



AMBIENT PARTICULATE METALS

For

KALGOORLIE CONSOLIDATED GOLD MINES

September 2007

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ENVIRON

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Kalgoorlie Consolidated Gold Mines
Black Street
Kalgoorlie WA 6430

Attention: Michelle Berryman

Dear Michelle,

AMBIENT PARTICULATE METALS

We are pleased to present our report on the analysis that has been conducted on the metals content in ambient particulates.

We will finalise this report upon receipt of comments from KCGM.

Should you require any additional information, please contact the undersigned directly.

Yours faithfully
ENVIRON Australia Pty Ltd



Brian Bell
Manager, Western Australia

EXECUTIVE SUMMARY

Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM), located approximately 600 km east of Perth, on the eastern boundary of the City of Kalgoorlie-Boulder proposes to extend its existing Fimiston Gold Mine Operations. The extension will include the mining of a westerly cutback (known as ‘the Golden Pike Cutback’) of the Fimiston Open Pit covering a surface extent of 46 hectares (ha). The extension of the Fimiston operations is currently being formally assessed by the Environmental Protection Authority (EPA) at the Public Environmental Review (PER) level of assessment. In its submissions on the PER, the Department of Health (DoH) requested that KCGM provide additional information on the management of ambient particulate metals.

An assessment of the concentration of metals in ambient particulate samples collected during 2006 has been completed. The results of this assessment indicate that the metal concentrations in the ambient particulate samples are generally consistent with those found in the surrounding soils and Fimiston waste rock (see Table E1).

Table E1: Concentrations of Metals in HVAS TSP Samples (all Sites), Soils and Fimiston Mine Waste

Metal	Concentration (mg/kg)					
	TSP Ambient Samples			Soils		
	2006 Data (BSY, HEW, CLY)		HOP	Kalgoorlie Urban	Gidji Rural	Fimiston Waste Rock
	Average	Maximum	Average			
Arsenic	5.22	19.25	34.09	15.8	14.6	26
Barium	139.89	2569.97	69.80	na	na	8
Beryllium	na	na	na	na	na	0.3
Cadmium	0.10	5.64	na	< 0.4	< 0.4	0.13
Chromium	38.20	214.60	44.81	322	390	177
Cobalt	7.51	98.71	11.01	na	na	35
Copper	10.72	77.27	31.19	36.1	20.4	78
Lead	29.12	573.95	64.91	22.7	9.8	5.6
Manganese	122.80	404.91	486.07	515	309	1480
Mercury	1.02	19.95	0.36	< 1.0	< 1.0	0.12
Nickel	46.59	293.27	103.69	65.1	50.6	61
Selenium	na	na	na	na	na	0.05
Silver	0.08	4.83	0.81	na	na	1.1
Zinc	62.07	866.36	109.05	78.2	25.5	88

Notes: BSY – Boulder Shire Yard
HEW – Hewitt Street
CLY – Clancy Street
HOP – Hopkins Street
na – Not Available

Air dispersion modelling of the fugitive emissions from the Fimiston Operations Extension completed for the PER was also revised to such that the waste rock dumps made a more realistic contribution to the predicted ambient concentrations resulting from the Fimiston Operations. The revised modelling resulted in the prediction of similar maximum 24-hour and annual average ground level

concentrations as the model results presented in the PER but the Fimiston Open Pit had a significantly reduced contribution.

A review of two years of ambient PM₁₀ data collected at the Boulder Shire Yard (BSY) and Hannan's Golf Club (HGC) monitoring sites indicates that the annual average PM₁₀ concentrations are both approximately 18 µg/m³ and that the 24-hour average concentrations are generally in compliance with the NEPM goal. The HGC monitoring site recorded 14 exceedences of the NEPM 24-hour average standard (50 µg/m³) over the two year period (1 August 2005 to 31 July 2007) while eight exceedences were recorded at BSY over the same period. Many of these HGC exceedences recorded in 2007 (eight of the 14) are likely to be associated with localized roadwork activities during the period January to April 2007 and are therefore not considered to be representative of the background PM₁₀ concentrations. An analysis of the days where the NEPM PM₁₀ standard was exceeded indicates the majority of the exceedance days were associated with regional dust storms and smoke from wood heaters. One of the days where the NEPM PM₁₀ standard was exceeded at BSY was associated with winds from KCGM's Fimiston Operations. However, in general the PM₁₀ emissions from KCGM's Fimiston Operations are not resulting in significant ambient PM₁₀ concentrations.

In May and June 2007, E-BAM PM₁₀ monitors were installed at the Hewitt St, Hopkins St and Clancy St monitoring sites. The data collected from these sites up to 10 August 2007, in addition to the data collected at the BSY and HGC monitoring sites over the same period were also reviewed and showed that that average PM₁₀ concentration was around 18 µg/m³ for all of the sites except the Hopkins St site that averaged 15 µg/m³. The Hewitt St monitoring site recorded one exceedance of the NEPM 24-hour average standard (6 August 2007) and this also corresponded with an exceedance recorded at the HGC monitoring site. A review of the wind data collected over the period that the elevated concentrations were recorded indicated that they occurred under strong westerly winds. Based on these winds and that the 24-hour exceedences were recorded only at HGC and Hewitt St, it is likely that the sources of the particulates were to the north and west of Kalgoorlie and not associated with the KCGM Operations.

The maximum and average metal concentrations in the ambient particulate samples, together with the maximum predicted 24-hour and the annual average PM₁₀ concentrations were used as inputs to a screening level health risk assessment. The screening health risk assessment used ambient air quality guidelines published by reputable authorities and found that the acute and chronic non-carcinogenic hazard indices were not of any concern being well below one.

In terms of the incremental carcinogenic risk, use of the maximum metal contents and assuming that all of the metals were bioavailable, resulted in a calculated ICR of 4×10^{-6} with nickel, and to a lesser extent arsenic, being the most significant contributors. However, consideration of the potential bioavailability of these metals or the use of the average metal concentrations in the ambient particulates both resulted in the ICR falling below the US EPA *de minimis* criterion of 1×10^{-6} . Nickel, which is the most significant contributor to the ICR, was found to occur at similar levels in the Kalgoorlie and Gidji soils as the concentrations in the ambient particulate samples.

In summary, the screening health risk assessment has indicated that nickel is the major contributor to the potential health risks associated with inhalation exposure to metals in the ambient particulate samples. However, the screening health risk assessment has found that the predicted metal concentrations will not result in unacceptable acute or chronic no carcinogenic hazards. Further, the incremental carcinogenic risks are also predicted to be below the US EPA *de minimis* criterion when realistic, but still conservative, data are considered.

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AMBIENT PARTICULATE METALS
for
Kalgoorlie Consolidated Gold Mines

1. INTRODUCTION

Kalgoorlie Consolidated Gold Mines Pty Ltd (KCGM), located approximately 600 km east of Perth, on the eastern boundary of the City of Kalgoorlie-Boulder proposes to extend its existing Fimiston Gold Mine Operations. The extension will include the mining of a westerly cutback (known as 'the Golden Pike Cutback') of the Fimiston Open Pit covering a surface extent of 46 hectares (ha). The extension of the Fimiston operations is currently being formally assessed by the Environmental Protection Authority (EPA) at the Public Environmental Review (PER) level of assessment.

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. KCGM has also implemented measures to reduce the point source emission of mercury from the Carbon Regeneration Kiln located at the Fimiston Mill and is currently working on the design of additional emission control to further reduce the emissions of mercury.

In its submissions on the PER, the Department of Health (DoH) requested that KCGM provide additional information on the management of ambient particulate metals. This report has been prepared to provide the information that KCGM has available relevant to the issue of ambient particulate metals in Kalgoorlie and presents details on:

1. the range of concentration of metals identified in the soils in and around Kalgoorlie including KCGM's Fimiston Operations;
2. the metals concentrations measured in ambient particulate samples collected by High Volume Air Samplers at monitoring locations around KCGM's Fimiston Operations;
3. ambient particulate monitoring data;
4. predicted ground level concentrations of particulate matter from KCGM's Fimiston Operations;
and
5. a screening health risk assessment of the exposure to the metals present in the ambient particulate samples.

2. PARTICULATE METALS IN KALGOORLIE

2.1 COMMUNITY AND REGIONAL SOILS

In 2005, KCGM commissioned Dr Keith Bentley from the Centre for Environmental Health Pty Ltd (CEH) to undertake an investigation 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 and from public recreational areas within and surrounding the City of Kalgoorlie-Boulder. The Lakewood historical tailing area was also included on the basis of its close proximity to the Kalgoorlie residential suburbs and its regular use for motor vehicle recreational activities. Samples were also collected from the KCGM vegetation monitoring sites in the vicinity of the Gidji Roaster.

Tables 1, 2 and 3 (taken from CEH, 2005) present the results from the soil sampling program for Kalgoorlie, Lakewood and Gidji respectively.

Table 1: Comparison of Kalgoorlie Residential Soils with NEPM Health-Based Soil Investigation Levels (All Values Total Metals mg/kg)

Substance	NEPM HILs Residential A	Range of values from present study		
		Mean	Median	Range
Arsenic (total)	100 = (40% PTWI)	21.2	19.5	5 - 36
Boron	3000	19.2	18	9 - 37
Cadmium	20 = (19% PTWI)	All values < DL 0.4 mg/kg		
Chromium (III)	120,000	344 (total)	310 (total)	120 – 560
Copper	1000 (no PTWI)	46.7	39.5	14 – 84
Lead	300 = (52% PTWI)	112.2	59.5	8 – 460
Manganese	1500	324	320	100 – 510
Mercury (inorg)	15 = (20% PTWI)	All values < DL 1.0 mg/kg		
Nickel	600	49.8	54.5	18 – 70
Zinc	7000 (no PTWI)	282.8	260	32 – 780

Notes:

1. HILs are Health Investigation Levels.
2. The present analysis has measured total chromium. Chromium (VI) has an allocated HIL of 100 mg/kg, based on skin sensitivity. 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.
3. There are no HIL values established by the NEPC for iron, selenium or sulphur, reflecting the low toxicity of iron and sulphur and the general deficiency of selenium in Australian soils.

Source: Centre for Environmental Health (2005)

Table 2: Comparison of Lakewood Tailings Recreational Soils with NEPM Health-Based Soil Investigation Levels (All Values Total Metals mg/kg)

Substance	NEPM HILs Parks, recreational open space etc	Range of values from present study		
		Mean	Median	Range
Arsenic (total)	200 = (20% PTWI)	158.5	145	110 – 240
Boron ¹	6000	27.3	18	4 - 81
Cadmium	40 = (10% PTWI)	All values < DL 0.4 mg/kg		
Chromium (III)	240,000	11.7	9.9	5 – 21
Copper	2000 (no PTWI)	83	77.5	34 – 151
Lead	600 = (26% PTWI)	30.6	29.5	6 – 61
Manganese	3000	1465	1400	1200 – 1800
Mercury (inorg) ¹	30 = (10% PTWI)	4	2	1 - 14
Nickel	600	24.8	24.5	15 – 35
Selenium	No value	All values < DL 4.0 mg/kg		
Sulphur	No value	14,850	13,550	5800 – 32,500
Zinc	14000 (no PTWI)	171.6	180	79- 270

Notes:

1. Boron and mercury have been calculated using the upper bound value for the detection limit for values below the DL.

Source: Centre for Environmental Health (2005)

Table 3: Comparison of Gidji Recreational Soils with NEPM Health-Based Soil Investigation Levels (All Values Total Metals mg/kg)

Substance	NEPM HILs Parks, recreational open space etc	Range of values from present study		
		Mean	Median	Range
Arsenic (total)	200 = (20% PTWI)	14.6	11	5 – 44
Boron ¹	6000	5.4	4	4 – 10
Cadmium	40 = (10% PTWI)	All values < DL 0.4 mg/kg		
Chromium (III)	240,000	390 (total)	350 (total)	150 – 1400
Copper	2000 (no PTWI)	20.4	19	9 – 62
Lead	600 = (26% PTWI)	9.8	10	6 – 16
Manganese	3000	309	310	110 – 720
Mercury (inorg)	30 = (10% PTWI)	All values < DL 1.0 mg/kg		
Nickel	600	50.6	47.5	20 – 83
Selenium	No value	All values < DL 4.0 mg/kg		
Sulphur	No value	140	110	50 – 360
Zinc	14000 (no PTWI)	25.5	23	11 – 53

Notes:

1. Boron has been calculated using the upper bound value for the detection limit.

Source: Centre for Environmental Health (2005)

The CEH (2005) also provided a summary of the total concentrations of metals in “background” soil samples around Australia for comparison with the Kalgoorlie and Gidji Soil data and this is reproduced as Table 4. These data show that the Kalgoorlie soils have elevated levels of arsenic, chromium and nickel compared to the other Australian locations.

Table 4: Total Concentrations of Metals in “Background” Surface Soils in Australia (All Values are the Arithmetic Mean and mg/kg)

Location	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn
Adelaide City ¹	1.8	0.39	11.4	19.7	-	309	14.9	64.0	80.3
Mt Lofty Range ¹	3.9	-	27.0	15	-	254	9.8	21.0	27.0
Hobart urban ²	2.5	4.2	16.7	30	0.4	-	13.7	91.7	214.0
Sydney urban ³	4.6	0.25	17.8	-	0.07	-	-	66.9	86.4
Sydney rural ⁴	2.5	0.03	18.7	11.3	0.03	-	8.6	21.3	30.1
Kalgoorlie urban	15.8	< 0.4	322	36.1	< 1.0	515	65.1	22.7	78.2
Gidji rural	14.6	< 0.4	390	20.4	< 1.0	309	50.6	9.8	25.5

Notes:

1. Tiller (1992)
2. Department of Environment and Planning (1992)
3. NSW EPA (unpublished)
4. Lawrie *et al* (1992)
5. These samples are not fully compatible in that the sample depth adopted differed between authors (eg Tiller 0 – 20 cm, DEP 0 – 2 cm NSW EPA unspecified.). The Hobart soils included samples impacted by the Pasmenco-EZ smelter and the Launceston rail yards. These latter soils are markedly elevated in the levels of cadmium, lead and zinc from anthropometric emissions.

Source: Centre for Environmental Health (2005)

2.2 FIMISTON PIT ORE AND WASTE

As part of National Pollutant Inventory (NPI) reporting, KCGM reviewed the data that it has available on the concentration of metals in ore and waste from the Fimiston Open Pit and the typical concentrations are summarised in Table 5.

Table 5: Typical Concentrations of Metals in Ore and Waste from the Fimiston Open Pit

Metal	Ore Milled (mg/kg)	Ore Mining (mg/kg)	Waste Rock (mg/kg)
As	104	190	26
B	6.23	41	8
Be	0.73	3.9	0.3
Cd	0.2	2.65	0.13
Cr (III)	58.14	144	177
Co	42.12	38	35
Cu	96.23	87	78
Pb	3.83	10.3	5.6
Mn	1575	1435	1480
Hg	0.96	1.36	0.12
Ni	49	44	61
Se	0.95	1.77	0.05
Sb	11	12.4	1.1
Zn	85	195	88

In terms of any fugitive dust from KCGM’s operations, the most likely source of the dust will be the waste rock material as this comprises the bulk of the mined material moved and is deposited in waste rock dumps around the perimeter of the Fimiston Open Pit.

Table 6 compares the total metals concentrations from the Kalgoorlie community and Gidji soil sampling reported by CEH (2005) with those in the waste rock from the Fimiston Open Pit. The data presented in Table 6 shows that the chromium concentration in the Fimiston waste rock is lower than that typically found in the Kalgoorlie and Gidji soils. The typical arsenic and copper concentrations are approximately two times higher in the Fimiston waste rock. Manganese concentrations are significantly higher in the Fimiston waste rock than the Kalgoorlie and Gidji soils. The concentrations of all other metals (cadmium, mercury, nickel, lead and zinc) are similar.

Table 6: Total Concentrations of Metals in Kalgoorlie Urban Soils, Gidji Rural Soils and Fimiston Waste Rock (All Values are the Arithmetic Mean and mg/kg)

Location	As	Cd	Cr	Cu	Hg	Mn	Ni	Pb	Zn
Kalgoorlie Urban	15.8	< 0.4	322	36.1	< 1.0	515	65.1	22.7	78.2
Gidji Rural	14.6	< 0.4	390	20.4	< 1.0	309	50.6	9.8	25.5
Fimiston Waste Rock	26	0.13	177	78	0.12	1480	61	5.6	88

3. METALS IN AMBIENT PARTICULATE SAMPLES

Historically, KCGM has operated a High Volume Air Sampler (HVAS) network to monitor ambient dust concentrations at a number of sites in close proximity to the Fimiston Operations (Figure 1). These HVAS have been typically operated between 09:00 hrs and 18:00 hrs on days where KCGM was intending to undertake blasting activities to monitor the ambient concentrations of total suspended particulate (TSP).

During construction of the southern noise bund KCGM also operates one HVAS at its Hopkins Street (HOP) monitoring site to measure PM₁₀ (i.e. particulate matter with an aerodynamic diameter of less than 10 µm) monitoring. This sampler is typically operated during construction periods for approximately 24-hours with the filter being changed at around 08:00 hrs. For a short period, KCGM also operated a second HVAS at this HOP site for monitoring TSP.

The HVAS draw approximately 70 m³/hr (expressed at STP) of air through a pre-weighed filter paper that captures the particulate matter. The filter papers are then re-weighed and the mass of particulate collected determined via subtraction. The average particulate concentration is then determined by dividing the mass by the sampled volume. KCGM typically uses quartz fibre filters in its HVAS sampling regime.

Wind direction data collected at the KCGM Metals Exploration (MEX) monitoring site were reviewed and a total of 58 TSP samples were selected for analysis of metal content from the HVAS filters collected during 2006. The filters were selected for the Boulder Shire Yard (BSY), Hewitt Street (HEW) and Clancy Street (CLY) monitoring stations on the basis of:

1. elevated dust loadings to ensure that there were sufficient particulate mass available for the analysis; and
2. days where the winds were primarily from directions associated with KCGM's Fimiston Operations and days where the winds were from other wind directions (i.e. Non-KCGM).

The quartz fibre filters used in the HVAS program contain trace amounts of the metals and the concentration of these metals in the filters varies between filter batches. As historically collected filter papers were being analysed, no blank filters from the relevant filter batches were available for separate testing. When used in the HVAS, the edges of the filter papers are not directly exposed to the air being sampled as the edges are used to clamp the filter to the sampling manifold. Therefore, in order to quantify the concentrations of metals in the HVAS filter papers, the laboratory were requested to use the edges of the filter papers to provide an indication of the background metal content of the filter papers.

In addition to the above TSP filter papers collected in 2006, KCGM analysed an additional 22 samples which consisted of 11 coincident HVAS TSP and PM₁₀ samples from the HOP monitoring site. The objective of this additional analysis was to determine if any of the metals existed in higher concentrations within the finer PM₁₀ fraction.

All samples were analysed by Leeder Consulting (Leeder) who provided the results of the analysis as the total of each metal present on each filter. The average of the total mass of each metal on the filter “blanks” were then subtracted from the sample results to indicate the total metal mass in the collected particulate. The concentration of each metal (in mg/kg) was then determined by using the total mass of the particulate collected in the sample (as determined by the pre and post filter weights recorded as part of the original HVAS monitoring program).

3.1 TOTAL SUSPENDED PARTICULATES

Table 7 presents the average and maximum concentration of metals determined from the analysis of the TSP filter papers. The data show that on average, the metals in the particulates 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 KCGM Operation related samples, while the concentration of lead is higher. In terms of the maximum concentrations, it can be seen that the KCGM Operation related samples recorded the highest concentrations of arsenic, cadmium, chromium, lead, manganese and zinc. The significant difference between the average and maximum values for barium, chromium, lead, nickel and zinc also indicates that these maximum concentrations were rare and could be considered as outliers.

Table 7: Concentrations of Metals in HVAS TSP Samples Collected at the BSY, HEW CLY Monitoring Sites

	Metals Concentration (mg/kg)			
	Average		Maximum	
	All Data	KCGM	All Data	KCGM
Arsenic	5.22	4.57	19.25	19.25
Barium	139.89	139.57	2569.97	1874.82
Beryllium	na	na	na	na
Cadmium	0.10	0.21	5.64	5.64
Chromium	38.20	40.00	214.60	214.60
Cobalt	7.51	0.50	98.71	11.84
Copper	10.72	5.72	77.27	46.52
Lead	29.12	43.59	573.95	573.95
Manganese	122.80	104.06	404.91	404.91
Mercury	1.02	na	19.95	na
Nickel	46.59	31.49	293.27	171.24
Selenium	na	na	na	na
Silver	0.08	0.18	4.83	4.83
Zinc	62.07	35.44	866.36	646.54

- Notes: 1 na is not applicable where either the metal concentration was below the limit of detection or the subtraction of the blank concentration resulted in a net metal mass or zero or less
 2 KCGM refers to samples collected when the wind direction was blowing from KCGM's operations for some or all of the sample period.

3.2 TSP AND PM₁₀

Twenty two samples, consisting of 11 coincident TSP and PM₁₀ samples collected at the HOP monitoring site were analysed to determine if any of the metals existed in higher concentrations in the PM₁₀ size fraction compared to the TSP samples. This was considered important as PM₁₀ is of more relevance with regards to potential health impacts resulting from particulate exposure. Table 8 presents a summary of the analysis results and shows that where the ratio of metals in the PM₁₀ and TSP samples could be determined, that only silver was at lower concentrations in the PM₁₀ samples. Arsenic and nickel concentrations were 9% and 11% higher in the PM₁₀ samples respectively while the lead concentration was nearly twice as high (although it should be noted that only two of the sample pairs had sufficient lead concentrations to be included in the analysis).

Table 8: Concentrations of Metals in HVAS TSP Samples Collected at the HOP Monitoring Site with the Calculated PM₁₀ to TSP Metal Ratio

Metal	Average Concentration in TSP Samples (mg/kg)	Average PM₁₀/TSP Ratio
Arsenic	34.09	1.09
Barium	69.80	na
Beryllium	na	na
Cadmium	na	na
Chromium	44.81	na
Cobalt	11.01	na
Copper	31.19	na
Lead	64.91	1.98
Manganese	486.07	1.06
Mercury	0.36	na
Molybdenum	4.31	1.52
Nickel	103.69	1.11
Selenium	na	na
Silver	0.81	0.78
Zinc	109.05	na

Notes: na is not applicable where either:

- 1 the metal concentration was below the limit of detection; or
- 2 the subtraction of the blank concentration resulted in a net metal mass or zero or less; or
- 3 the metal concentrations were less than two times the average blank filter value for the PM₁₀/TSP ratio

3.3 SUMMARY

Table 9 presents a summary of the concentrations of metals measured in all of the TSP samples that have been analysed and also compares these with the soil sample concentrations presented in Section 2 (Table 6).

Table 9: Concentrations of Metals in HVAS TSP Samples (all Sites), Soils and Fimiston Mine Waste

Metal	Concentration (mg/kg)					
	TSP Ambient Samples			Soils		
	2006 Data (BSY, HEW, CLY)		HOP	Kalgoorlie Urban	Gidji Rural	Fimiston Waste Rock
	Average	Maximum	Average			
Arsenic	5.22	19.25	34.09	15.8	14.6	26
Barium	139.89	2569.97	69.80	na	na	8
Beryllium	na	na	na	na	na	0.3
Cadmium	0.10	5.64	na	< 0.4	< 0.4	0.13
Chromium	38.20	214.60	44.81	322	390	177
Cobalt	7.51	98.71	11.01	na	na	35
Copper	10.72	77.27	31.19	36.1	20.4	78
Lead	29.12	573.95	64.91	22.7	9.8	5.6
Manganese	122.80	404.91	486.07	515	309	1480
Mercury	1.02	19.95	0.36	< 1.0	< 1.0	0.12
Nickel	46.59	293.27	103.69	65.1	50.6	61
Selenium	na	na	na	na	na	0.05
Silver	0.08	4.83	0.81	na	na	1.1
Zinc	62.07	866.36	109.05	78.2	25.5	88

Figure 2 presents these data graphically.

The data presented in Table 9 and Figure 2 shows that:

1. The concentrations of metals in the ambient TSP samples are generally consistent with those concentrations present in the Kalgoorlie and Gidji soils.
2. There were not any significant differences between the metal concentrations measured in samples that were or were not associated with winds that traversed KCGM's operations.
3. The HOP TSP average concentrations of arsenic, copper, lead, manganese, nickel and zinc were higher than the average metals concentrations measured in the BSY, CLY and HEW TSP samples but generally within the range of measured concentrations.

Finally, a review of coincident HVAS TSP and PM₁₀ data indicate that arsenic and nickel concentrations were 9% and 11% higher in the PM₁₀ samples respectively while the lead concentration was nearly twice as high (although it should be noted that only two of the sample pairs had sufficient lead concentrations to be included in the analysis).

4. AMBIENT PM₁₀ MONITORING DATA

In July 2005 KCGM commenced monitoring real time PM₁₀ concentrations at its BSY and Hannan's Golf Club (HGC) monitoring sites (Figure 1). The BSY monitoring site is located in relatively close proximity to the Fimiston Open Pit whereas the HGC site is well removed and was established to provide an indication of the background PM₁₀ concentrations in Kalgoorlie. The BSY and HGC PM₁₀ monitoring is undertaken on a continuous basis using Beta Attenuation Monitors (BAM) which produce 5-minute average concentrations.

In addition to the BSY and HGC BAMs, KCGM commissioned PM₁₀ E-BAM monitors at the HEW, CLY and HOP monitoring sites between May and June 2007. These E-BAMs produce 10-minute average concentrations.

The data collected by the BSY and HGC BAMs between 1 August 2005 and 31 July 2007 (two years) were reviewed as part of this study. The review of these data indicates that:

1. over the two year period, the 24-hour average PM₁₀ concentration exceeded 50 µg/m³ on 14 occasions at HGC and on eight 8 occasions at BSY.
2. the average PM₁₀ concentration over the two year period was 18.3 µg/m³ at both the BSY and HGC monitoring sites.

Figure 3 presents the 24-hour average PM₁₀ concentrations for each day between 1 August 2005 and 31 July 2007 recorded at the HGC and BSY monitoring sites. This figure shows that the PM₁₀ concentrations are typically more variable at BSY on a day to day basis. It also indicates that the PM₁₀ concentrations recorded at HGC generally increased between December 2006 and April 2007 and these higher concentrations are likely to be associated with roadwork activities that were undertaken in the vicinity of the monitoring station.

Four of the eight days where the BSY monitor exceeded the NEPM PM₁₀ standard coincided with similar exceedences being recorded at the HGC monitor, indicating that these were associated with wider scale dust and not directly attributable to KCGM's Fimiston Operations. Further analysis of the wind speed and direction data associated with the other four days where the BSY monitor exceeded the NEPM PM₁₀ standard show that only one day was associated with winds from Fimiston Operations and that the other days were associated with other wind directions. It is also likely that some of the high PM₁₀ concentrations recorded on winter days were associated with smoke from wood heaters.

PM₁₀ E-BAM data for the following periods were provided by KCGM (the first dates represent the date that the monitoring stations were commissioned):

1. HOP 24 May to 9 August 2007
2. HEW 30 May to 10 August 2007; and
3. CLY 16 June to 10 August 2007.

During this period there was one exceedance of the 24-hour average of 50 µg/m³ recorded on 6 August 2007 at the HEW monitoring site. Additional BAM data were obtained for the BSY and HGC monitoring sites such that the BAM data were available for the same period as the E-BAM data. The HGC monitoring site also recorded a 24-hour average PM₁₀ concentration greater than 50 µg/m³ on 6 August 2007. A review of the wind speed and wind direction data for 6 August 2007 showed that the high PM₁₀ concentrations were recorded under very strong westerly winds indicating that the particulate emission sources were probably to the north and to the west of Kalgoorlie and therefore not associated with the KCGM Operations.

Table 10 presents the average PM₁₀ concentrations recorded at each of the ambient BAM and E-BAM monitoring sites over the period 25 May to 9 August 2007. The average PM₁₀ concentrations for all of the monitoring stations are very similar and of similar magnitude to the longer term average concentrations recorded at the BSY and HGC BAM monitoring sites.

Table 10: Average PM₁₀ Concentrations Recorded at the Ambient Monitoring Stations - 25 May to 9 August 2007

Monitoring Site	Average Concentration (µg/m ³)
Hewitt St (HEW)	17.8
Clancy St (CLY)	18.3
Hopkins St (HOP)	15.2
Boulder Shire Yard (BSY)	17.7
Hannan's Golf Club (HGC)	18.0

Notes: Only available data used to determine the average concentration

The available monitoring data indicates that there are periodic exceedances of the NEPM PM₁₀ standard and that in general the sites are in compliance with the NEPM goal of no more than five exceedance days in any one year. An exception to compliance with the NEPM goal has occurred during 2007 where eight exceedances have been recorded at the HGC site. Many of these exceedances are likely to be associated with localized roadwork activities in the period January to April 2007 and are therefore not considered to be representative of the background PM₁₀ concentrations. An analysis of the days where the NEPM PM₁₀ standard was exceeded indicates the majority are associated with regional dust storms and potentially smoke from wood heaters. One of the days where the NEPM PM₁₀ standard was exceeded at BSY is associated with winds from KCGM's Fimiston Operations but in general the particulate emissions from KCGM's Fimiston Operations are not resulting in significant ambient PM₁₀ concentrations.

5. AIR DISPERSION MODELLING OF PARTICULATE EMISSIONS

Air dispersion modelling has been completed for KCGM's point source emissions of mercury (Gidji Roaster and Fimiston Carbon Regeneration Kilns) and for the fugitive dust emissions from the Fimiston Operations.

5.1 MERCURY EMISSIONS

The air dispersion modelling of KCGM's point source emissions of mercury was completed by ENVIRON (2006a). The report summary was as follows:

“The air dispersion model CALPUFF has been used to predict the annual average ground level concentrations of mercury resulting from the Gidji Roaster and the Fimiston Carbon Regeneration Kilns in the Kalgoorlie-Boulder residential area.

The results of the modelling are likely to be very conservative (i.e. more likely to over- than under-estimate the potential health risks), and indicate the following:

- 1 the annual average ground level concentrations of mercury predicted in the Kalgoorlie-Boulder residential area comfortably comply with the USEPA's IRIS and the WHO guidelines;
- 2 while the Californian OEHAA 1-hour (or acute exposure) guideline is predicted to be approached on the edge of Kalgoorlie, to the west of the Fimiston Carbon Regeneration Kilns, the conservative assumptions used in deriving the emissions means this is unlikely to occur; and
- 3 emissions from the Fimiston Carbon Regeneration Kilns are predicted to result in higher ground level concentrations in the Kalgoorlie-Boulder residential area than the Gidji Roaster due to its closer proximity to the residences.

Based on the results of the modelling it can be concluded that the emissions of mercury from the Gidji Roaster and the Fimiston Carbon Regeneration Kilns are not expected to result in any acute (i.e. short-term) or chronic (i.e. long-term) health affects in the Kalgoorlie-Boulder residential area.”

This mercury modelling did not consider the potential cumulative impacts between the point source emissions of mercury and the mercury contained in the fugitive particulate emissions from the Fimiston operations. As presented in Section 2, typically the waste rock from the Fimiston Open Pit contains very low mercury concentrations at around 0.00001% by weight. The percentage of mercury present in the ore within the Fimiston Mill circuit (after flotation) is around 0.00010% while the overall concentration of mercury in ore is 0.00014%.

The analysis of metal concentrations in TSP filter papers presented in Section 3 found that the typical level of mercury present in the dust samples was around 0.002%, or less than 0.01 $\mu\text{g}/\text{m}^3$, over a 24-hour period. This calculated 24-hour average mercury concentration is less than 1% of the WHO

annual average guideline. Therefore, it is concluded that mercury contained in the fugitive dust emissions from KCGM’s Operations represent a very small and negligible environmental and health risk. As such, the results of the air dispersion that only considered mercury emissions from the Gidji Roaster and the Fimiston Carbon Regeneration Kilns would not be significantly changed by including mercury from the fugitive dust emissions.

5.2 PREDICTED AMBIENT IMPACTS OF FUGITIVE PARTICULATE EMISSIONS

Air dispersion modelling of the fugitive emissions from KCGM’s Fimiston Operations was undertaken as part of the PER for the extension of the Fimiston Operations and was reported in ENVIRON (2006b). Since the fugitive dust modelling was completed for the PER, further work has been undertaken relating to the quantification of the particulate emission rates from each of the Fimiston sources that were modelled. This review has resulted in a reduction of the influence of the Fimiston Open Pit and an increase in the influence of the Fimiston Waste Rock Dumps on the predicted ground level concentrations. The maximum 24-hour and annual average predicted ground level concentrations of particulate are presented in Figures 4 and 5 for the existing operations and following the implementation of the Fimiston Extension. The predicted ground level concentrations at both BSY and HEW are similar to those presented in the PER and the HEW monitoring site continues to be the site with the greatest predicted concentrations.

The current modelling indicates that the proposed North-West Waste Rock Dump is predicted to be a large contributor to the impacts at the HEW monitoring site due to its close proximity. Figure 6 presents the maximum predicted 24-hour average ground level concentrations without the North-West Waste Rock Dump included. This highlights the need for continued implementation of strong dust management practices at KCGM’s Fimiston Operations.

A summary of the modelling results for HEW and BSY are presented in Table 11

Table 11: Predicted Maximum and 99.5th Percentile 24-hour Average and Annual Average PM₁₀ Concentrations for HEW and BSY

	24-hour Maximum (µg/m ³)	99.5th Percentile 24-hour (µg/m ³)	Annual Average (µg/m ³)
Boulder Shire Yard			
Existing	41	39	8.3
Proposed	45	43	9.2
Hewitt St			
Existing	77	72	18.9
Proposed	61	59	16.4

The predicted concentrations presented in Table 11 are not inconsistent with the ambient monitoring data presented in Section 4 when it is considered that the modelling results are only for KCGM's Fimiston Operations in isolation. The average concentration recorded at BSY over the two year period that was reviewed was around $18 \mu\text{g}/\text{m}^3$, or approximately $10 \mu\text{g}/\text{m}^3$ greater than that predicted by the modelling. Therefore, for the purposes of the HRA, it has been assumed that the annual average PM_{10} concentration at Hewitt St is approximately $28.9 \mu\text{g}/\text{m}^3$.

6. HEALTH RISK ASSESSMENT OF METALS IN FUGITIVE EMISSIONS

6.1 OVERVIEW OF SCREENING HEALTH RISK ASSESSMENT

Risk assessment provides a systematic approach for characterising the nature and magnitude of the risks associated with environmental health hazards, and is an important tool for decision-making (enHealth, 2002). The generic steps involved in health risk assessment (HRA) include:

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;

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);

Risk Characterisation: the combining of exposure and toxicity data to estimate the magnitude of potential health risks associated with exposure periods of interest; and

Uncertainty Assessment: identification of potential sources of uncertainty and qualitative discussion of the magnitude of uncertainty and expected effects on risk estimates.

This HRA conducted for the metals present in the fugitive emissions from the Fimiston Operations is considered to be a screening-level assessment in that it makes generally conservative assumptions regarding the potential magnitude of exposure and uses conservative toxicity criteria. 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. 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 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.

6.2 EXPOSURE ASSESSMENT

6.2.1 Metals Considered

This screening health risk assessment is focussed on metals that are present in the ambient particulate samples. The metals considered are:

- 1 Arsenic;
- 2 Barium;
- 3 Beryllium;
- 4 Cadmium;
- 5 Chromium;
- 6 Cobalt;
- 7 Copper;
- 8 Lead;
- 9 Manganese;
- 10 Mercury;
- 11 Nickel;
- 12 Selenium;
- 13 Silver; and
- 14 Zinc.

6.2.2 Ambient Concentrations of Metals at Hewitt St

The ambient concentration of the above metals were calculated for the Hewitt St (HEW) location based on the maximum predicted 24-hour and annual average ground level concentrations for the Fimiston Operations Extension (Section 5) and the maximum metal concentrations reported from the 2006 sample analysis (Section 3) and these are presented in Table 12. It is considered that these assumptions will result in a very conservative estimate (i.e. more likely to over- than under-estimate the potential health risks) of ambient particulate metal concentrations.

Table 12: Estimated Maximum 24-hour and Annual Average PM₁₀ Metal Concentrations for the Fimiston Operations Extension

		Maximum Predicted PM ₁₀ Concentrations (µg/m ³)	
		24-hr	Annual
Hewitt St		77	28.9
Metal	Max. Metal Concentration	Maximum PM ₁₀ Metal Concentrations For Hewitt St (µg/m ³)	
		24-hour	Annual
Arsenic	0.0019%	0.001	0.001
Barium	0.2570%	0.198	0.074
Beryllium	0.0000%	0.000	0.000
Cadmium	0.0006%	0.000	0.000
Chromium	0.0215%	0.017	0.006
Cobalt	0.0099%	0.008	0.003
Copper	0.0077%	0.006	0.002
Lead	0.0574%	0.044	0.017
Manganese	0.0405%	0.031	0.012
Mercury	0.0020%	0.002	0.001
Nickel	0.0293%	0.023	0.008
Selenium	0.0000%	0.000	0.000
Silver	0.0005%	0.000	0.000
Zinc	0.0866%	0.067	0.025

6.2.3 Receptor Location

This screening level health risk assessment has focused on the HEW monitoring site as this is predicted to be the greater affected receptor as a result of the fugitive emissions as a result of the Fimiston Operations Extension (refer to Section 5.2).

6.2.4 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 (US EPA, 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 and Last, 1996). No data indicates that absorption of particulates occurs in the upper airways. From an analysis of human experimental data, the US EPA (1989) 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 (2005a, b) interpreted the US EPA (1989) 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). 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 6.4.7.

CEH (2005) also tested soil samples for the bioavailability of metals and the results for the Kalgoorlie residential samples are presented in Table 13. The data presented in Table 13 indicates that the bioavailability of the metals varies widely from around 1.2% for chromium up to around 73% for lead.

Table 13: Kalgoorlie Residential Bioavailability Summary Data (All Values mg/kg)

Element	Mean	Standard Deviation	Median	Minimum	Maximum	% of total metal
Arsenic	2.1	1.4	1.5	0.8	4.4	9.9
Boron	7.7	3.5	8.5	2.4	12.0	40.1
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	19.2	11.3	15.0	7.0	33.0	41.1
Iron	1242.5	462.0	1300.0	620.0	1800.0	-
Lead	81.5	111.9	32.0	3.4	310.0	72.9
Manganese	189.4	70.4	185.0	75.0	310.0	58.4
Nickel	7.4	2.5	7.2	4.1	12.0	14.9
Sulphur	166.1	175.8	135.5	18.0	560.0	-
Zinc	180.9	183.8	123.5	30.0	560.0	63.9

Notes:

1. All mercury and selenium values were below the limit of detection of 0.05 mg/kg.
2. For all values, below the respective limits of detection, the upper bound detection limit has been adopted as a conservative approach.

Source: Centre for Environmental Health (2005)

6.2.5 Potential Exposure Pathways and Estimated Concentrations in Air

This screening level health risk assessment has only considered the inhalation exposure pathway.

The 24-hour and annual average ground level concentrations of particulate at Hewitt St used in this health risk assessment were predicted by the air dispersion modelling discussed in Section 5.2. The maximum and average metal concentrations in the particulates (Section 3.3) were then used to calculate the 24-hour and annual average metal concentrations at Hewitt St.

6.3 TOXICITY ASSESSMENT

The toxicity assessment determines the relationship between the magnitude of exposure to a chemical of interest and the nature and severity of adverse health effects that may result from such exposure. 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. Health protective guidelines from the following reputable authorities were considered for use in the screening assessment:

- National Environment Protection (Ambient Air Quality) Measure (NEPC, 1998);
- World Health Organisation (WHO) Air Quality Guidelines for Europe Second Edition (WHO, 2000);
- Guidelines for Air Quality (WHO, 2000a)
- 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;
- Dutch National Institute of Public Health and the Environment (RIVM) human-toxicological Maximum Permissible Risk Levels (RIVM, 2001);
- Health Canada’s health-based Tolerable Daily Intakes/Concentrations and Tumorigenic Doses/Concentrations for priority substances (Health Canada, 1996); and

- California Office of Environmental Health Hazard Assessment's (OEHHA) Toxicity Criteria Database.

Health protective guidelines published by the National Environment Protection Council (NEPC), followed by the WHO, have been applied in preference to the other health protective guidelines listed above. This is consistent with the enHealth Guidelines for Assessing Human Health Risks from Environmental Hazards (2002), and consistent with advice previously received by ENVIRON from the Department of Health (Western Australia).

For those compounds not covered by the NEPC or WHO, the guidelines most recently determined (on an individual compound basis) by the USEPA (IRIS), ATSDR, RIVM and Health Canada have been applied, on the basis that the most recent guidelines are most likely to have been developed from the most up-to-date toxicological information.

The OEHHA guidelines have been applied for the compounds not covered by the other health protective guidelines. The other published guidelines have been used in preference to the OEHHA as the OEHHA guidelines are not applicable at a national level whilst the other health protective guidelines are. Also the OEHHA guidelines tend to be based upon values published by other reputable authorities rather than being developed from first principles based on results of actual toxicological studies. The OEHHA guidelines are, however, considered useful for the HRA in that they are one of the few sources that publish acute health protective guidelines for a comprehensive list of compounds.

The health protective guidelines applied within the HRA are presented in Table 14, and are briefly discussed in the following sections.

Table 14: Health Protective Guidelines

Compound Name	Guideline	Units	Averaging Period	Reference
Acute Health Effects				
Particulate matter < 10 µm	50	µg/m ³	24 h	NEPC
Nickel	6	µg/m ³	1 h	OEHHA
Mercury	1.8	µg/m ³	1 h	OEHHA
Copper	100	µg/m ³	1 h	OEHHA
Chronic Non-Carcinogenic Health Effects				
Arsenic	0.03	µg/m ³	Annual	OEHHA
Selenium	20	µg/m ³	Annual	OEHHA
Manganese	0.15	µg/m ³	Annual	WHO
Cadmium	0.005	µg/m ³	Annual	WHO
Chromium (VI)	0.1	µg/m ³	Annual	IRIS
Nickel	0.05	µg/m ³	Annual	OEHHA
Mercury	1	µg/m ³	Annual	WHO
Beryllium	0.02	µg/m ³	Annual	IRIS
Lead	0.5	µg/m ³	Annual	NEPC
Incremental Carcinogenic Risk				
Arsenic	1.50E-03	per µg/m ³	Annual	WHO
Cadmium	1.80E-03	per µg/m ³	Annual	IRIS
Chromium (VI)	4.00E-02	per µg/m ³	Annual	WHO
Nickel	3.80E-04	per µg/m ³	Annual	WHO
Beryllium	2.40E-03	per µg/m ³	Annual	IRIS
Lead	1.20E-05	per µg/m ³	Annual	OEHHA

Note: Only those compounds with a health protective guideline are listed under each category (i.e. acute, chronic non-carcinogenic and carcinogenic).

6.3.1 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. Indeed, increasing evidence suggests that low doses of chemicals generally have beneficial effects, a phenomenon known as hormesis (e.g. Calabrese, 2004). 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 dose level that produces an observable adverse effect (a 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. Thus, 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 will necessarily occur.

6.3.2 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. Although derived from different sources, the guidelines selected for this assessment are all intended to be protective of continually exposed (i.e. residential) receptors, including potentially sensitive subpopulations.

6.3.3 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

6.3.4 Carcinogenic Effects

Cancers are generally defined as diseases of mutation affecting cell growth and differentiation. 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 15.

Table 15: 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 16.

Table 16: IARC Compound Classifications

Compound Name	IARC Classification
Arsenic	1
Cadmium	1
Beryllium	1
Chromium (VI)	1
Lead	2A
Nickel	2B

Health protective guidelines for genotoxic compounds carcinogens are expressed as unit risk (UR) factors. A UR factor is defined as the theoretical upper bound probability of extra cases 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.

6.3.5 Metals Lacking Health Protective Guidelines

Health protective guidelines for inhalation exposure for non-carcinogenic (acute or chronic) and/or carcinogenic health effects published by the reputable authorities used in this study (Section 6.3) were not available for barium, cobalt, silver and zinc.

6.4 RISK CHARACTERISATION

Quantitative health risk indicators have been calculated for potential acute and chronic non-carcinogenic health effects, and carcinogenic health effects for the predicted PM₁₀ concentrations at Hewitt St arising from the Fimiston Operations Extension.

6.4.1 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.

$$HI_{Acute} = \sum^i \frac{C_{\leq 24h}}{Gdl_{Acute}} \quad \text{Equation 1}$$

$$HI_{Chronic} = \sum^i \frac{C_{Annual}}{Gdl_{Chronic}} \quad \text{Equation 2}$$

Where:

HI_{Acute}	= acute Hazard Index
$C_{\leq 24h}$	= ground level concentration predicted 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 ($\mu\text{g}/\text{m}^3$)

For this HRA the acute air concentration used to calculate the acute HI has been based upon the maximum 24-hour average ground level concentration predicted by the air dispersion modelling.

A general rule of thumb for interpreting the HI (Toxikos, 2003) 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.

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).

$$Risk = \sum_1^i C_{i Annual} \times \frac{EF \times ED}{AT} \times UR_i = \sum_1^i C_{i Annual} \times UR \quad \text{Equation 3}$$

Where:

- Risk* = lifetime incremental total cancer risk
- C_{Annual}* = annual average ground level concentration for compound (µg/m³)
- EF* = exposure frequency (365 days/year)
- ED* = exposure duration (70 years)
- AT* = averaging time (365 days/year x 70 years, or 25,550 days)
- UR_i* = Unit Risk factor for compound (per µg/m³)

The incremental carcinogenic risk that is considered acceptable varies amongst jurisdictions, typically ranging from one in a million (1x10⁻⁶) to one in ten thousand (1x10⁻⁴). The most stringent criterion of one in a million represents the USEPA’s *de minimis*, or essentially negligible incremental risk level, and has therefore been adopted for this screening assessment as a conservative (i.e. health protective) indicator of acceptable carcinogenic risk.

6.4.2 Acute Non-Carcinogenic Effects

The calculated acute non carcinogenic HI resulting from metals in particulates for Hewitt St is presented in Table 17 and this shows that the overall HI is much less than one and presents no cause for concern.

Table 17: Calculated Acute HI for Hewitt St

Metal	Acute HI
Copper	0.0001
Mercury	0.0016
Nickel	0.0071
Total	0.0088

6.4.3 Chronic Non-Carcinogenic Effects

The calculated chronic non-carcinogenic HI resulting from metals in particulates for Hewitt St is presented in Table 18. The data indicates that nickel is the dominant contributor (43%) to the overall HI for Hewitt St but that the total HI is less than one and therefore presents in cause for concern.

Table 18: Calculated Chronic HI for Hewitt St

Metal	Chronic HI
Arsenic	0.0185
Cadmium	0.0326
Chromium	0.0620
Lead	0.0332
Manganese	0.0780
Mercury	0.0006
Nickel	0.1695
Total	0.3944

6.4.4 Carcinogenic Effects

The calculated ICR resulting from metals in particulates for Hewitt St is presented in Table 19. The total calculated IC is 4.55×10^{-6} which is higher than the US EPA *de minimis* criterion but is below the criteria used by some jurisdictions. Nickel and arsenic are the largest contributors to the overall ICR.

Table 19: Calculated ICR for Hewitt St

Metal	ICR
Arsenic	8.34E-07
Cadmium	2.93E-07
Lead	1.99E-07
Nickel	3.22E-06
Total	4.55E-06

The ICRs presented in Table 19, have not considered the bioavailability of the metals. Data presented by Centre for Environmental Health (2005) indicates that the bioavailability of arsenic, lead and nickel in the Kalgoorlie soils was approximately 10%, 73% and 15% respectively. The application of these factors to the ICR values presented in Table 19, reduces the total ICR to 1×10^{-6} .

It should also be noted that the ICRs in Table 19 were calculated using the maximum recorded metal concentrations in any 24-hour period. Consideration of the average metal concentrations in all samples, which is more typical of a life-time exposure, reduces the calculated ICR to 7.5×10^{-7} without consideration of the bioavailability of metals. In this case, nickel contributes over 68% of the calculated total ICR and the total cumulative ICR is below the US EPA's *de minimus* level of 1×10^{-6} .

In summary, it is considered that the calculated incremental carcinogenic risk arising from exposure to the metals contained in the ambient particulate samples is likely to be below the US EPA's *de minimis* criterion.

6.4.5 Uncertainties Associated with Calculated Risks

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 emissions).

For this HRA, uniformly conservative assumptions have been used 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.

6.4.6 Variability of Particulate Metal Concentrations

The concentrations of metals present in ambient particulate samples can vary depending upon a number of factors including the source of the particulate. 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 Centre for Environmental Health (2005).

6.4.7 Bioavailability Assumptions Uncertainty

As noted in Section 6.2.4, 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 US EPA (1989), 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 (2005b) 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, (US EPA, 1989), this statement 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 characterized airway deposition, retention, or net absorption of cadmium following inhalation exposure to cadmium particulate. ATSDR's review of animal data (ATSDR, 1999a) 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, 1999a) 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 US EPA (1989), 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, 2000). 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 US EPA (1989) 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 volatilizes 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, 1999b). Analyses of blood, plasma, and urine in humans exposed by inhalation provide an estimate of absorption that ranges between 69% and 80% (ATSDR, 1999b; Hirsch *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 16.

Table 16: Absorption of Metals After Inhalation Exposure.

Metal	Absorption (expressed as a percentage of total particulate concentration in ambient air)	Primary Sources
Arsenic	30% to 60 %	ATSDR (2005a); US EPA (1989)
Nickel	25% to 35 %	ATSDR, 2005b; US EPA (1989)
Cadmium	15% to 60 %	ATSDR (199a); Nordberg <i>et al.</i> (1985); US EPA(1989)
Selenium	30% to 60 %	ATSDR (2003); US EPA (1989)
Manganese	30% to 60 %	ATSDR (2000); US EPA (1989)
Mercury	69% to 80 %	ATSDR (1999b); Hursch <i>et al.</i> (1976); Sandborgh-Englund <i>et al.</i> (1998).

6.4.8 Exposure Assumptions Uncertainty

To calculate the incremental carcinogenic risk it has been assumed that residences located at the key receptor locations spend every hour of every day outdoors at that location for 70 years. Clearly, these exposure conditions are unlikely to be realised, with the actual exposure concentration resulting from the emissions from the Fimiston Operations typically expected to be lower in the indoor environment than that experienced in the outdoor air, and the exposure frequency (i.e. days per year) and exposure duration (years) likely to be considerably lower as people move about.

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.

6.4.9 Toxicity Assessment Uncertainty

A further uncertainty associated with the HRA is related to the derivation of the health protective guidelines. Health protective guidelines published by reputable authorities have been applied within this assessment and have been derived by applying various conservative (i.e. health protective) assumptions. The extrapolation of animal bioassay results or occupational exposure studies to human risk at much lower levels of exposure involves a number of assumptions regarding effect threshold, interspecies extrapolation, high- to low-dose extrapolation, and route-to-route extrapolation. 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 very significant overestimation of risk.

6.4.10 Risk Characterisation Uncertainty

It should be 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.

6.4.11 Potential Synergistic Impacts

The Centre for Environmental Health (2007) undertook a review of the potential synergistic impacts that may occur as a result of exposure to metals and the findings are outlined 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 (US EPA 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 2004, 2007). 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 (eg 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 (eg 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 (US EPA 2004).

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

An assessment of the concentration of metals in ambient particulate samples collected during 2006 has been completed. The results of this assessment indicate that the metal concentrations in the ambient particulate samples are generally consistent with those found in the surrounding soils and Fimiston waste rock.

Air dispersion modelling of the fugitive emissions from the Fimiston Operations Extension completed for the PER was also revised to such that a more realistic contribution to the predicted ambient concentrations occurred from the waste rock dumps. The revised modelling resulted in the prediction of similar maximum 24-hour and annual average ground level concentrations as the model results presented in the PER but the Fimiston Open Pit had a significantly reduced contribution.

A review of two years of ambient PM₁₀ data collected at the Boulder Shire Yard (BSY) and Hannan's Golf Club (HGC) monitoring sites indicates that the annual average PM₁₀ concentrations are both approximately 18 µg/m³ and that the 24-hour average concentrations are generally in compliance with the NEPM goal. The HGC monitoring site recorded 14 exceedences of the NEPM 24-hour average standard (50 µg/m³) over the two year period (1 August 2005 to 31 July 2007) while eight exceedences were recorded at BSY over the same period. Many of these HGC exceedences recorded in 2007 (eight of the 14) are likely to be associated with localized roadwork activities during the period January to April 2007 and are therefore not considered to be representative of the background PM₁₀ concentrations. An analysis of the days where the NEPM PM₁₀ standard was exceeded indicates the majority of the exceedance days were associated with regional dust storms and smoke from wood heaters. One of the days where the NEPM PM₁₀ standard was exceeded at BSY is associated with winds from KCGM's Fimiston Operations. However, in general the PM₁₀ emissions from KCGM's Fimiston Operations are not resulting in significant ambient PM₁₀ concentrations.

In May and June 2007, E-BAM PM₁₀ monitors were installed at the Hewitt St, Hopkins St and Clancy St monitoring sites. The data collected from these sites up to 10 August 2007, in addition to the data collected at the BSY and HGC monitoring sites over the same period were also reviewed and showed that that average PM₁₀ concentration was around 18 µg/m³ for all of the sites except the Hopkins St site that averaged 15 µg/m³. The Hewitt St monitoring site recorded one exceedance of the NEPM 24-hour average standard (6 August 2007) and this also corresponded with an exceedance recorded at the HGC monitoring site. A review of the wind data collected over the period that the elevated concentrations were recorded indicated that they occurred under strong westerly winds. Based on these winds and that the 24-hour exceedences were recorded only at HGC and Hewitt St, it is likely that the sources of the particulates were to the north and west of Kalgoorlie and not associated with the KCGM Operations.

The maximum and average metal concentrations in the ambient particulate samples, together with the maximum predicted 24-hour and the annual average PM₁₀ concentrations were used as inputs to a screening level health risk assessment. The screening health risk assessment used ambient air quality guidelines published by reputable authorities and found that the acute and chronic non-carcinogenic hazard indices were not of any concern being well below one.

In terms of the incremental carcinogenic risk, use of the maximum metal contents and assuming that all of the metals were bioavailable, resulted in a calculated ICR of 4×10^{-6} with nickel, and to a lesser extent arsenic, being the most significant contributors. However, consideration of the potential bioavailability of these metals or the use of the average metal concentrations in the ambient particulates both resulted in the ICR falling below the US EPA *de minimis* criterion of 1×10^{-6} . Nickel, which is the most significant contributor to the ICR, was found to occur at similar levels in the Kalgoorlie and Gidji soils as the concentrations in the ambient particulate samples.

In summary, the screening health risk assessment has indicated that nickel is the major contributor to the potential health risks associated with inhalation exposure to metals in the ambient particulate samples. However, the screening health risk assessment has found that the predicted metal concentrations will not result in unacceptable acute or chronic no carcinogenic hazards. Further, the incremental carcinogenic risks are also predicted to be below the US EPA *de minimis* criterion when realistic, but still conservative, data are considered.

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Figures



Figure 1

Location of the Ambient Dust Monitoring Stations (Green dots) and Meteorological Monitoring (Red dots)

Client: KCGM		
Project: Particulate Metals	Drawn: BPB	Date: 28 August 07

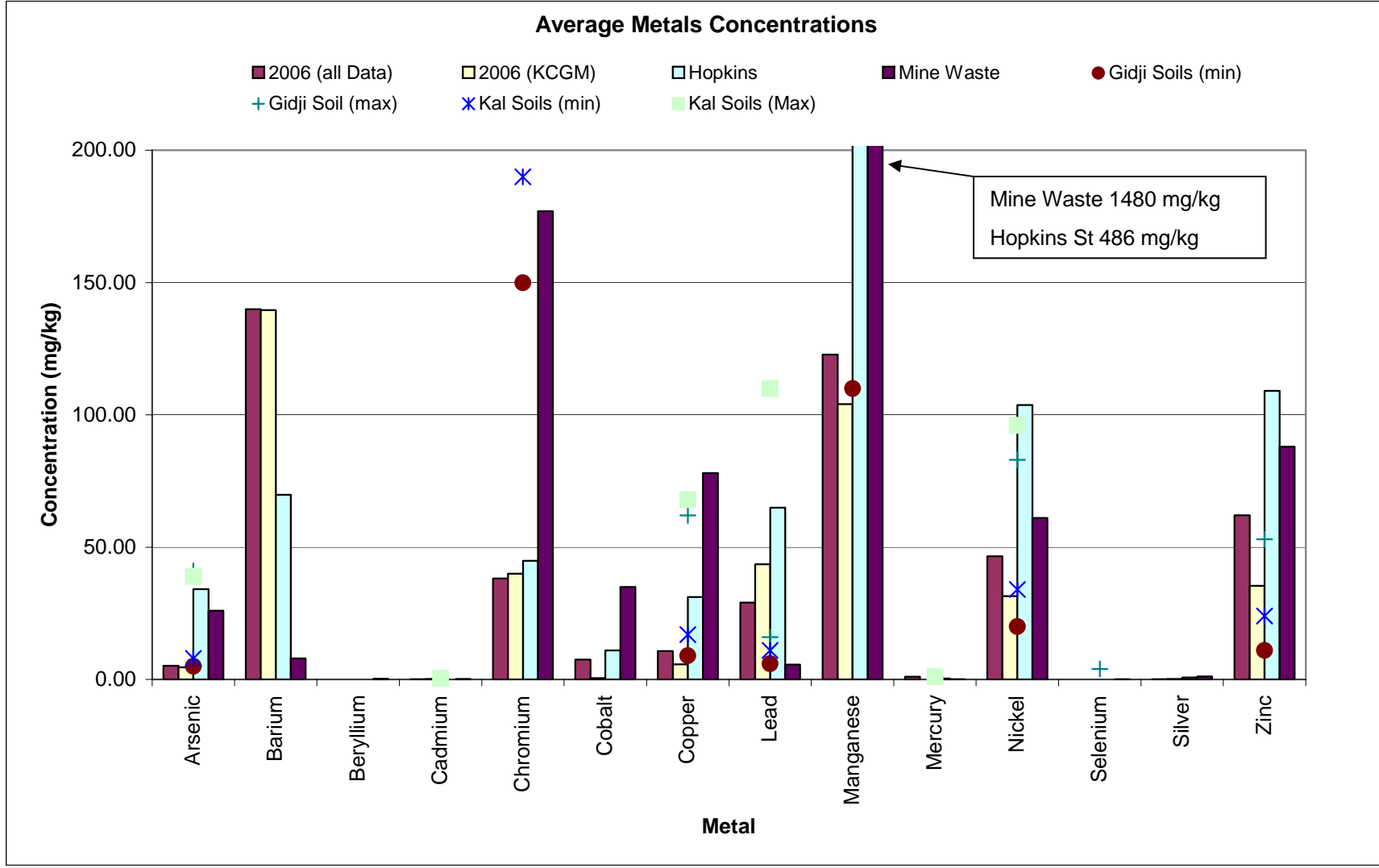


Figure 2: Metals Concentrations in TSP Samples, Soil Samples and Fimiston Mine Waste

Client: KCGM	ENVIRON	
Project: Particulate Metals	Drawing Ref: BPB	Date: 28 Aug 07

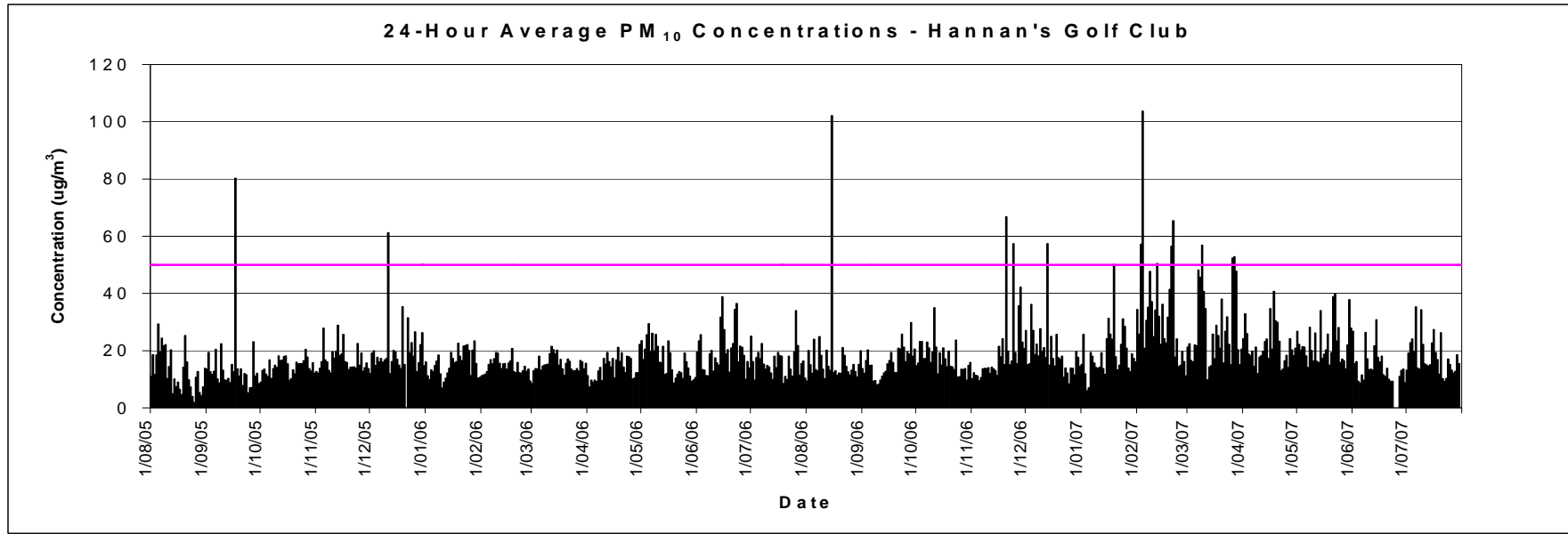
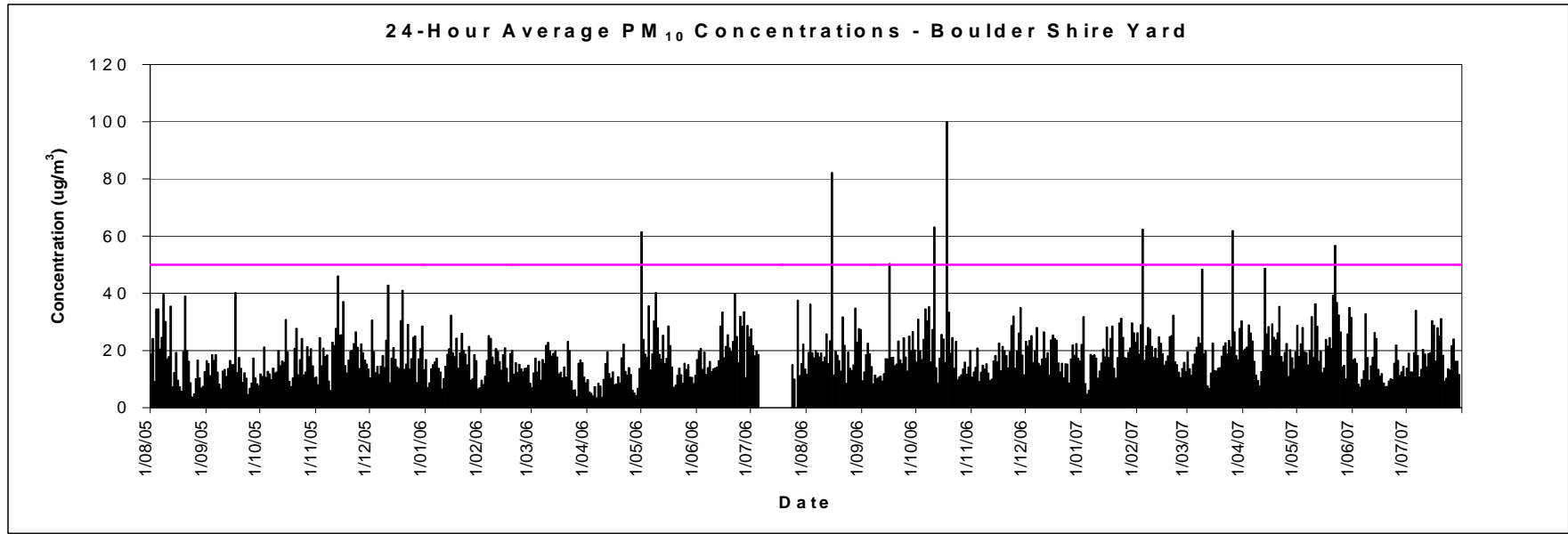


Figure 3: 24-Hour Average PM₁₀ Concentrations Recorded at Boulder Shire Yard and Hannan's Golf Club. 1 August 2005 to 31 July 2007

Client: KCGM	ENVIRON	
Project: Particulate Metasl	Drawing Ref: BPB	Date: 28 Aug 07

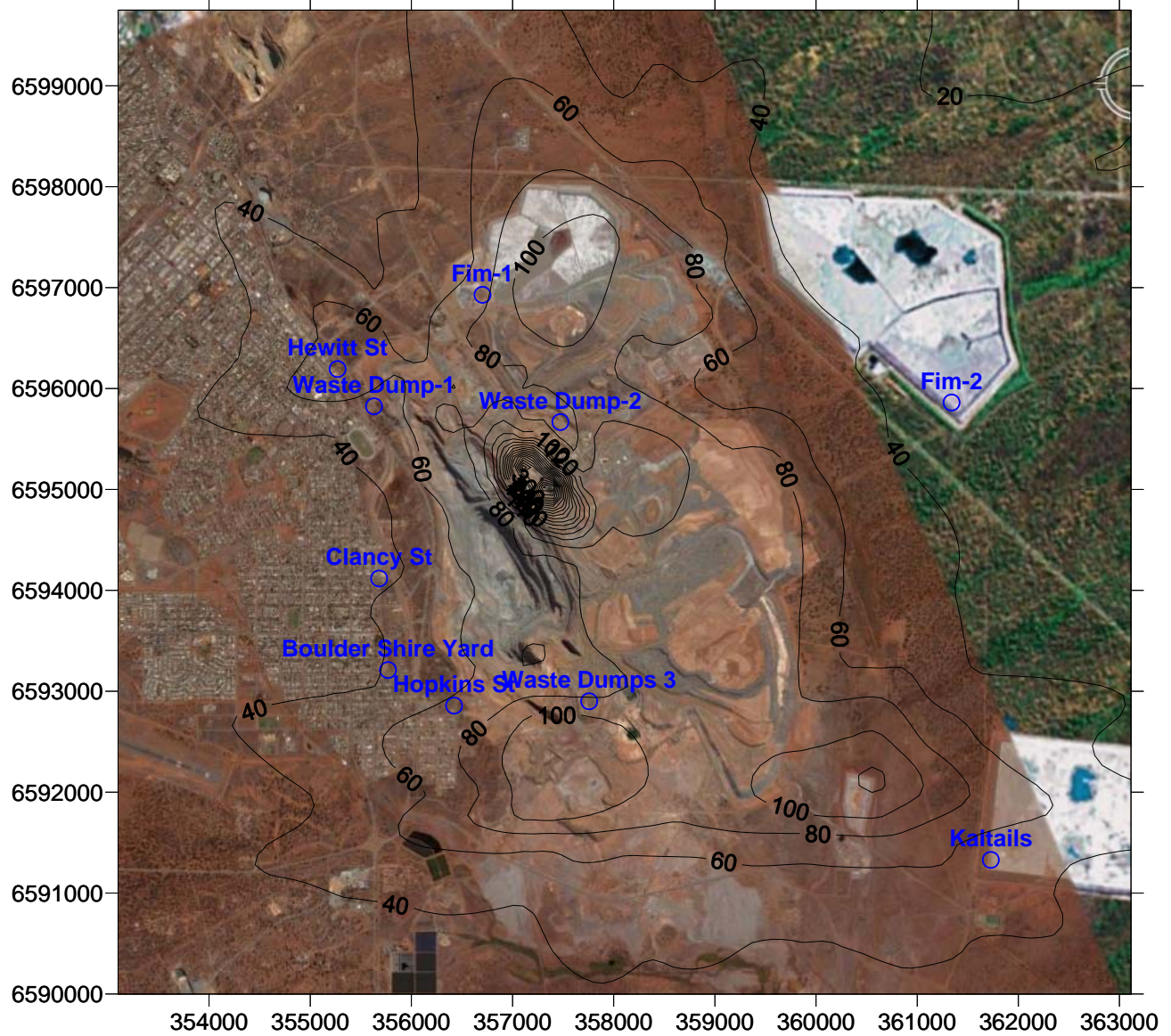


Figure 4

Predicted Maximum 24-Hour Average PM₁₀ Concentrations Resulting from KCGM's Existing Fimiston Operations in Isolation (µg/m³)

Client: KCGM		
Project: Particulate Metals	Drawn: BPB	Date: 28 August 07

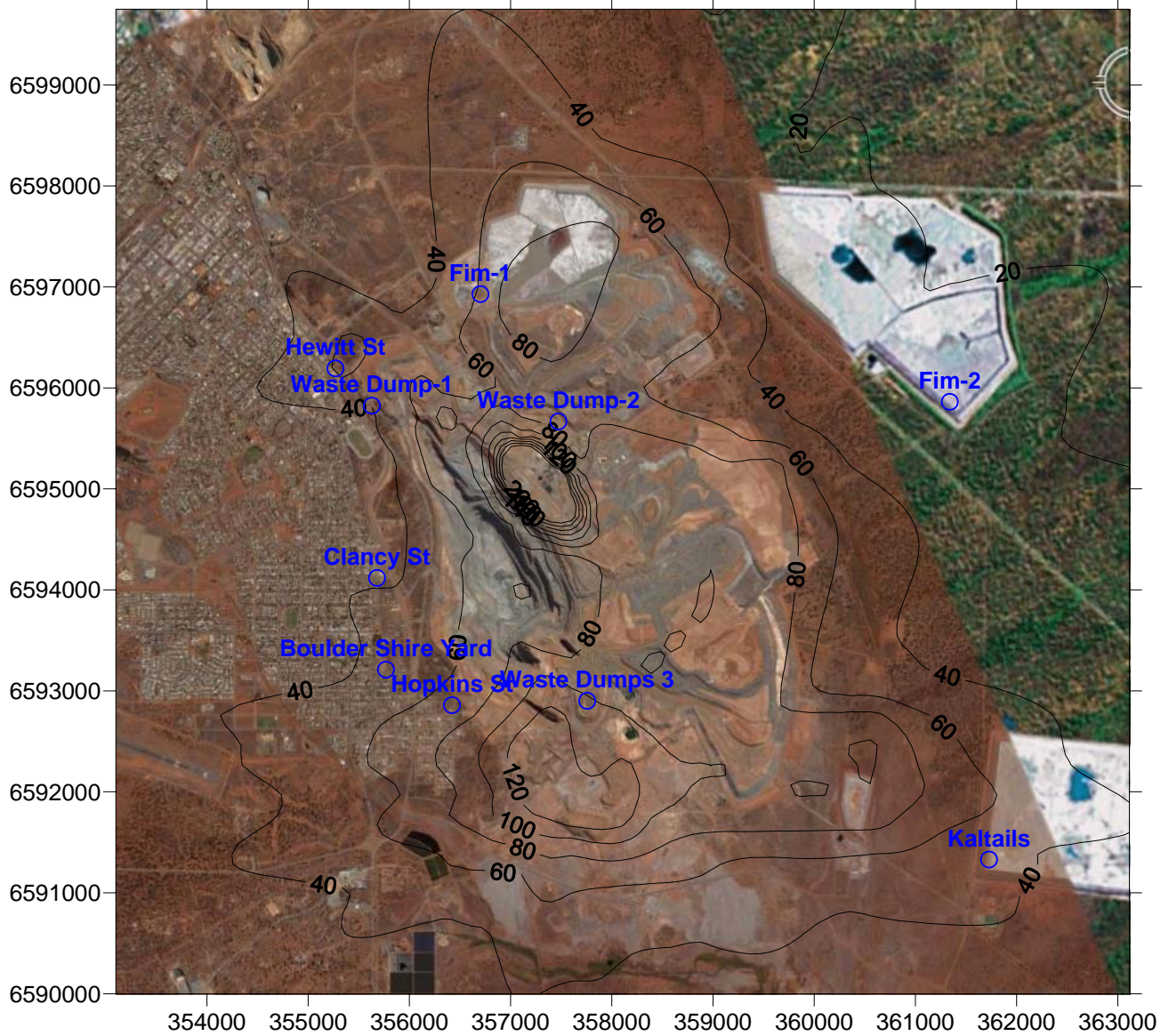


Figure 5

Predicted Maximum 24-Hour Average PM_{10} Concentrations Resulting from KCGM's Fimiston Operations in Isolation Following the Implementation of the Fimiston Extension ($\mu g/m^3$)

Client: KCGM		
Project: Particulate Metals	Drawn: BPB	Date: 28 August 07

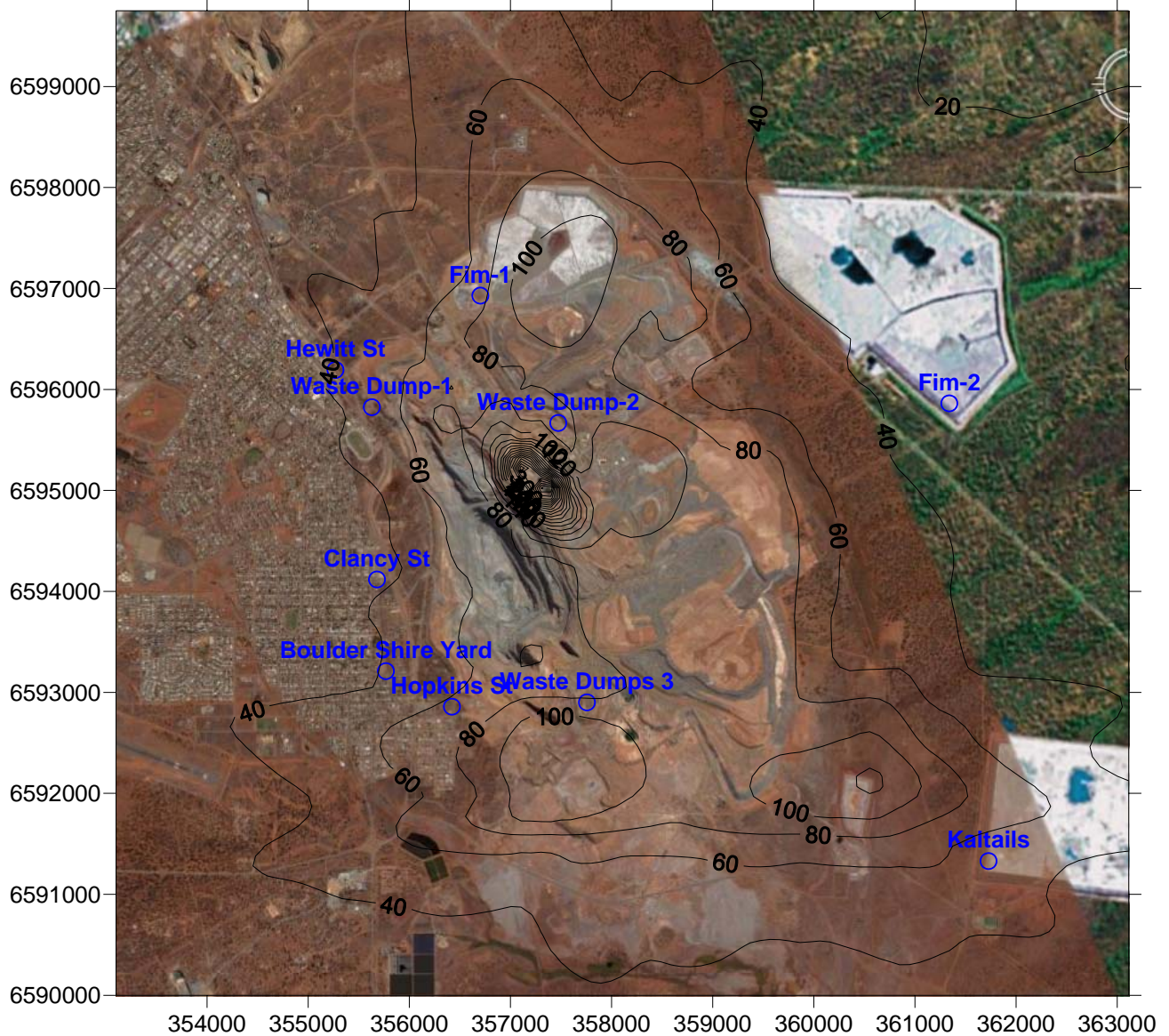


Figure 6

Predicted Maximum 24-Hour Average PM₁₀ Concentrations Resulting from KCGM's Exiting Fimiston Operations in Isolation without the North Western Waste Dump (µg/m³)

Client: KCGM		
Project: Particulate Metals	Drawn: BPB	Date: 28 August 07