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FIMISTON SOUTH PROJECT SCREENING HEALTH RISK ASSESSMENT

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Prepared by **Dr Anand Chandra**
Checked by **Martin Parsons**
Approved by **Martin Parsons**
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Ramboll
Level 7
41 St Georges Terrace
Perth
Western Australia 6000
Australia

T +61 8 9225 5199
<https://ramboll.com>

EXECUTIVE SUMMARY

Preamble

Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM) operates the Fimiston Gold Mine Operations, located adjacent to the City of Kalgoorlie-Boulder. The Fimiston Operations consist of the Fimiston Open Pit (FOP), Fimiston Processing Plant, three Tailings Storage Facilities (TSFs), Waste Rock Dumps (WRDs), run of mine (ROM) and associated infrastructure. KCGM has undertaken a series of extensions of the Fimiston Operations since 2009 and is currently developing the Fimiston South (FS) Project, consisting of the Morrison (MO) and Southern Extension (SE) resources at the southern end of the existing FOP. To facilitate the environmental approvals process, a number of studies are required for the proposed FS Project, including the update of previous screening Health Risk Assessment (HRA) completed in 2007 and 2020.

Background and objectives

Ramboll has been engaged by KCGM to undertake an update of the screening HRA to support their regulatory approval process for the proposed FS Project. The update involved a review of the previous screening HRA and re-assessment of potential health risks, taking into consideration available additional ambient monitoring data from 2020 to 2021, latest air dispersion modelling and the proposed changes at the Fimiston Operations. The HRA also compared the expected change in potential health risks from the current operations to the future when FS project would be operational, based primarily on air dispersion modelling data.

The previous HRA study involved assessment of metal concentrations in ambient particulate samples collected by KCGM during a 2006 monitoring campaign. These data were used together with predicted particulate concentrations for the GP Cutback Project as inputs to the 2006 screening HRA, the result of which indicated the predicted metal concentrations would not result in unacceptable health risks. Similar health risk conclusions were reached in the Ramboll (2020) HRA update which included PM₁₀ data collected from 2010 to 2019. PM₁₀ metal concentrations were calculated using historic metals concentration data and applied bioavailability factors based on analysis of regional soil samples. No unacceptable acute or chronic non-carcinogenic or carcinogenic risks were found at any of the sampling locations.

The objective of this update was to re-assess acute and chronic (including carcinogenic) health risks by considering additional monitoring data available from 2020 to 2021 (in addition to previously used data from 2010 to 2019) and compare health risks from current worst-case emissions to future worst-case emissions when FS project would be operational.

Approach

A screening HRA was conducted by comparing either monitored or modelled exposure concentrations against available acute, chronic (non-carcinogenic), and carcinogenic health guideline values. Overall assessment of health risks was conducted by considering PM₁₀ monitored data from 2010 to 2021 and historic dust metal concentrations. Comparative analysis of current and future operations was undertaken by using current monitored and future modelled data.

During the past twelve years (2010-2021), 2019 had the highest average monitored PM₁₀ concentrations in the region. Hence, 2019 was adopted as worst-case scenario for current operations at KCGM. The maximum annual material movement for the FS project is expected to be approximately 96 Mt. peaking in the year 2029, when operational. However, 2025 (86 Mtpa) was selected as the year to be modelled as the worst-case future scenario due to the higher level of activity located close to the town and a larger amount of material extracted from the pit and dumped externally.

The results of the historic metals analysis have been used in conjunction with ambient PM₁₀ monitoring data collected between 2010 and 2021 and air dispersion modelling to update the screening HRA. Ramboll understands mining operations associated with the proposed FS Project will occur within the same geological bounds as previous activities and as such, the concentration of metals within fugitive dust emissions from KCGM's proposed operations are not expected to differ significantly from those measured historically.

A review of ambient PM₁₀ data collected across KCGM's seven ambient PM₁₀ monitoring stations between 2010 and 2021 was undertaken to identify the maximum short-term and long-term PM₁₀ concentrations for use in the screening HRA. The historic maximum metals concentrations measured in ambient particulate samples, together with the maximum recorded 1-hour and 24-hour average PM₁₀ concentration for which KCGM was identified as a potential contributor, and the highest annual average PM₁₀ concentrations measured at each monitoring site, were used as inputs to the screening HRA. The HRA also included air dispersion modelling data presented in Ramboll (2022a) to assess the potential health impacts when the FS project is in operational phase. The change in modelled PM₁₀ concentrations were calculated from 2019 to 2025 and then estimated PM₁₀ concentrations in 2025 were calculated using monitored data from 2019. Historic maximum metals concentration data was then used to estimate current (2019) and future (2025) PM₁₀ metal concentrations.

Health protective guidelines published by reputable authorities were used in conjunction with the measured and modelled PM₁₀ concentrations and estimated metals concentrations to calculate quantitative risk indicators. As the main transport pathway for atmospheric emissions associated with the FS project is atmospheric dispersion, inhalation is expected to remain the most significant exposure route and the screening HRA considers the inhalation pathway only (as per the previous studies).

Findings

The acute hazard indices (HIs) calculated based on 2010-2021 monitored PM₁₀ and historic metals data for the nominated receptors were below target risk level, when considering bioavailability of metals in PM₁₀ particles. This indicated that there was no cause for concern in terms of potential short-term acute health effects at any receptor locations.

For comparative assessment of acute exposure risks, no material change in acute HIs have been noted from current (2019) to future operations (2025), with bioavailability adjusted HI values below target risk for all receptor locations under both scenarios. No change in acute (short-term) exposure risks is expected when the FS project is operational, and acute exposure risks are expected to remain low and acceptable.

The chronic non-carcinogenic HIs based on 2010-2021 monitored PM₁₀ and historic metals data, conservatively assuming 100% bioavailability for each metal, remain well below target risk at each of the monitoring locations, indicating no cause for concern in terms of potential long-term non-carcinogenic health effects.

For comparative assessment of chronic non-carcinogenic exposure risks, no material change in chronic HIs have been noted from current (2019) to future operations (2025), with all values below target risk for all receptor locations under both scenarios. No change in chronic (long-term) exposure risks is expected when the FS project is operational, and chronic exposure risks are expected to remain low and acceptable.

The maximum incremental carcinogenic risk (ICRs) calculated based on 2010-2021 monitored PM₁₀ and historic metals data is below the risk target for PM₁₀ particles with arsenic and nickel as the largest contributor towards the calculated ICRs. The ICR results indicated that there was no cause for concern in terms of potential carcinogenic health effects at any receptor locations from life-time exposures.

For comparative assessment of carcinogenic exposure risks, no material change in ICR values have been noted from current (2019) to future operations (2025), with ICR values below the recommended risk target of 1E-05 for all receptor locations under both scenarios. No change in carcinogenic exposure risks is expected when the FS project is operational, and carcinogenic exposure risks are expected to remain low and acceptable.

Conclusion

The assessment has assumed that the fugitive dust impacts associated with the proposed FS Project will be similar to those of previous operations, as the mining activities and dust management procedures will also remain the same.

It is concluded from the overall assessment using monitored PM₁₀ data and historic metals data that no unacceptable acute or chronic non-carcinogenic or carcinogenic health risks currently exists at the receptor locations from any KCGM generated PM₁₀ dusts. These potential short-term and long-term health effects are also expected to remain unchanged in the future based on air dispersion modelling, with no unacceptable risks expected when FS project is operational in the future.

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1. INTRODUCTION

1.1 Background

Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM), a wholly owned subsidiary of Northern Star Resources Limited, operates the Fimiston Gold Mine Operations, located adjacent to the City of Kalgoorlie-Boulder approximately 600 km east of Perth, Western Australia. The Fimiston Operations consist of the Fimiston Open Pit (FOP), the Fimiston Processing Plant, three Tailings Storage Facilities (TSFs), waste rock dumps (WRDs), run of mine, infrastructure corridors and workshop area (Figure 1).

Ministerial approval for the Fimiston Gold Mine Operations Extension (Stage 3) and Mine Closure Planning Public Environmental Review (PER) was granted in January 2009 under Ministerial Statement No. 782 (MS782). This allowed mining of a cutback along part of the western edge of the FOP, referred to as the 'Golden Pike (GP) Cutback', bringing mining closer to residential areas of Kalgoorlie-Boulder, and extending the life of the mine. Several amendments to MS782 have since been made allowing modifications to the Fimiston Operations, including an expansion of the FOP to facilitate mining of the Morrison and Brownhill areas (located on the southern and north-eastern boundaries of the FOP respectively). Conditional approval for the Morrison/Brownhill Project was received in January 2018, however the project was subsequently amended in October 2018 to comprise only the smaller Morrison Starter Pit (MOSP). KCGM is now developing the Fimiston South (FS) Project, consisting of the Morrison (MO) and Southern Extension (SE) resources at the southern end of the existing FOP (Figure 2).

To facilitate the environmental approvals process, a number of studies are required for the proposed FS Project, including the update of previous screening Health Risk Assessments (HRA) completed in 2007 (ENVIRON, 2007) and 2020 (Ramboll 2020a) to inform an assessment of potential impacts to the environment and the health of people that could be exposed to dust from the Fimiston Operations during implementation of the Fimiston South Project. The Environ (2007) study involved assessment of metal concentrations in ambient particulate samples collected by KCGM during a 2006 monitoring campaign. The measured metal concentrations were used together with predicted particulate concentrations for the GP Cutback Project as inputs to the screening HRA. Acute and chronic non-carcinogenic hazard indices and the incremental carcinogenic risk associated with the GP Cutback Project were calculated, the result of which indicated the predicted metal concentrations would not result in unacceptable health risks. Similar health risk conclusions were reached in the Ramboll (2020) HRA update which included PM₁₀ data collected from 2010 to 2019. PM₁₀ metal concentrations were calculated using historic metals concentration data and applied bioavailability factors based on analysis of regional soil samples. No unacceptable acute or chronic non-carcinogenic or carcinogenic risks were found at any of the sampling locations.

In support of the regulatory approval process for the proposed FS Project, Ramboll Australia Pty Ltd (Ramboll) has been engaged by KCGM to undertake a further review of the previous screening HRA and update the assessment, taking into consideration available ambient monitoring data from 2020 to 2021, air dispersion modelling and the proposed changes at the Fimiston Operations. This involves evaluation of the potential health risks using conservative exposure estimates based on available ambient monitoring data for comparison with published health-based guidelines. The HRA report also includes an assessment of potential health risks for the proposed worst-case emissions from KCGM once the FS project is operational, based on air dispersion modelling data. A comparison is also provided for the current worst-case emissions against the future worst-case emissions to determine any significant change in health risks under operational phase. The applicability of the findings for the revised screening HRA is considered in light of the

outcomes of the qualitative assessment of dust impacts associated with the FS Project, as outlined in Ramboll (2020b; 2022a and 2022b).

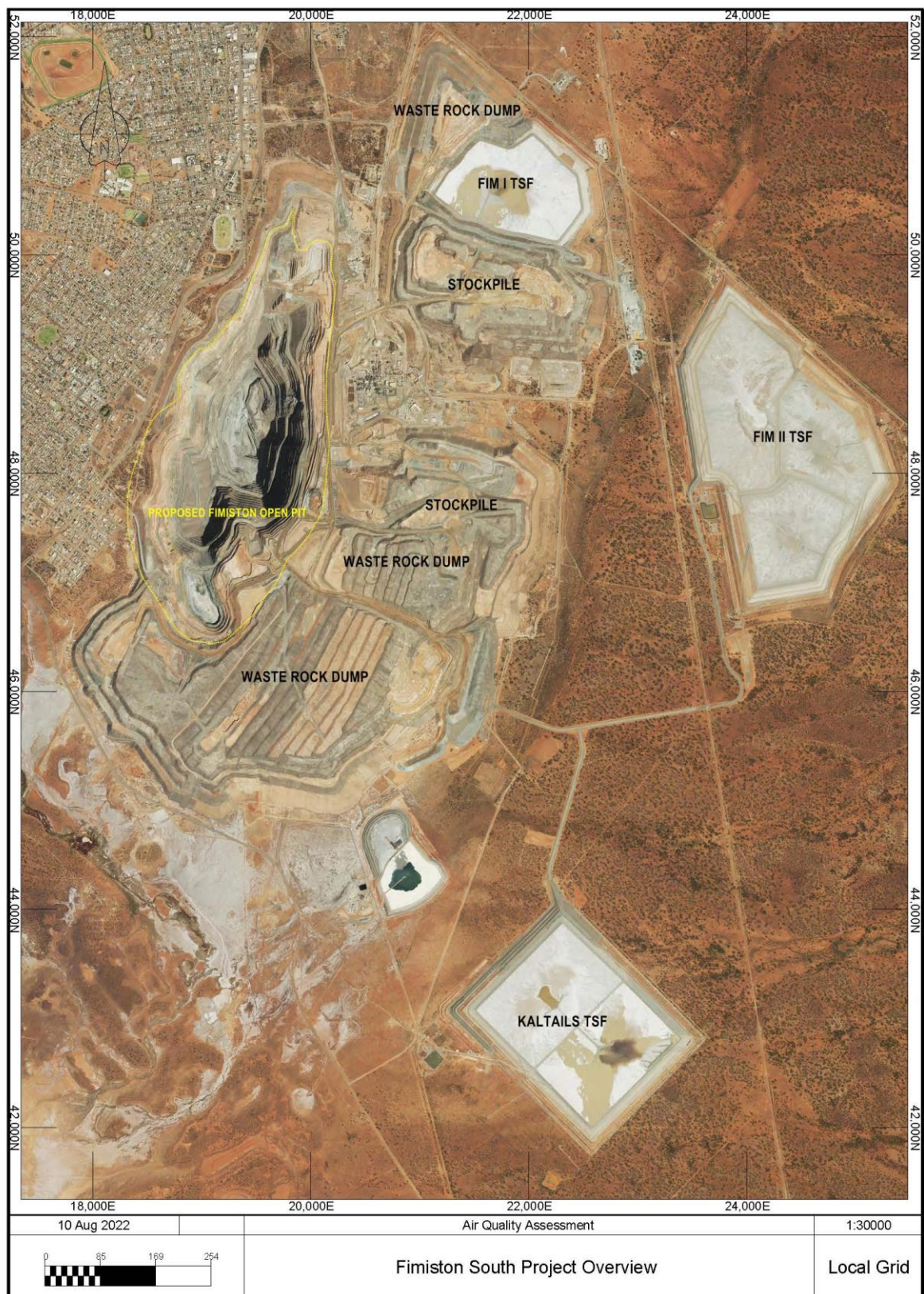


Figure 1: KCGM Mining Areas

Source: KCGM



Figure 2: Location of FOP Mining Areas

Source: KCGM

1.2 Approach to the Screening HRA

HRA is a systematic process of defining the nature and magnitude of human exposure (dose) to environmental hazard, and evaluation of potential adverse health impact that can result from that exposure. The process employs protective assumptions to ensure that health of exposed individuals and populations are adequately protected. In its simplest form, the risk assessment process compares an estimated exposure level of environmental hazard against levels that are considered to result in no observable adverse health impact, as published by authoritative bodies and health protection agencies. Generally, a risk may exist if there is a potential pathway linking sources of environmental hazard with any identified receptors such as individuals or local populations. The outcomes of the HRA process are mostly used by decision-makers to assist in management of contamination issues, assess impacts of new and existing developments, and formulation of new- or amendments to existing policies, programmes, regulations and projects.

Risk assessment is mainly conducted as a tiered process with increasing level of complexity in each successive tier. The tier 1 assessment process (or screening HRA) uses generic guideline values to characterise risk. If unacceptable risks are found or if there are high uncertainties in results, then the risk assessment process moves up a tier to undertake a more site-specific assessment with careful consideration of site-based conditions. The generic steps involved in HRA are outlined in Table 1.

Table 1: Overview of HRA Process

Steps	Description
Issues Identification	Establishes the context for the risk assessment and includes planning and scoping, and problem formulation stages.
Toxicity Assessment	Identifies the nature and degree of toxicity of chemical compounds and characterises the relationship between magnitude of exposure and adverse health effects (i.e. the dose-response relationship).
Exposure Assessment	Defines the amount, frequency, duration and routes of exposure to compounds present in environmental media. In this assessment, exposure is estimated as the concentration of a compound that a person may be exposed to over both short (i.e. acute) and long-term (i.e. chronic) exposure periods.
Risk Characterisation	The combining of exposure and toxicity data to estimate the magnitude of potential health risks associated with exposure periods of interest

There are sources of uncertainty inherent at each stage of the HRA process, such as information gaps on effects of pollutant mixtures, effects of low-level and variable exposures overtime, variations in receptor sensitivities, and limitations of toxicological and epidemiological information on pollutant health impacts. A HRA should therefore carefully consider all uncertainties and its impacts on final risk determination and provide explanations of how 'scientific judgement' was used to manage uncertainties during any development of risk management policies. Where uncertainties are recognised, protective assumptions are normally used so that potential exposure and risks are overestimated rather than underestimated.

This screening HRA has been conducted in accordance with the enHealth (2012) *Environmental Health Risk Assessment* guidance for screening level HRAs. This involves evaluation of the risks using conservative exposure estimates for comparison with published health-based guidelines. The quantitative health risk indicators calculated for potential acute and chronic health effects are based on the assumption that the health effects arising from exposure to each of the individual metals in the particulates emitted from the Fimiston Operations are additive, where the combined effect of two or more agents is equal to the sum of the individual effects (enHealth, 2012). The additive approach is considered to be appropriate for screening assessment purposes, and is considered to be conservative (i.e. health protective) in most circumstances. On account of the conservatism of such a screening assessment, the results are considered more likely to over- than under-estimate the potential health risks associated with particulate emissions from the Fimiston Operations. The results of the screening HRA are able to be used to assess the individual metals exhibiting the highest contribution to potential health risks in order to help define particulate emissions management strategies or identify further work that may be required.

2. SITE AND PROJECT DESCRIPTION

2.1 Project Description

KCGM's operations currently consist of the Fimiston Operations, Mt Charlotte Underground Mine (approximately 2 km north of the FOP), and the Gidji processing plant (approximately 20 km north of Kalgoorlie-Boulder). The active mining areas within the current FOP are the GP and MOSP laybacks, located on the western and southern sides of the pit respectively (Figure 1). The current FOP footprint extends approximately 1.5 km in width, 3.4 km in length and to a depth of approximately 640 m. The FOP hosts gold-bearing ores that are refractory in nature. The gold is associated with sulfides (mainly pyrite) and tellurides. Ore is processed through the Fimiston and Gidji process plants and includes crushing, milling, gravity separation, flotation, ultra-fine grinding (UFG) and cyanidation of the subsequent product streams. The majority of flotation concentrate is treated at the Gidji processing plant and surplus concentrate is sold to a third-party smelter.

The proposed FS Project comprises the MO and SE resources at the southern end of the existing FOP (Figure 2). The FS Project is an extension of the southern mineralization and is consistent with previously mined ore bodies in Chaffers layback (completed in 2013) and the previously mined MO pit, which was completed in the late 1980s. The FS Project will be mined in the same manner as the GP Cutback, namely drilling and blasting the in-situ material and excavating and hauling via a conventional truck and shovel fleet.

The maximum annual material movement will be approximately 96 Mt. A summary of the material movements for the proposed FS Project and KCGM's total operations are presented in Figure 5.

As the proposed FS Project is a layback of the existing FOP, the mineral and waste characteristics are expected to be consistent with the ore that has historically and is currently being mined and processed at the Fimiston and Gidji processing plants and alternate processing routes will not be required. The FS layback features Golden Mile dolerite, with black flag beds (a mix of shale and porphyry) on the eastern extent (KCGM, 2019b). Similar geological units characterise the existing Chaffers layback (completed in 2013) and Morrison pit (completed in the late 1980s) and have been mined extensively at Fimiston (KCGM, 2019b).

The maximum annual material movement will be approximately 96 Mt. A summary of the material movements for the proposed FS Project and KCGM's total operations are presented in Figure 3.

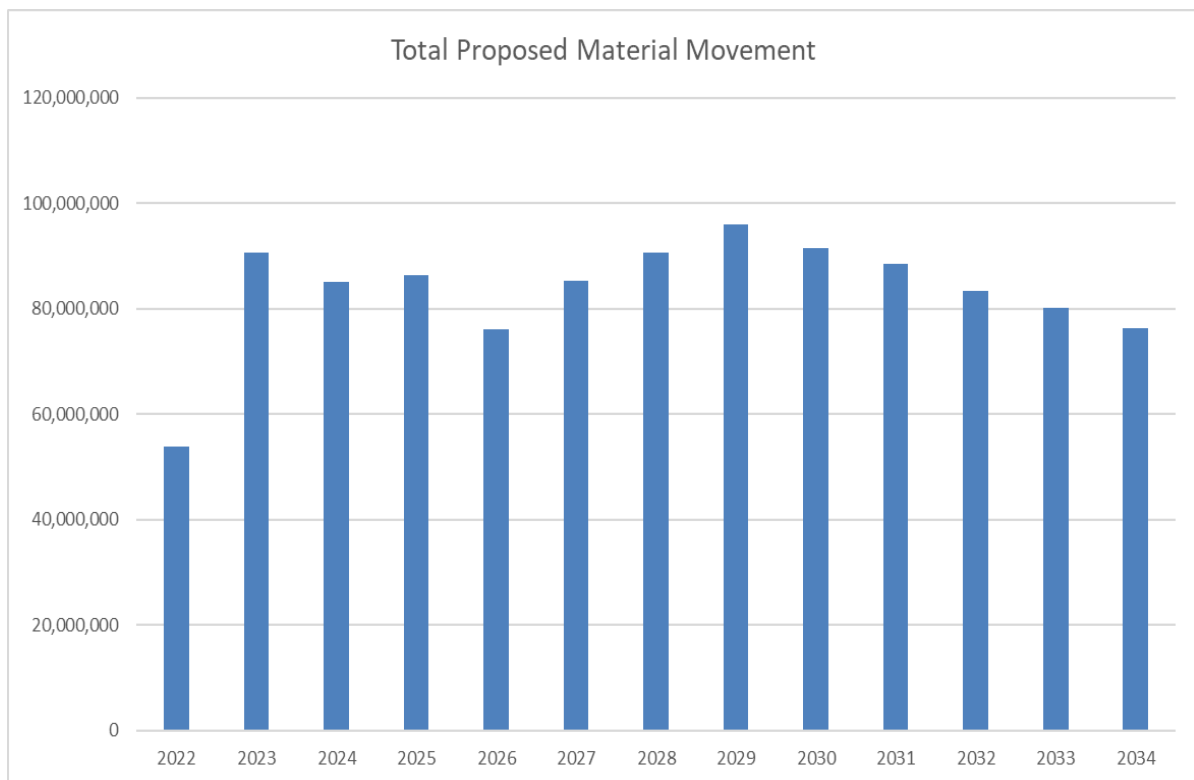


Figure 3: Summary of Total Material Movements

The FS Project is expected to begin operations at -70mRL (based on the final stages of the GP operations) and a maximum of 10 benches will be mined in a given year (bench heights being 10 m). During the initial stage of the FS Project, waste material will be hauled to the existing SE surface dumps. Upon completion of the GP Cutback, waste dumping will transition to in-pit deposition (Figure 4). Approximately 75% of the total waste material from the FS Project will be deposited in-pit. The proposed waste rock and mill haulage routes for the FS Project are shown in Figure 4.

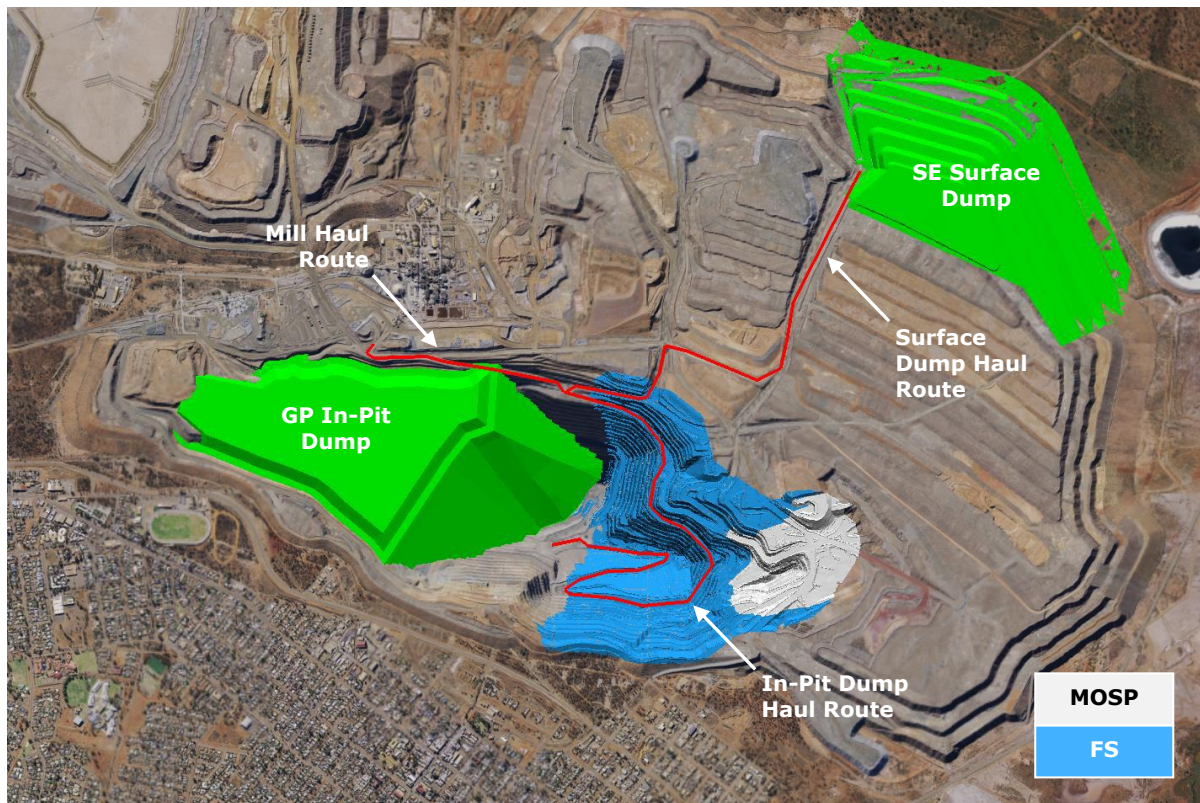


Figure 4: Proposed Haulage Routes for FS Project

Source: KCGM

As the proposed FS Project is a layback of the existing FOP, Ramboll understands the mineral and waste characteristics are expected to be consistent with the ore that has historically and is currently being mined and processed at the Fimiston and Gidji processing plants, and alternate processing routes will not be required.

The processing facility currently operates at a production rate of ~13.4 Mtpa through two parallel Semi-Autogenous Grinding and Ball Circuits (SABC): Mt Charlotte and Fimiston. The Mt Charlotte circuit comprises a three-stage crushing, Semi-Autogenous Grinding (SAG), ball milling, gravity concentration and flotation circuit. The Fimiston circuit comprises single-stage crushing, SAG, ball milling, gravity concentration and flotation circuit. The two circuits combine post flotation for concentrate to be treated via UFG and high-cyanide leach, primarily at the Gidji plant site, while the flotation tail is treated via a low-cyanide leach at Fimiston. Simplified process flow diagrams for the Fimiston processing plant are provided in Figure 5.

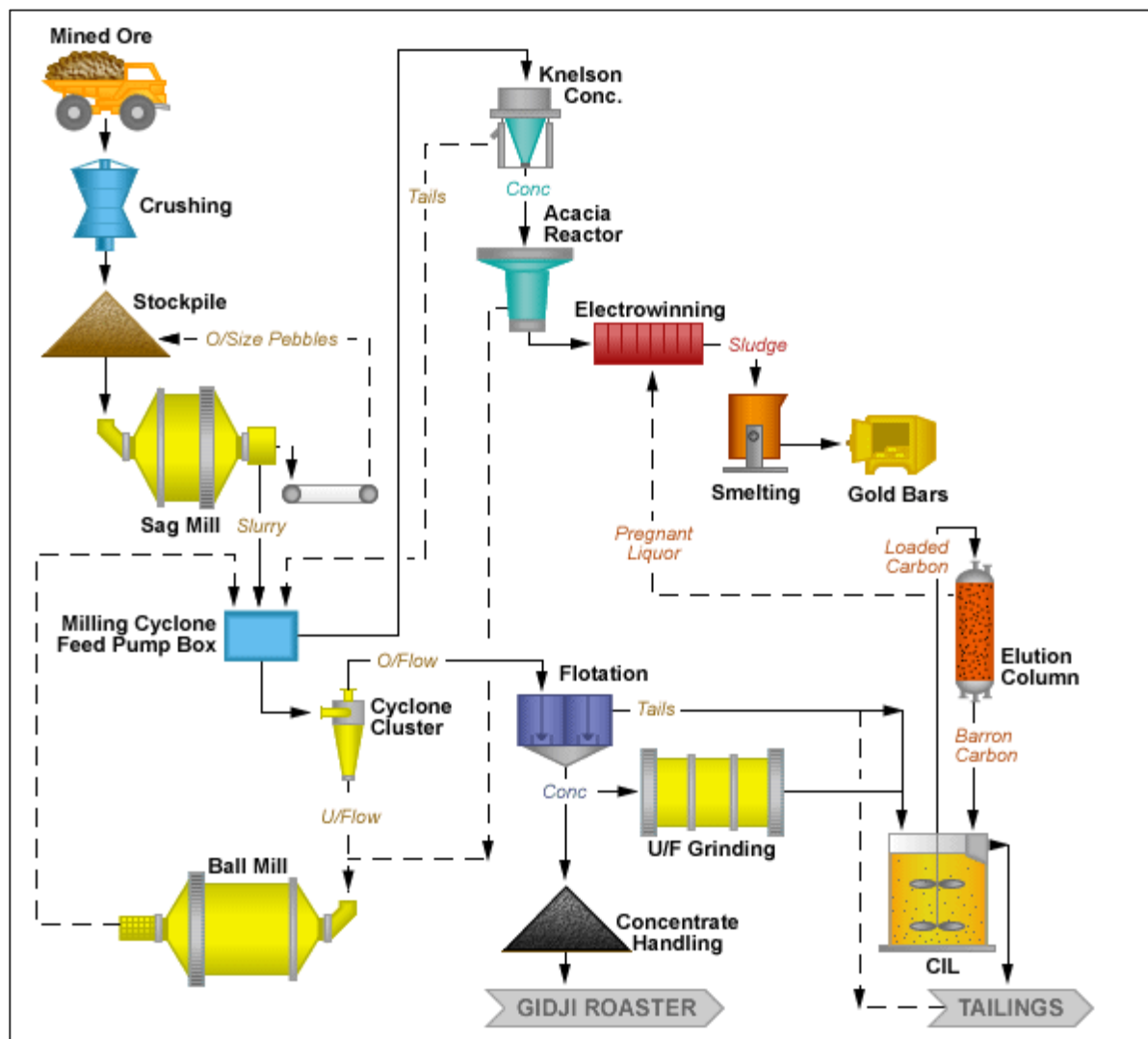


Figure 5: Fimiston Plant Simplified Process Flow Diagram

Source: KCGM

2.2 Air Emissions

The primary air quality issues for the Fimiston Operations have primarily been related to the management of dust and mercury emissions from the operations. Sources of fugitive dust emissions include the following activities:

- Mining operations
 - Drilling and blasting;
 - Excavation of waste rock and ore;
 - Loading/unloading of haul trucks;
- Ore processing
 - Crushing;
 - Conveyor transfer points;
- Wheel generated dust emissions
 - Haul trucks and other vehicles travelling on unsealed roads; and
- Wind-blown dust emissions from exposed surface areas, such as the TSFs.

Dust management practices targeting these emission sources are outlined in KCGM's Fimiston Air Quality Management Plan (FAQMP) (KCGM, 2019a).

2.3 Point Source Mercury Emissions

Investigations during 2005 revealed that naturally occurring mercury compounds in the Golden Mile ore are released to the environment during processing. As a result of this finding, KCGM completed a number of ambient air quality studies that concluded that the mercury emissions in their own right do not represent a local health concern (see ENVIRON 2006). Point source mercury emissions were not included in the air dispersion modelling study that formed the basis of a previous screening HRA (see ENVIRON, 2007).

Since this time KCGM has implemented measures to further reduce the point source emission of mercury from the Carbon Regeneration Kiln located at the Fimiston Mill. The Carbon Kiln Mercury Emissions Reduction Programme was introduced in 2015 and involved the Carbon Regeneration Kiln Emissions Control Strategy used to restrict operation of the carbon regeneration kilns when the wind is blowing towards Kalgoorlie-Boulder; and the installation of a hypersaline wet scrubbing system that reduced mercury emissions within the off-gas of select carbon regeneration kilns by 60-70%. In 2015, KCGM also implemented the Fimiston Emissions Reduction Project (Fimiston ERP), designed to reduce gaseous emissions of mercury from the Fimiston Processing Plant by more than 90%. The Fimiston ERP involves installation of new emissions control equipment including a retort oven in the Gold Room, an off-gas scrubber, Regenerative Thermal Oxidiser (RTO) and a sulphur impregnated carbon scrubber to capture mercury from the carbon regeneration kilns off-gas prior to release.

2.4 Regional Metal Concentrations

2.4.1 Soils and Assays

In 2005, KCGM commissioned a series of investigations to determine the typical concentrations of a suite of elements in the surface soils present in Kalgoorlie and its surrounds. Soil samples were collected from residential premises within Kalgoorlie, from the Lakewood historical tailing area (used for recreational motor vehicle activities) and from KCGM vegetation monitoring sites in the vicinity of the Gidji Roaster. A comparison of the Kalgoorlie and Gidji soil samples was made to 'background' soil samples from around Australia, indicating Kalgoorlie soils have elevated levels of arsenic, chromium and nickel compared to the other Australian locations (see ENVIRON, 2007). Metal assay data for KCGM's ore and waste rock material were also collated for comparison against the regional soil samples. The most likely source of fugitive dust emissions is the waste rock material as this comprises the bulk of the mined material moved and deposited in waste rock dumps around the perimeter of the FOP.

A summary of the reported mean metal concentrations for the Kalgoorlie and Gidji soil samples and the FOP ore (mined and milled) and waste rock material collected in 2006 is presented in Table 2. These data indicate the average concentration of chromium in the waste rock material is lower than that found in the Kalgoorlie and Gidji soil samples. The average arsenic and copper concentrations reported for the waste rock sample are approximately twice as high as the average concentrations reported for the Kalgoorlie and Gidji soil samples; and the average manganese concentration reported for the waste rock sample is almost 10 times as high. The average concentrations of all other metals (i.e. boron, cadmium, mercury, nickel, lead and zinc) are comparable.

Table 2: Average Concentrations of Metals in Soil, Ore and Waste Rock Samples

Metals	Average Concentrations of Metals in Soil, Ore and Waste Rock Samples (mg/kg) ^{1,2}					
	Kalgoorlie Residential	Lakewood Recreational	Gidji Recreational	KCGM Ore Mined	KCGM Ore Milled	KCGM Waste Rock
Arsenic (total)	15	159	15	190	104	26
Boron	19	27 ^[3]	5.4 ^[3]	41	6.2	8
Beryllium	ND	ND	ND	3.9	0.7	0.3
Cadmium	<DL of 0.4	<DL of 0.4	<DL of 0.4	2.7	0.2	0.1
Chromium (III)	322 (total) ⁴	12	390 (total) ⁴	144	58	177
Cobalt	ND	ND	ND	38	42	35
Copper	36	83	20	87	96	78
Lead	23	31	9.8	10	3.8	5.6
Manganese	515	1,465	309	1,435	1,575	1,480
Mercury (Inorganic)	<DL of 1.0	4 ^[3]	<DL of 1.0	1.4	1.0	0.1
Nickel	65	25	51	44	49	61
Selenium	ND	<DL of 4.0	<DL of 4.0	1.8	1.0	0.05
Antimony	ND	ND	ND	12	11	1.1
Zinc	78	172	26	195	85	88

Notes

1. ND = No data
2. <DL = Below detection limit
3. Concentration was calculated using the upper bound value of the detection limit.
4. The analysis measured total chromium. Chromium (VI) is generally unstable and is readily transformed to chromium (III) in the environment. It is not expected to be present in the current soil samples at measurable levels.

2.4.2 Ambient Particulate Samples

Historically, KCGM has operated a network of High-Volume (Hi-Vol) air samplers to monitor ambient dust concentrations at a number of sites in close proximity to the FOP; Boulder Shire Yard (BSY), Hewitt Street (HEW) and Clancy Street (CLY) (Figure 6). The Hi-Vols were primarily used to monitor total suspended particulate (TSP) emissions associated with blasting and were only operated between 09:00 hrs and 18:00 hrs on days when blasting was undertaken. A fourth sampler was established at the Hopkins Street (HOP) site in 2004 to measure PM₁₀ concentrations during construction of the southern portion of the Environmental Noise Bund (ENB). This unit was typically operated for 24-hour periods during the ENB construction phase. A second Hi-Vol was also operated at the same site for a short period, monitoring ambient TSP concentrations.

Hi-Vols draw air through a pre-weighed filter paper that captures particulate matter. The filter papers are subsequently re-weighed and the mass of particulate collected is determined via subtraction. KCGM selected 58 TSP samples collected from the BSY, HEW and CLY sites during 2006 for analysis¹. An additional 22 samples collected from the HOP site were also analysed, which comprised 11 coincident Hi-Vol TSP and PM₁₀ samples. The objective of this additional analysis was to determine if any of the metals existed in higher concentrations within the finer PM₁₀ fraction.

A summary of the average and maximum concentrations of metals determined from the analysis of TSP filter papers collected from the BSY, HEW and CLY Hi-Vol units is presented in Table 3. Results are presented for all data (regardless of wind direction) and for samples collected on days where the winds were primarily from directions associated with KCGM's Fimiston Operations. The average concentration of metals within the TSP samples collected from the HOP site is also included, along with the ratio of metals in the average PM₁₀ and TSP samples, where this could be determined.

The data in Table 3 indicates that on average, the concentrations of metals in the particulate samples collected at BSY, CLY and HEW for wind directions that are associated with KCGM's Operations are not overly different to those for all of the data. The average cobalt, copper, manganese, nickel and zinc concentrations are lower in the samples associated with winds from KCGM's operations compared to samples for all wind directions, while the concentration of lead is higher. The maximum concentrations of arsenic, cadmium, chromium, lead, manganese and zinc are highest in the samples associated with KCGM's Operations compared to the samples for all wind directions.

¹ Further detail of the sample selection and analytical process is provided in ENVIRON (2007).

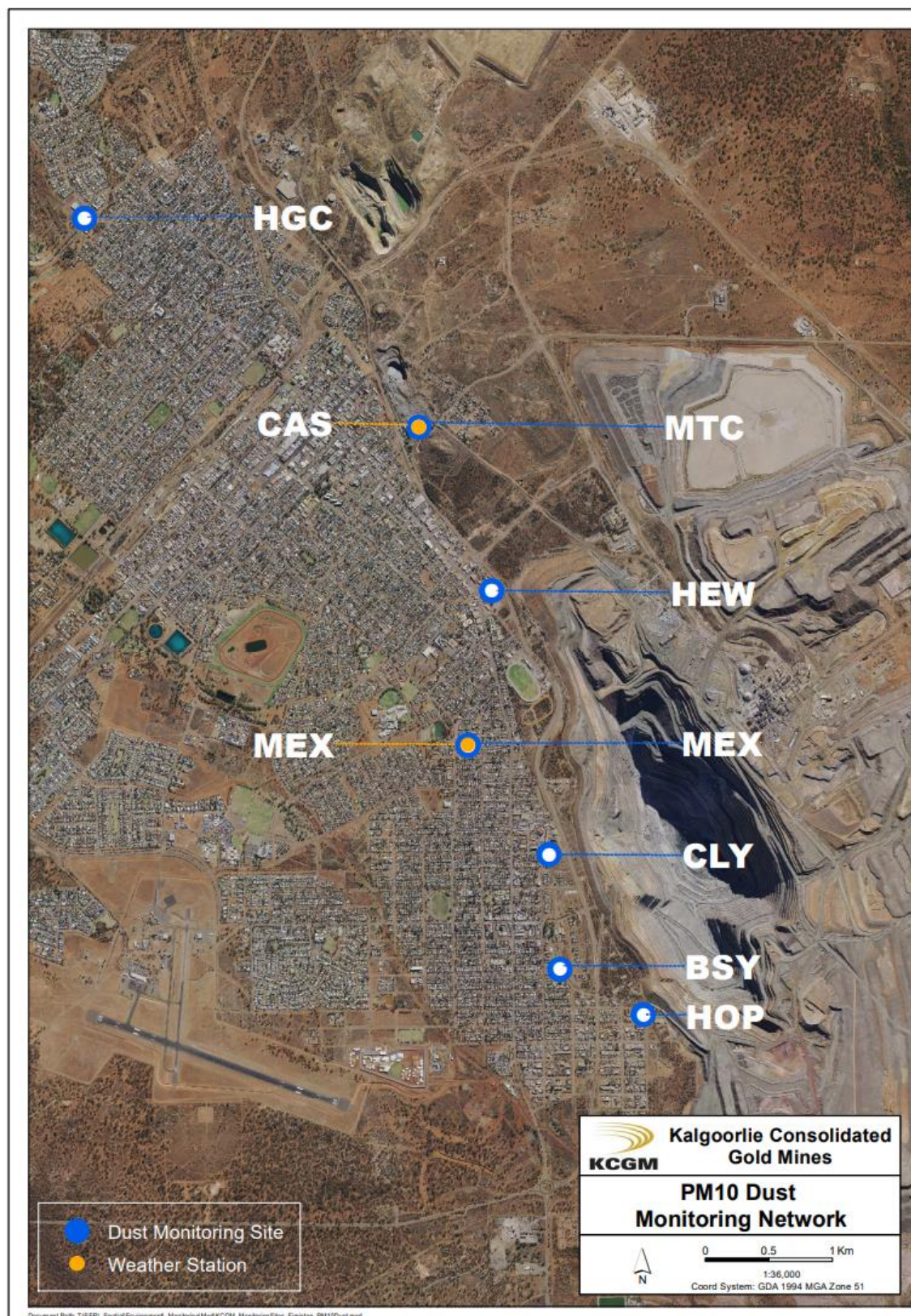


Figure 6: Dust Monitoring Sites

Table 3: Summary of Metals Concentrations in Hi-Vol TSP Samples

Metals	Metals Concentration in TSP Samples (mg/kg) ¹					
	BSY, CLY, HEW				HOP	
	Average		Maximum		Average	PM ₁₀ :TSP
	All Data	KCGM ²	All Data	KCGM ²	All Data	Ratio
Arsenic	5.2	4.6	19	19	34	1.09
Barium	140	139	2,570	1,875	70	ND
Beryllium	ND	ND	ND	ND	ND	ND
Cadmium	0.1	0.2	5.6	5.6	ND	ND
Chromium	38	40	215	215	45	ND
Cobalt	7.5	0.5	99	12	11	ND
Copper	11	5.7	77	46	31	ND
Lead	29	44	574	574	65	2.0
Manganese	123	104	405	405	486	1.1
Mercury	1.0	ND	20	ND	0.4	ND
Molybdenum	ND	ND	ND	ND	4.3	1.5
Nickel	47	31	293	171	104	1.1
Selenium	ND	ND	ND	ND	ND	ND
Silver	0.08	0.2	4.8	4.8	0.8	0.8
Zinc	62	35	866	646	109	ND

Notes

1. ND = No data
2. Results for samples collected on days where the winds were primarily from directions associated with KCGM's Fimiston Operations

The ratio of metals in the PM₁₀ and TSP samples collected at the HOP site indicates arsenic, manganese and nickel concentrations were higher in the PM₁₀ samples by approximately 10% (Table 3). The lead concentrations in the PM₁₀ samples were nearly doubled that of the TSP samples, although it is noted that only two of the 11 sample pairs had sufficient lead concentrations to be included in the analysis (ENVIRON, 2007). Silver was the only metal reported to be at higher concentrations in the TSP samples compared to the PM₁₀ samples.

A comparison of the average metal concentrations measured in the regional soil, waste rock and TSP samples is presented in Figure 7 (note logarithmic scale). This figure illustrates the average concentration of metals measured in the TSP samples are generally within the same order of magnitude as the concentrations measured in the Kalgoorlie and Gidji soil samples. The average concentration of metals in the TSP samples collected from the HOP site are slightly higher than those reported for the samples collected from the BSY, CLY and HEW sites (Figure 7).

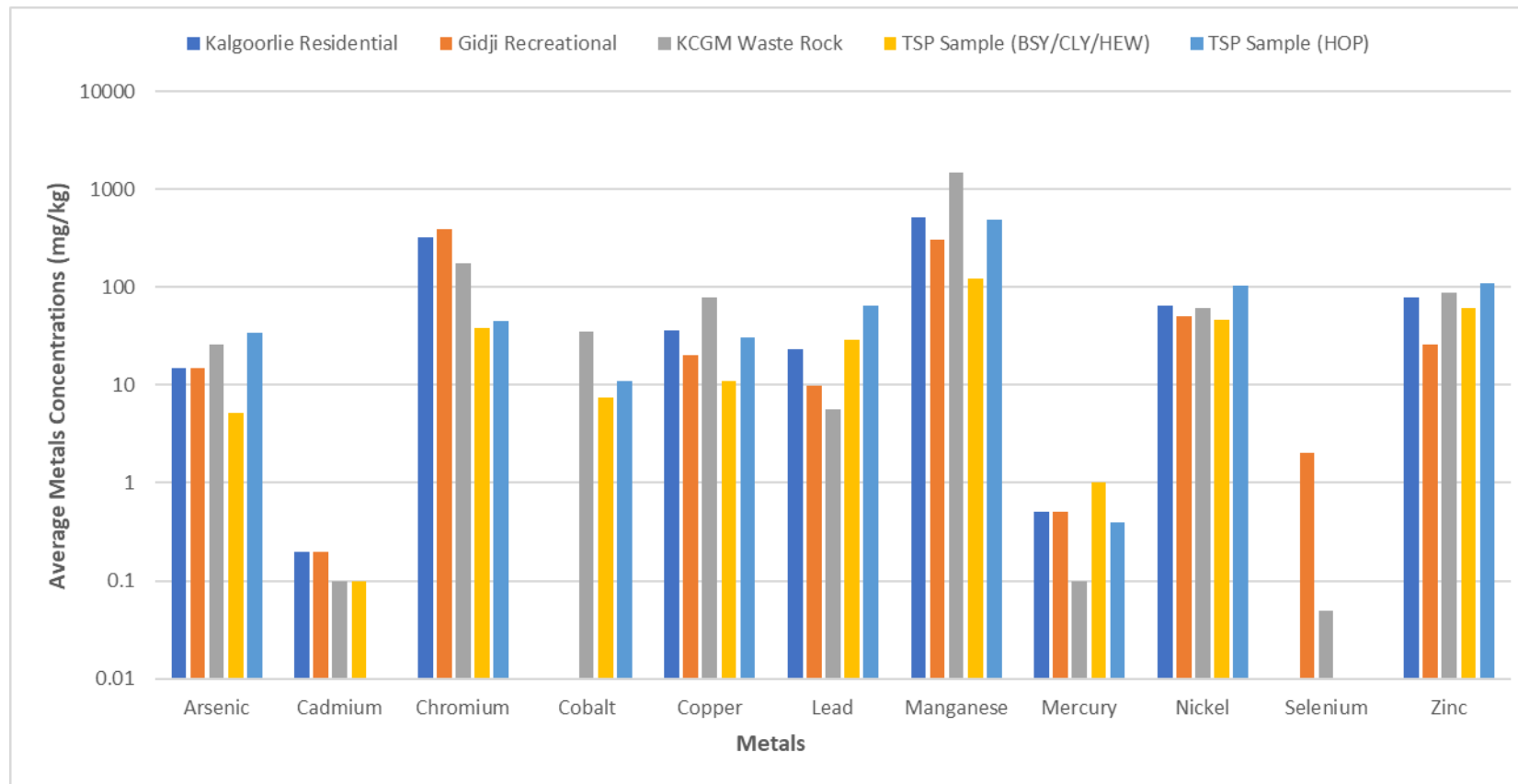


Figure 7: Comparison of Average Metal Concentrations in Regional Soil, Waste Rock and Ambient TSP Samples

2.5 Ambient PM₁₀ Monitoring Data

Dust emissions from KCGM's Fimiston Operations are managed via the Dust Monitoring and Management Programme (DMMP), a component of the FAQMP. A key performance target of the DMMP is to manage KCGM's operations such that there are no more than five events above the National Environmental Protection Measure (NEPM) 24-hour PM₁₀ standard (i.e. 50 µg/m³) at any dust monitoring site per annum, where KCGM is a significant contributor.

The DMMP utilises a network of seven ambient PM₁₀ monitoring stations, six of which are established in the residential and light industrial area near the FOP Operations. These comprise BSY, HEW, CLY, HOP, Mt Charlotte (MTC) and Metals Exploration Yard (MEX) sites (Figure 6). The seventh monitor, Hannan's Golf Course (HGC), is located northwest of the Fimiston Operations and generally provides background PM₁₀ concentrations. Meteorological monitoring stations are located at the MEX site and the Cassidy Headframe (CAS).

The design of KCGM's DMMP has evolved over time in response to regulatory requirements, technological advancements and operational practices at the Fimiston site. The current network utilises Beta Attenuation Monitors (BAM) at each of the seven monitoring locations, measuring real-time ambient PM₁₀ concentrations. The real-time data are compared to site-specific Alert and Action levels:

- Alert levels are set at values that are indicative of the possibility of on-site activities contributing to ambient concentrations that may approach the NEPM standard and where reasonable and practicable management measures could be implemented to reduce this risk; and
- Action levels are set at values that indicate it is likely that on-site activities are contributing to ambient concentrations that may result in an exceedance of the DMMP target concentration and where reasonable and practicable, immediate management measures should be implemented to reduce this potential.

A detailed review of KCGM's ambient PM₁₀ and meteorological monitoring data collected over twelve years from January 2010 to December 2021 is presented in Ramboll (2020b and 2022b) and a summary of the key parameters relevant to the screening HRA is presented here.

The annual average PM₁₀ concentrations for each of the monitoring sites from 2010 to 2021 is presented in Figure 8. This figure shows that the highest annual average concentrations are recorded at the BSY, HEW, and CLY sites. Similar annual average concentrations have also been recorded at the HOP site since 2013 (Ramboll believes that this is more likely due to the change in the monitoring equipment from e-BAM to BAM that occurred in late 2012 than an actual increase in PM₁₀ concentrations).

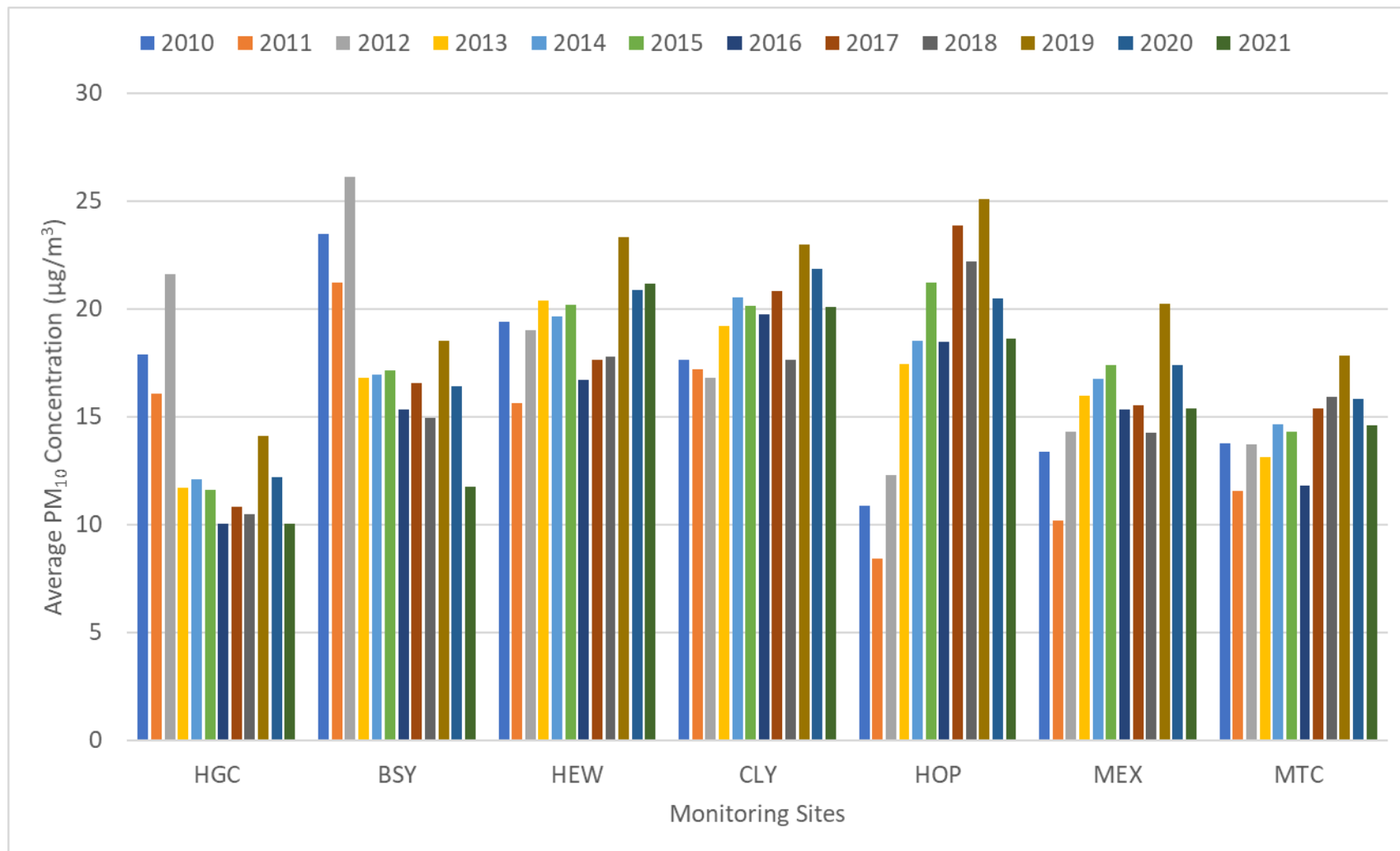


Figure 8: Annual Average PM₁₀ Concentration for Each Monitoring Site

The total number of days at each site where a 24-hour average PM_{10} concentration of greater than $50 \mu g/m^3$ was recorded between 2010 and 2021 is presented in Figure 9. In 2012, the BSY site experienced a total of 23 days where the 24-hour average PM_{10} concentration was greater than $50 \mu g/m^3$. It is believed that the majority of these days were associated with non-KCGM earthworks that occurred adjacent to the monitoring site. The CLY and HOP monitoring sites typically record the highest number of days with an average PM_{10} concentration greater than $50 \mu g/m^3$, with a much lower frequency recorded at HGC, MEX and MTC.

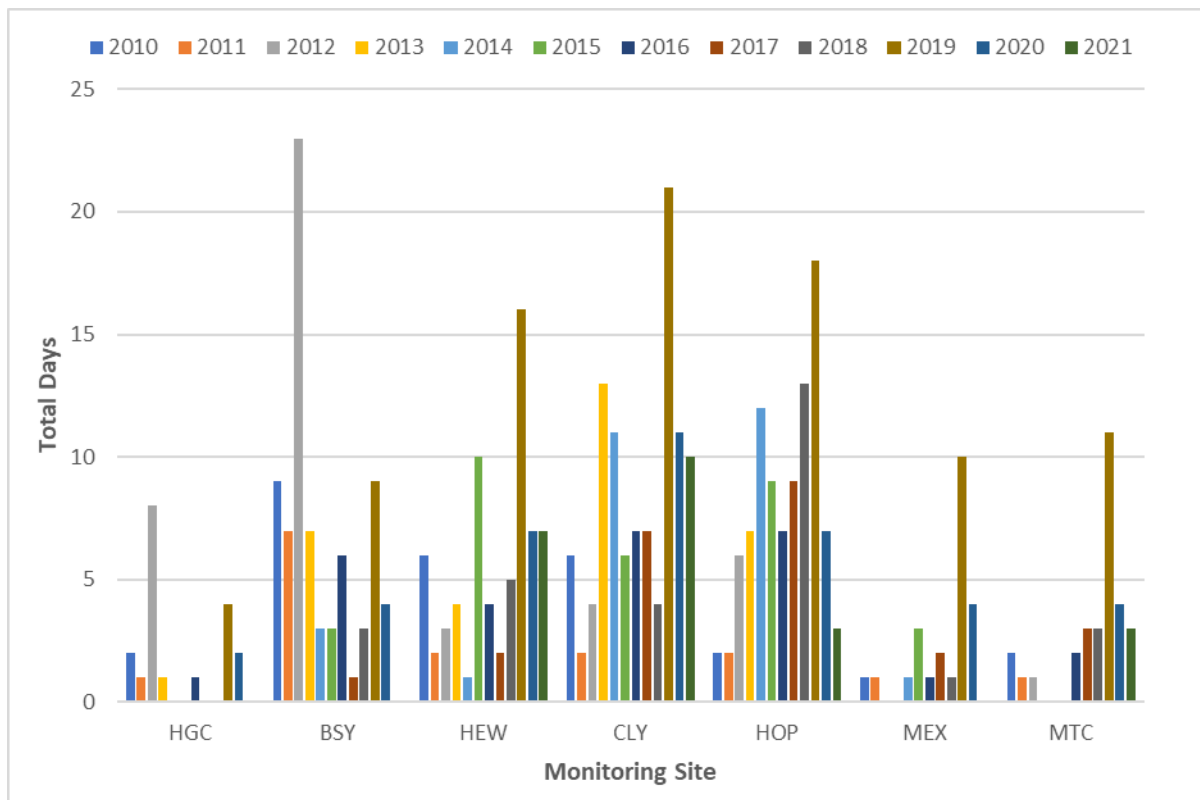


Figure 9: Days Where 24-Hour Average PM_{10} Concentration $> 50 \mu g/m^3$ for Each Site

For each day where a PM_{10} concentration of greater than $50 \mu g/m^3$ is recorded, KCGM reviews the data to determine if the Fimiston Operations may have been a significant contributor. In brief, the procedure involves a review of the 5-minute average PM_{10} concentrations and meteorological monitoring data for the period in question to:

1. Determine the daily average concentration, if any, that was associated with wind directions that were within the arcs that align with KCGM's Fimiston Operations and use this value to calculate the ratio of the KCGM arc;
2. Based on an assessment of the winds that occurred, determine which ambient PM_{10} monitoring station is most likely to represent the "background" monitoring site (usually the HGC site) and the daily average "background" concentration recorded at that site;
3. Calculate the difference between the recorded daily average exceedance concentration and the daily average background concentration and determine the ratio of this difference and the recorded daily average exceedance concentration; and
4. If the ratios determined from steps 1 and 3 are both greater than 60% then KCGM is considered to be a potential significant contributor.

The number of days where a PM₁₀ concentration of greater than 50 µg/m³ is recorded and the Fimiston Operations are considered to be a potential significant contributor (based on the above procedure) is presented in Figure 10. It is not always possible to eliminate non-KCGM dust emission sources from the analysis particularly where the emissions may have occurred between the monitoring site and the Fimiston Operations (e.g. motor cross bikes, earth works). Where the contribution of these non-KCGM sources cannot be quantified (e.g. via photographic evidence), KCGM conservatively reports itself as a contributor. Therefore, the number of days presented in Figure 10 may be overstated.

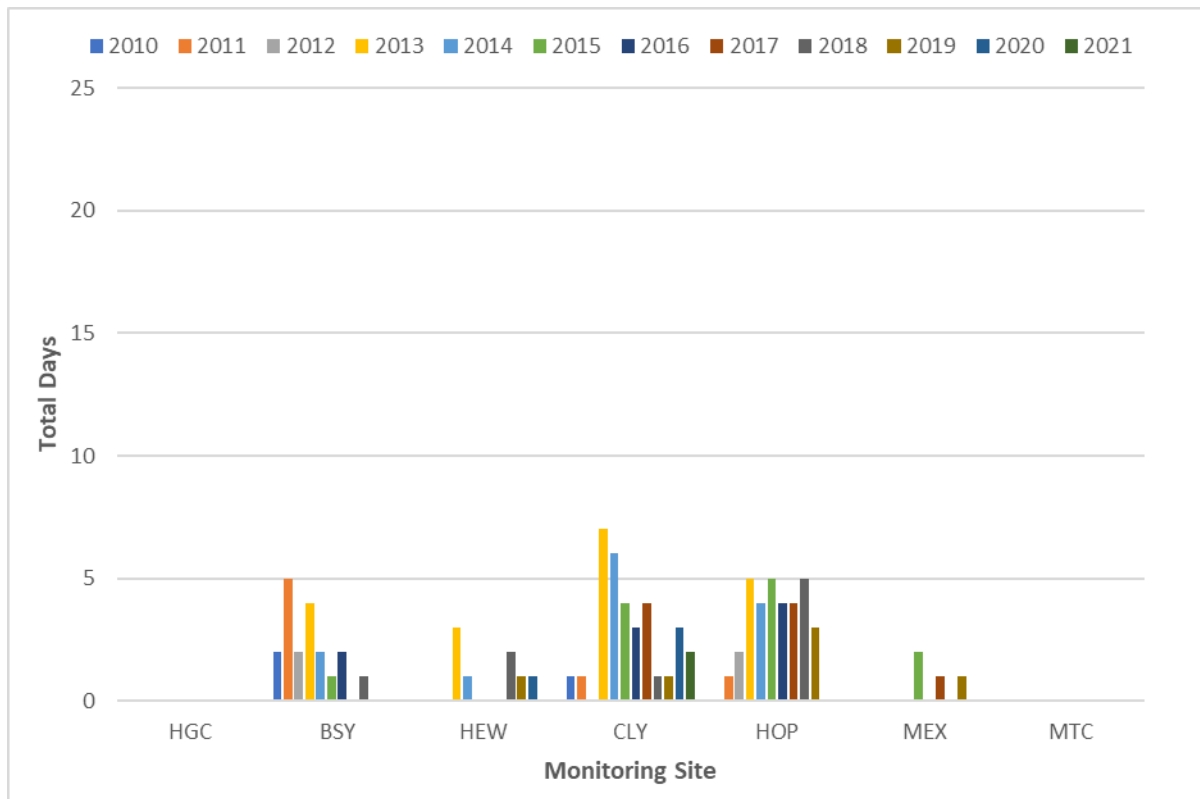


Figure 10: Days Where 24-Hour Average PM₁₀ Concentration >50 µg/m³ for Each Site and KCGM Identified as Significant Contributor

Comparison of the data presented in Figure 9 and Figure 10 indicates that the majority of 24-hour average PM₁₀ concentrations greater than 50 µg/m³ are related to non-KCGM dust sources. In 2019 for example, there were 21 days for which the 24-hour average PM₁₀ concentration was greater than 50 µg/m³ at the CLY site; however KCGM was determined to be a significant contributor on only one of these occasions. Similarly, the HOP site recorded 24-hour average PM₁₀ concentrations above 50 µg/m³ on 18 occasions in 2019; KCGM was found to be a significant contributor to just three of these events. The number of days for which KCGM has been identified as a significant contributor to a 24-hour average PM₁₀ concentrations greater than 50 µg/m³ has remained relatively consistent from 2014 onwards.

With the exception of the CLY monitoring site during 2013 and 2014, KCGM has achieved its FAQMP target of having less than 5-days per year with PM₁₀ concentrations greater than 50 µg/m³ where it was a potentially significant contributor. The PM₁₀ monitors located in more urban or adjacent to rehabilitated areas (e.g. HGC, MEX and MTC) generally record lower longer-term averages and a lower frequency of days with PM₁₀ concentrations greater than 50 µg/m³. While it could be concluded that KCGM is the primary contributor to the elevated PM₁₀ concentrations for sites located closer to its Fimiston Operations (i.e., BSY, HOP, CLY and HEW), Ramboll considers

that other non-KCGM related sources are also likely to be significant contributors for much of the time. These sources include smoke from wood heaters in winter, particulates from wind erosion of cleared areas, local non-KCGM earthworks, truck and car movement on sealed and unsealed roads and tracks, and motor cross bike generated dust from activity on nearby tracks.

A summary of the 1-hour, 24-hour and annual average PM₁₀ concentrations recorded at each site between 2010 and 2021 is presented in Table 4. The 1-hour averages exclude concentrations associated with winds from outside KCGM's arc of influence (i.e. winds between 160° and 340°) and concentrations measured during recorded bushfires or other regional dust events. The maximum 24-hour PM₁₀ concentrations represent those for which KCGM was found to be a significant contributor.

Table 4: Summary of Measured PM₁₀ Concentrations (2010 – 2021) for winds in KCGM Arc of Influence

Averaging Period		Measured PM ₁₀ Concentrations (µg/m ³)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC
1-hour ¹	Max	NA ⁴ (467)	184	791 ²	1324	622 ²	711 ²	NA ⁴
	Average	13	17	14	14	15	15	12
24-hour	Max ³	NA ⁴	80	86	125	96	64	NA ⁴
	Average	13	18	20	20	21	15	14
Annual	Max ⁵	22	26	23	23	25	20	18
	Average	13	18	20	20	21	16	14

Notes

- 1-hour average PM₁₀ concentrations associated with winds from within KCGM's arc of influence and excluding concentrations associated with regional dust events (i.e. bushfires).
- Maximum 1-hour average PM₁₀ concentration associated with maximum 24-hour average PM₁₀ concentrations.
- Maximum recorded 24-hour PM₁₀ concentrations for which KCGM was found to be a significant contributor.
- KCGM has not been found to have contributed to any PM₁₀ concentrations above 50 µg/m³ at HGC or MTC between 2010 and 2021. 1-hour maximum value of 467 µg/m³ at HGC adopted for comparative purposes only as it represents background conditions.
- Highest annual average PM₁₀ concentration recorded between 2010 and 2021.

The highest 1-hour average PM₁₀ concentration associated with winds from KCGM's arc of influence (and excluding regional dust events) was 1324 µg/m³ recorded at CLY site on 15 December 2021 at about 11 pm. Analysis of the 5-minute data at CLY on 15/12/2021 indicates a period of high 5-min concentration from 9:55 pm to 11:15 pm across all the PM₁₀ monitoring stations. High wind speeds were recorded at the met station during this time with an average of 8.5 m/s and a peak 5-min wind speed of 12 m/s. The wind direction was on average within KCGM's arc of influence. A revision of the Department of Fire and Emergency services (DFES) records was conducted, indicating no fire or smoke alarms reported on that day. This analysis suggests that the most likely cause of high PM₁₀ 1-hour average on 15/12/2021 could be associated with wind erosion.

The highest 1-hour average PM₁₀ concentration at HEW site of 791 µg/m³ recorded on 14 May 2018 was associated with a rock fall event that occurred within the FOP on the same day. The highest 1-hour average PM₁₀ concentration recorded at the HOP site (622 µg/m³ recorded on 24 May 2018) was associated with mobilisation of fine material in the days following the rock fall, from a safety exclusion zone within which watercart access was restricted.

Along with the maximums measured at the HEW and HOP sites, the maximum 1-hour average PM₁₀ concentrations recorded at the MEX (711 µg/m³) monitoring station occurred on days where KCGM was found to have been a significant contributor to elevated 24-hour average PM₁₀ concentrations (i.e. >50 µg/m³).

The highest 24-hour average PM₁₀ concentration for which KCGM was found to be a significant contributor was 125 µg/m³, recorded at the CLY site on 15 November 2016. Analysis of this event identified KCGM as a potential significant contributor based on the ratio of wind directions that were within the arcs aligned with the Fimiston Operations, although fugitive dust emissions from vehicles travelling along unsealed access routes adjacent to the CLY monitor and the nearby Super Pit public lookout road were also observed on the day and are considered to have contributed to the measured concentration².

The maximum 24-hour average PM₁₀ concentrations for which KCGM was found to be a significant contributor as recorded at the BSY, HEW and HOP sites were between 80 to 96 µg/m³; with a lower peak concentration of 64 µg/m³ recorded at the MEX site (Table 4). KCGM has not been found to have contributed to any PM₁₀ concentrations above 50 µg/m³ at HGC or MTC between 2010 and 2021.

The highest annual average PM₁₀ concentrations are recorded at the BSY, HOP, HEW and CLY sites, while PM₁₀ monitors located in more urban areas or adjacent to rehabilitated land (i.e. HGC, MEX and MTC) record slightly lower long-term averages.

2.6 Air Dispersion Modelling Data

An air dispersion modelling was undertaken by Ramboll (2022a) to assess potential changes associated with the implementation of the FS Project, which was used to comparatively assess current and potential future operations.

The FS Project will be mined in the same manner as the GP Cutback, with drilling and blasting of the in-situ material and excavating and hauling via a conventional truck and shovel fleet. The sources of fugitive dust emissions for the proposed FS Project are therefore expected to remain the same as the current operations.

Given the proximity of the proposed FS Project to the City of Kalgoorlie-Boulder, the south-western expansion of the FOP is likely to have the greatest potential impact on ambient PM₁₀ concentrations at the nearest monitoring locations (i.e. HOP, BSY and CLY). This will primarily be the case during construction works to realign the ENB and when mining activity is close to the surface, during the initial stages of the Project.

During the past twelve years (2010-2021), 2019 had the highest average monitored PM₁₀ concentrations in the region. Hence, Ramboll (2022a) adopted emissions estimates derived from KCGM operations in 2019 to model current operations at KCGM. The maximum annual material movement for the FS project is expected to be approximately 96 Mt. peaking in the year 2029, when operational. However, 2025 (86 Mtpa) was selected as the year to be modelled as this involved a higher level of activity located close to the town and a larger amount of material extracted from the pit and dumped externally and was therefore considered to represent a worst-case assessment. Emissions estimates from this year were used in Ramboll (2022a) to predict worst case impacts associated with operational phase of the project using the meteorology from

² Sourced from KCGM's Environmental Notification Form for 15 November 2016 (dated 21 November 2016).

2019. The CALPUFF modelling system was used for air dispersion modelling and further details are provided in Ramboll (2022a).

The change in modelled PM₁₀ concentration from 2019 to 2025 was calculated (Table 5) and then PM₁₀ concentrations in 2025 was estimated using monitored data from 2019 (Table 6). The data shows that no material change in ambient worst-case PM₁₀ concentrations are expected when FS project is operational in the future compared to worst-case concentrations from current operations.

Table 5: Modelled current (2019) and future (2025) worst-case PM₁₀ concentrations Ratio of Change.

Value	Averaging Period		Ratio (2025/2019)						
			HGC	BSY	HEW	CLY	HOP	MEX	MTC
Change from current to future	1-hour	Max	0.95	1.00	1.00	1.00	1.00	1.00	1.00
	24-hour	Average	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	Annual	Average	1.00	1.02	0.99	1.01	1.06	1.01	1.00

Table 6: Measured worst-case current (2019) and estimated worst-case future (2025) PM₁₀ concentrations based on ratios.

Value	Averaging Period		Measured PM ₁₀ Concentration (µg/m ³)						
			HGC	BSY	HEW	CLY	HOP	MEX	MTC
Current (2019)	1-hour	Max	739	824	960	827	810	773	725
	24-hour	Average	77	103	93	91	95	91	131
	Annual	Average	14	19	23	23	25	20	18
			Estimated PM ₁₀ Concentration (µg/m ³)						
Future (2025)	1-hour	Max	702	824	960	827	810	773	725
	24-hour	Average	77	103	93	91	95	91	131
	Annual	Average	14	19	23	23	26	20	18

3. ISSUES IDENTIFICATION

Issues identification is the first stage in risk assessment which establishes the context for the risk assessment and includes planning and scoping, and problem formulation stages. It includes consultation between decision-makers, risk assessors and other stakeholders to establish the goals of the assessment and indication of how and why the assessment will be conducted with identification of inclusions and exclusions from the assessment.

Following consultation with the Department of Health (DoH) in relation to the GP Cutback Project in 2005, KCGM was requested to provide additional information on the management of ambient particulate metals. A report was subsequently prepared, outlining information that KCGM had available relevant data to the issue of ambient particulate metals in Kalgoorlie (see ENVIRON, 2007). The report comprised the following information:

- The range of concentration of metals identified in the soils in and around Kalgoorlie including KCGM's Fimiston Operations;
- The metals concentrations measured in ambient particulate samples collected by KCGM's historical Hi-Vol sampling network;
- Ambient particulate monitoring data;
- Predicted ground level concentrations of particulate matter from KCGM's Fimiston Operations; and
- A screening HRA of the exposure to the metals present in the ambient particulate samples.

In support of the regulatory approval process for the FS Project, KCGM has requested Ramboll undertake a review of the previous report and screening HRA and update the assessment to reflect the proposed changes associated with the FS Project.

Conceptual site models (CSMs) can assist in understanding how human receptors may be exposed to contaminants from relevant sources, illustrating the source of contamination, the pathways by which contaminants may migrate through the environment and the populations that may potentially be exposed (enHealth, 2012). While CSMs are particularly important in HRA for contaminated sites, they are also useful for illustrating exposure pathways associated with airborne pollutants from industrial sites. An example CSM flow chart from enHealth (2012) for potential airborne exposure from an industrial facility is presented in Figure 11. This image is representative of the potential exposure pathways associated with fugitive particulate emissions from the Fimiston Operations.

In line with the previous assessment, the revised screening HRA for the FS project considers the inhalation pathway only. As the main transport pathway for atmospheric emissions associated with the FS project is atmospheric dispersion, inhalation is expected to remain the most significant exposure route. The receptor groups considered in the screening HRA are off-site residents, including sensitive receptors such as children and elderly. Consideration of on-site workers is not included in the scope of this screening HRA.

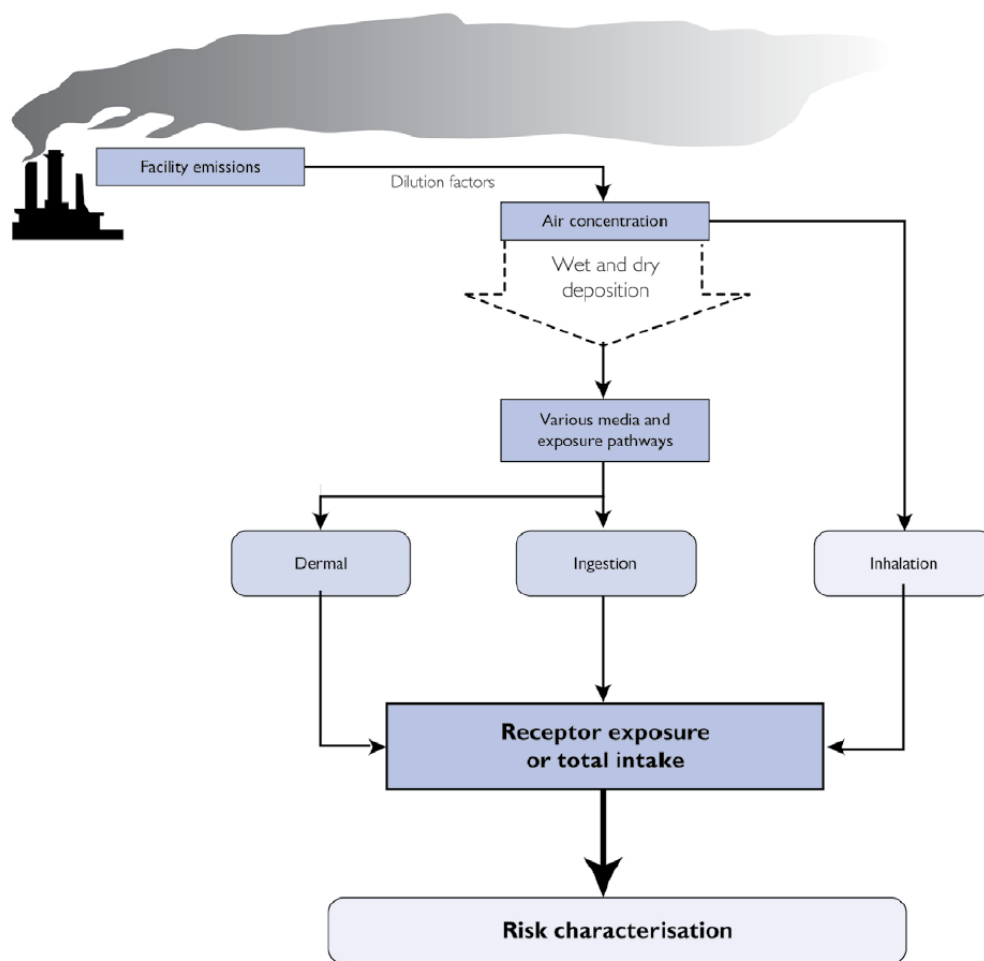


Figure 11: Example CSM for Potential Airborne Exposures from an Industrial Site

Source: enHealth (2012)

In order to determine exposure estimates for metals contained within the ambient PM₁₀, measured concentrations of these compounds are required. The previous screening HRA utilised metal concentrations determined from the analysis of particulate samples collected from KCGM's historic Hi-Vol sampling network, which is no longer utilised by KCGM. As outlined in Section 2.5, KCGM's current DMMP utilises BAMs to measure ambient PM₁₀ concentrations. Ramboll understands there are limitations with regard to the ability to analyse metals from the samples collected by these units, due to the potential for contamination of samples, as the tape on which the samples are collected also contains metals.

In the absence of updated metals analysis data, the results of the historic metals analysis have been used in conjunction with the available PM₁₀ ambient monitoring data, to update the screening HRA. Information provided by KCGM indicates that KCGM's previous mining operations occurred within the same geological bounds as current activities and those of the proposed FS Project; the proposed FS Project comprises the MO and SE resources at the southern end of the existing FOP (Figure 1). The FS Project is an extension of the southern mineralization and is consistent with previously mined ore bodies in Chaffers layback (completed in 2013) and the previously mined MO pit, which was completed in the late 1980s. As such, the concentration of metals within fugitive dust emissions from KCGM's current and proposed operations are not expected to differ significantly from those measured historically.

The proposed FS Project is similar in nature to the GP Cutback, due to its proximity to the City of Kalgoorlie-Boulder and active mining occurring on the western side of the FOP. As the impacts of fugitive dust emissions associated with the proposed FS Project are expected to be similar to those of previous operations, the historical ambient monitoring data are assumed to be representative of the potential ambient air quality impacts of the proposed FS Project.

This HRA also considers air dispersion modelling data presented in Ramboll (2022a) to assess the potential health impacts when the FS project is in operational phase. The HRA calculated the change in modelled PM₁₀ concentration from 2019 to 2025 and then estimated PM₁₀ concentrations in 2025 based on monitored data from 2019.

A review of the national and international guidance documents has been completed to ensure appropriate health protective guidelines are applied (Section 4). Acute and chronic non-carcinogenic hazard indices and the incremental carcinogenic risk are calculated for the nominated receptors to determine whether the potential risks associated with the measured ambient concentrations are considered acceptable (Section 6). Estimated concentrations from the modelled future worst-case scenario (year 2025) has also been included to compare the expected change in potential health risks from the current (based on 2019 data) operations. The applicability of the findings for the revised screening HRA have been considered in light of the outcomes of the qualitative assessment of the dust impacts associated with the proposed FS Project (Section 7).

4. TOXICITY ASSESSMENT

Toxicity assessment involves hazard identification and dose-response assessment. Hazard identification is the process of understanding the health effects of contaminants, while dose response assessment is the process of making a quantitative link between the degree of exposure to a chemical and the effects it can cause. Health effects can generally be acute or chronic. Acute effects occur within minutes, hours or days of a relatively short period of exposure, while chronic effects occur as a result of prolonged or repeated exposures over many days, months or years.

Chemical toxicity is divided into two categories for purposes of risk assessment: carcinogenic and non-carcinogenic. Some chemicals exert both types of effects. Whilst all non-carcinogenic effects are assumed to occur only at exposure levels greater than some threshold at which defence mechanisms are overwhelmed, carcinogens are thought to act via both threshold and non-threshold mechanisms. By convention, exposure to even one molecule of a genotoxic carcinogen is assumed to incur some small but finite risk of causing cancer; hence, the action of such compounds is considered to lack a threshold below which adverse effects are not expected to occur. In contrast, the effects of non-genotoxic carcinogens are thought to be manifested only at exposures in excess of compound-specific thresholds. Potential health risks are calculated differently for threshold and non-threshold effects because their toxicity criteria are based on different mechanistic assumptions and expressed in different units.

A number of national and international regulatory agencies have reviewed the toxicity of environmental chemicals and developed acceptable exposure criteria (herein referred to as "health protective guidelines") in accordance with both carcinogenic and non-carcinogenic endpoints. The Department of Water and Environmental Regulation (DWER) *Guidance Statement for Risk Assessments* (DER, 2017) references the following sources for determination of specific consequence criteria in relation to public and environmental health impacts:

- National Environment Protection (Ambient Air Quality) Measure as amended 2015 (NEPC, 2015); and
- New South Wales Environment Protection Authority (NSW EPA) Approved Methods for the Modelling and Assessment of Air Pollutants in New South Wales (NSW EPA, 2022).

Where available, health protective guidelines for use in the screening HRA were sourced from these documents. For compounds not covered by the NEPC or NSW EPA references, guidelines were sourced from the following reputable authorities (consistent with the hierarchical recommendation of the DWER *Air Emissions Draft Guideline* (DWER, 2019)):

- Western Australian Guidelines, Australian National Guidelines and other states and territory guidelines
- World Health Organisation (WHO) Air Quality Guidelines for Europe Second Edition (WHO, 2000);
- United Kingdom Department of Health;
- Netherlands National Institute of Public Health and the Environment (RIVM) human-toxicological Maximum Permissible Risk Levels (RIVM, 2001);
- Health Canada;
- U.S. Environment Protection Agency's (USEPA) Integrated Risk Information System (IRIS);
- U.S. Agency for Toxic Substances and Disease Registry's (ATSDR) Minimal Risk Levels (MRLs) for Hazardous Substances; and
- California Office of Environmental Health Hazard Assessment's (OEHHA) Toxicity Criteria Database.

The health protective guidelines applied within the screening HRA are presented in Table 7. Where guideline values differed between the reputable authorities listed above, the most conservative value was selected for use.

Table 7: Summary of Health Protective Guidelines

Compound Name	Guideline	Units	Averaging Period	Reference
Acute Health Effects				
Arsenic	0.09	µg/m ³	1-hour	NSW EPA
Barium	9.0	µg/m ³	1-hour	NSW EPA
Cadmium	0.018	µg/m ³	1-hour	NSW EPA
Chromium (III)	9.0	µg/m ³	1-hour	NSW EPA
Copper	18	µg/m ³	1-hour	NSW EPA
Manganese	18	µg/m ³	1-hour	NSW EPA
Mercury	1.8	µg/m ³	1-hour	NSW EPA
Nickel	0.18	µg/m ³	1-hour	NSW EPA
Silver	0.18	µg/m ³	1-hour	NSW EPA
Chronic Non-Carcinogenic Health Effects				
Arsenic	0.0027	µg/m ³	Annual	Toxikos 2010
Barium	1.0	µg/m ³	Annual	RIVM
Cadmium	0.005	µg/m ³	Annual	WHO
Chromium (III)	0.1	µg/m ³	Annual	ATSDR
Cobalt	0.1	µg/m ³	Annual	ATSDR
Copper	1.0	µg/m ³	Annual	RIVM
Lead	0.5	µg/m ³	Annual	NEPC
Manganese	0.15	µg/m ³	Annual	WHO
Mercury	0.03	µg/m ³	Annual	OEHHA
Nickel	0.003	µg/m ³	Annual	DoH/Duffus 2009
Zinc	46	µg/m ³	24-hour	Toxikos 2012
Incremental Carcinogenic Risk				
Arsenic	4.30E-03	per µg/m ³	Annual	IRIS
Cadmium	4.20E-03	per µg/m ³	Annual	IRIS
Lead	1.20E-05	per µg/m ³	Annual	OEHHA
Nickel	3.80E-04	per µg/m ³	Annual	WHO

Note:

Chromium in dust particles is assumed to be present as chromium (III) as chromium (VI) is considered unlikely to be a component of ore dust at mining operations (DWER, 2020).

4.1 Non-Carcinogenic Effects

A non-carcinogenic effect is defined as any adverse response to a chemical that is not cancer. Any chemical can cause adverse health effects if given at a high enough dose. When the dose is sufficiently low, no adverse effect is observed. Thus, in characterising the non-carcinogenic effects of a chemical, the key parameter is the threshold dose at which an adverse effect first becomes

evident. Doses below the threshold are considered to be "safe" (i.e. not associated with adverse effects), while doses above the threshold may cause an adverse effect.

The threshold dose is typically estimated from toxicological or epidemiological data by finding the highest dose level that produces no observable adverse effect (a NOAEL) or the lowest observed adverse effect level (LOAEL). Where more than one such value is available, preference is given to studies using most sensitive species, strain and sex of experimental animal known, the assumption being that humans are no less sensitive than the most sensitive animal species tested.

For the guidelines developed by all the authorities considered, NOAELs or LOAELs are divided by the product of a series of uncertainty factors representing experimental vs. environmental exposure duration, inter- and intra-species variability and the quality and completeness of the toxicological database. This procedure ensures that the resultant health protective guidelines are not higher than (and may be orders of magnitude lower than) the threshold level for adverse effects in the most sensitive potential receptor. As such, there is a "margin of safety" built into the guideline, and doses equal to or less than that level are nearly certain to be without any adverse effect. The likelihood of an adverse effect at doses higher than the guideline increases, but because of the margin of safety, a greater dose does not mean that such an effect may occur.

4.1.1 Short-Term (Acute) Exposure

Health protective guidelines for acute non-carcinogenic health effects are expressed as concentrations in air that are not expected to cause any adverse effects as a result of continuous exposure over a defined averaging period (typically 24 hours or less). These guidelines are appropriate for comparison with 1-hour or 24-hour average exposure estimates. The guidelines selected for this assessment are all intended to be protective of continually exposed (i.e. residential) receptors, including potentially sensitive subpopulations.

4.1.2 Long-Term (Chronic) Exposure

Health protective guidelines for chronic non-carcinogenic health effects are expressed as concentrations in air that are not expected to cause any adverse health effects as a result of continuous long-term exposure (a year or more). These guidelines are appropriate for comparison with annual average exposure estimates

4.2 Carcinogenic Effects

Cancers are generally defined as diseases caused by an uncontrolled division of abnormal cells in a part of the body. Although many chemicals are known to cause cancer at high doses in studies with experimental animals, relatively few chemicals have been shown to be carcinogenic in humans at doses likely to be encountered in the ambient environment. Cancers are relatively slow to develop, and usually require prolonged exposure to carcinogenic chemicals. As a result, potential carcinogenic risks are only calculated for long-term exposures.

The International Agency for Research on Cancer (IARC) classifies substances according to their potential for human carcinogenicity as indicated in Table 8.

Table 8: IARC Classification Criteria

Group	Description
1	Carcinogenic to humans (sufficient evidence of carcinogenicity to humans)
2A	Probably carcinogenic to humans (sufficient evidence of carcinogenicity in animals, limited evidence of carcinogenicity in humans)
2B	Possibly carcinogenic to humans (less than sufficient evidence of carcinogenicity in animals, limited evidence of carcinogenicity in humans)
3	Not classifiable as to carcinogenicity in humans (inadequate or limited evidence of carcinogenicity in animals, inadequate evidence of carcinogenicity in humans)
4	Probably not carcinogenic to humans (evidence suggesting lack of carcinogenicity in animals and humans)

Those compounds present in the particulates that are classified by the IARC as Group 1, Group 2A or Group 2B are presented in Table 9.

Table 9: IARC Compound Classifications

Group	IARC Classification	Route of Exposure
Arsenic	1	Inhalation, ingestion
Cadmium	1	Inhalation, ingestion
Beryllium	1	Inhalation
Lead	2A	Inhalation, ingestion
Nickel	1 (Nickel compounds); 2B (Nickel, metallic and alloys)	Inhalation

The IARC has classified nickel compounds as a Group 1 carcinogen; and nickel, metallic and alloys as a Group 2B carcinogen. The most recent IARC (2012) evaluation of the carcinogenicity of nickel and nickel compounds found that there is sufficient evidence in humans for the carcinogenicity of mixtures that include nickel compounds and nickel metal. The ultimate carcinogenic species in nickel carcinogenesis is the nickel ion Ni (II). The evidence is strongest for water-soluble nickel compounds and risk for lung cancer, however it is not possible to entirely separate various nickel compounds in dose-response analysis for specific nickel compounds (IARC, 2012).

Health protective guidelines for genotoxic carcinogens are expressed as unit risk (UR) factors. A UR factor is defined as the probability of cancer per unit theoretical upper bound probability of extra cases (i.e. above background) of cancer occurring in the exposed population assuming lifetime exposure by inhalation to 1 µg/m³ of the compound (hence units are per µg/m³) (WHO, 2000). These guidelines are appropriate for comparison with annual average exposure estimates.

4.3 Uncertainties in Toxicity Assessment

There is a wide body of research and data related to the derivation of the health protective guidelines for chemicals of potential concern (COPCs), including animal exposure, human exposure and epidemiological studies. However, despite this there are a number of uncertainties that affect final assessment of exposure and effects. While the level of uncertainty can be different for different chemicals, it is generally applicable to all.

Toxicological studies mainly focus on the primary health effects caused by the COPCs, and therefore the scientific understanding of secondary and lesser known health effects is lacking. There is also a general lack of information on acute and intermittent exposures and the likely

short-term (and any long-term) health effects that can be caused. The lack of sufficient toxicity data affects the development of a robust dose-response relationships which normally informs the final guideline values or assessment of risks. More controlled human exposure studies may be required to support epidemiological observations and assist in better characterisation of dose-response curves and identification of more appropriate threshold concentrations.

Most human exposure studies use healthy individuals and therefore direct effect information for sensitive individuals such as elderly, children and people with pre-existing conditions are lacking. Children have bodily systems that are developing (e.g. haematology, endocrine, nervous, immune systems) and therefore may have greater sensitivities. Furthermore, extrapolations are normally made from animal studies to prediction of health impacts and threshold concentrations in human populations. Development of reference concentrations therefore requires application of uncertainty factors to allow for these extrapolations. This can include interspecies uncertainty factor to allow for differences between humans and animals, intraspecies uncertainty factor to allow for population sensitivity variations, uncertainty factor if a lowest observed adverse effect level (LOAEL) is used as point of departure rather than a no observed adverse effect level (NOAEL), and other factor for exposure conversions and data deficiencies. These factors are arbitrarily chosen (2-10 times) and are combined to apply to point-of-departure data to allow calculation of reference concentrations. The scientific validity of these assumptions is uncertain; because each of the individual extrapolations are intended to prevent underestimation of risk, in concert they result in unquantifiable but potentially significant overestimation of risk.

A number of epidemiological studies do not sufficiently account for the effects from other cofactors and co-pollutants. For example, metals may interact either synergistically, additively or antagonistically, depending on the combination of metals and their relative amounts (CEH, 2005). These interactions may also occur for metal-organic mixtures. However, there are few controlled studies on the toxicological interaction of metals found in occupational or environmental contamination scenarios (USEPA 2004). Evaluation of interaction studies involving the suite of metals present in the KCGM monitored particulates are available only for arsenic, cadmium, chromium and lead and separately for copper, lead, manganese and zinc (ATSDR 2004a, 2004b). These reports highlight that comparisons between the published studies are problematic, with most studies that have attempted to quantify the magnitude of toxicologic interactions providing results that are equivocal at best, including an inability to demonstrate if the interactions are synergistic, additive or less than additive.

Despite the number of uncertainties, the hazard assessment has adopted the most recent scientific understanding of health effect from exposure to the COPCS, primarily from documents produced by reputable national and international organisations involved with human-health protection and as recommended by the DWER (DER, 2017 and DWER, 2019) and enHealth (2012). Reference values used have been developed with conservative assumptions which would overestimate risks and ensure protection of human-health.

5. EXPOSURE ASSESSMENT

Exposure assessment involves the estimation of the magnitude, frequency, extent and duration of individual or public exposure to emitted substances. It uses information such as pollutant source(s), exposure pathway(s) and exposed population(s)/individual(s), to generate numerical representation of exposure pathways, determine exposure point concentrations, and estimate pathway specific contaminant intakes.

5.1 Compounds Considered

The screening HRA is focussed on the same suite of metals present in KCGM's historic metals analysis. As noted in Section 3, the concentration of metals within fugitive dust emissions from KCGM's current and proposed operations are not expected to differ significantly from those measured historically, as the operations occur within the same geological bounds. The metals considered are:

- Arsenic;
- Barium;
- Cadmium;
- Chromium;
- Cobalt;
- Copper;
- Lead;
- Manganese;
- Mercury;
- Nickel;
- Silver; and
- Zinc

5.2 Receptor Locations

The locations of receptors considered in the screening HRA correspond with the locations of KCGM's ambient PM₁₀ monitoring stations. These comprise the HGC, BSY, HEW, CLY, HOP, MTC, and MEX sites (Figure 6). The HGC site is located approximately 4.8 km north-west of the FOP and is considered representative of the local environment. The MTC site is located approximately 2 km north-northwest of the FOP at KCGM's Mount Charlotte Operations. The HOP, BSY, CLY and HEW sites are located along the western boundary of KCGM's mine development envelope, among a mix of light industrial and residential properties; and the MEX site is located within a primarily residential area approximately 1 km west of the FOP.

The BSY, HEW, CLY, HOP, MTC and MEX PM₁₀ monitoring stations were located as close to the western side of the Fimiston operations as could be reasonably achieved (making use of existing infrastructure as far as possible), in order to provide monitoring data that KCGM is able to use within the DMMP component of the FAQMP. Given these sites are located in areas where peak concentrations are expected to be recorded, they are not considered compliance monitoring sites as defined in the National Environment Protection (Ambient Air Quality) Measure (NEPM), namely:

"Performance monitoring station(s) must be located in a manner such that they contribute to obtaining a representative measure of the air quality likely to be experienced by the general population in the region or sub-region." National Environment Protection (Ambient Air Quality) Measure clause 13.2.

5.3 Potential Exposure Pathways

The main transport pathway of air emissions is via atmospheric dispersion, and inhalation is expected to represent the most significant exposure route in relation to atmospheric emissions associated with the FS project. The inhalation exposure pathway therefore remains the focus of the current screening HRA, as per the previous assessment (ENVIRON 2007 and Ramboll 2020a).

5.4 Exposure Point Concentrations

Estimated ambient concentrations of the specified metals based on the maximum 1-hour³ average, maximum 24-hour average and annual average PM₁₀ concentrations measured at KCGM's monitoring sites between 2010 and 2021 (see Table 4), and the maximum metal concentrations reported from the 2006 sample analysis (see Table 3) are presented in Table 10 (1-hour averages), Table 11 (24-hour averages) and Table 12 (annual averages). To demonstrate the change in ambient PM₁₀ concentrations when FS project is operational, calculated worst-case metal concentrations for current operations (2019) and future operations (2025) are presented in Table 13 (1-hour averages), Table 14 (24-hour averages) and Table 15 (annual averages).

The concentrations of metals present in ambient particulate samples can vary depending upon a number of factors, including the source of the particulate. Application of the maximum metal concentrations present in the ambient samples is expected to result in a very conservative estimate (i.e. more likely to over- than under-estimate the potential health risks) of ambient particulate metal concentrations.

Ramboll understands that chromium concentrations reported from the 2006 sample analysis represent total chromium. The speciation of chromium is important for HRA purposes as hexavalent chromium (chromium (VI)) is considerably more toxic than the trivalent form (chromium (III)) and only chromium (VI) is considered carcinogenic to humans when inhaled (ATSDR, 2012b; WHO, 2000). Chromium is most commonly found as chromium (III) in natural environments and while there are some natural sources for chromium (VI), the majority originates from industrial activities (Department of Agriculture, Water and the Environment [DAWE], n.d.). Chromium (VI) is considered unlikely to be a component of ore dust at mining operations, although it could be a product of combustion (DWER, 2020).

The ATSDR reports that approximately one-third of the atmospheric releases of chromium are believed to be in the form of Chromium (VI) (ATSDR, 2012b). In the absence of speciation data for the chromium reported within the historical TSP samples, it has been assumed that the total chromium is present only as chromium (III). This estimate is considered reasonable as the primary sources of dust emissions from the Fimiston Operations are associated with the handling and processing of ore and waste rock material, vehicle movements on unsealed roads (wheel-generated dust) and wind erosion from exposed surfaces (see Section 2.2), rather than combustion related sources.

³ 1. Associated with winds from within KCGM's arc of influence and excluding concentrations associated with regional dust events (i.e. bushfires).

Table 10: Estimated Maximum 1-hour Average PM₁₀ Metals Concentrations (2010 – 2021).

Maximum Measured Metals Concentration in TSP Samples		Maximum Measured PM ₁₀ Concentrations (µg/m ³)						
		Maximum 1-hour Average ¹						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC
		467	184	791	1324	622	711	NA
		Estimated Maximum PM ₁₀ Metal Concentrations (µg/m ³)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.0019%	8.9E-03	3.5E-03	1.5E-02	2.5E-02	1.2E-02	1.4E-02	NA
Barium	0.2570%	1.2E+00	4.7E-01	2.0E+00	3.4E+00	1.6E+00	1.8E+00	NA
Cadmium	0.0006%	2.8E-03	1.1E-03	4.7E-03	7.9E-03	3.7E-03	4.3E-03	NA
Chromium (III)	0.0215%	1.0E-01	4.0E-02	1.7E-01	2.8E-01	1.3E-01	1.5E-01	NA
Cobalt	0.010%	4.7E-02	1.8E-02	7.9E-02	1.3E-01	6.2E-02	7.1E-02	NA
Copper	0.008%	3.7E-02	1.5E-02	6.3E-02	1.1E-01	5.0E-02	5.7E-02	NA
Lead	0.057%	2.7E-01	1.0E-01	4.5E-01	7.5E-01	3.5E-01	4.1E-01	NA
Manganese	0.041%	1.9E-01	7.5E-02	3.2E-01	5.4E-01	2.6E-01	2.9E-01	NA
Mercury	0.002%	9.3E-03	3.7E-03	1.6E-02	2.6E-02	1.2E-02	1.4E-02	NA
Nickel	0.029%	1.4E-01	5.3E-02	2.3E-01	3.8E-01	1.8E-01	2.1E-01	NA
Silver	0.001%	4.7E-03	1.8E-03	7.9E-03	1.3E-02	6.2E-03	7.1E-03	NA
Zinc	0.087%	4.1E-01	1.6E-01	6.9E-01	1.2E+00	5.4E-01	6.2E-01	NA

Notes

- Maximum recorded 1-hour average PM₁₀ concentrations associated with winds from within KCGM's arc of influence and excluding concentrations associated with regional dust events (i.e. bushfires). NA – no contribution from KCGM (KCGM has not been found to have contributed to any PM₁₀ concentrations above 50 µg/m³ between 2010 and 2021).

Table 11: Estimated Maximum 24-hour Average PM₁₀ Metals Concentrations (2010 – 2021).

Maximum Measured Metals Concentration in TSP Samples		Maximum Measured PM ₁₀ Concentrations (µg/m ³)						
		Maximum 24-hour Average ¹						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC
		NA	80	86	125	96	64	NA
		Estimated Maximum PM ₁₀ Metal Concentrations (µg/m ³)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.0019%	0.0E+00	1.5E-03	1.6E-03	2.4E-03	1.8E-03	1.2E-03	NA
Barium	0.2570%	0.0E+00	2.1E-01	2.2E-01	3.2E-01	2.5E-01	1.6E-01	NA
Cadmium	0.0006%	0.0E+00	4.8E-04	5.2E-04	7.5E-04	5.8E-04	3.8E-04	NA
Chromium (III)	0.0215%	0.0E+00	1.7E-02	1.8E-02	2.7E-02	2.1E-02	1.4E-02	NA
Cobalt	0.010%	0.0E+00	8.0E-03	8.6E-03	1.3E-02	9.6E-03	6.4E-03	NA
Copper	0.008%	0.0E+00	6.4E-03	6.9E-03	1.0E-02	7.7E-03	5.1E-03	NA
Lead	0.057%	0.0E+00	4.6E-02	4.9E-02	7.1E-02	5.5E-02	3.6E-02	NA
Manganese	0.041%	0.0E+00	3.3E-02	3.5E-02	5.1E-02	3.9E-02	2.6E-02	NA
Mercury	0.002%	0.0E+00	1.6E-03	1.7E-03	2.5E-03	1.9E-03	1.3E-03	NA
Nickel	0.029%	0.0E+00	2.3E-02	2.5E-02	3.6E-02	2.8E-02	1.9E-02	NA
Silver	0.001%	0.0E+00	8.0E-04	8.6E-04	1.3E-03	9.6E-04	6.4E-04	NA
Zinc	0.087%	0.0E+00	7.0E-02	7.5E-02	1.1E-01	8.4E-02	5.6E-02	NA

Notes

- Maximum recorded 24-hour average PM₁₀ concentrations associated with winds from within KCGM's arc of influence and excluding concentrations associated with regional dust events (i.e. bushfires). NA – no contribution from KCGM (KCGM has not been found to have contributed to any PM₁₀ concentrations above 50 µg/m³ between 2010 and 2021).

Table 12: Estimated Maximum Annual Average PM₁₀ Metals Concentrations (2010 – 2021).

Maximum Measured Metals Concentration in TSP Samples		Maximum Measured PM ₁₀ Concentrations (µg/m ³)						
		Annual Average ¹						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC
		22	26	23	23	25	20	18
		Estimated Maximum PM ₁₀ Metal Concentrations (µg/m ³)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.0019%	4.2E-04	4.9E-04	4.4E-04	4.4E-04	4.8E-04	3.8E-04	3.4E-04
Barium	0.2570%	5.7E-02	6.7E-02	5.9E-02	5.9E-02	6.4E-02	5.1E-02	4.6E-02
Cadmium	0.0006%	1.3E-04	1.6E-04	1.4E-04	1.4E-04	1.5E-04	1.2E-04	1.1E-04
Chromium (III)	0.0215%	4.7E-03	5.6E-03	4.9E-03	4.9E-03	5.4E-03	4.3E-03	3.9E-03
Cobalt	0.010%	2.2E-03	2.6E-03	2.3E-03	2.3E-03	2.5E-03	2.0E-03	1.8E-03
Copper	0.008%	1.8E-03	2.1E-03	1.8E-03	1.8E-03	2.0E-03	1.6E-03	1.4E-03
Lead	0.057%	1.3E-02	1.5E-02	1.3E-02	1.3E-02	1.4E-02	1.1E-02	1.0E-02
Manganese	0.041%	9.0E-03	1.1E-02	9.4E-03	9.4E-03	1.0E-02	8.2E-03	7.4E-03
Mercury	0.002%	4.4E-04	5.2E-04	4.6E-04	4.6E-04	5.0E-04	4.0E-04	3.6E-04
Nickel	0.029%	6.4E-03	7.5E-03	6.7E-03	6.7E-03	7.3E-03	5.8E-03	5.2E-03
Silver	0.001%	2.2E-04	2.6E-04	2.3E-04	2.3E-04	2.5E-04	2.0E-04	1.8E-04
Zinc	0.087%	1.9E-02	2.3E-02	2.0E-02	2.0E-02	2.2E-02	1.7E-02	1.6E-02

Notes

1. Highest annual average PM₁₀ concentration recorded between 2010 and 2021.

Table 13: Estimated Maximum 1-hour Average PM₁₀ Metals Concentrations for current (2019) and future (2025) operations.

Maximum Measured Metals Concentration in TSP Samples		PM ₁₀ Concentrations (µg/m³)													
		Measured Current (2019) 1-hour Maximum ¹							Estimated Future (2025) 1-hour Maximum ²						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
		739	824	960	827	810	773	725	702	824	960	827	810	773	725
		Estimated Maximum PM ₁₀ Metal Concentrations (µg/m³)													
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.0019%	1.4E-02	1.6E-02	1.8E-02	1.6E-02	1.5E-02	1.5E-02	1.4E-02	1.3E-02	1.6E-02	1.8E-02	1.6E-02	1.5E-02	1.5E-02	1.4E-02
Barium	0.2570%	1.9E+00	2.1E+00	2.5E+00	2.1E+00	2.1E+00	2.0E+00	1.9E+00	1.8E+00	2.1E+00	2.5E+00	2.1E+00	2.1E+00	2.0E+00	1.9E+00
Cadmium	0.0006%	4.4E-03	4.9E-03	5.8E-03	5.0E-03	4.9E-03	4.6E-03	4.3E-03	4.2E-03	4.9E-03	5.8E-03	5.0E-03	4.9E-03	4.6E-03	4.3E-03
Chromium (III)	0.0215%	1.6E-01	1.8E-01	2.1E-01	1.8E-01	1.7E-01	1.7E-01	1.6E-01	1.5E-01	1.8E-01	2.1E-01	1.8E-01	1.7E-01	1.7E-01	1.6E-01
Cobalt	0.010%	7.4E-02	8.2E-02	9.6E-02	8.3E-02	8.1E-02	7.7E-02	7.2E-02	7.0E-02	8.2E-02	9.6E-02	8.3E-02	8.1E-02	7.7E-02	7.2E-02
Copper	0.008%	5.9E-02	6.6E-02	7.7E-02	6.6E-02	6.5E-02	6.2E-02	5.8E-02	5.6E-02	6.6E-02	7.7E-02	6.6E-02	6.5E-02	6.2E-02	5.8E-02
Lead	0.057%	4.2E-01	4.7E-01	5.5E-01	4.7E-01	4.6E-01	4.4E-01	4.1E-01	4.0E-01	4.7E-01	5.5E-01	4.7E-01	4.6E-01	4.4E-01	4.1E-01
Manganese	0.041%	3.0E-01	3.4E-01	3.9E-01	3.4E-01	3.3E-01	3.2E-01	3.0E-01	2.9E-01	3.4E-01	3.9E-01	3.4E-01	3.3E-01	3.2E-01	3.0E-01
Mercury	0.002%	1.5E-02	1.6E-02	1.9E-02	1.7E-02	1.6E-02	1.5E-02	1.4E-02	1.4E-02	1.6E-02	1.9E-02	1.7E-02	1.6E-02	1.5E-02	1.4E-02
Nickel	0.029%	2.1E-01	2.4E-01	2.8E-01	2.4E-01	2.3E-01	2.2E-01	2.1E-01	2.0E-01	2.4E-01	2.8E-01	2.4E-01	2.3E-01	2.2E-01	2.1E-01
Silver	0.001%	7.4E-03	8.2E-03	9.6E-03	8.3E-03	8.1E-03	7.7E-03	7.2E-03	7.0E-03	8.2E-03	9.6E-03	8.3E-03	8.1E-03	7.7E-03	7.2E-03
Zinc	0.087%	6.4E-01	7.2E-01	8.4E-01	7.2E-01	7.0E-01	6.7E-01	6.3E-01	6.1E-01	7.2E-01	8.4E-01	7.2E-01	7.0E-01	6.7E-01	6.3E-01

Notes

1. Maximum recorded 1-hour average PM₁₀ concentrations associated with winds from within KCGM’s arc of influence and excluding concentrations associated with regional dust events (i.e. bushfires).
2. Maximum 1-hour average PM₁₀ concentrations estimated from air dispersion modelling and 2019 monitored data.

Table 14: Estimated Maximum 24-hour Average PM₁₀ Metals Concentrations for current (2019) and future (2025) operations.

Maximum Measured Metals Concentration in TSP Samples		PM ₁₀ Concentrations (µg/m ³)													
		Measured Current (2019) 24-hour Average ¹							Estimated Future (2025) 24-hour Average ²						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
		77	103	93	91	95	91	131	77	103	93	91	95	91	131
		Estimated Maximum PM ₁₀ Metal Concentrations (µg/m ³)													
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.0019%	1.5E-03	2.0E-03	1.8E-03	1.7E-03	1.8E-03	1.7E-03	2.5E-03	1.5E-03	2.0E-03	1.8E-03	1.7E-03	1.8E-03	1.7E-03	2.5E-03
Barium	0.2570%	2.0E-01	2.6E-01	2.4E-01	2.3E-01	2.4E-01	2.3E-01	3.4E-01	2.0E-01	2.6E-01	2.4E-01	2.3E-01	2.4E-01	2.3E-01	3.4E-01
Cadmium	0.0006%	4.6E-04	6.2E-04	5.6E-04	5.5E-04	5.7E-04	5.5E-04	7.9E-04	4.6E-04	6.2E-04	5.6E-04	5.5E-04	5.7E-04	5.5E-04	7.9E-04
Chromium (III)	0.0215%	1.6E-02	2.2E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.8E-02	1.6E-02	2.2E-02	2.0E-02	2.0E-02	2.0E-02	2.0E-02	2.8E-02
Cobalt	0.010%	7.7E-03	1.0E-02	9.3E-03	9.1E-03	9.5E-03	9.1E-03	1.3E-02	7.7E-03	1.0E-02	9.3E-03	9.1E-03	9.5E-03	9.1E-03	1.3E-02
Copper	0.008%	6.1E-03	8.2E-03	7.4E-03	7.3E-03	7.6E-03	7.3E-03	1.0E-02	6.1E-03	8.2E-03	7.4E-03	7.3E-03	7.6E-03	7.3E-03	1.0E-02
Lead	0.057%	4.4E-02	5.9E-02	5.3E-02	5.2E-02	5.4E-02	5.2E-02	7.5E-02	4.4E-02	5.9E-02	5.3E-02	5.2E-02	5.4E-02	5.2E-02	7.5E-02
Manganese	0.041%	3.1E-02	4.2E-02	3.8E-02	3.7E-02	3.9E-02	3.7E-02	5.4E-02	3.1E-02	4.2E-02	3.8E-02	3.7E-02	3.9E-02	3.7E-02	5.4E-02
Mercury	0.002%	1.5E-03	2.1E-03	1.9E-03	1.8E-03	1.9E-03	1.8E-03	2.6E-03	1.5E-03	2.1E-03	1.9E-03	1.8E-03	1.9E-03	1.8E-03	2.6E-03
Nickel	0.029%	2.2E-02	3.0E-02	2.7E-02	2.6E-02	2.8E-02	2.6E-02	3.8E-02	2.2E-02	3.0E-02	2.7E-02	2.6E-02	2.8E-02	2.6E-02	3.8E-02
Silver	0.001%	7.7E-04	1.0E-03	9.3E-04	9.1E-04	9.5E-04	9.1E-04	1.3E-03	7.7E-04	1.0E-03	9.3E-04	9.1E-04	9.5E-04	9.1E-04	1.3E-03
Zinc	0.087%	6.7E-02	9.0E-02	8.1E-02	7.9E-02	8.3E-02	7.9E-02	1.1E-01	6.7E-02	9.0E-02	8.1E-02	7.9E-02	8.3E-02	7.9E-02	1.1E-01

Notes

- Maximum recorded 24-hour average PM₁₀ concentrations associated with winds from within KCGM's arc of influence and excluding concentrations associated with regional dust events (i.e. bushfires).
- Maximum 24-hour average PM₁₀ concentrations estimated from air dispersion modelling and 2019 monitored data.

Table 15: Estimated Maximum Annual Average PM₁₀ Metals Concentrations for current (2019) and future (2025) operations.

Maximum Measured Metals Concentration in TSP Samples		PM ₁₀ Concentrations (µg/m ³)													
		Measured Current (2019) Annual Average ¹							Estimated Future (2025) Annual Average ²						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
		14	19	23	23	25	20	18	14	19	23	23	26	20	18
		Estimated Maximum PM ₁₀ Metal Concentrations (µg/m ³)													
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.0019%	2.7E-04	3.5E-04	4.4E-04	4.4E-04	4.7E-04	3.8E-04	3.4E-04	2.7E-04	3.6E-04	4.4E-04	4.4E-04	5.0E-04	3.9E-04	3.4E-04
Barium	0.2570%	3.6E-02	4.8E-02	6.0E-02	5.9E-02	6.4E-02	5.2E-02	4.6E-02	3.6E-02	4.9E-02	6.0E-02	5.9E-02	6.8E-02	5.3E-02	4.6E-02
Cadmium	0.0006%	8.4E-05	1.1E-04	1.4E-04	1.4E-04	1.5E-04	1.2E-04	1.1E-04	8.4E-05	1.1E-04	1.4E-04	1.4E-04	1.6E-04	1.2E-04	1.1E-04
Chromium (III)	0.0215%	3.0E-03	4.0E-03	5.0E-03	4.9E-03	5.4E-03	4.4E-03	3.8E-03	3.0E-03	4.1E-03	5.0E-03	5.0E-03	5.7E-03	4.4E-03	3.8E-03
Cobalt	0.010%	1.4E-03	1.9E-03	2.3E-03	2.3E-03	2.5E-03	2.0E-03	1.8E-03	1.4E-03	1.9E-03	2.3E-03	2.3E-03	2.6E-03	2.0E-03	1.8E-03
Copper	0.008%	1.1E-03	1.5E-03	1.9E-03	1.8E-03	2.0E-03	1.6E-03	1.4E-03	1.1E-03	1.5E-03	1.9E-03	1.8E-03	2.1E-03	1.6E-03	1.4E-03
Lead	0.057%	8.0E-03	1.1E-02	1.3E-02	1.3E-02	1.4E-02	1.2E-02	1.0E-02	8.0E-03	1.1E-02	1.3E-02	1.3E-02	1.5E-02	1.2E-02	1.0E-02
Manganese	0.041%	5.8E-03	7.6E-03	9.6E-03	9.4E-03	1.0E-02	8.3E-03	7.3E-03	5.8E-03	7.8E-03	9.5E-03	9.5E-03	1.1E-02	8.4E-03	7.3E-03
Mercury	0.002%	2.8E-04	3.7E-04	4.7E-04	4.6E-04	5.0E-04	4.0E-04	3.6E-04	2.8E-04	3.8E-04	4.6E-04	4.6E-04	5.3E-04	4.1E-04	3.6E-04
Nickel	0.029%	4.1E-03	5.4E-03	6.8E-03	6.7E-03	7.2E-03	5.9E-03	5.2E-03	4.1E-03	5.5E-03	6.7E-03	6.7E-03	7.7E-03	5.9E-03	5.2E-03
Silver	0.001%	1.4E-04	1.9E-04	2.3E-04	2.3E-04	2.5E-04	2.0E-04	1.8E-04	1.4E-04	1.9E-04	2.3E-04	2.3E-04	2.6E-04	2.0E-04	1.8E-04
Zinc	0.087%	1.2E-02	1.6E-02	2.0E-02	2.0E-02	2.2E-02	1.8E-02	1.6E-02	1.2E-02	1.6E-02	2.0E-02	2.0E-02	2.3E-02	1.8E-02	1.6E-02

- Notes
- Maximum recorded annual average PM₁₀ concentrations associated with winds from within KCGM’s arc of influence and excluding concentrations associated with regional dust events (i.e. bushfires).
 - Maximum annual average PM₁₀ concentrations estimated from air dispersion modelling and 2019 monitored data.

5.5 Bioavailability of Particulate Metals

The uptake, distribution and absorption of inhaled metals present as particles in dust are primarily a function of particle size, the metal species and solubility. The size of particulate matter is one of the key determinants for identifying the region of the respiratory tract where a particle deposits (USEPA, 2007). In turn, the site of deposition governs absorption following inhalation exposure.

In general, particles 1 µm and smaller reach the alveoli, with larger particles (5 µm and larger) being removed from the nasopharyngeal region by sneezing or blowing, or from the tracheobronchi (1-5 µm) by mucociliary clearance. Once in the lower airways (i.e. bronchiolar and alveolar regions), particles are cleared by phagocytosis, or absorbed into the bloodstream or the lymphatic system (Witschi & Last, 1996). No data indicates that absorption of particulates occurs in the upper airways. From an analysis of human experimental data, the USEPA (1994) concluded that for inhalation that occurs via both the nose and mouth (such as may occur in healthy exercising adults), particles up to approximately 3.5 µm can deposit in alveolar regions, in amounts that can reach approximately 60% of an exposure concentration.

The ATSDR interpreted the USEPA (1994) analysis to be applicable to most respirable particles, including metal particulates, concluding that 30% to 60% of respirable particles are deposited onto the lung surface (i.e. lower airway) (e.g. ATSDR, 2007). Although some portion of the particles may be removed from the lower airway via phagocytosis, estimates of the efficiency of this removal mechanism are not available. These data indicate that in the absence of compound-specific information, it is reasonable to assume that the deposition fraction represents the percentage of particulate available for absorption. Although availability does not necessarily imply that absorption will occur, or that absorption will be complete, the fraction available likely represents a plausible upper bound on the amount that may actually be absorbed from the lower airways into the body. The applicable conservatism of this HRA due to uncertainty associated with bioavailability of particulate metals is discussed in Section 5.6.1.

As part of KCGM's 2005 series of investigations to determine the typical concentrations of a suite of elements in the surface soils present in Kalgoorlie and its surrounds, Kalgoorlie residential soil samples were tested for the bioavailability of metals by the Centre for Environmental Health (CEH). The results of this investigation are presented in Table 16.

Table 16: Kalgoorlie Residential Bioavailability Summary Data

Element	Bioavailability (mg/kg) ¹					% of Total Metal
	Mean	Standard Deviation	Median	Minimum	Maximum	
Arsenic	2.1	1.4	1.5	0.8	4.4	9.9%
Boron	7.7	3.5	8.5	2.4	12	40%
Cadmium	0.2	0.2	0.1	0.0	0.5	-
Chromium	4.0	1.6	4.0	1.9	6.7	1.2%
Copper	19	11	15	7.0	33	41%
Iron	1,243	462	1,300	620	1,800	-
Lead	82	112	32	3.4	310	73%
Manganese	189	70	185	75	310	58%
Nickel	7.4	2.5	7.2	4.1	12	15%
Sulphur	166	176	136	18	560	-
Zinc	181	184	124	30	560	64%

Notes:

1. Source Centre for Environmental Health (CEH) (2005).
2. All mercury and selenium values were below the limit of detection of 0.05 mg/kg.
3. For all values, below the respective limits of detection, the upper bound detection limit has been adopted as a conservative approach.

The data presented in Table 16 indicates that the bioavailability of the metals in residential soil samples varies widely from around 1.2% for chromium up to around 73% for lead.

5.6 Uncertainties in Exposure Assessment

For the purposes of the screening HRA, it has been assumed that residences are located at the receptor locations and that they spend every hour of every day outdoors at that location for 70 years. These exposure conditions are unlikely to be realised, with the actual exposure concentration resulting from emissions associated with the Fimiston Operations typically expected to be lower in the indoor environment than that experienced in the ambient environment, and the exposure frequency (i.e. days per year) and exposure duration (years) likely to be considerably lower as people move about. In addition, the MEX and HGC sites are the only DMMP monitoring sites located in residential areas, with the other sites located in area of light industry (and MTC being located within KCGM's site boundary).

The use of historic ambient PM₁₀ monitoring data and metals analysis data represent a source of uncertainty in the exposure assessment. It has been assumed the fugitive dust impacts associated with the proposed FS Project will be similar to those of previous operations, as captured within the monitoring data. The maximum 24-hour and annual average PM₁₀ concentrations recorded at each monitoring location between 2010 and 2021 have conservatively been selected to calculate screening level quantitative health risk indicators (capturing seasonal and long-term variations).

The application of historic metals analysis data to more recent PM₁₀ monitoring data assumes the composition of ambient particulate matter has remained unchanged. The concentrations of metals in ambient particulate samples can vary depending upon a number of factors including the source of the particulate. Ramboll understands the FS Project is an extension of previously mined ore bodies and as such, the composition of fugitive particulates generated from the handling of this material is expected to be similar as was reported in 2005. As per the previous screening HRA, the maximum metal concentrations present in the ambient samples analysed have been used for

this study. These values are generally within the range of metals present in Kalgoorlie soils based on testing by the CEH (2005).

Inherent uncertainties are also associated with monitoring technologies. These are in-part mitigated in part by KCGM's utilisation of Beta Attenuation Monitors (BAMs), certified to US EPA Federal Equivalence Methods (FEM) and the implementation of an independent calibration and servicing regime.

The HRA has been confined to exposure via the inhalation pathway. There is therefore a potential that total exposure to specific compounds has been underestimated. Exposure to compounds can occur via direct and indirect exposures, defined as follows:

- Direct exposure: when exposure to a chemical occurs in the media in which it is released from the source. For an atmospheric emission source direct exposure occurs via inhalation.
- Indirect exposure: when exposure to a chemical occurs after it has crossed into a different media. For an atmospheric emission source indirect exposure may occur, for example, as a result of deposition of the chemicals onto soils from which home grown vegetables are consumed.

In most circumstances direct exposure (i.e. inhalation) is expected to represent the most significant exposure route for atmospheric emission sources. However exceptions do occur, most notably if the chemicals tend to bioaccumulate, or are particularly persistent and hence do not break-down readily in the environment. Particulate compounds are likely candidates for multi-pathway exposure as they will tend to deposit on to the surfaces (e.g. soil and crops) and be available for ingestion.

5.6.1 Uncertainties in Bioavailability Assumptions

As noted in Section 5.5, the ambient air concentration or inhaled dose of a particulate metal does not necessarily equate to the fraction of absorption that will occur for that particular metal. In this brief review of the likely bioavailability of selected metal species for which information is readily available, inhaled dose refers to the total particulate concentration in ambient air. The alveolar deposition fraction refers to the percentage of an inhaled dose that is available for absorption.

For arsenic, data from occupational studies have documented that 30% to 60% of an inhaled dose of arsenic particulate is excreted in urine, the principal route of elimination. Since the deposition fraction is also 30% to 60%, this indicates that while virtually all of the deposited arsenic is absorbed, the remaining portion of an inhaled dose is not biologically available. This is consistent with the USEPA (1994), and indicates that a significant portion of inhaled arsenic particulate may not reach the lower airways.

From a comprehensive review of available data, the ATSDR (2005) concluded that subsequent to inhalation exposure, approximately 20% to 30% of the retained nickel particulate is absorbed. Because only a fraction of inhaled nickel particulate is deposited to the lower airways, where it is subject to retention (USEPA, 1994), it suggests that when expressed as a percentage of inhaled dose, the amount absorbed is markedly lower than the fraction cited by the ATSDR. However, given uncertainties with respect to the nickel species and solubility, use of the ATSDR data likely represents a health-conservative estimate of the bioavailability of inhaled nickel particulate.

There are no data from human studies that have characterised airway deposition, retention, or net absorption of cadmium following inhalation exposure to cadmium particulate. ATSDR's review of animal data (ATSDR, 2012a) show that retention of cadmium ranges from 5% to 20% following

exposures of 15 minutes to 2 hours, and decreases with increasing exposure duration. A physiologically-based pharmacokinetic (PBPK) model of inhaled cadmium (Nordberg *et al.*, 1985 as cited in ATSDR, 2012a) indicates that between 50% and 100% of inhaled cadmium deposited (retained) in the alveoli will be absorbed. Integrating the PBPK analysis with that of the USEPA (1994), suggests that 15% to 60% of inhaled particulate cadmium is available for absorption.

The absorption of selenium following inhalation exposure is the least well documented of the six metals in question. There are no direct or quantitative human data on the extent or rate of absorption of inhaled selenium particulate. Qualitative human data establish that airborne selenium particulate is absorbed by inhalation, and that the quantity eliminated in urine increases with increasing exposure concentration (ATSDR, 2003). Similarly, there are no quantitative or specific data on the absorption of manganese particulate by humans exposed by inhalation (ATSDR, 2012c). Experimental animal data have confirmed that particle size is one of the most significant variables that affect manganese uptake, deposition, and retention, with smaller particles (1.3 µm) resulting in higher lung burdens than large (18 µm) particles (Fetcher *et al.* 2002). In the absence of specific data on selenium and manganese, the general conclusions of the USEPA (1994) can be used to support an estimate that 30% to 60% of inhaled selenium or magnesium may be available for absorption.

Mercury represents a unique case, in that elemental (i.e. metallic) mercury volatilises at standard temperature and pressure. Mercury vapour partitions readily across membranes and is rapidly and extensively absorbed from the alveoli into the circulatory system (ATSDR, 1999). Analyses of blood, plasma, and urine in humans exposed by inhalation provide an estimate of absorption that ranges between 69% and 80% (ATSDR, 1999; Hursch *et al.*, 1976; Sandborgh-Englund *et al.*, 1998).

The range of realistic inhalation absorption values for arsenic, nickel, cadmium, selenium, manganese and mercury are summarised in Table 17.

Table 17: Absorption of Metals After Inhalation Exposure

Element	Absorption ¹	Primary Sources
Arsenic	30% to 60%	ATSDR (2007); USEPA (1994)
Nickel	25% to 35%	ATSDR (2005); USEPA (1994)
Cadmium	15% to 60%	ATSDR (2012a); Nordberg <i>et al.</i> (1985); USEPA (1994)
Selenium	30% to 60%	ATSDR (2003); USEPA (1994)
Manganese	30% to 60%	ATSDR (2012c); USEPA (1994)
Mercury	69% to 80%	ATSDR (1999); Hursch <i>et al.</i> (1976); Sandborgh-Englund <i>et al.</i> (1998).

Notes:

1. Expressed as a percentage of total particulate concentration in ambient air.

6. RISK CHARACTERISATION

Screening level quantitative health risk indicators have been calculated for potential acute and chronic non-carcinogenic health effects, and carcinogenic health effects based on the PM₁₀ concentrations measured at the monitoring locations utilised within KCGM's DMMP.

6.1 Quantitative Risk Indicators

The Hazard Index (HI) is calculated to evaluate the potential for non-carcinogenic adverse health effects from simultaneous exposure to multiple compounds by summing the ratio of the estimated concentration in air to the health protective guidelines for individual compounds. The HI is calculated for acute (Equation 1) and chronic (Equation 2) exposures.

Equation 1

$$HI_{Acute} = \sum^i \frac{C_{\leq 24h}}{Gdl_{Acute}}$$

Equation 2

$$HI_{Chronic} = \sum^i \frac{C_{Annual}}{Gdl_{Chronic}}$$

Where:

HI_{Acute}	= Acute Hazard Index
$C_{\leq 24h}$	= Ground level concentration over an averaging period of typically ≤ 24 hours, matching the averaging time of the health protective guideline for compound ($\mu\text{g}/\text{m}^3$)
Gdl_{Acute}	= Acute health protective guideline for compound ($\mu\text{g}/\text{m}^3$)
$HI_{Chronic}$	= Chronic Hazard Index
C_{Annual}	= Annual average ground level concentration predicted for compound ($\mu\text{g}/\text{m}^3$)
$Gdl_{Chronic}$	= Chronic health protective guideline for compound ($\mu\text{g}/\text{m}^3$)

A general rule of thumb for interpreting the HI (enHealth, 2012; NSW EPA 2022) is that:

- values less than one represent no cause for concern;
- values greater than one but less than 10 generally do not represent cause for concern because of the inherent conservatism embedded in the exposure and toxicity assessments; and
- values greater than 10 may present some concern with respect to possible health effects and further investigation is warranted.

The carcinogenic risk provides an indication of the incremental probability that an individual will develop cancer over a lifetime as a direct result of exposure to potential carcinogens, and is expressed as a unitless probability. The incremental carcinogenic risk (ICR) for individual compounds is summed to calculate the potential total ICR from exposure to multiple compounds (Equation 3).

Equation 3

$$Risk = \sum^i C_{i Annual} \times \frac{EF \times ED}{AT} \times UR_i = \sum^i C_{i Annual} \times UR$$

Where:

<i>Risk</i>	= Lifetime incremental total cancer risk
C_{Annual}	= Annual average ground level concentration for compound ($\mu\text{g}/\text{m}^3$)
<i>EF</i>	= Exposure frequency (365 days/year)
<i>ED</i>	= Exposure duration (70 years)
<i>AT</i>	= Averaging time (365 days/year x 70 years, or 25,550 days)
UR_i	= Unit Risk factor for compound (per $\mu\text{g}/\text{m}^3$)

The enHealth (2012) guidelines consider a target risk level of one in 100,000 ($1\text{E}-05$) to be generally acceptable, in line with the *National Environment Protection (Assessment of Site Contamination) Measure 1999*.

6.2 Acute Non-Carcinogenic Effects

Acute non-carcinogenic HIs have been calculated based on the maximum 1-hour average PM_{10} concentrations associated with winds from within KCGM's arc of influence and excluding regional dust events (i.e. bushfires), as measured across the DMMP monitoring network between 2010 and 2021 (refer to Section 2.5). The estimated concentrations of metals within the maximum PM_{10} concentrations have been determined using historical metal analysis data (refer to Section 5.4). A summary of the calculated acute HIs is presented in Table 18.

Table 18: Summary of Acute HIs Calculated using 1-hour Average Concentrations (2010 – 2021).

Metal	Receptor Locations						
	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	9.9E-02	3.9E-02	1.7E-01	2.8E-01	1.3E-01	1.5E-01	NA
Barium	1.3E-01	5.3E-02	2.3E-01	3.8E-01	1.8E-01	2.0E-01	NA
Cadmium	1.6E-01	6.1E-02	2.6E-01	4.4E-01	2.1E-01	2.4E-01	NA
Chromium (III)	1.1E-02	4.4E-03	1.9E-02	3.2E-02	1.5E-02	1.7E-02	NA
Copper	2.1E-03	8.2E-04	3.5E-03	5.9E-03	2.8E-03	3.2E-03	NA
Manganese	1.1E-02	4.2E-03	1.8E-02	3.0E-02	1.4E-02	1.6E-02	NA
Mercury	5.2E-03	2.0E-03	8.8E-03	1.5E-02	6.9E-03	7.9E-03	NA
Nickel	7.5E-01	3.0E-01	1.3E+00	2.1E+00	1.0E+00	1.1E+00	NA
Silver	2.6E-02	1.0E-02	4.4E-02	7.4E-02	3.5E-02	4.0E-02	NA
Total HI	1.2	0.5	2.0	3.4	1.6	1.8	NA

Note:

NA - no contribution from KCGM (KCGM has not been found to have contributed to any PM_{10} concentrations above $50 \mu\text{g}/\text{m}^3$ between 2010 and 2021).

The acute HIs calculated for the nominated receptors range between 1.2 at the HGC site, to a maximum of 3.4 at the CLY site (Table 18). The metal that contributes the greatest proportion to the acute HIs is nickel (62%). As per the enHealth (2012) guidance, values greater than one but less than 10 generally do not represent cause for concern because of the inherent conservatism embedded in the exposure and toxicity assessments.

The calculation of the HIs presented in Table 18 conservatively assumes 100% bioavailability of the maximum recorded metal concentrations. However, the assessment of metals within Kalgoorlie residential soil samples indicates the bioavailability of most metals to be much lower; the bioavailability of nickel and chromium for example, was 1.2% and 15% respectively (see Table 16). Application of the bioavailability factors presented in Table 16 to the calculated HIs reduces these values below one for all receptor locations, except CLY (Table 19). The calculated HI at CLY marginally exceeds HI of one and is below one for nickel when 24-hour average values are considered (Table 20). This shows that higher concentrations do not persist for long and therefore any potential exposures are short and not of concern.

Table 19: Summary of Acute HIs (with bioavailability factors applied) Calculated using 1-hour Average Concentrations (2010 – 2021).

Metal	Receptor Locations						
	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic ¹	9.8E-03	3.8E-03	1.7E-02	2.8E-02	1.3E-02	1.5E-02	NA
Barium	1.3E-01	5.3E-02	2.3E-01	3.8E-01	1.8E-01	2.0E-01	NA
Cadmium	1.6E-01	6.1E-02	2.6E-01	4.4E-01	2.1E-01	2.4E-01	NA
Chromium (III) ¹	1.3E-04	5.3E-05	2.3E-04	3.8E-04	1.8E-04	2.0E-04	NA
Copper ¹	8.5E-04	3.4E-04	1.4E-03	2.4E-03	1.1E-03	1.3E-03	NA
Manganese ¹	6.2E-03	2.4E-03	1.0E-02	1.7E-02	8.2E-03	9.4E-03	NA
Mercury	5.2E-03	2.0E-03	8.8E-03	1.5E-02	6.9E-03	7.9E-03	NA
Nickel ¹	1.1E-01	4.4E-02	1.9E-01	3.2E-01	1.5E-01	1.7E-01	NA
Silver	2.6E-02	1.0E-02	4.4E-02	7.4E-02	3.5E-02	4.0E-02	NA
Total HI	0.4	0.2	0.8	1.3	0.6	0.7	NA

Notes

1. Bioavailability factor applied.
2. NA - no contribution from KCGM (KCGM has not been found to have contributed to any PM₁₀ concentrations above 50 µg/m³ between 2010 and 2021).

Table 20: Summary of Acute HIs Calculated using 24-hour Average Concentrations (2010 – 2021).

Metal	Receptor Locations						
	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Nickel ¹	NA	1.7E-01	1.8E-01	2.6E-01	2.0E-01	1.3E-01	NA
Total HI	NA	0.2	0.2	0.3	0.2	0.1	NA

Note:

NA - no contribution from KCGM (KCGM has not been found to have contributed to any PM₁₀ concentrations above 50 µg/m³ between 2010 and 2021).

1. Used 24-hour guideline value available from DoH/Duffus (2009)

Similarly, acute non-carcinogenic HIs have been calculated for the worst-case current operations (2019) and worst-case future operations (2025) using 1-hour maximum averages. The acute HIs assuming 100% bioavailability are shown in Table 21 and bioavailability adjusted HIs are shown in Table 22. No material change in acute HIs have been noted from current to future operations, with bioavailability adjusted HI values below one for all receptor locations under both scenarios. HI values calculated for nickel from 24-hour maximum average data are also all below one (Table 23), for all receptor locations under both scenarios. It also suggests that any high PM₁₀

concentrations are short-lived and dispersed within 24 hours. Therefore, no change in acute exposure risks is expected when FS project is operational, and acute exposure risks are expected to remain low and acceptable.

Table 21: Summary of Acute HIs for Current (2019) and Future (2025) Operations, Calculated using 1-hour Average Concentrations.

Metal	Acute Guideline (µg/m³)	Current Operation (2019)							Future Operations (2025)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.09	1.6E-01	1.7E-01	2.0E-01	1.7E-01	1.7E-01	1.6E-01	1.5E-01	1.5E-01	1.7E-01	2.0E-01	1.7E-01	1.7E-01	1.6E-01	1.5E-01
Barium	9.0	2.1E-01	2.4E-01	2.7E-01	2.4E-01	2.3E-01	2.2E-01	2.1E-01	2.0E-01	2.4E-01	2.7E-01	2.4E-01	2.3E-01	2.2E-01	2.1E-01
Cadmium	0.018	2.5E-01	2.7E-01	3.2E-01	2.8E-01	2.7E-01	2.6E-01	2.4E-01	2.3E-01	2.7E-01	3.2E-01	2.8E-01	2.7E-01	2.6E-01	2.4E-01
Chromium (III)	9.0	1.8E-02	2.0E-02	2.3E-02	2.0E-02	1.9E-02	1.8E-02	1.7E-02	1.7E-02	2.0E-02	2.3E-02	2.0E-02	1.9E-02	1.8E-02	1.7E-02
Copper	18	3.3E-03	3.7E-03	4.3E-03	3.7E-03	3.6E-03	3.4E-03	3.2E-03	3.1E-03	3.7E-03	4.3E-03	3.7E-03	3.6E-03	3.4E-03	3.2E-03
Manganese	18	1.7E-02	1.9E-02	2.2E-02	1.9E-02	1.8E-02	1.8E-02	1.7E-02	1.6E-02	1.9E-02	2.2E-02	1.9E-02	1.8E-02	1.8E-02	1.7E-02
Mercury	1.8	8.2E-03	9.2E-03	1.1E-02	9.2E-03	9.0E-03	8.6E-03	8.1E-03	7.8E-03	9.2E-03	1.1E-02	9.2E-03	9.0E-03	8.6E-03	8.1E-03
Nickel	0.18	1.2E+00	1.3E+00	1.5E+00	1.3E+00	1.3E+00	1.2E+00	1.2E+00	1.1E+00	1.3E+00	1.5E+00	1.3E+00	1.3E+00	1.2E+00	1.2E+00
Silver	0.18	4.1E-02	4.6E-02	5.3E-02	4.6E-02	4.5E-02	4.3E-02	4.0E-02	3.9E-02	4.6E-02	5.3E-02	4.6E-02	4.5E-02	4.3E-02	4.0E-02
Total HI		2	2	2	2	2	2	2	2	2	2	2	2	2	2

Table 22: Summary of Acute HIs (with bioavailability factors applied) for Current (2019) and Future (2025) Operations, Calculated using 1-hour Average Concentrations.

Metal	Bioavailability (%)	Current Operation (2019)							Future Operations (2025)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic ¹	9.9%	1.5E-02	1.7E-02	2.0E-02	1.7E-02	1.7E-02	1.6E-02	1.5E-02	1.5E-02	1.7E-02	2.0E-02	1.7E-02	1.7E-02	1.6E-02	1.5E-02
Barium	100.0%	2.1E-01	2.4E-01	2.7E-01	2.4E-01	2.3E-01	2.2E-01	2.1E-01	2.0E-01	2.4E-01	2.7E-01	2.4E-01	2.3E-01	2.2E-01	2.1E-01
Cadmium	100.0%	2.5E-01	2.7E-01	3.2E-01	2.8E-01	2.7E-01	2.6E-01	2.4E-01	2.3E-01	2.7E-01	3.2E-01	2.8E-01	2.7E-01	2.6E-01	2.4E-01
Chromium (III) ¹	1.2%	2.1E-04	2.4E-04	2.8E-04	2.4E-04	2.3E-04	2.2E-04	2.1E-04	2.0E-04	2.4E-04	2.8E-04	2.4E-04	2.3E-04	2.2E-04	2.1E-04
Copper ¹	41.0%	1.3E-03	1.5E-03	1.7E-03	1.5E-03	1.5E-03	1.4E-03	1.3E-03	1.3E-03	1.5E-03	1.7E-03	1.5E-03	1.5E-03	1.4E-03	1.3E-03
Manganese ¹	58.0%	9.8E-03	1.1E-02	1.3E-02	1.1E-02	1.1E-02	1.0E-02	9.6E-03	9.3E-03	1.1E-02	1.3E-02	1.1E-02	1.1E-02	1.0E-02	9.6E-03
Mercury	100.0%	8.2E-03	9.2E-03	1.1E-02	9.2E-03	9.0E-03	8.6E-03	8.1E-03	7.8E-03	9.2E-03	1.1E-02	9.2E-03	9.0E-03	8.6E-03	8.1E-03
Nickel ¹	15.0%	1.8E-01	2.0E-01	2.3E-01	2.0E-01	2.0E-01	1.9E-01	1.8E-01	1.7E-01	2.0E-01	2.3E-01	2.0E-01	2.0E-01	1.9E-01	1.8E-01
Silver	100.0%	4.1E-02	4.6E-02	5.3E-02	4.6E-02	4.5E-02	4.3E-02	4.0E-02	3.9E-02	4.6E-02	5.3E-02	4.6E-02	4.5E-02	4.3E-02	4.0E-02
Total HI		0.7	0.8	0.9	0.8	0.8	0.7	0.7	0.7	0.8	0.9	0.8	0.8	0.7	0.7

Notes

- Bioavailability factor applied.

Table 23: Summary of Acute HIs for Current (2019) and Future (2025) Operations, Calculated using 24-hour Average Concentrations.

Metal	Acute Guideline (µg/m³)	Current Operation (2019)							Future Operations (2025)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Nickel ¹	0.14	1.6E-01	2.1E-01	1.9E-01	1.9E-01	2.0E-01	1.9E-01	2.7E-01	1.6E-01	2.1E-01	1.9E-01	1.9E-01	2.0E-01	1.9E-01	2.7E-01
Total HI		0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3

Note:

- Used 24-hour guideline value available from DoH/Duffus (2009)

6.3 Chronic Non-Carcinogenic Effects

Chronic non-carcinogenic HIs have been calculated based on the highest annual average PM₁₀ concentrations measured at each of the DMMP monitoring sites between 2010 and 2021 (refer to Section 2.5). The estimated concentrations of metals within the annual average PM₁₀ concentrations have been determined using historical metal analysis data (refer to Section 5.4). A summary of the calculated chronic HIs is presented in Table 24.

Table 24: Summary of Chronic HIs calculated using Annual Average concentrations (2010 – 2021).

Metal	Receptor Locations						
	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	2.8E-02	3.3E-02	2.9E-02	2.9E-02	3.2E-02	2.5E-02	2.3E-02
Barium	5.7E-02	6.7E-02	5.9E-02	5.9E-02	6.4E-02	5.1E-02	4.6E-02
Cadmium	2.6E-02	3.1E-02	2.8E-02	2.8E-02	3.0E-02	2.4E-02	2.2E-02
Chromium (III)	4.7E-02	5.6E-02	4.9E-02	4.9E-02	5.4E-02	4.3E-02	3.9E-02
Cobalt	2.2E-02	2.6E-02	2.3E-02	2.3E-02	2.5E-02	2.0E-02	1.8E-02
Copper	1.8E-03	2.1E-03	1.8E-03	1.8E-03	2.0E-03	1.6E-03	1.4E-03
Lead	2.5E-02	3.0E-02	2.6E-02	2.6E-02	2.9E-02	2.3E-02	2.1E-02
Manganese	6.0E-02	7.1E-02	6.3E-02	6.3E-02	6.8E-02	5.5E-02	4.9E-02
Mercury	1.5E-02	1.7E-02	1.5E-02	1.5E-02	1.7E-02	1.3E-02	1.2E-02
Nickel	2.1E+00	2.5E+00	2.2E+00	2.2E+00	2.4E+00	1.9E+00	1.7E+00
Zinc	4.2E-04	4.9E-04	4.4E-04	4.4E-04	4.7E-04	3.8E-04	3.4E-04
Total HI	2.4	2.8	2.5	2.5	2.7	2.2	2.0

The chronic HIs calculated for the nominated receptors range between 2.0 at the HGC site, to a maximum of 2.8 at the BSY site (Table 24). The metal that contributes the greatest proportion to the chronic HIs at BSY is nickel (90%). As per the enHealth (2012) guidance, values greater than one but less than 10 generally do not represent cause for concern because of the inherent conservatism embedded in the exposure and toxicity assessments. It should also be noted that long-term metal concentrations in PM₁₀ particles were calculated using maximum concentrations from all sources measured previously (Table 3). Average concentrations are more representative of long-term exposures and average concentrations of nickel is about 3 to 6 times lower than maximum concentrations (Table 3). Therefore, if average concentrations were adopted, calculated chronic HI would have been <1. Application of the bioavailability factors presented in Section 5.5 to the calculated HIs further reduces the HI to below one.

Table 25: Summary of Chronic HIs (with bioavailability factors applied) Calculated using Annual Average Concentrations (2010 – 2021).

Metal	Receptor Locations						
	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	2.8E-03	3.3E-03	2.9E-03	2.9E-03	3.1E-03	2.5E-03	2.3E-03
Barium	5.7E-02	6.7E-02	5.9E-02	5.9E-02	6.4E-02	5.1E-02	4.6E-02
Cadmium	2.6E-02	3.1E-02	2.8E-02	2.8E-02	3.0E-02	2.4E-02	2.2E-02
Chromium (III)	5.7E-04	6.7E-04	5.9E-04	5.9E-04	6.5E-04	5.2E-04	4.6E-04
Copper	7.2E-04	8.5E-04	7.5E-04	7.5E-04	8.2E-04	6.6E-04	5.9E-04
Lead	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Manganese	3.5E-02	4.1E-02	3.6E-02	3.6E-02	4.0E-02	3.2E-02	2.9E-02
Mercury	1.5E-02	1.7E-02	1.5E-02	1.5E-02	1.7E-02	1.3E-02	1.2E-02
Nickel	3.2E-01	3.8E-01	3.3E-01	3.3E-01	3.6E-01	2.9E-01	2.6E-01
Zinc	2.7E-04	3.1E-04	2.8E-04	2.8E-04	3.0E-04	2.4E-04	2.2E-04
Total HI	0.5	0.5	0.5	0.5	0.5	0.4	0.4

Chronic non-carcinogenic HIs was also calculated for the worst-case current operations (2019) and worst-case future operations (2025) using annual average maximums (Table 26). No material change in chronic HIs have been noted from current to future operations, with bioavailability adjusted HI values (Table 27) below one for all receptor locations under both scenarios. Therefore, no change in chronic (long-term) exposure risks is expected when FS project is operational, and chronic exposure risks are expected to remain low and acceptable.

Table 26: Summary of Chronic HIs for Current (2019) and Future (2025) Operations, Calculated using Annual Average concentrations.

Metal	Chronic Guideline (µg/m³)	Current Operation (2019)							Future Operations (2025)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	0.003	9.9E-02	1.3E-01	1.6E-01	1.6E-01	1.8E-01	1.4E-01	1.3E-01	9.9E-02	1.3E-01	1.6E-01	1.6E-01	1.9E-01	1.4E-01	1.3E-01
Barium	1.0	3.6E-02	4.8E-02	6.0E-02	5.9E-02	6.4E-02	5.2E-02	4.6E-02	3.6E-02	4.9E-02	6.0E-02	5.9E-02	6.8E-02	5.3E-02	4.6E-02
Cadmium	0.005	1.7E-02	2.2E-02	2.8E-02	2.8E-02	3.0E-02	2.4E-02	2.1E-02	1.7E-02	2.3E-02	2.8E-02	2.8E-02	3.2E-02	2.5E-02	2.1E-02
Chromium (III)	0.10	3.0E-02	4.0E-02	5.0E-02	4.9E-02	5.4E-02	4.4E-02	3.8E-02	3.0E-02	4.1E-02	5.0E-02	5.0E-02	5.7E-02	4.4E-02	3.8E-02
Cobalt	0.10	1.4E-02	1.9E-02	2.3E-02	2.3E-02	2.5E-02	2.0E-02	1.8E-02	1.4E-02	1.9E-02	2.3E-02	2.3E-02	2.6E-02	2.0E-02	1.8E-02
Copper	1.0	1.1E-03	1.5E-03	1.9E-03	1.8E-03	2.0E-03	1.6E-03	1.4E-03	1.1E-03	1.5E-03	1.9E-03	1.8E-03	2.1E-03	1.6E-03	1.4E-03
Lead	0.5	1.6E-02	2.1E-02	2.7E-02	2.6E-02	2.8E-02	2.3E-02	2.0E-02	1.6E-02	2.2E-02	2.6E-02	2.6E-02	3.0E-02	2.3E-02	2.0E-02
Manganese	0.15	3.8E-02	5.1E-02	6.4E-02	6.3E-02	6.8E-02	5.5E-02	4.9E-02	3.8E-02	5.2E-02	6.3E-02	6.3E-02	7.2E-02	5.6E-02	4.9E-02
Mercury	0.03	9.4E-03	1.2E-02	1.6E-02	1.5E-02	1.7E-02	1.3E-02	1.2E-02	9.4E-03	1.3E-02	1.5E-02	1.5E-02	1.8E-02	1.4E-02	1.2E-02
Nickel	0.003	1.4E+00	1.8E+00	2.3E+00	2.2E+00	2.4E+00	2.0E+00	1.7E+00	1.4E+00	1.8E+00	2.2E+00	2.2E+00	2.6E+00	2.0E+00	1.7E+00
Zinc	46	2.7E-04	3.5E-04	4.4E-04	4.3E-04	4.7E-04	3.8E-04	3.4E-04	2.7E-04	3.6E-04	4.4E-04	4.4E-04	5.0E-04	3.9E-04	3.4E-04
Total HI		1.6	2.1	2.7	2.6	2.9	2.3	2.1	1.6	2.2	2.7	2.7	3.0	2.4	2.1

Table 27: Summary of Chronic HIs (with bioavailability factors applied) for Current (2019) and Future (2025) Operations, Calculated using Annual Average Concentrations.

Metal	Bioavailability (%)	Current Operation (2019)							Future Operations (2025)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	9.9%	9.8E-03	1.3E-02	1.6E-02	1.6E-02	1.7E-02	1.4E-02	1.2E-02	9.8E-03	1.3E-02	1.6E-02	1.6E-02	1.8E-02	1.4E-02	1.2E-02
Barium	100.0%	3.6E-02	4.8E-02	6.0E-02	5.9E-02	6.4E-02	5.2E-02	4.6E-02	3.6E-02	4.9E-02	6.0E-02	5.9E-02	6.8E-02	5.3E-02	4.6E-02
Cadmium	100.0%	1.7E-02	2.2E-02	2.8E-02	2.8E-02	3.0E-02	2.4E-02	2.1E-02	1.7E-02	2.3E-02	2.8E-02	2.8E-02	3.2E-02	2.5E-02	2.1E-02
Chromium (III)	1.2%	3.6E-04	4.8E-04	6.0E-04	5.9E-04	6.4E-04	5.2E-04	4.6E-04	3.6E-04	4.9E-04	6.0E-04	6.0E-04	6.8E-04	5.3E-04	4.6E-04
Copper	41.0%	4.6E-04	6.1E-04	7.6E-04	7.5E-04	8.2E-04	6.6E-04	5.8E-04	4.6E-04	6.2E-04	7.6E-04	7.6E-04	8.7E-04	6.7E-04	5.9E-04
Manganese	58.0%	2.2E-02	2.9E-02	3.7E-02	3.6E-02	4.0E-02	3.2E-02	2.8E-02	2.2E-02	3.0E-02	3.7E-02	3.7E-02	4.2E-02	3.2E-02	2.8E-02
Mercury	100.0%	9.4E-03	1.2E-02	1.6E-02	1.5E-02	1.7E-02	1.3E-02	1.2E-02	9.4E-03	1.3E-02	1.5E-02	1.5E-02	1.8E-02	1.4E-02	1.2E-02
Nickel	15.0%	2.0E-01	2.7E-01	3.4E-01	3.3E-01	3.6E-01	2.9E-01	2.6E-01	2.0E-01	2.7E-01	3.4E-01	3.3E-01	3.8E-01	3.0E-01	2.6E-01
Silver	100.0%	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Zinc	64.0%	1.7E-04	2.2E-04	2.8E-04	2.8E-04	3.0E-04	2.5E-04	2.2E-04	1.7E-04	2.3E-04	2.8E-04	2.8E-04	3.2E-04	2.5E-04	2.2E-04
Total HI		0.3	0.4	0.5	0.5	0.5	0.4	0.4	0.3	0.4	0.5	0.5	0.6	0.4	0.4

6.4 Carcinogenic Effects

The ICRs have been calculated based on the highest annual average PM₁₀ concentrations measured at each of the DMMP monitoring sites between 2010 and 2021 (refer to Section 2.5). The estimated metals concentrations have been determined using the historical metal analysis data (refer to Section 5.4). A summary of the calculated ICR values is presented in Table 28.

Table 28: Summary of ICRs Calculated using Annual Average Concentrations (2010 – 2021).

Metal	Receptor Locations						
	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	1.8E-06	2.1E-06	1.9E-06	1.9E-06	2.0E-06	1.6E-06	1.5E-06
Cadmium	5.5E-07	6.6E-07	5.8E-07	5.8E-07	6.3E-07	5.0E-07	4.5E-07
Lead	1.5E-07	1.8E-07	1.6E-07	1.6E-07	1.7E-07	1.4E-07	1.2E-07
Nickel	2.4E-06	2.9E-06	2.5E-06	2.5E-06	2.8E-06	2.2E-06	2.0E-06
ICR	4.9E-06	5.8E-06	5.2E-06	5.2E-06	5.6E-06	4.5E-06	4.0E-06

Notes

- ICR values have been calculated using the maximum recorded metal concentrations in any 24-hour period.

The calculated ICRs resulting from the estimated metals concentrations in ambient PM₁₀ are below the *National Environment Protection (Assessment of Site Contamination) Measure 1999* and *enHealth (2012) Environmental Health Risk Assessment* recommended risk target of one in 100,000 (i.e. 1E-05). Arsenic and nickel are the largest contributor to the overall ICR at each receptor location. Furthermore, the ICRs presented in Table 28 have been calculated using the maximum recorded metal concentrations in any 24-hour period, although the average metal concentrations would be considered more typical of a life-time exposure.

A summary of the calculated ICR values following application of the bioavailability factors outlined in Table 16, is presented in Table 29. These values remain below the recommended risk target of 1E-05 at each receptor location (Table 29).

Table 29: Summary of ICRs (with bioavailability factors applied) Calculated using Annual Average Concentrations (2010 – 2021).

Metal	Receptor Locations						
	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	1.8E-07	2.1E-07	1.9E-07	1.9E-07	2.0E-07	1.6E-07	1.5E-07
Cadmium	5.5E-07	6.6E-07	5.8E-07	5.8E-07	6.3E-07	5.0E-07	4.5E-07
Lead	1.1E-07	1.3E-07	1.1E-07	1.1E-07	1.2E-07	1.0E-07	9.0E-08
Nickel	3.6E-07	4.3E-07	3.8E-07	3.8E-07	4.1E-07	3.3E-07	3.0E-07
ICR	1.2E-06	1.4E-06	1.3E-06	1.3E-06	1.4E-06	1.1E-06	9.9E-07

The estimates presented in Table 29 are considered conservative as they were calculated using the maximum recorded metal concentrations in any 24-hour period.

Similarly, ICRs have been calculated for the worst-case current operations (2019) and worst-case future operations (2025) using annual maximum average PM₁₀ concentrations and 24-hour maximum metal concentrations. The ICRs assuming 100% bioavailability are shown in Table 30 and bioavailability adjusted ICRs are shown in Table 31. No material change in ICR values have been noted from current to future operations, with ICR values (including bioavailability adjusted values) below the recommended risk target of 1E-05 for all receptor locations under both scenarios. Therefore, no change in carcinogenic exposure risks is expected when FS project is operational, and carcinogenic exposure risks are expected to remain low and acceptable.

Table 30: Summary of ICRs for Current (2019) and Future (2025) Operations, Calculated using Annual Average concentrations.

Metal	Carcinogenic Guideline (µg/m3)-1	Current Operation (2019)							Future Operations (2025)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	4.3E-03	1.1E-06	1.5E-06	1.9E-06	1.9E-06	2.0E-06	1.7E-06	1.5E-06	1.1E-06	1.5E-06	1.9E-06	1.9E-06	2.2E-06	1.7E-06	1.5E-06
Cadmium	4.2E-03	3.5E-07	4.7E-07	5.9E-07	5.8E-07	6.3E-07	5.1E-07	4.5E-07	3.5E-07	4.8E-07	5.8E-07	5.8E-07	6.7E-07	5.1E-07	4.5E-07
Lead	1.2E-05	9.6E-08	1.3E-07	1.6E-07	1.6E-07	1.7E-07	1.4E-07	1.2E-07	9.6E-08	1.3E-07	1.6E-07	1.6E-07	1.8E-07	1.4E-07	1.2E-07
Nickel	3.8E-04	1.6E-06	2.0E-06	2.6E-06	2.5E-06	2.8E-06	2.2E-06	2.0E-06	1.5E-06	2.1E-06	2.6E-06	2.5E-06	2.9E-06	2.3E-06	2.0E-06
ICR		3.2E-06	4.2E-06	5.2E-06	5.1E-06	5.6E-06	4.5E-06	4.0E-06	3.1E-06	4.2E-06	5.2E-06	5.2E-06	5.9E-06	4.6E-06	4.0E-06

Table 31: Summary of ICRs for Current (2019) and Future (2025) Operations, Calculated using Annual Average concentrations.

Metal	Bioavailability (%)	Current Operation (2019)							Future Operations (2025)						
		HGC	BSY	HEW	CLY	HOP	MEX	MTC	HGC	BSY	HEW	CLY	HOP	MEX	MTC
Arsenic	9.9%	1.1E-07	1.5E-07	1.9E-07	1.9E-07	2.0E-07	1.6E-07	1.4E-07	1.1E-07	1.5E-07	1.9E-07	1.9E-07	2.1E-07	1.7E-07	1.4E-07
Cadmium	100.0%	3.5E-07	4.7E-07	5.9E-07	5.8E-07	6.3E-07	5.1E-07	4.5E-07	3.5E-07	4.8E-07	5.8E-07	5.8E-07	6.7E-07	5.1E-07	4.5E-07
Lead	73.0%	7.0E-08	9.3E-08	1.2E-07	1.1E-07	1.2E-07	1.0E-07	8.9E-08	7.0E-08	9.4E-08	1.2E-07	1.2E-07	1.3E-07	1.0E-07	8.9E-08
Nickel	15.0%	2.3E-07	3.1E-07	3.9E-07	3.8E-07	4.1E-07	3.3E-07	2.9E-07	2.3E-07	3.1E-07	3.8E-07	3.8E-07	4.4E-07	3.4E-07	3.0E-07
ICR		7.7E-07	1.0E-06	1.3E-06	1.3E-06	1.4E-06	1.1E-06	9.8E-07	7.7E-07	1.0E-06	1.3E-06	1.3E-06	1.4E-06	1.1E-06	9.8E-07

6.5 Uncertainties in Risk Characterisation

The risk assessment process relies on a set of assumptions and estimates with varying degrees of certainty and variability. Major sources of uncertainty in risk assessment include:

- Natural variability (e.g. differences in body weight in a population);
- Lack of knowledge about basic physical, chemical, and biological properties and processes;
- Assumptions in the models used to estimate key inputs (e.g. air dispersion modelling, dose response models); and
- Measurement error (e.g. used to characterise exposure).

For this screening HRA, uniformly conservative assumptions have been applied to ensure that potential exposures and associated health risks are over- rather than under-estimated. As a result of the compounding of conservatism, the quantitative risk indicators are considered to be upper-bound estimates, with the actual risk likely to be lower.

It is noted that the summing of the quantitative risk indicators for individual compounds to calculate the overall risk from exposure to multiple compounds does not take into account that different compounds can target different organs and therefore the potential health risk arising from exposure to multiple compounds is not necessarily additive, nor does it account for potential antagonistic or synergistic effects. However, the additive approach is considered to be conservative (i.e. health protective) in most circumstances.

6.5.1 Potential Synergistic Impacts

The CEH (2007) undertook a review of the potential synergistic impacts that may occur as a result of exposure to metals, the findings of which are summarised below.

Metals may interact either synergistically, additively or antagonistically, depending on the combination of metals and their relative amounts. These interactions may also occur for metal-organic mixtures. However, there are few controlled studies on the toxicological interaction of metals found in occupational or environmental contamination scenarios (USEPA 2004).

Evaluation of interaction studies involving the suite of metals present in the KCGM monitored particulates are available only for arsenic, cadmium, chromium and lead and separately for copper, lead, manganese and zinc (ATSDR 2004a, 2004b). These reports highlight that comparisons between the published studies are problematic, with most studies that have attempted to quantify the magnitude of toxicologic interactions providing results that are equivocal at best, including an inability to demonstrate if the interactions are synergistic, additive or less than additive.

There is a substantial body of peer-reviewed literature to support other metal interactions at normal physiological concentrations. These interactions may arise from metals having the same mode of action (e.g. zinc and cadmium affecting calcium regulation), or may be a result of metals present at different concentrations in the particulate mixture affecting the *in vivo* complexation capacity and hence the bioavailability of specific metal constituents and the potential for adverse health effects.

A decrease in the rate of uptake of one or more metal species is also widely recognised either by direct competition (e.g. calcium at elevated nutritional intakes will result in a reduction in the intakes of cadmium and zinc) or may occur following membrane mediated interaction as for lead and copper. Finally, the relative contribution of metals to joint effects depends on each of their

relative concentrations, which impact on molecular or ionic mimicry. Examples of this latter phenomenon include the mitigation of mercury toxicity by zinc and selenium and a reduction in cadmium toxicity by copper. Conversely, a deficient copper or iron status may enhance the lead intakes and hence the potential for exposures (USEPA 2004b).

The role of diet (and more particularly dietary trace metal deficiencies) is recognised as a critical factor in determining whether potential adverse health effects of additional metal exposures are moderated or enhanced. With a population in which there are no reported significant trace metal deficiencies such as Kalgoorlie, the role of diet will assume a much lower significance.

In summary, while there are models that can be applied to risk assessment for metal mixtures in aquatic environments using predictions based on Toxicity Equivalence Factors these have not been reliably applied to human exposures. In the absence of epidemiological study results, there remains no realistic means to rank mixtures of atmospherically derived mixtures of metals or individual metals within these mixtures for human exposure assessments.

7. SUMMARY

KCGM operates the Fimiston Gold Mine Operations, located adjacent to the City of Kalgoorlie-Boulder. The Fimiston Operations consist of the FOP, Fimiston Processing Plant, three TSFs, WRDs, run of mine and associated infrastructure. KCGM has undertaken a series of extensions of the Fimiston Operations since 2009 and is currently developing the FS Project, consisting of the MO and SE resources at the southern end of the existing FOP. To facilitate the environmental approvals process, a number of studies are required for the proposed FS Project, including the update of previous screening health risk assessments (HRA) completed in 2007 and 2020.

The previous study involved assessment of metal concentrations in ambient particulate samples collected by KCGM during a 2006 monitoring campaign. These data were used together with predicted particulate concentrations for the GP Cutback Project as inputs to the 2006 screening HRA, the result of which indicated the predicted metal concentrations would not result in unacceptable health risks. Similar health risk conclusions were reached in the Ramboll (2020) HRA update which included PM₁₀ data collected from 2010 to 2019. PM₁₀ metal concentrations were calculated using historic metals concentration data and applied bioavailability factors based on analysis of regional soil samples. No unacceptable acute or chronic non-carcinogenic or carcinogenic risks were found at any of the sampling locations.

In support of the regulatory approval process for the proposed FS Project, Ramboll has been engaged by KCGM to undertake a review of these previous screening HRA and update the assessment, taking into consideration available ambient monitoring data from 2020 to 2021, air dispersion modelling and the proposed changes at the Fimiston Operations. The HRA also compared the expected change in potential health risks from the current operations to the future when FS project would be operational, based primarily on air dispersion modelling data.

During the past twelve years (2010-2021), 2019 had the highest average monitored PM₁₀ concentrations in the region. Hence, 2019 was adopted as worst-case scenario for current operations at KCGM. The maximum annual material movement for the FS project is expected to be approximately 96 Mt. peaking in the year 2029, when operational. However, 2025 (86 Mtpa) was selected as the year to be modelled as the worst-case future scenario due to the higher level of activity located close to the town and a larger amount of material extracted from the pit and dumped externally.

In the absence of updated metals analysis data, the results of the historic metals analysis have been used in conjunction with ambient PM₁₀ monitoring data collected between 2010 and 2021 and air dispersion modelling to update the screening HRA. Ramboll understands mining operations associated with the proposed FS Project will occur within the same geological bounds as previous activities and as such, the concentration of metals within fugitive dust emissions from KCGM's proposed operations are not expected to differ significantly from those measured historically.

A review of ambient PM₁₀ data collected across KCGM's seven ambient PM₁₀ monitoring stations between 2010 and 2021 was undertaken to identify the maximum short-term and long-term PM₁₀ concentrations for use in the screening HRA. The historic maximum metals concentrations measured in ambient particulate samples, together with the maximum recorded 1-hour and 24-hour average PM₁₀ concentration for which KCGM was identified as a potential contributor, and the highest annual average PM₁₀ concentrations measured at each monitoring site, were used as inputs to the screening HRA. The HRA also included air dispersion modelling data presented in Ramboll (2022a) to assess the potential health impacts when the FS project is in operational phase. The change in modelled PM₁₀ concentration were calculated from 2019 to 2025 and then

estimated PM₁₀ concentrations in 2025 were calculated using monitored data from 2019. Historic maximum metals concentration data was then used to estimate current (2019) and future (2025) PM₁₀ metal concentrations.

Health protective guidelines published by reputable authorities were used in conjunction with the measured and modelled PM₁₀ concentrations and estimated metals concentrations to calculate quantitative risk indicators. As the main transport pathway for atmospheric emissions associated with the FS project is atmospheric dispersion, inhalation is expected to remain the most significant exposure route and the screening HRA considers the inhalation pathway only (as per the previous studies).

The acute HIs calculated based on 2010-2021 monitored PM₁₀ and historic metals data for the nominated receptors marginally exceed target HI of one (based on maximum 1-hour data); values greater than one but less than 10 generally do not represent cause for concern because of the inherent conservatism embedded in the exposure and toxicity assessments. However, the acute HIs are considered highly conservative as they assume 100% bioavailability of the maximum recorded metal concentrations. Application of bioavailability factors based on historical analysis of regional soil samples to the calculated HIs results in values below one for each receptor location. Acute HI based on 24-hour data is also below one, indicating that any high particulate metal concentrations are short-lived and do not have the potential to cause extended acute exposures.

For comparative assessment of acute exposure risks, no material change in acute HIs have been noted from current (2019) to future operations (2025), with bioavailability adjusted HI values below one for all receptor locations under both scenarios. No change in acute (short-term) exposure risks is expected when FS project is operational, and acute exposure risks are expected to remain low and acceptable.

The chronic non-carcinogenic HIs based on 2010-2021 monitored PM₁₀ and historic metals data, conservatively assuming 100% bioavailability for each metal, remain well below one at each of the monitoring locations, indicating no cause for concern in terms of potential long-term non-carcinogenic health effects.

For comparative assessment of chronic non-carcinogenic exposure risks, no material change in chronic HIs have been noted from current (2019) to future operations (2025), with all values below one for all receptor locations under both scenarios. No change in chronic (long-term) exposure risks is expected when the FS project is operational, and chronic exposure risks are expected to remain low and acceptable.

The maximum ICRs calculated based on 2010-2021 monitored PM₁₀ and historic metals data were below the risk target of 1E-05. Arsenic and nickel were the largest contributor to the overall ICR at each receptor location. Furthermore, the ICRs have been calculated using the maximum recorded metal concentrations in any 24-hour period, although the average metal concentrations would be considered more typical of a life-time exposure; and assuming 100% bioavailability for each metal. Application of the bioavailability factors based on historical analysis of regional soil samples to the ICRs further reduces the calculated values.

For comparative assessment of carcinogenic exposure risks no material change in ICR values have been noted from current (2019) to future operations (2025), with bioavailability adjusted ICR values below the recommended risk target of 1E-05 for all receptor locations under both

scenarios. No change in carcinogenic exposure risks is expected when FS project is operational, and carcinogenic exposure risks are expected to remain low and acceptable.

It has been assumed that the fugitive dust impacts associated with the proposed FS Project will be similar to those of previous operations, as the mining activities and dust management procedures will also remain the same. The calculation of quantitative risk indicators based historic metals analyses and ambient PM₁₀ monitoring and modelled data and the adoption of realistic, but conservative assumptions in the application of bioavailability factors determined from the analysis of regional soil samples, indicate no unacceptable acute or chronic non-carcinogenic or carcinogenic risks. These potential short-term and long-term health effects are also expected to remain unchanged with no unacceptable risks when FS project is operational in the future.

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9. LIMITATIONS

Ramboll prepared this updated HRA report in accordance with the agreed scope of work for Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM) and in accordance with our understanding and interpretation of current regulatory standards in WA, Australia.

The report has assessed health risks based on currently available monitored and modelled data and information about the site. Where such data is inadequate, the report has identified the data/information gaps and has used protective assumptions to estimate risks. The report has also assumed that there will not be any change in exposure scenario in the future. The outcomes of this report are based on the assumptions and calculations/modelling used for assessment of exposure risks. The conclusions are applicable to the extent these assumptions remain relevant for the site. The air dispersion modelling undertaken to predict future concentrations at receptor locations carries inherent uncertainties similar to any other analytical model. Any findings of this HRA should be viewed in relation to those uncertainties/sensitivities.

The conclusions presented in this report represent Ramboll's professional judgment based on information made available during the course of this assignment and are true and correct to the best of Ramboll's knowledge as at the date of the assessment. Ramboll did not independently verify all of the written or oral information provided to Ramboll during the course of this assessment. While Ramboll has no reason to doubt the accuracy of the information provided to it, the report is complete and accurate only to the extent that the information provided to Ramboll was itself complete and accurate.

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