to sleep disturbance. A number of these existing roads are infrequently used with low background noise. Hence changes in traffic volumes on these roads are expected to be noticeable by the community and may result in increased levels of annoyance and sleep disturbance, where mitigation measures are not implemented. The potential for adverse health impacts within the off-site community associated with construction vibration or blasting is considered to be negligible.
Mitigation	The Noise and Vibration Impact Assessment describes a range of mitigation measure that would be adopted for the project to minimise noise impacts within the community. These mitigation measures will be implemented to mitigate impacts identified and minimise the potential for health impacts in the community.
Water	
Impacts	A range of assessments have been undertaken in relation to changes in surface water and groundwater, associated with the project. In relation to changes that have the potential to impact on community health, the assessments completed indicate the following: ▪ the project would not result in substantial changes to flood risks for properties downstream of the project ▪ water quality, as raw water and treated water, from the new Dungowan Dam would not be expected to change with the operation of the project ▪ the project would not change water availability or water quality within groundwater, where extracted and used in the surrounding community.
Mitigation	The above outcomes are dependent on a range of mitigation measures proposed to be implemented during construction and operation, specifically: ▪ mitigation measures identified to minimise the potential for algal blooms to impact on raw water quality (Surface Water Assessment, EMM 2022f)

	- mitigation measures detailed in the Groundwater Impact Assessment (EMM 2022g), particularly during pipeline construction.
Contamination	
Impacts	The available information indicates there is a limited potential for contamination to be present in the project footprint. Further, where the proposed management measures are implemented, the potential for construction works to disturb and mobilise contamination in the project footprint, such that the offsite community may be exposed to contaminants from these activities is considered negligible.
Mitigation	A range of mitigation measures are outlined in the Contamination Assessment Preliminary Site Investigation that would be adopted to ensure contamination can be characterised and appropriately managed and impacts on community health are negligible.
Bushfire risks	
Impacts	The project does not change the existing bushfire risk to the surrounding community. Hence there are no health impacts of concern in relation to bushfire risk.
Mitigation	The Bushfire Risk Assessment provided recommendations to minimise impacts on construction and project infrastructure as a result of a bushfire.
Traffic	
Impacts	Where traffic management measures are implemented, to address safety and access aspects, the potential for changes in traffic to impact on community health is considered to be low.
Mitigation	A range of mitigation measures are detailed in the Traffic Impact Assessment that would be required to be implemented to ensure minimal impacts on community safety and access.

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Appendix A Respirable crystalline silica

A1 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 mad 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
- in pet litter and furniture foam.

A2 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. 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 increased 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 A1**, 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).

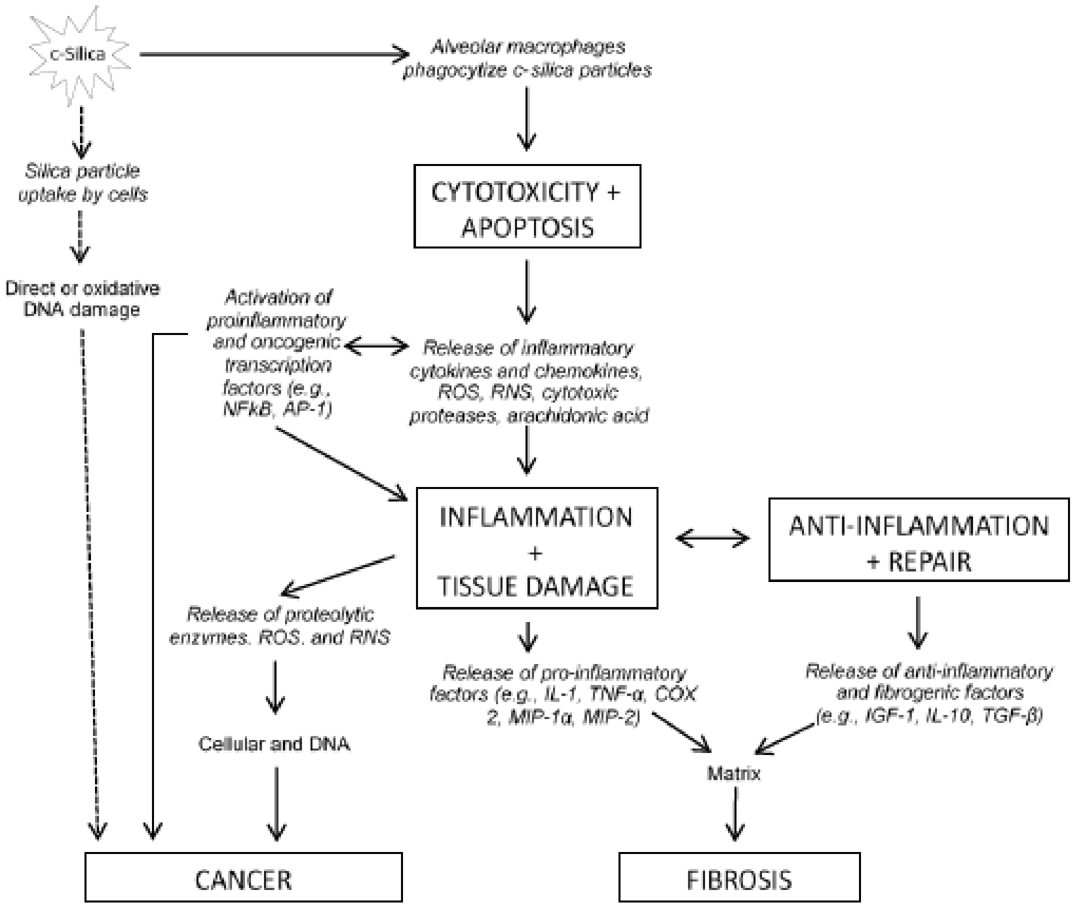

Figure A1: Biological pathways for the formation of silicosis and lung cancer (ATSDR 2019)

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 the 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.

A3 Classification

Inhaled crystalline silica dust in the former 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 that mice and hamsters. The mechanism 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 that 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.

A4 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 A1** 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 a specific project. The occupational air guidelines have been provided for reference, as many of the health effects identified are of most significance for occupational exposures.

Table A1: Summary of relevant TRVs for RCS

Source	Value	Basis/Comments
Occupational Air Guidelines		
Australian		
Work Safe Victoria[10]	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 no 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. 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.*"
ACGIH (ACGIH 2010)	25 µg/m^3 (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: <u>α-quartz</u> Based on no change in longevity of lung function in workers exposed to 50 µg/m^3, an increase in risk from silicosis in workers at 60 µg/m^3, and an increase in risk from lung cancer in workers at 65 µg/m^3. 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. <u>Cristobalite</u> TVL for α-quartz recommended as the available human studies indicate a similar toxicity.

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

Source	Value	Basis/Comments
Cal/OSHA	50 µg/m^3 (respirable fraction)	Permissible Exposure Limit (PEL) enforced in workplaces under the jurisdiction of the California Division of Occupational Safety and Health.[11] 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.[12]
Community Air Guidelines		
Australian		
EPA Victoria (2007)	3 µg/m^3 ($PM_{2.5}$ 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/m^3 (PM_4 fraction) Cancer: 0.27 µg/m^3 (PM_4 fraction)	Effects Screening Levels (ESLs) for quartz, cristobalite, tripoli and tridymite. <u>Non-cancer effects:</u> 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/m^3. 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/m^3, based on the rounding of results from both studies. A chronic non-cancer ESL of 0.6 µg/m^3 was also derived based on a Hazard Quotient (HQ) of 0.3 (this is not relevant to Australia where the applicable HQ is 1). <u>Cancer:</u> Unit Risk (UR) of 3.6x10^{-5} (µg/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/m^3 at a target risk level of 1x10^{-5}.
TCEQ (TCEQ 2020)	Acute health-base screening value = 24 µg/m^3 (PM_4 fraction)	Acute guideline established, based on 24-hour average exposure levels, based on the protection of the most sensitive effect, respiratory inflammation and cytotoxicity which have been observed to occur after acute and subacute exposures to RCS. The guidelines is based on data from a rat study, with adjustment for animal to human inhalation doses resulting in a PODHEC = 6450 µg/m^3, and incorporation of a 270 fold uncertainty factor (addressing intraspecies variability, extrapolation from animals to humans, extrapolation of LOAEL to NOAEL and database deficiencies (in terms of acute studies).
Minnesota Department of Health (MDH 2013)	3 µg/m^3 (PM fraction not stated)	<u>Non-cancer effects:</u> 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/m^3 and an UF of 3. The main difference in the TCEQ and MDH

[11] https://www.dir.ca.gov/title8/5155table_ac1.html#_blank

[12] https://www.osha.gov/dsg/annotated-pels/

Source	Value	Basis/Comments
		assessments was the assumed %RCS in dust inhaled by the workers (30% by MDH versus 54% by TCEQ; a difference of around 2-fold). Cancer: 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/m^3 (PM_4 fraction)	Non-cancer effects: 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/m^3 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/m^3. 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. Cancer: 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)[13]	0.12 µg/m^3 (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.

[13] 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 A1** 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 site. 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 protection against silicosis from data from occupational studies. 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:[14]

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

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

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.

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.

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

For the assessment of short-term peak exposures that may occur during construction activities, the 24-hour acute guideline from TCEQ (2020) has been adopted.

A5 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 µg/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 A1**) 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 two 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 four facilities, of which three were frac sand mines and one 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 eight sampling locations at the four 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 seven 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 four sites in Australia (including two sites in Queensland) three of which are where monitoring for RCS has been undertaken in the vicinity of quarrying or tunnelling sites in response to community concern. One of these sites relates to monitoring in an urban environment at a location where there are no quarrying or tunnelling activities, which is more likely to be representative of urban background levels. 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 six 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 A1**) 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 5 µg/m^3 and PM_{10} of 12 µg/m^3
- 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 two 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
- 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 2 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 two 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.

Brooklyn, Victoria

EPA Victoria does not routinely monitor for RCS in air, however monitoring was conducted at the Brooklyn Industrial Precinct during 2010/2011 that included analysis for RCS. Data is also available for Footscray. These air monitoring locations are not adjacent to any specific sources and would be consider urban air environments. At both locations no RCS was detected, with the annual average concentration of RCS reported as < 40 ng/m^3 (<0.04 µg/m^3).

A6 Background exposures

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, or 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 A2**.

Table A2: 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.

Location	Concentration (µg/m^3)	Comments
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)
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/m^3.
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/m^3 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, noting that all these sites are near RCS generating industries.

Where the site is located in an urban environment away from RCS generating sources the background levels are even lower, with that indicating annual average concentrations <1 µg/m^3, with data from Melbourne suggesting negligible background levels <0.04 µg/m^3.