October 2015

ALLIANCE LORNEVILLE

Assessment of Coal-Fired Boiler Air Emissions

Submitted to:
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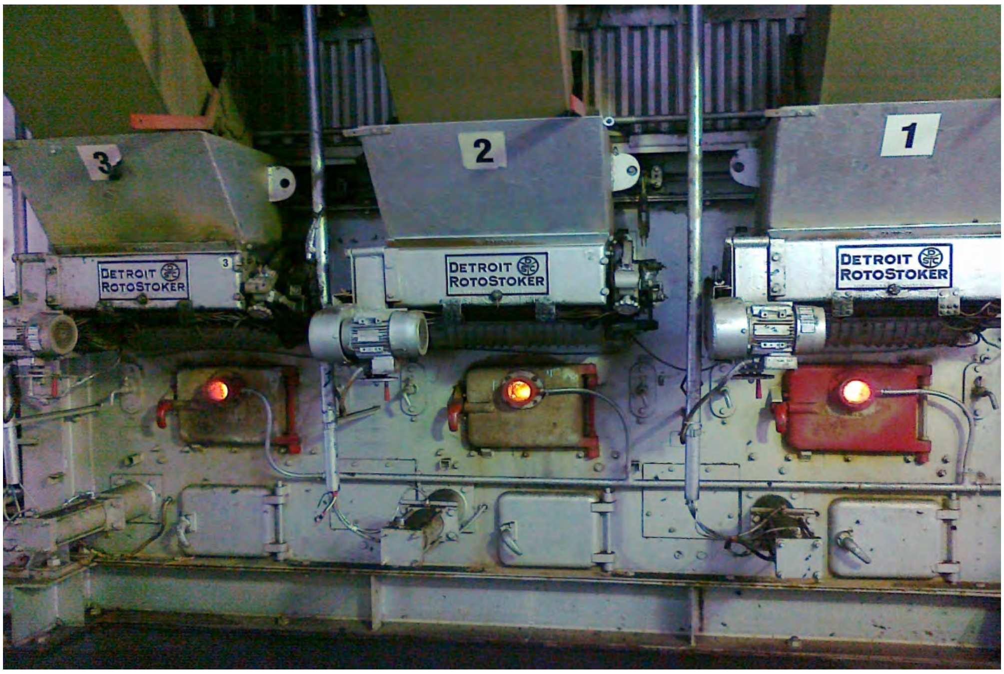

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1.0 INTRODUCTION

This report[1] presents an assessment of effects resulting from air contaminants discharged from two coal-fired boilers operated at the Alliance Group Limited (Alliance) meat processing and export plant at Lorneville, Southland. The site is approximately 3 km north of the residential area of Invercargill City and located off the Lorneville-Wallacetown highway as shown in Figure 1. The processing site is one of the largest ovine meat processing sites in the world and has operated at this location since 1960.

Alliance holds an existing resource consent (Environment Southland Consent No. 95077) that authorises air discharges from the site, which expires on 7 August 2016. This consent authorises the discharges to air from the operation of two coal-fired steam boilers. This report will form part of an assessment of effects (AEE) and an associated application for renewal of the site's existing air discharge consent. The application is planned for lodgement with the Southland Regional Council in late 2015. Alliance operate a small 155 kW diesel-fired unit for heating their main administration block. Air contaminant emissions from this unit are considered to be sufficiently small to exclude these from the scope of this assessment.

The objective of this assessment is to ascertain the potential air quality related effects on the surrounding environment that are likely to result from the operation of the site's coal fired boilers (CFBs) given their continued operation under a new long-term consent. A modelling based assessment of short and long term air contaminant exposure concentrations (arising from the boiler discharges and background contaminant levels), combined with directly measured ambient air contaminant levels at a key off-site location, provided the necessary information to evaluate the environmental significance of cumulative air quality in areas surrounding the Alliance site. To support this cumulative air quality impact assessment, direct monitoring of existing background air quality (reported by Golder 2014) was also undertaken.

The scope of this report includes the prediction of ambient air contaminant concentrations due to the coal-fired boiler emissions, their cumulative effects with existing background air quality and mitigation of coal-fired boiler emissions. The air contaminant impacts assessed by this report included common air pollutants (i.e., respirable particulate matter (PM_{10} and $PM_{2.5}$), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2)). Metal contaminant impacts and long-term trace concentrations of dioxin type compounds that arise from most combustion processes are also assessed by this report. Metal deposition has also been assessed.

The current and potential future mitigation of air contaminant emissions from the site's coal-fired boilers is also summarised in this report.

2.0 SITE AND BOILER INFORMATION

Alliance Lorneville is a large, modern meat processing and export plant that primarily processes sheep and lambs (ovine), and bobby calves (bovine), fallen stock and beef renderables. The site is currently the largest ovine processing plant in the world. The plant, and therefore the site boilers, typically operates its main season from early November to July each year. Processing rates reach a peak during the late summer and continue at reduced levels during the winter. Each boiler has a short maintenance shut down usually in June July or August.

The plant processes stock mainly from the surrounding farming areas, but can draw stock from the whole South Island. Processing levels vary from year to year depending on climatic conditions, market demands and competitive pressures. Some items, such as skins and rendering of raw materials, may be transferred to and from the site for additional processing. These transfers usually occur between other Alliance owned plants.

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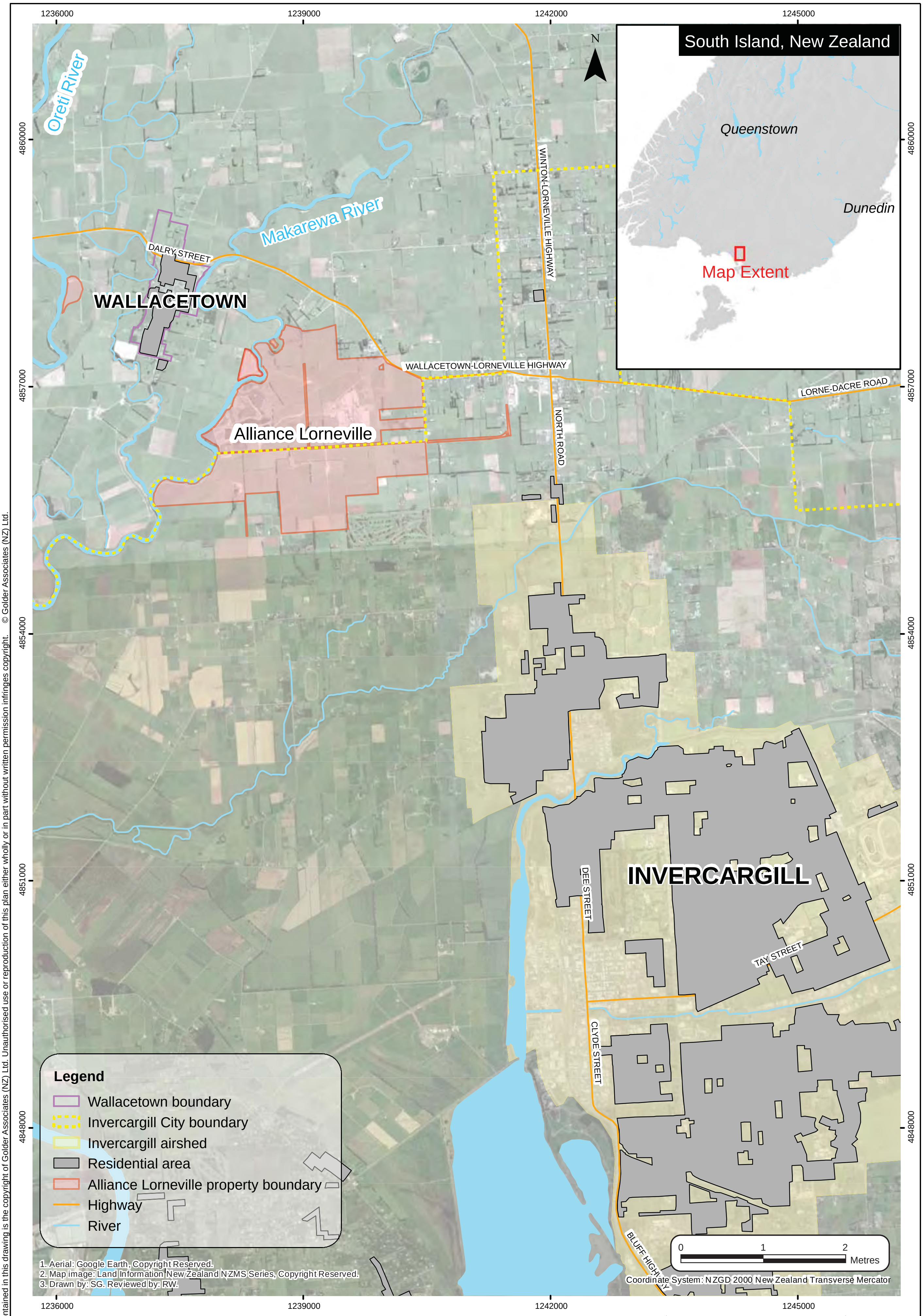
[1] Your attention is drawn to the document "Report Limitations" in APPENDIX A.



1. Aerial: Google Earth, Copyright Reserved.
2. Map image: Land Information New Zealand NZMS Series, Copyright Reserved.
3. Drawn by: SG. Reviewed by: RW.

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Two CFBs are operated on site to meet the site's steam and hot water needs. These include an 18 megawatt (MW) Babcock and Wilcox (B&W) boiler (CFB 1) and a 12.7 MW Foster Wheeler (FW) boiler (CFB 2). The CFBs are fired on a lignite coal that is supplied from the Newvale coal mine. The maximum coal consumption (tonnes/hr) and steam production rates (tonnes/hr) are as follows:

- CFB 1: coal rate 7.23 tonnes/hr and steam output 26.65 tonnes/hr (at 8 Bar)
- CFB 2: coal rate 4.57 tonnes/hr and steam output 18.80 tonnes/hr (at 8 Bar)

The location of the boilers and the processing site layout is shown in Figure 2. The calculation of air contaminant emission rates from each boiler stack and associated stack discharge parameters are described in Section 3.0.

3.0 NATURE OF AIR DISCHARGES

3.1 Introduction

The CFBs produce hot exhaust air streams containing combustion products and particulates. The latter arise due to a wide range of processes including fly ash carry over, un-combusted carbon (soot) and from the condensation of un-combusted organic volatiles.

The main portion of the exhaust consists of nitrogen (N_2) and residual oxygen (O_2) from the combustion air. The primary products of combustion include carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and water vapour. There is also a range of products of incomplete combustion (PICs) that mainly include volatile organic compounds (VOCs), carbon monoxide (CO), nitrogen oxide (NO) and nitrous oxide (N_2O).

The condensation of VOCs within the boiler stack and un-burnt carbon particulates (soot) are a key source of fine respirable particulate ($PM_{2.5}$), whereas PM_{10} and larger suspended particulates are derived from these sources as well larger fractions of fine fly ash and coal fines. VOCs also include trace levels of poly aromatic hydrocarbons and dioxin like compounds.

The metal and mineral composition of coal also results in trace levels of various heavy metals being discharged, mainly in association with particulate emissions, however, a significant proportion of metals are captured in the recovered fly ash. However, mercury is volatile and mostly discharges with the exhaust air as either a gas or as a condensed component of the particulate emissions.

Given the above, the primary air pollutant impacts that were assessed included SO_2, PM_{10}, NO_2, mercury, chromium, lead, arsenic and dioxins / furans. While the discharge of $PM_{2.5}$ was not directly modelled, its ambient impacts can be established from the PM_{10} results and knowledge of the PM_{10} to $PM_{2.5}$ discharge ratio that was established via ambient monitoring data.

Ambient impacts of CO from coal-fired boiler plants site are typically very low when compared against ambient health guidelines and standard and therefore are not assessed in this assessment.

The emissions of greenhouse gases, such as CO_2, do not cause local health effects and are not included in the scope of this assessment. Section 104E of the RMA was inserted into the RMA under the Resource Management Act (Energy and Climate Change) Amendment Act in 2004. This states that when processing resource consent applications for discharges of greenhouse gases to air, a consent authority must not have regard to the effects of the discharge on climate change, except to the extent that the use and development of renewable energy enables a reduction in the discharge into air of greenhouse gases.

The individual boiler plant operates at varying rates throughout the day and year. The assumed operational rates were based on the steam production data for 23 November 2013 to 22 November 2014 and subsequently the dispersion modelling used a real hour by hour varying emissions and stack parameter file. The derivation of contaminant emission rates and other input parameters from maximum boiler output capacities are discussed below and followed by a description of methods used to develop hourly emissions / stack parameter files for each CFB stack.

Label	Name	Label	Name
1	Sheepyards	15	No. 1 engine room & boiler house
2	Biofilter	16	Water treatment
3	tallow and hot water storage	17	Untreated river water reservoir
4a	raw material collection, blood processing and hydrolysers	18	Treated potable water reservoir
4b	low temperature rendering	19	Further processing 5
4c	off-site raw material reception	20	Cooling towers
5	Development Services Building	21	Pallet stores
6	Office	22	Further processing 1 and 2 along with carcase chillers and freezers
7	Main DAF and screens	23	No. 2 engine room and cooling towers
8	Slaughter board & Further processing 3	24	Pallet Store offices
9	Fellmongery	25	Further processing 4
10	Meeting room / union offices	26	Old beef house
11	Laboratory	27	Old cattleyards - bulkshed / storage
12	Workshops	28	Woolshed
13	disused fellmongery saveall	29	Truck wash
14	Garage & workshop	30	Soupstock

Legend

● Boiler stacks
— Building

1. Aerial:Bing Maps.
2. Schematic only, not to be interpreted as an engineering design or construction drawing
3. Drawn by: RW. Reviewed by: SG.

Coordinate System: NZGD 2000 New Zealand Transverse Mercator

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TITLE

PROCESSING SITE LAYOUT

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3.2 Coal Analysis

Newvale lignite is currently used to fire the two CFBs and is projected to be the main fuel supply for the foreseeable future at the Alliance Lorneville site. Test results for this coal's composition and energy content for the period of July 2013 to February 2015 are summarised in Table 1.

Table 1: Newvale coal properties.

Property	Value	Source
Moisture	40.3 %	Average of testing from July 2012 to February 2015
Ash	3.6 %	Average of testing from July 2012 to February 2015
Volatile	30.5 %	Average of testing from July 2012 to February 2015
Fixed Carbon	25.6 %	Average of testing from July 2012 to February 2015
Gross Calorific Value (as received basis)	15.0 MJ/kg	Average of testing from July 2012 to February 2015
Hydrogen (dry basis)	4.8 %	CRANZ 1978
Oxygen (dry basis)	24.4 %	CRANZ 1978
Nitrogen (dry basis)	0.6 %	CRANZ 1978
Sulfur (as received basis)	Min 0.35 % Average 0.41 % Max 0.45 %	Testing from July 2012 to February 2015

3.3 Combustion Stoichiometry

The stack exhaust flow rates (actual and normalised to standard atmospheric pressure and temperature) for each CFB were calculated using stoichiometric equations that utilise the coal's elemental composition and specific coal usage rates. These calculations, combined with knowledge of the excess combustion air or residual exhaust oxygen content (vol. % dry), can be used to accurately calculate the exhaust air flows per unit mass of combusted coal. The maximum coal usage rate for each CFB is established from their respective energy output (tonnes/hour of steam corrected to 8 Bar pressure), the thermal efficiency of the CFBs and the reported energy content (calorific value) of the as-received coal.

Historical stack test results for particulate emissions typically report normalised and actual exhaust air flows including the associated oxygen content. These results were used to confirm that the calculated boiler exhaust flow rates were accurate.

A summary of the stoichiometry calculations are provided in APPENDIX B. The discharge stack parameters determined from these calculations for the CFBs operating at their maximum capacity rating (i.e., 100 % MCR), are summarised in Table 2.

3.4 Particulates

Historical testing of the two CFBs in-stack particulate concentrations showed relatively high TSP concentrations especially within CFB 2 (see APPENDIX H). Stack testing results indicated flow averaged PM_{10} concentrations in the discharge to be above 350 mg/Nm^3. This was consistent with ambient monitoring data that was recorded during the summer / autumn of 2014 and assessed in APPENDIX I.

Table 2: Stack discharge parameters.

Parameter	CFB 1 (B&W)	CFB 2 (FW)
Maximum capacity rating (MW)	18	12.7
Stack height (m)	30.9	34.1
Stack diameter (m)	1.21	0.93
Efflux velocity @ 100 % MCR (m/s)	18	19
Stack oxygen (vol. % dry)	5	5
Efflux temperature (°C)	170[#]	170[*]
Efficiency (%)	70	78
Fuel burning rate (kg/s)	2.01	1.27

Notes: [#] measured as high as 210 °C, but lower temperature assumed to allow for stack cooling and ensure efflux velocity is not overstated.

[*] measured at 180 °C

Following the commissioning of the new multi-clone grit arrestor on CFB 2, subsequent stack testing in February 2015 indicates that the flow average PM_{10} discharge concentration from CFB 1 and 2 is less than 300 mg/Nm^3 (corrected to 12 vol. % CO_2 and dry basis) or less. The associated PM_{10} discharge rates when the CFB's operate at 100 % MCR for a discharge concentration of 300 mg/m^3 are calculated in APPENDIX B and summarised as follows:

- CFB 1: 3.7 g/s (PM_{10})
- CFB 2: 2.3 g/s (PM_{10})

3.5 Nitrogen Dioxide/Oxide

Typically 90 % of oxides of nitrogen (NO_x) mass discharged from a CFB occur in the form of nitrogen monoxide (NO). The remainder of the NO_X discharge (approximately 10 %), is in the form of nitrogen dioxide (NO_2), with trace levels of nitrates (NO_3) that are not considered in this assessment. The mass percentages relate to equivalent weights of NO_2. Therefore NO_2 comprises approximately 10 % of the total NO_x at the stack discharge point.

Once discharged, NO undergoes oxidation within the atmosphere to form NO_2. The proportion of NO to NO_2 conversion post discharge is calculated based on typical ozone background concentrations and distance from the discharge point. The methodology used to calculate the NO conversion rate is documented in APPENDIX C.

The total NO_x emissions from the combustion of coal were calculated using United States Environmental Protection Agency (USEPA) "AP42" emission factors for boilers burning lignite coal (USEPA 1998b, Table 1.7-1). For a spreader stoker boiler (of which both CFB 1 and 2 are), the emission factor for NO_x formation is 2.9 kg of NOx per tonne of coal burned.

Based on the above emission factor and maximum coal burning rates of 7.24 tonnes per hour (t/h) and 4.57 t/hr for CFB 1 and 2 respectively, then the following NO_x emissions rates are calculated:

- CFB No. 1: 5.8 g/s (10 % NO_2 and 90 % NO as NO_2 mass equivalents (100 % MCR))
- CFB No. 2: 3.7 g/s (10 % NO_2 and 90 % NO as NO_2 mass equivalents (100 % MCR))

3.6 Sulfur Dioxide

Alliance's coal supply contract specified the maximum sulfur content of the coal blend to be 0.6 wt.% (as received). This equates to a theoretic SO_2 emission rate of 112 kg/hr assuming 5 % retention of sulfur in the ash. This theoretical rate above was found to significantly over state actual SO_2 emissions from the CFBs, as discussed below.

The test results for coal sulfur content from July 2012 to February 2015 give as-received sulfur contents that range from 0.35 wt.% to 0.45 wt.% with an average of 0.41 wt.% (see APPENDIX F). These values are consistent with other published coal sulfur values for New Vale coal (CANZ 2010).

The ambient SO_2 monitoring undertaken in 2014 indicated that modelling the theoretic maximum discharge rate resulted in predicted hourly ambient concentrations of SO_2 that were approximately 30 % higher than actual measured levels when allowing for actual boiler operating rates (see APPENDIX I). Therefore for this assessment, the peak hourly and daily average SO_2 impacts due to the CFBs were modelled when assuming a combined maximum SO_2 emission rate of 78 kg/hr.

The discrepancy between theoretical maximum SO_2 emission (based on maximum coal sulfur content) and the actual emissions arises for two possible reasons. Firstly the typical coal sulfur content is much lower than the maximum specified in the coal supply contract and there is also the real prospect that sulfur retention within the ash is higher than the 5 % level, which is an old rule of thumb.

Given the above, maximum SO_2 emission rates for each CFB were assumed as follows:

- CFB 1: peak rate of 13.4 g/s
- CFB 2: peak rate of 8.4 g/s

3.7 Dioxins

All combustion processes, both natural and man-made (including domestic wood fires, forest fires etc.), produce trace level of dioxins type compounds. By international convention, the quantity of all dioxin compounds is reported in terms of a toxic equivalency factor (TEF). This enables the test results for complex mixtures of dioxins and furans like compounds to be quoted in terms of the quantity of 2, 3, 7, 8-TCDD that would exhibit the same toxicity. These quantities are expressed as international toxic equivalents (I-TEQ) for a given mixture of dioxin and furans.

The size of the coal-fired boiler is a contributing factor to the extent of I-TEQ emissions per unit of coal combustion or unit of energy release. For this report, the I-TEQ emission factor of 10 micrograms (µg) per Terra Joule (TJ) is assumed to provide an approximate estimation of annual average ambient I-TEQ concentrations due to the CFB operation. This emission factor was assumed for coal-fired boilers above 10 MW output when developing New Zealand's last dioxin emission inventory as reported by MfE (2011b).

3.8 Metal Emissions

Raw data for the various metal and mineral compositions of the lignite coal is summarised in APPENDIX F. This data was combined with the maximum coal burning rates of 2 kilograms per second (kg/s) for CFB No. 1 and 1.3 kg/s for CFB No. 2 to produce maximum hourly emission rates of metal contaminants. These are summarised below in Table 3.

Table 3: Concentrations of metals in coal and subsequent emission rates.

Contaminant	Concentration of metals in coal - recommended value (ppm)†	Boiler 1 emission rate (g/s)	Boiler 2 emission rate (g/s)
Arsenic	2.3	6.6×10^{-4}	4.1×10^{-4}
Cadmium	0.1	4.3×10^{-5}	2.7×10^{-5}
Chromium	2.2	3.0×10^{-4}	1.9×10^{-4}
Lead	0.4	1.5×10^{-4}	9.1×10^{-5}
Mercury	0.06	1.2×10^{-4}	7.6×10^{-5}

Note: † Composition data summarised in APPENDIX F.

3.9 Contaminant Emissions (Maximum Operating Capacity)

A summary of the maximum emission rates for each of the boilers is given in Table 4.

Table 4: Summary of maximum emission rates for the boilers.

Contaminants	Emission rate (g/s)	
	CFB No. 1 (B&W)	**CFB No. 2 (FW)**
SO_2	13.4	8.4
NO_x	5.8	3.7
PM_{10}	3.7	2.3
Lead	1.5×10^{-4}	9.1×10^{-5}
Arsenic	6.6×10^{-4}	4.1×10^{-4}
Cadmium	4.3×10^{-5}	2.7×10^{-5}
Chromium VI	3.0×10^{-4}	1.9×10^{-4}
Chromium metal and Chromium III		
Mercury	1.2×10^{-4}	7.6×10^{-5}
Dioxins (I-TEQ)	259 pg I-TEQ/s	164 pg I-TEQ/s

3.10 Contaminant Emissions and Parameters (Hourly Varying)

The maximum emission rates for contaminants summarised in Table 4 are scaled for each hour of the modelling period based on the operating rate of the boilers for that hour. Therefore, the modelling is completed for a year of hourly varying emissions data that is repeated to cover the two year dispersion modelling period (using meteorological data from 2010 and 2011). These hourly varying contaminant emissions were derived from actual hourly varying steam production data (tonnes/hour) for CFB No. 1 and CFB No. 2 from 23 November 2013 to 22 November 2014. This data period was chosen to reflect the operation of the boilers after the new rendering line was installed and other plant changes (including winter processing) had been implemented. A detailed summary of the method is provided in APPENDIX G.

4.0 RECEIVING ENVIRONMENT

4.1 Introduction

In order to assess the potential effects on the environment from the activities at Alliance Lorneville, it is necessary to identify the nature of the potentially affected environment. It is also useful to generally describe the values that society recognises as being associated with the area. The following sections discuss the location of the site, the meteorology, the existing air quality and the location of neighbours to the site.

4.2 Site Location

As shown in Figure 1, the Alliance Lorneville site is 3 km to the northeast of Invercargill City residential area. It is in a predominately rural area with Wallacetown approximately 3 km to the northwest of the processing site. The processing site has a large footprint and as shown in Figure 1. Alliance also owns a large area of rural land surrounding the site.

The Alliance site is surrounded by predominantly small rural blocks to the south and east of the plant. North and west of the site tend to be more rural areas that include larger blocks of farmland. Wallacetown (approximate population 600) is approximately 3 km northwest of the processing plant and 1.5 km from Alliance's Wastewater Treatment Plant. Recreational and public facilities surrounding the site include a golf club, school, and various community halls. The edge of the Invercargill airshed is located approximately 2 km to the southeast of the boilers.

Regarding the narrow strip of privately owned land to the east of the Alliance Lorneville plant (bounded by Alliance owned land on three sides), this is currently zoned as rural and is most impacted by the Alliance CFB emissions due to its relatively close proximity compared to other areas of land beyond the Alliance site boundary. It would seem unlikely that this land use would change to a more sensitive activity over time.

4.3 Meteorology

Southland has a temperate oceanic climate. Invercargill has a mean temperature of 9.9 °C, and a range from highest to lowest of 32.2 °C to -9.0 °C. The rainfall total at Invercargill is on average 1112 mm per year, with rain occurring on 158 days per year, and ground frosts on 94 days (source: NIWA data; mean annual values from 1971-2000). The mean wind speed is 18 km/h (or 5 m/s), with 18 'gale' days per year (with average speed greater than 63 km/h, or 17.5 m/s).

Wind roses from the Invercargill Airport and Wallacetown monitoring sites are shown in Figure 3. The distribution of wind speed and direction differs slightly between the sites due to their differing proximities to the New River Estuary and the coast. However, both sites have predominant westerly and southwesterly components due to their exposure to large-scale weather systems approaching from the Tasman Sea and the Southern Ocean. High winds from other directions also occur as weather systems pass over the region, but the wind flow is on average from west to east.

The area also experiences land- and sea-breezes, and terrain-driven flows such as valley-channelling and slope flows. Although the terrain within 20 km of Invercargill is quite flat, drainage flows are likely from the north (via Winton) and northwest (via Gore and Mataura). These are likely to be relatively weak when they reach Invercargill and Wallacetown, as the flow is no longer channelled along a valley. However, there is a signature of weaker winds with speeds up to 2-3 m/s from the north and northwest in the wind roses at both sites. These flows are in the same general direction of the Makarewa and Oreti River flows towards the New River Estuary. In periods of low wind speed (particularly on cold days when there is very little vertical mixing), the general air flow is expected to be to the southwest approximately following the river system.

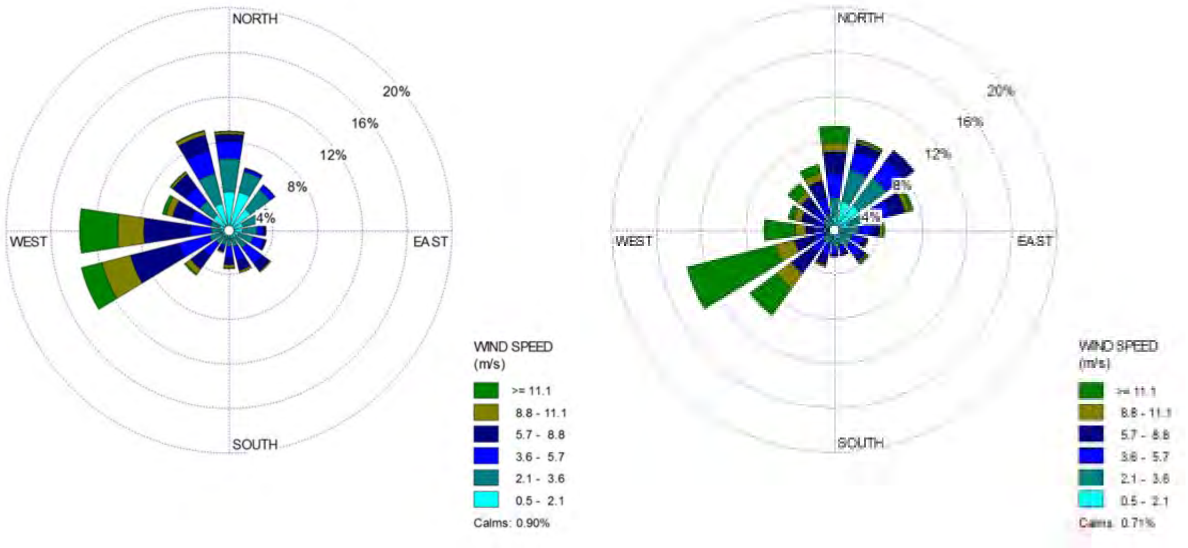


Figure 3: Wind roses from climate station data: (left) Invercargill Airport 2011, (right) Wallacetown 2012.

4.4 Background Air Quality

Background air quality concentrations were established for the site within the baseline ambient air quality report prepared by Golder (2014). A summary of background pollutant concentrations from this report is provided in Table 5.

Table 5: Background pollutant (Golder 2014).

Pollutant	Averaging period	Background concentration
PM_{10}	24-hour	15 µg/m³
	Annual	10 µg/m³
NO_2	1-hour	15 µg/m³
	24-hour	15 µg/m³
SO_2	1-hour	5 µg/m³
	24-hour	5 µg/m³
	Annual	3 µg/m³
Metals;	3-month and Annual	0 µg/m³
Dioxins and Furans	Annual	16.0 fg I-TEQ /m³ †

Note: † femtograms (10^{-15}g) International Toxic Equivalents per cubic metre (fg I TEQ / m³).

There is one significant industrial site located near Alliance Lorneville. Prime Range Meats operates meat processing and rendering plants at a site that is approximately 3 km from the Alliance Lorneville. The air discharge consent (Environment Southland Consent No. 202210) allows them to operate a 4.2 MW CFB and a 3 MW standby oil-fired boiler. The 4.2 MW CFB uses a maximum of 1,330 kg/h of coal (maximum 0.5 wt.% sulfur) and discharges via a 17 m stack. The oil-fired boiler uses a maximum of 345 L/h of oil (maximum 1.9 wt.% sulfur) and discharges via a 22 m stack. This rate of steam energy production is approximately 15 % of those produced by Alliance Lorneville.

4.5 House Locations

Based on aerials and topographic maps, residential locations within 2 kilometres of the boiler stacks were identified and are shown in Figure 4 as residential dwellings. Note that some of the residential dwellings shown in Figure 4 may actually be farm sheds as it can be difficult to differentiate from aerials. The grid co-ordinates for the residential dwellings are given in APPENDIX E.

5.0 ASSESSMENT METHODOLOGY

5.1 Overview

This assessment was undertaken using a combination of atmospheric dispersion modelling and ambient monitoring at a key location that preliminary modelling identified as being close to the most impacted off-site residential dwelling (located to the east of the CFB discharge stacks). This approach provided direct measurements of PM_{10}, $PM_{2.5}$ and SO_2 at a key off-site location that allowed an assessment of existing key air quality contaminant cumulative concentrations without any reliance upon the dispersion modelling of CFB stack contaminant discharges to air.

There were other benefits arising from the combined modelling and ambient monitoring assessment approach. Firstly, the comparison of monitored ambient PM_{10} and $PM_{2.5}$ allowed for the ratio of these contaminants within the CFB stack discharge to be reliably estimated and therefore modelled PM_{10} values can be used to assess $PM_{2.5}$ impacts from the CFBs in all areas assessed. Furthermore the comparison of modelled and monitored air quality impacts increased the reliability of the modelling-based assessment of potential air quality effects in all surrounding areas assessed, but for which ambient monitoring data was not available.

The atmospheric dispersion modelling predicted contaminant ground level concentrations (GLCs) over a large area (at 100 m grid resolution) that included the Alliance site and surrounding locations. The surrounds included nearby residential and urban locations (Invercargill and Wallacetown) and surrounding rural areas. The existing background air contaminant concentrations were added to the predicted GLCs due to the CFBs. The resultant cumulative concentrations were compared with applicable health-based standard and guideline values including:

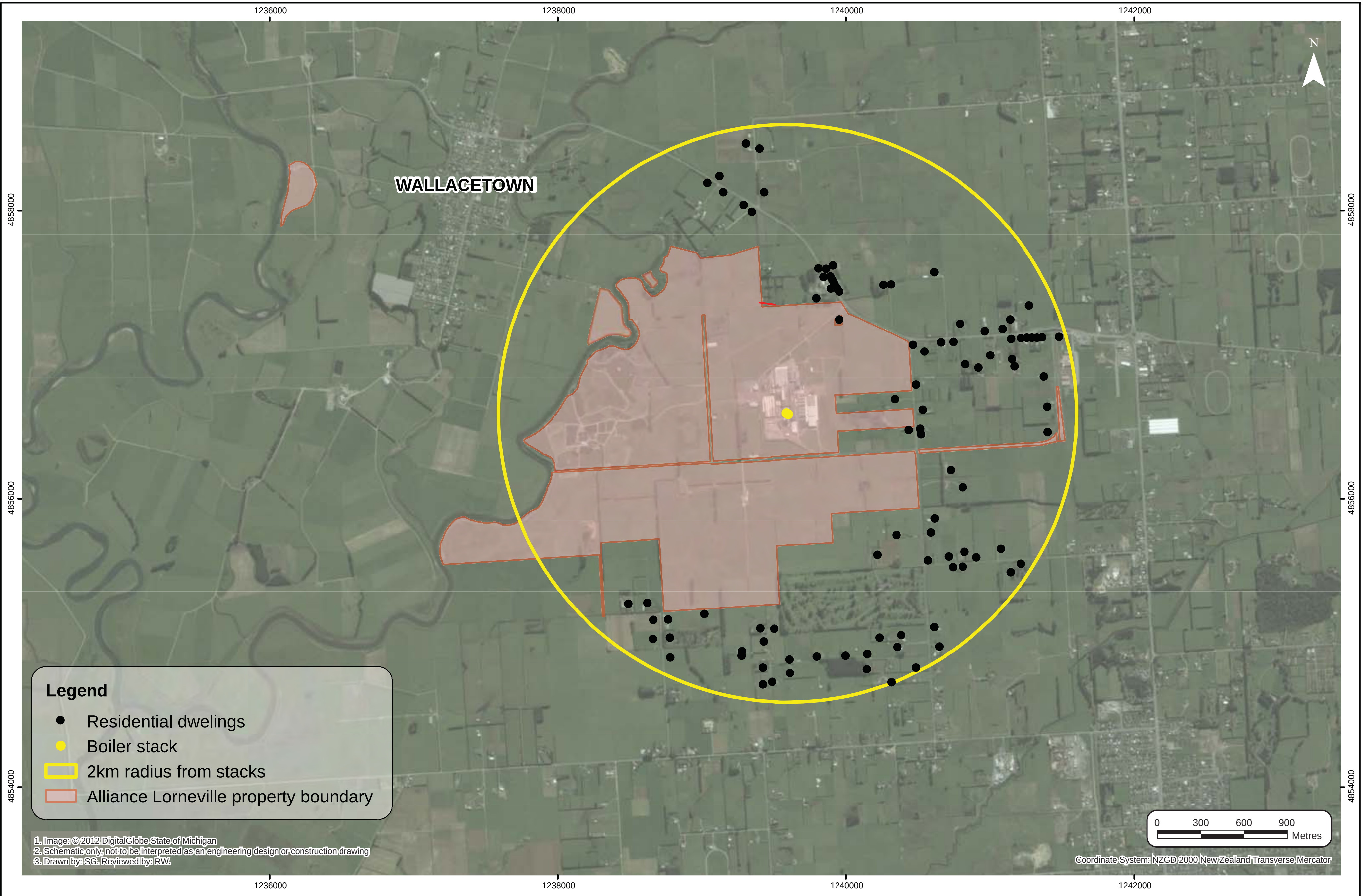
- The National Environmental Standards for air quality (NES).
- The Ministry for the Environment (MfE) Ambient Air Quality Guidelines (AAQG).
- Other appropriate health risk criteria for cumulative long term exposure to air pollutants.

5.2 Assessment Criteria

5.2.1 General

Golder have reviewed the Mitchell Partnerships (MP) preliminary statutory assessment (MP 2013), from this the three main regulations that have relevance to this project in terms of defining the relevant air quality assessment criteria are:

- The Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins and Other Toxics) Regulations 2004 (the “NES”) (MfE 2005, 2011).
- The Ambient Air Quality Guidelines (AAQG) (MfE/MoH, 2002).
- The Regional Air Quality Plan for Southland (Environment Southland, 1999).



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LOCATIONS OF RESIDENTIAL DWELLINGS

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While the AAQGs are not mandatory, the NES are, and their requirements over-ride those of any regional plan except where such a plan imposes stricter requirements. The requirements of the NES, AAQG and the Regional Ambient Air Quality Targets (RAAQT) are discussed as follows.

There are a number of criteria available for assessing the impact of discharges to air. The Ministry for the Environment (MfE, 2008) provides recommendations as to which assessment criteria take precedence. Where there are national standards or guidelines, these are given highest priority, followed by any relevant RAAQTs. After these, any World Health Organisation guidelines and California reference levels (OEHAA, 2012) should be used. Where no guideline exists in the above sources, MfE (2008) recommends that the guidelines from the Texas Commission of Environment Quality (TCEQ, 2013) be used. For the Alliance Lorneville site, no TCEQ guidelines have been used.

5.2.2 National Environmental Standards

The NES regulations were published in 2004 and amended in April 2011 (with amendments taking effect from 1 June 2011). The regulations are mandatory and include standards related to the ambient concentrations of SO_2, NO_2, CO, PM_{10}, and ozone (O_3). They include concentration limits, maximum numbers of allowable exceedances, and monitoring methods. The NES time-averaging periods are 1-hour for SO_2, NO_2 and O_3, 8-hour for CO, and 24-hour for PM_{10}. Further details of the standards are provided in Table 6.

Regulation 14 of the NES sets out the locations that ambient air quality standards apply, as follows:

> *"14 Application of standards*
>
> *(1) The ambient air quality standard for a contaminant applies at any place –*
>
> *(a) that is in an airshed; and*
>
> *(b) that is in the open air; and*
>
> *(c) where people are likely to be exposed to the contaminant.*
>
> *(2) However, if the discharge of a contaminant is permitted by a resource consent, the ambient air quality standard for the contaminant does not apply to area that the resource consent applies to."*

"Airsheds" include parts of the region of a regional council that are specifically gazetted as airshed, and any remaining areas of the region that are not gazetted. This means that the standards apply in all areas of New Zealand, in the open air, wherever people may be exposed over the relevant time averaging period. The main exception is that if the discharge is authorised by a resource consent, then the standards do not apply on the site to which that consent applies. Therefore, the key areas for this assessment in terms of NES compliance are the residential and amenity areas around the Alliance Lorneville site. The effect of Alliance's discharges on the Invercargill airshed will need to be considered.

5.2.3 National Ambient Air Quality Guidelines

The AAQGs applicable to this assessment have very similar limits to the NES, but also include guidelines additional to those in the NES, particularly for 24-hour NO_2 (100 $\mu g/m^3$) and an annual PM_{10} guideline of 20 $\mu g/m^3$. Compliance with the AAQGs is similar in intent to that of NES. However, AAQGs are not linked to specific airsheds, or regulations which could require a regulatory authority to decline a consent application if there is non-compliance.

5.2.4 The Regional Air Quality Plan for Southland

ES notified Stage 1 of a proposed Regional Air Plan (RAP) change in September 2014. This is focused upon air quality effects from domestic heating, outdoor burning, rural activities and fire training. Stage 2 of the proposed RAP change is expected to be notified later in 2015 and will specifically address industrial air discharges. Because this second stage is yet to be notified, the existing ES air plan and relevant national air quality criteria need to be considered for this assessment. Policy 4.3.1 of the Regional Air Quality Plan for

Southland (ES 1999) defines a number of ambient air quality guidelines. The plan notes that these guidelines will be used to promote or maintain good quality ambient air for the Region. The ambient air quality guidelines values adopted by ES are higher than those given in either the NES or the AAQGs for the respective air contaminants. The Regional Air Quality Plan for Southland is the subject of a discussion paper (ES 2013). In this discussion paper the council note that a plan review is required to address the significant environmental issues in regard to air quality in the region since the document was adopted in 1999, and to meet more recent legal requirements. Therefore we consider it is more appropriate to use the respective NES or AAQG values rather than the ES guidelines. MP (2013) has not identified any specific criteria by ES that need to be considered further.

5.2.5 California Office of Environmental Health Hazard Assessment

The Californian Office of Environmental Health Hazard Assessment (OEHHA) provides a list of a number of chemicals with acute, 8-hour and chronic reference exposure levels (REL). Acute REL are based on a 1-hour average and chronic REL are based on an annual average exposure. These are the limits at which studies have shown adverse health effects in humans and a range of laboratory animals.

5.2.6 World Health Organization

The World Health Organization (WHO 2006) has published ambient air quality guidelines which are designed to offer guidance in reducing the health impacts of air pollution. The guidelines include ambient concentration values of different averaging periods for particulate matter, ozone, nitrogen dioxide and sulfur dioxide. For this assessment, the WHO guidelines for particulate matter less than 2.5 µm in diameter ($PM_{2.5}$) have been considered for comparison with ambient monitoring results.

The WHO 24-hour average SO_2 guideline is 20 µg/m^3, which is substantially lower than the current MfE AAQG guideline of 120 µg/m^3. Golder considers that the WHO guideline for SO_2 should not be used to assess the significance of emissions from the Alliance CFBs. The original analysis of research by WHO (2006) on SO_2 health effects and their updated research analysis WHO (2013) do not provide sound scientific basis for imposing a very stringent guideline for 24-hr SO_2 on the localised impacts of the Alliance CFB emissions. A summary of expert testimony provided by Frangos (2015) and Cudmore (2015) is provided as follows:

The WHO guideline for 24-hour SO_2 (i.e. 20 µg/m^3) would effectively require maximal hourly SO_2 impacts from industrial stack discharges to be a small fraction of the NES for hourly SO_2 (i.e. 570 µg/m^3 maximum and 99.9 percentile of 350 µg/m^3). In effect, the criteria is vastly more restrictive to industrial stack discharges than is either the NES, the current US EPA standard for hourly SO_2, the equivalent Australian standard, or standards and guidelines adopted by most other countries.

From a health effects perspective, it is the short term 5-10 min peak exposures to SO_2 that are most strongly associated with adverse effects in people. As such, hourly and 24-hour average SO_2 criteria are most useful from the perspective of controlling the extent of maximum 5-10 minute peaks levels. This appears to be a key factor that has led the US EPA to have deleted their old 24-hour SO_2 standard.

The ratios between the MfE national environmental standard (NESAQ) for hourly SO_2 and the MfE ambient air quality guideline for 24-hour SO_2 (120 µg/m^3) indicates a consistent level of control over maximum 5-10 minute SO_2 peaks. However the WHO guideline would effectively control 5-10 min peak SO_2 exposures to significantly lower levels than is otherwise imposed by either of the NES, MfE or US EPA ambient criteria. In other words, it is vastly more conservative than these currently accepted national standards and guidelines. In summary, applying this particular WHO ambient criterion to the assessment of an industrial discharge such as the Alliance CFBs is not considered appropriate or justified.

5.2.7 Summary of criteria

A summary of the main assessment criteria that are applicable to this application is presented in Table 6.

Table 6: Summary of standards and guidelines relevant to this application.

Contaminant	Guideline/standard ($\mu g/m^3$)	Averaging period	Allowable exceedances per year	Source
SO_2	350	1-hour	9	NES
	570	1-hour	0	NES
	120	24-hour	0	AAQG
	30	Annual	0	AAQG
NO_2	200	1-hour	9	NES
	100	24-hour	0	AAQG
PM_{10}	50	24-hour	1	NES
	20	Annual	0	AAQG
$PM_{2.5}$	25	24-hour	N/A	WHO
	10	Annual	N/A	WHO
Lead	0.2	3-month moving average, calculated monthly	N/A	AAQG
Arsenic	0.0055	Annual	N/A	AAQG
Cadmium	0.02	Annual	N/A	OEHHA (2012)
Chromium VI	0.0011	Annual	N/A	AAQG
Chromium metal and Chromium III	0.11	Annual	N/A	AAQG
Mercury	0.33	Annual	NA	AAQG
Dioxins	Tolerable daily intake 1 pg TEQ/kg body weight/day†	Annual	N/A	MfE (2001)

Notes: †Acceptable incremental risk of increased cancer rates in the population of <1 in 1,000,000.

5.3 Atmospheric Dispersion Modelling

5.3.1 Overview

The assessment of air quality impacts from the boilers involves predicting contaminant ground level concentration (GLCs) using dispersion modelling. The dispersion modelling approach allows prediction of contaminant concentrations over a wide area. The modelling approach is schematically illustrated in Figure 5. It requires three main stages:

- Source configuration and emissions estimation.
- Meteorological and terrain data file development.
- Evaluation of predicted impacts and cumulative effects against ambient guideline criteria and standards.

5.3.2 Hourly varying discharge parameters

The emission rate of contaminants from each CFB stack were input to the dispersion model as hourly varying rates (g/s) that were established from boiler steam production records from November 2013 to November 2014. This data period was chosen to reflect the operation of the boilers after the new rendering line was installed and other plant changes (including winter processing) had been implemented. The hourly steam production records for each CFB were used to generate hourly coal combustion rates and associated exhaust stack flows and contaminant discharge rates.

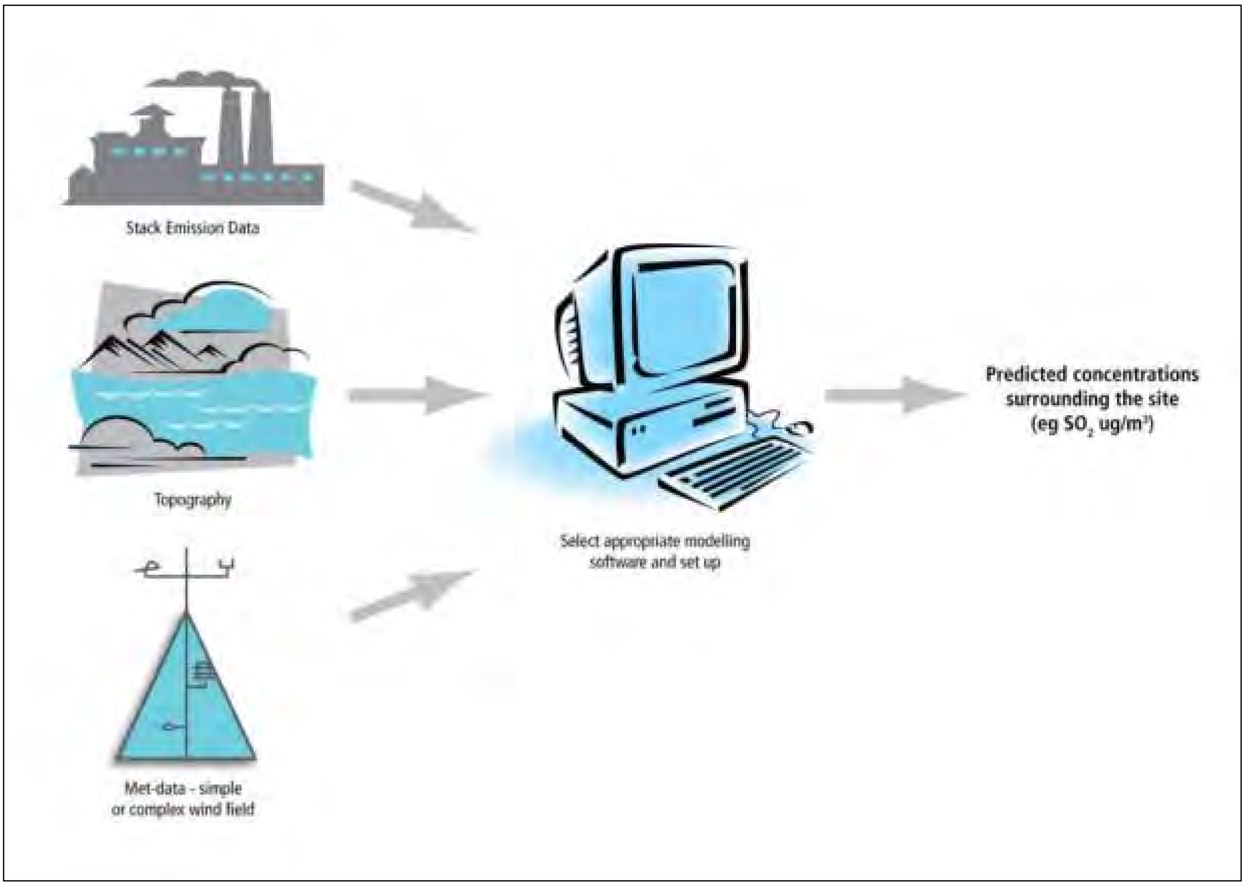


Figure 5: Schematic of dispersion modelling process.

5.3.3 Meteorological modelling – CALMET

The modelling of exposure to airborne pollutants requires a detailed meteorological data set that accounts for spatial variation in wind speed, direction and other atmospheric parameters on an hourly basis and as a function of height above ground level. This hourly three-dimensional (3D) meteorological data set allows for more accurate and defensible predictions of air pollution dispersion, and deposition of contaminants to the ground.

The 3D meteorological data set has been developed using the CALMET model (Scire et al. 1999; TRC 2011) with input developed using the meteorological component of The Air Pollution Model (TAPM) (Hurley, Physick & Luhar 2005; Hurley 2000; Hurley et al. 2003), data from local weather stations and terrain and land-use information.

The weather model TAPM has been used to simulate the large-scale weather patterns and their modification by the coasts and terrain of New Zealand. The TAPM model outputs (including vertical wind profiles) assist in providing the synoptic (large) scale air flows to the regional meteorological model, CALMET. The CALMET model then uses the large scale weather patterns in combination with local weather stations to determine wind patterns of the Invercargill area.

To ensure local winds are accounted for, inputs to CALMET also incorporate data from local weather stations usually run by MetService or NIWA. Automatic weather stations in the vicinity are located at Invercargill Airport, Tiwai Point, and Gore. Rainfall information is available from gauges at several sites. Golder understands that a weather station has been in operation on the Alliance site, but that good-quality data have been available from this site only sporadically over the years. Therefore these data have not been used in the modelling. CALMET also requires upper-air information. Vertical profiles are available from

Invercargill Airport, but soundings are taken every 12 hours. This low frequency of monitoring leaves large gaps in information on the varying atmospheric conditions throughout the day. However, TAPM provides hourly profiles and these have been used in preference in the meteorological modelling. TAPM has also been used to fill gaps in the time series of cloud cover and cloud ceiling height from the Airport.

The CALMET 3D data set incorporates high-resolution terrain and land-use information (generated from the LINZ database), which allows it to account for wind flows driven by terrain features, such as slope and valley flows, and sea breezes.

CALMET was run for a two-year period, over a 12 km by 13 km area centred on the Alliance Lorneville site. This area covers part of the Invercargill urban area, and the Airport (so as to include the location of the airport weather station). The CALMET model domain is show in Figure 6.

Further information regarding the CALMET modelling is contained in APPENDIX D.

5.3.4 Dispersion modelling – CALPUFF

The potential air quality effects resulting from the CFB discharges have been assessed using the Calpuff (Version 6) dispersion model. Information regarding the CALPUFF configuration is contained in APPENDIX E.

For any dispersion model, hourly-averaged conditions can lead to over-prediction of GLCs. To account for this, the Ministry for the Environment (MfE) has recommended that the 1-hour average 99.9th percentile value of the modelled GLC be reported as the maximum predicted 1-hour average GLC (MfE, 2004). For predicted GLCs with longer averaging periods (i.e., 24 hour and annual), the maximum modelled values at any location are considered to provide the best estimate of the probable maximum that will occur for the contaminant emission rates assumed.

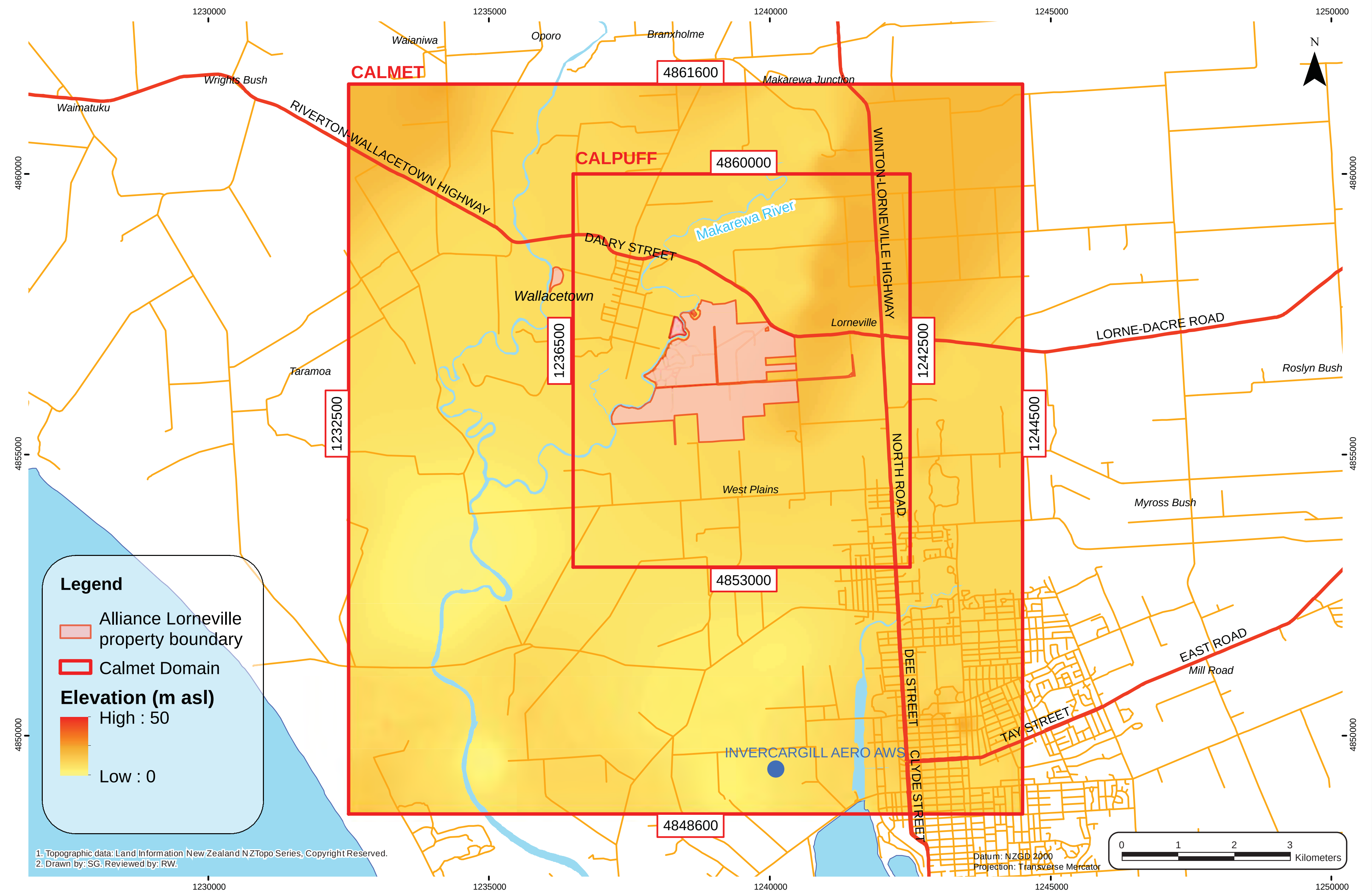
In this report, predicted maximum 1-hour average GLCs are based on the 99.9th percentile modelled value. Following from this, the predicted 99.9th percentile 1-hour average GLC is based on the 99.8th percentile modelled GLC. Predicted maximum GLCs of 24-hour or longer averaging periods are based on the maximum modelled value. The CALPUFF model domain is shown in Figure 6.

5.4 Assessment of Dioxins

The cancer potency from exposure to dioxins is estimated from what is termed the “Lifetime Average Daily Dose (LADD) to dioxins and furans. Whereas the potential for chronic health effects is assessed by a similar term called the Tolerable Daily Intake (TDI). These exposure terms have the same units of picograms of TEQ per day per kg of body weight (i.e., pg-TEQ/kg-bw/day). Note that a picogram is equal to 0.000000000001 grams, or 1 x 10^{-12} grams.

For chronic health effects assessments the TDI value can be compared to the recommended World Health Guideline values of 1 to 4 pg-TEQ/kg-bw/day. The New Zealand Ministry for Health have a guideline of 1 pg-TEQ/kg-bw/day.

When assessing the individual risk of causing cancer due to long term exposure, the LADD value can be multiplied by a “risk factor or slope factor (q_1^*)”. Therefore for this assessment the risk of cancer effects (R) is estimated using the equation; $R = LADD * q_1^*$. For a high-end conservative risk assessment, the draft US EPA dioxin reassessment report is currently recommending that q_1^* be set at $1.4 * 10^{-3}$ kg-bw.day/pg. This value is based upon a revision of the US EPA’s official slope factor of at $1.6 * 10^{-4}$ kg-bw.day/pg that indicates a cancer potency that is ten times lower than the proposed new value. In this assessment we have used a slope factor $1.4 * 10^{-3}$ kg-bw. day/pg which is subject to review.



1. Topographic data: Land Information New Zealand NZTopo Series, Copyright Reserved.
2. Drawn by: SG. Reviewed by: RW.

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TITLE **CALMET AND CALPUFF DOMAINS**

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For this assessment it is necessary to calculate an LADD or TDI for the inhalation exposure pathway. The LADD and TDI are terms used respectively by the US EPA and WHO and both appear to represent the same type of exposure, that is the daily average rate in which 1-TEQ is accumulated within people's body fat (on a per body weight basis) when averaged over a long term period. Therefore for the inhalation pathway, these exposure values are a function of the following factors:

- Long term ambient concentration from the modelling (annual average)
- Average adult body weight (assumed to be 70 kg by convention)
- The amount of air we breathe a day (typical value of 13 m^3/day can be assumed)
- Fraction of time spent in exposed location (68 % to 73 % of time at home assumed)
- Long term exposure duration (9 years for residential scenarios and 30 years for rural)
- Average Life time (70 years assumed by convention)

Therefore to calculate an LADD or TDI due to the inhalation of dioxin exposure emissions for the proposed NZMP boiler emissions value it was necessary to calculate the highest long-term exposure concentration of 1-TEQ dioxin using the atmospheric dispersion model CALPUFF.

6.0 AMBIENT AIR MONITORING

6.1 Overview

Ambient monitoring of SO_2 and particulate matter (PM_{10} and $PM_{2.5}$) concentrations was carried out at a site located on the property of a private householder at 237 Steel Road, Lorneville, approximately 650 metres east of the Alliance boiler stacks. The monitoring site location, the equipment and methods used including a summary of the results are provided in APPENDIX H.

The ambient monitoring confirmed background air quality of key contaminants surrounding the site as well as impacts due to the CFBs discharges to air. Preliminary modelling was undertaken to help establish the ambient monitoring location and to provide actual SO_2 and PM_{10} concentrations for comparison with impacts predicted to result from the CFBs discharges (see APPENDIX I).

The ambient monitoring programme was carried out over two periods as follows:

- First ambient monitoring: from 31 January to 21 May 2014, including SO_2 and PM_{10} concentrations.
- Second ambient monitoring: from 19 December 2014 to 17 March 2015, including two sub-periods:
  - PM_{10} concentrations measured from 19 December 2014 to 16 February 2015 and
  - $PM_{2.5}$ concentrations measured from 17 February to 17 March 2015.

A brief assessment of the ambient monitoring results provided in APPENDIX H against relevant standards and guidelines is provided below.

6.2 Sulfur Dioxide

The SO_2 ambient monitoring found levels to be well below the NES limits for hourly SO_2 as demonstrated in the following:

- The peak hourly SO_2 concentration is 120 µg/m³, which is 21 % of the NES limit for maximum SO_2 of 570 µg/m³.
- The 99.9th percentile hourly SO_2 concentration is 108 µg/m³, which is 31 % of the NES limit for 99.9th percentile SO_2 of 350 µg/m³.

The 24-hour SO_2 monitoring data found levels to be well below the MfE AAQG for 24-hour SO_2 as demonstrated in the following:

- The peak 24-hour SO_2 concentration is 52 µg/m³, which is 43 % of the AAQG for maximum SO_2 of 120 µg/m³.
- Typically the 24-hour SO_2 concentrations are well below 20 µg/m³.

6.3 Particulate Matter – PM_{10}

The first monitoring programme (31 January to 21 May 2014) produced ambient 24-hour PM_{10} results that were compliant with but approached the NES limit for ambient PM_{10} on occasions. This occurred during the peak processing season. The average of all the monitoring data also indicated compliance with the MfE AAQG for annual average PM_{10}. General findings were as follows:

- The highest measured 24-hour PM_{10} value was 47 µg/m³
- 96 % of days had ambient PM_{10} concentrations less than 25 µg/m³
- The average PM_{10} for the four month monitoring period was 13 µg/m³
- Background 24-hour PM_{10} levels were typically 15 µg/m³ or less

The second ambient monitoring (19 December 2014 to 16 February 2015) also found cumulative 24-hour PM_{10} to comply with the NES and AAQG. During this period the 24-hour PM_{10} concentrations were generally lower than during the 2014 monitoring period summarised above. General findings were as follows:

- The highest measured 24-hour PM_{10} value was 27 µg/m³
- 98 % of days had ambient PM_{10} concentrations less than 25 µg/m³

6.2 Particulate Matter – $PM_{2.5}$

The ambient monitoring results for $PM_{2.5}$ (from 17 February to 17 March 2015) found concentrations to be well below the WHO guideline for daily $PM_{2.5}$. A comparison between different percentiles of 10-minute averaged PM_{10} and $PM_{2.5}$ concentrations is also provided in APPENDIX H. The higher $PM_{2.5}$ percentile concentrations (i.e., 90th and above), are likely to be dominated by CFB discharges to air. In this case the ratio of $PM_{10}/PM_{2.5}$ is approximately 2. As the WHO guidelines for $PM_{2.5}$ are half than those for PM_{10}, this indicates that if the discharges from the boilers comply with PM_{10} guidelines, they will likely comply with the $PM_{2.5}$ guidelines as well.

The lower range of $PM_{2.5}$ percentile concentrations (i.e., 40th and below), are likely to be dominated by background sources. The comparison shown in APPENDIX H indicates that the ratio of $PM_{10}/PM_{2.5}$ increases considerably as the percentiles decrease. This further confirms that the monitored peak $PM_{2.5}$

concentrations were due to discharges from the CFBs with relatively low contributions from background sources.

6.3 Summary of Ambient Air Quality Monitoring

In summary, the ambient monitoring results summarised in APPENDIX H show that compliance was achieved for all relevant SO_2, PM_{10} and $PM_{2.5}$ standards and guidelines. These results were monitored close to the house that is predicted by the modelling assessment to be the most impacted by the CFB air contaminant discharges.

The highest measured 24-hour PM_{10} concentration at this location approached the NES limit of 50 µg/m^3 on one occasion during the 160 days of ambient monitoring (including both periods). Apart from the isolated peak daily values that exceeded 30 µg/m^3, 96 % of the 24-hour PM_{10} concentrations were less than 50 % of the NES limit value. The measured PM_{10} concentrations at the monitoring location are expected to have reduced by approximately 20 % following the completion of the CFB 2 multi-clone upgrade. This indicates that NES for ambient PM_{10} is likely to be complied with over the course of a full year at the monitoring location following the recent multi-clone upgrade to Boiler #2. Furthermore, compliance with the NES for PM_{10} at the nearest private residential dwelling is also likely to be met.

The 24-hour average $PM_{2.5}$ concentrations at the monitoring location were all well below (i.e., 29 % or less) the WHO guideline value of 25 µg/m^3.

The monitored SO_2 concentrations reached 21 % and 31 % of the NES limits for maximum and 99.9th percentile 1-hour SO_2, respectively. Finally, the peak 24-hour SO_2 reached 43 % of the AAQG value.

7.0 AIR DISCHARGE MODELLING RESULTS

7.1 Introduction

This section of the report provides a summary of the dispersion modelling predictions for GLCs of contaminants discharged from the boilers. Predictions are made for the:

- 9th highest 1-hour average concentration (99.8 percentile modelled value) - for comparison against 1-hour average assessment criteria.
- Maximum 1-hour average concentration (99.9 percentile modelled value) - for comparison against the SO_2 1-hour never-to-be exceeded assessment criteria.
- 24-hour average concentrations.
- Three month average concentrations, lead only.
- Annual average concentrations.

Predicted GLCs are presented for the maximum offsite location and the most impacted off-site dwelling. Contour plots are presented for each of the averaging periods relevant to the respective contaminant. Each of the contour plot figures show the:

- Site boundary - indicated by the green line.
- Location of the boiler stacks - marked with a black cross.
- Relevant assessment criterion - indicated by the orange contour.

- Location of the maximum off-site concentration - marked with a red cross.
- Location of the maximum concentration at an off-site dwelling - marked with a blue cross.

The dispersion modelling predictions presented in this section do not include background concentrations. Background concentrations are incorporated into the dispersion modelling results and the cumulative effects of the discharges of plant evaluated against the relevant assessment criteria in Section 9.0.

7.2 Particulate Matter – PM_{10}

The modelling results for PM_{10} emissions from the boilers are summarised in Table 7 along with the applicable assessment criteria. Contour plots of the predicted maximum 24-hour average and annual average concentrations are provided in Figure 7 and Figure 8 respectively. Figure 7 and Figure 8 are based on the hourly varying boiler emission scenario and exclude any contribution from background sources of PM_{10}.

Table 7: Maximum predicted PM_{10} GLCs, excluding background.

Averaging period	**Off-site GLC**		**GLC at an off-site dwelling**		**Assessment criterion (µg/m³)**
	(µg/m³)	**Location** (red cross)	**(µg/m³)**	**Location** (blue cross)	
24-hour (maximum)	40*	400 m east of boiler stacks	17*	800 m east of boiler stacks	50
Annual average	5*	400 m east of boilers stacks	1.7*	800 m east of boilers stacks	20

Note: *Based on realistic hourly varying boiler emissions.

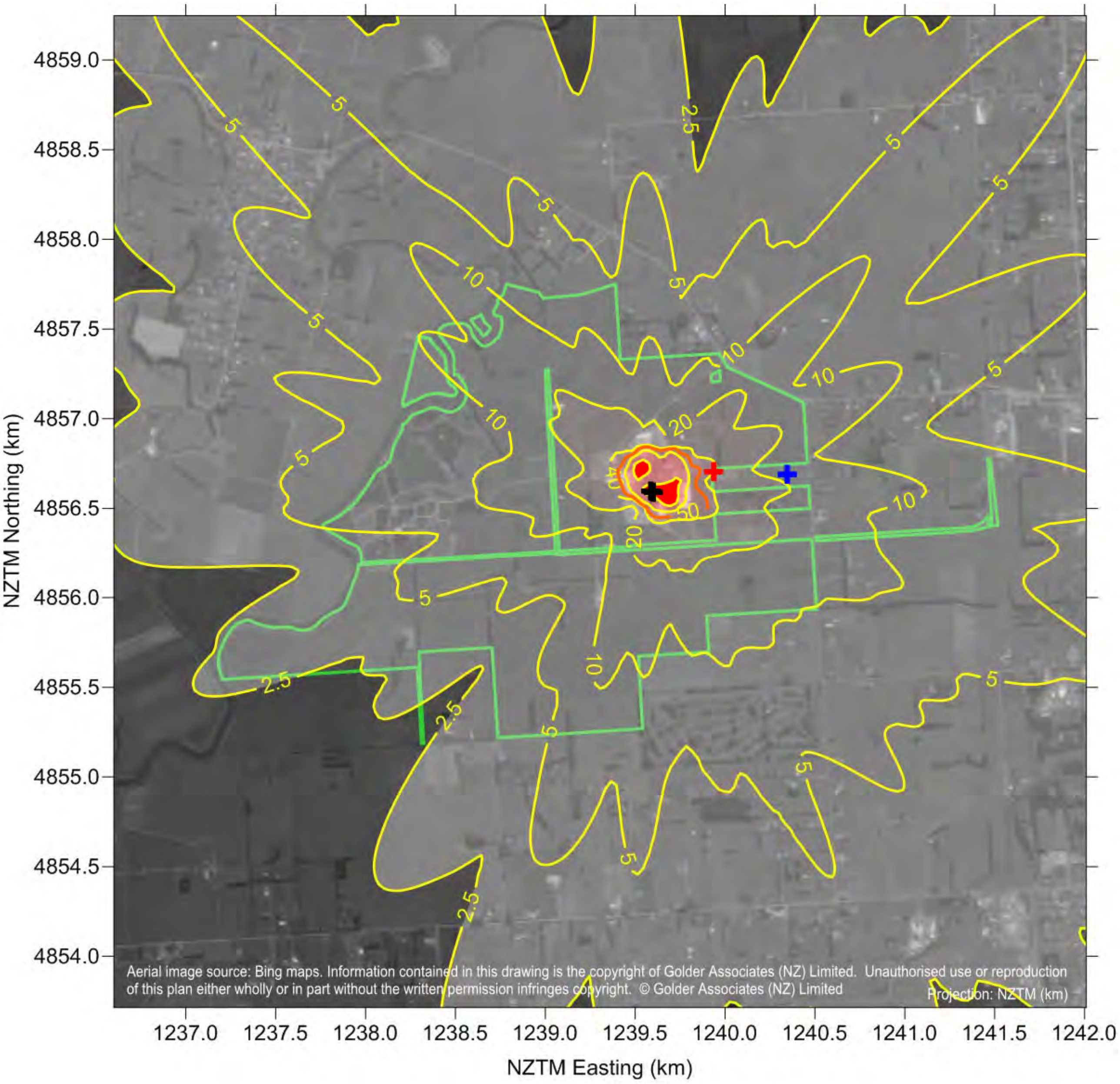

Figure 7: Predicted maximum 24-hour average PM_{10} ground level concentrations ($\mu g/m^3$) based on the hourly varying emissions but excluding background concentrations. The assessment criterion ($50\mu g/m^3$) is indicated by the orange contour.

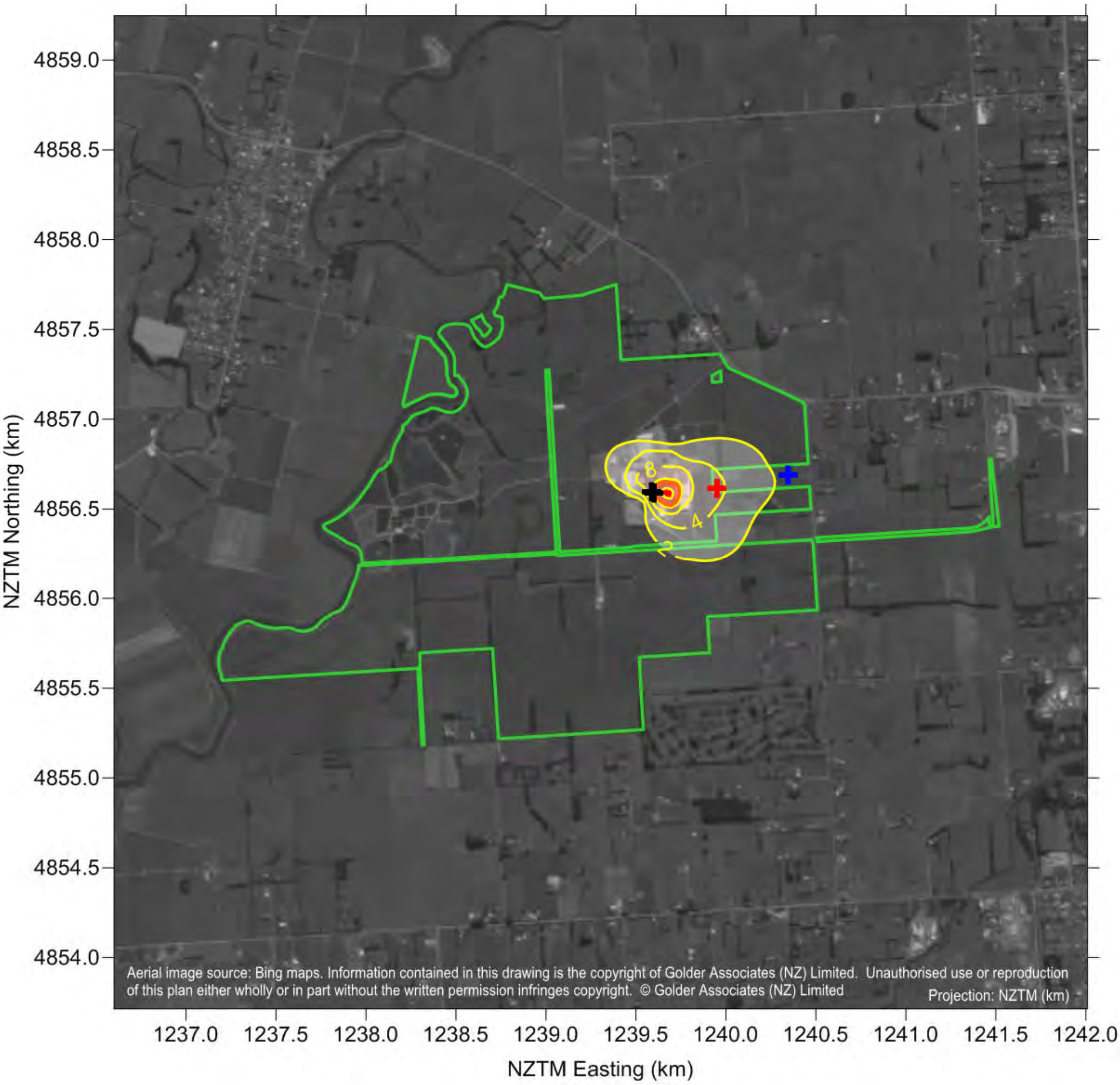

Figure 8: Predicted annual average PM_{10} ground level concentrations ($\mu g/m^3$) based on the hourly varying emissions but excluding background concentrations. The assessment criterion ($20\mu g/m^3$) is indicated by the orange contour.

7.3 Nitrogen Dioxide

The modelling results for NO_2 ambient impacts due to the boilers are summarised in Table 8 along with the applicable assessment criteria. Contour plots of the predicted 1-hour average (99.8th percentile value) and maximum modelled 24-hour average concentrations are provided in Figure 9 and Figure 10 respectively. Figure 9 and Figure 10 are based on the envelope and hourly varying boiler emission scenarios respectively and exclude any contribution from background sources of NO_2.

Table 8: Maximum predicted NO_2 GLCs, excluding background.

Averaging period	**Off-site GLC**		**GLC at an off-site dwelling**		**Assessment criterion (µg/m³)**
	(µg/m³)	**Location (red cross)**	**(µg/m³)**	**Location (blue cross)**	
1-hour (99.8th percentile[‡])	16[#]	400 m east-southeast of boiler stacks	13[#]	1000 m northeast of boiler stacks	200
24-hour	9*	400 m east of boiler stacks	6*	1000 m east of boiler stacks	100

Notes: † Based on the modelled 99.8th percentile in accordance with MfE guidance for predicted 1-hour concentrations.

[#] Based on envelope boiler emission scenario

* Based on hourly varying boiler emission scenario

7.4 Sulfur Dioxide

The modelling results for SO_2 emissions from the boilers are summarised in Table 9 along with the applicable assessment criteria. Contour plots of the predicted 1-hour maximum (99.9th percentile modelled value), 1-hour average (99.8th percentile modelled value), 24-hour average and annual average concentrations are provided in Figure 11, Figure 12 Figure 13 and Figure 14 respectively. These figures exclude any contribution from background sources of SO_2. Figure 11 and Figure 12 are based on the envelope boiler emission scenario. Figure 12 and Figure 14 are based on the hourly varying boiler emission scenario.

Table 9: Maximum predicted SO_2 GLCs, excluding background.

Averaging period	**Off-site GLC**		**GLC at an off-site dwelling**		**Assessment criterion (µg/m³)**
	(µg/m³)	**Location (red cross)**	**(µg/m³)**	**Location (red cross)**	
1-hour maximum (99.9 percentile[†])	290[#]	400 m east-southeast of boiler stacks	169[#]	900 m east-southeast of boiler stacks	570
1-hour (99.8th percentile[‡])	260[#]	400 m east-southeast of boiler stacks	143[#]	800 m east of boiler stacks	350
24-hour	140*	400 m east of boiler stacks	62*	800 m east of boiler stacks	120
Annual	18*	200 m east of boiler stacks	7*	800 m east of boiler stacks	30

Notes: † Based on the modelled 99.9th percentile in accordance with MfE guidance for predicted 1-hour concentrations.

‡ Based on the modelled 99.8th percentile.

[#] Based on envelope boiler emission scenario.

* Based on hourly varying boiler emission scenario.

Figure 9: Predicted maximum 1-hour average NO_2 ground level concentrations ($\mu g/m^3$) (99.8th percentile value) based on the envelope emission scenario but excluding background concentrations. The assessment criterion is 200 $\mu g/m^3$.

Figure 10: Predicted maximum 24-hour average NO_2 ground level concentrations ($\mu g/m^3$) based on the hourly varying boiler emissions but excluding background concentrations. The assessment criterion is 100 $\mu g/m^3$.

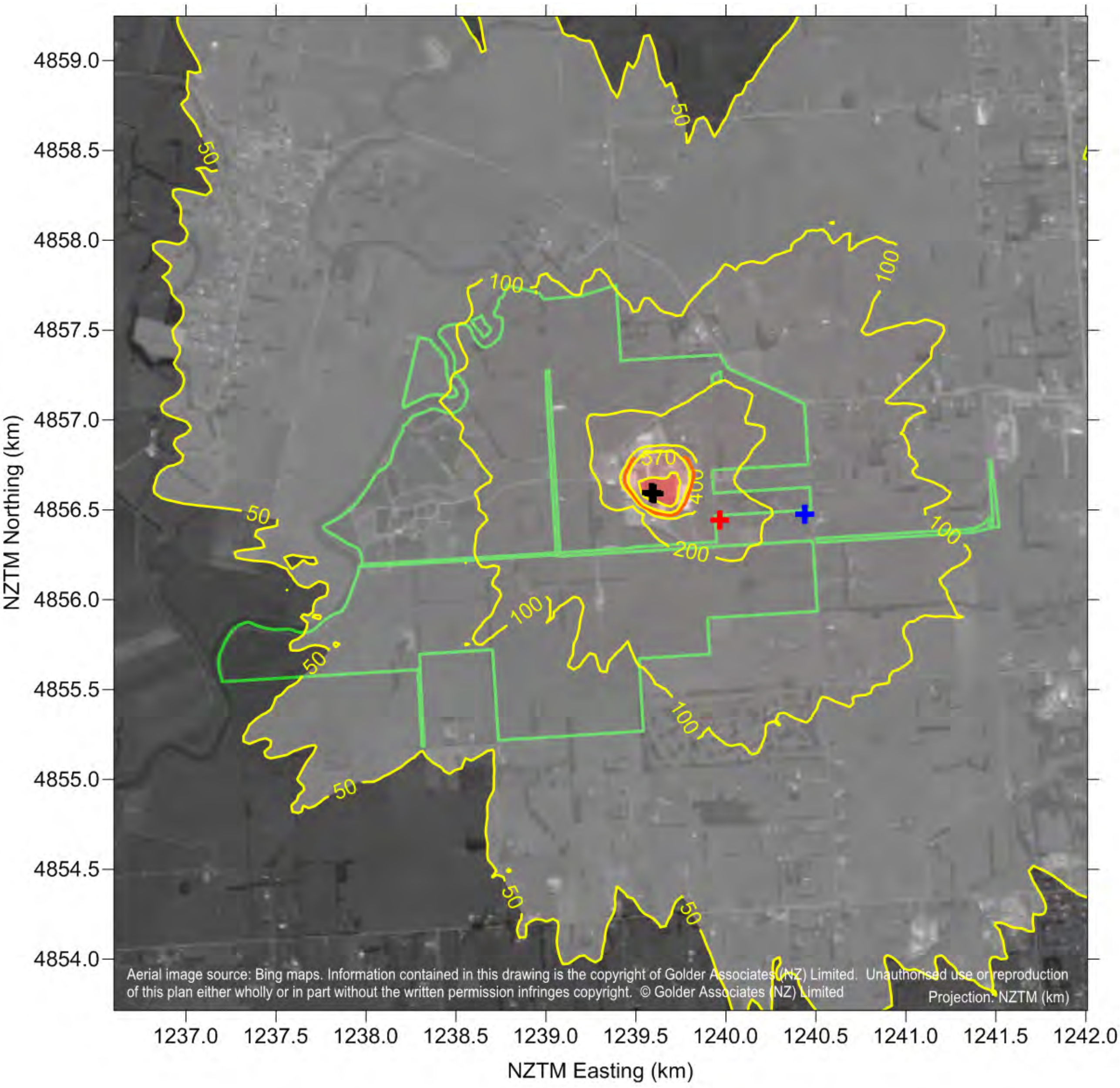

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Figure 11: Predicted maximum 1-hour SO_2 ground level concentrations ($\mu g/m^3$) (modelled 99.9th percentile value) based on envelope scenario boiler emissions but excluding backgrounds concentrations. The assessment criterion ($570 \mu g/m^3$) is indicated by the orange contour.

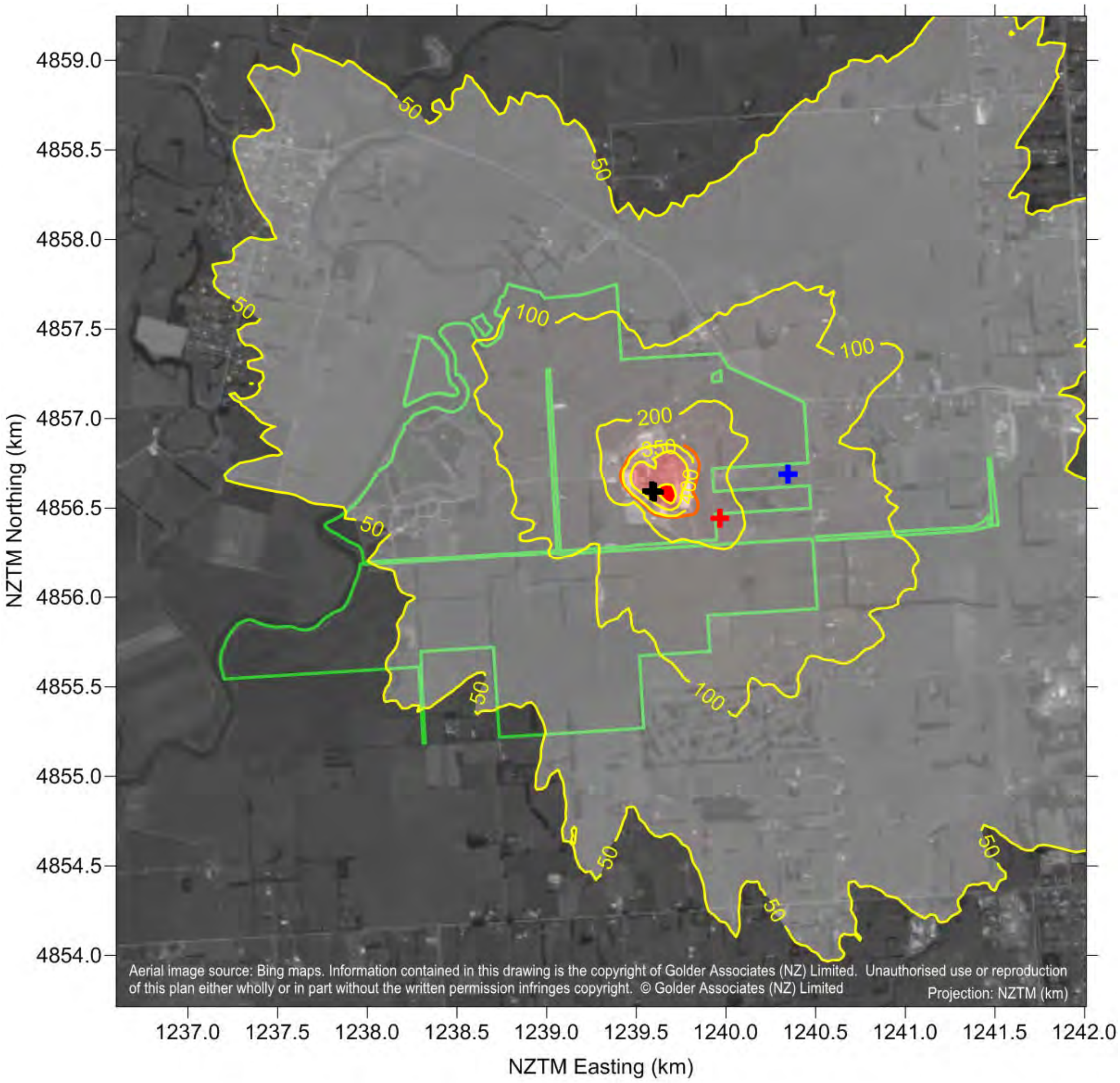

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Figure 12: Predicted 1-hour average SO_2 ground level concentrations ($\mu g/m^3$) (modelled 99.8th percentile value) based on envelope scenario boiler emissions but excluding background concentrations. The assessment criterion ($350\mu g/m^3$) is indicated by the orange contour.

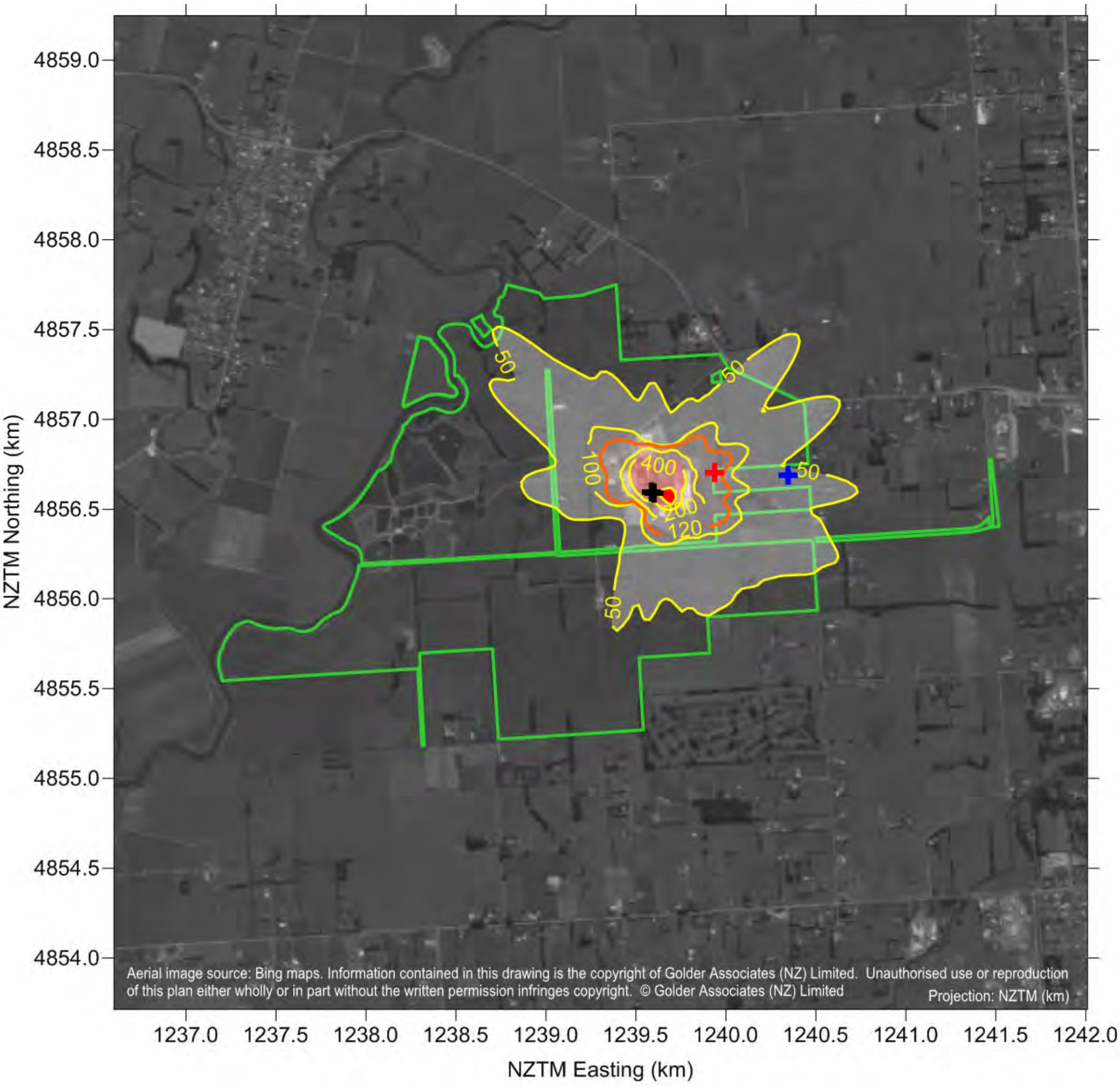

Figure 13: Predicted 24-hour average SO_2 ground level concentrations, ($\mu g/m^3$) based on the hourly varying boiler emissions but excluding background concentrations. The assessment criterion ($120\mu g/m^3$) is indicated by the orange contour.

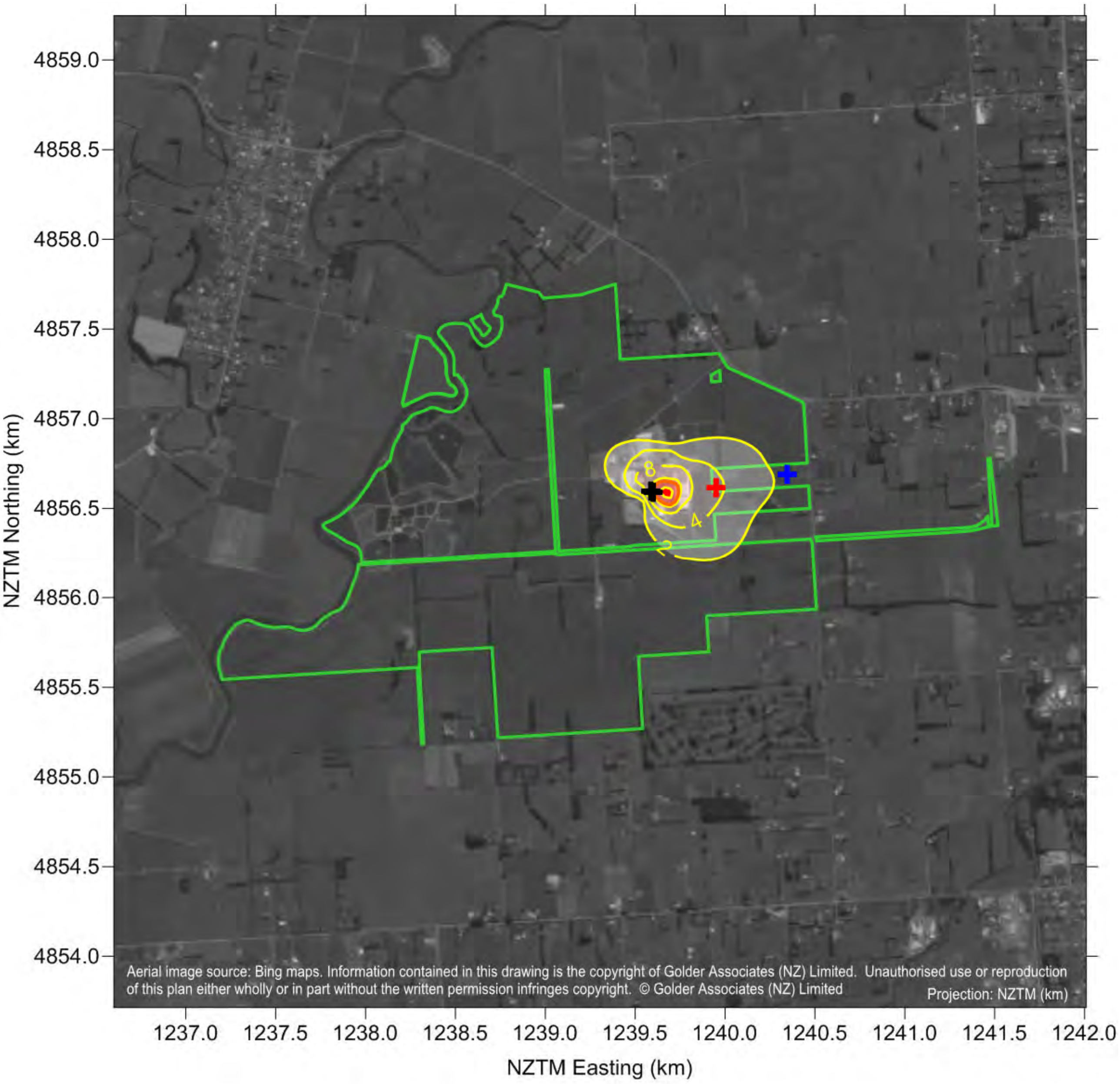

Figure 14: Predicted annual average SO_2 ground level concentrations ($\mu g/m^3$) based on the hourly varying emissions but excluding background concentrations. The assessment criterion ($30\mu g/m^3$) is indicated by the orange contour.

7.5 Metals

The modelling results for metal emissions are summarised in Table 10 along with the applicable assessment criteria. Contour plots of the predicted annual average concentrations for arsenic, cadmium, chromium and mercury are provided in Figure 15, Figure 16, Figure 17 and Figure 18 respectively. Figure 15 to Figure 18 are based on the hourly varying boiler emission scenario and exclude any contribution from background sources. Given the somewhat complicated nature of the averaging period used for calculating the lead GLCs, a contour plot for lead is not presented.

Table 10: Predicted GLCs for metals excluding background.

Contaminant	Averaging period	Maximum off-site GLC		Maximum GLC at an off-site dwelling		Assessment criterion (µg/m³)
		(µg/m³)	Location (red cross)	(µg/m³)	Location (blue cross)	
Arsenic	Annual	8.6 x 10^{-4}	400 m east of boiler stacks	3.1 x 10^{-4}	800 m east of boiler stacks	5.5 x 10^{-3}
Cadmium	Annual	5.6 x 10^{-5}	400 m east of boiler stacks	2.0 x 10^{-5}	800 m east of boiler stacks	2 x 10^{-2}
Chromium	Annual	3.8 x 10^{-4}	400 m east of boiler stacks	1.4 x 10^{-4}	800 m east of boiler stacks	1.1 x 10^{-3} (Cr VI) 1.1 x 10^{-1} (Cr metal and Cr III)
Mercury	Annual	1.6 x 10^{-4}	400 m east of boiler stacks	5.7 x 10^{-5}	800 m east of boiler stacks	3.3 x 10^{-1}
Lead	3-month moving average, calculated monthly	3.0 x 10^{-4}	400 m east of boiler stacks	1.2 x 10^{-4}	800 m east of boiler stacks	2 x 10^{-1}

7.6 Dioxins

The modelling results for dioxin emissions are summarised in Table 11 along with the applicable assessment criterion. A contour plot of the predicted annual average concentrations of dioxins is presented in Figure 19. Figure 19 is based on the hourly varying boiler emission scenario and excludes any contribution from background sources.

Table 11: Predicted GLCs for Dioxins excluding background.

Contaminant	Averaging period	Maximum off-site GLC		Maximum GLC at an off-site dwelling		Assessment criterion (pg/kg/day)
		(pg I-TEQ/m³)	Location (red cross)	(pg I-TEQ/m³)	Location (blue cross)	
Dioxin	Annual	0.0003	400 m east of boiler stacks	0.0001	400 m east of boiler stacks	1.0

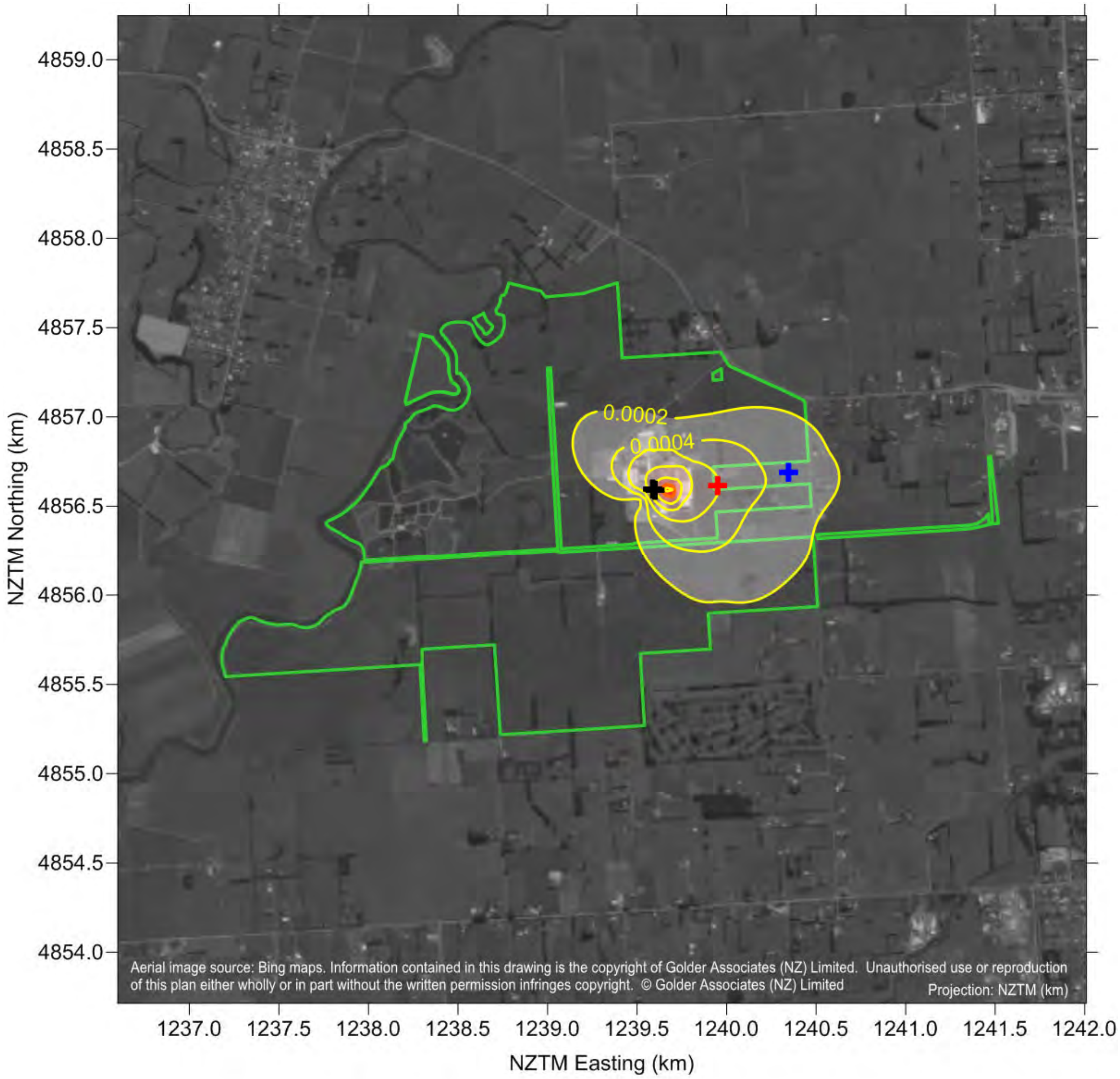

Figure 15: Predicted annual average arsenic (As) ground level concentrations based on the hourly varying emissions file. Contour intervals: 0.0002, 0.0004, 0.0008, 0.0016, 0.0032, 0.0064 $\mu g/m^3$. The assessment criterion (0.0055$\mu g/m^3$) is indicated by the orange contour.

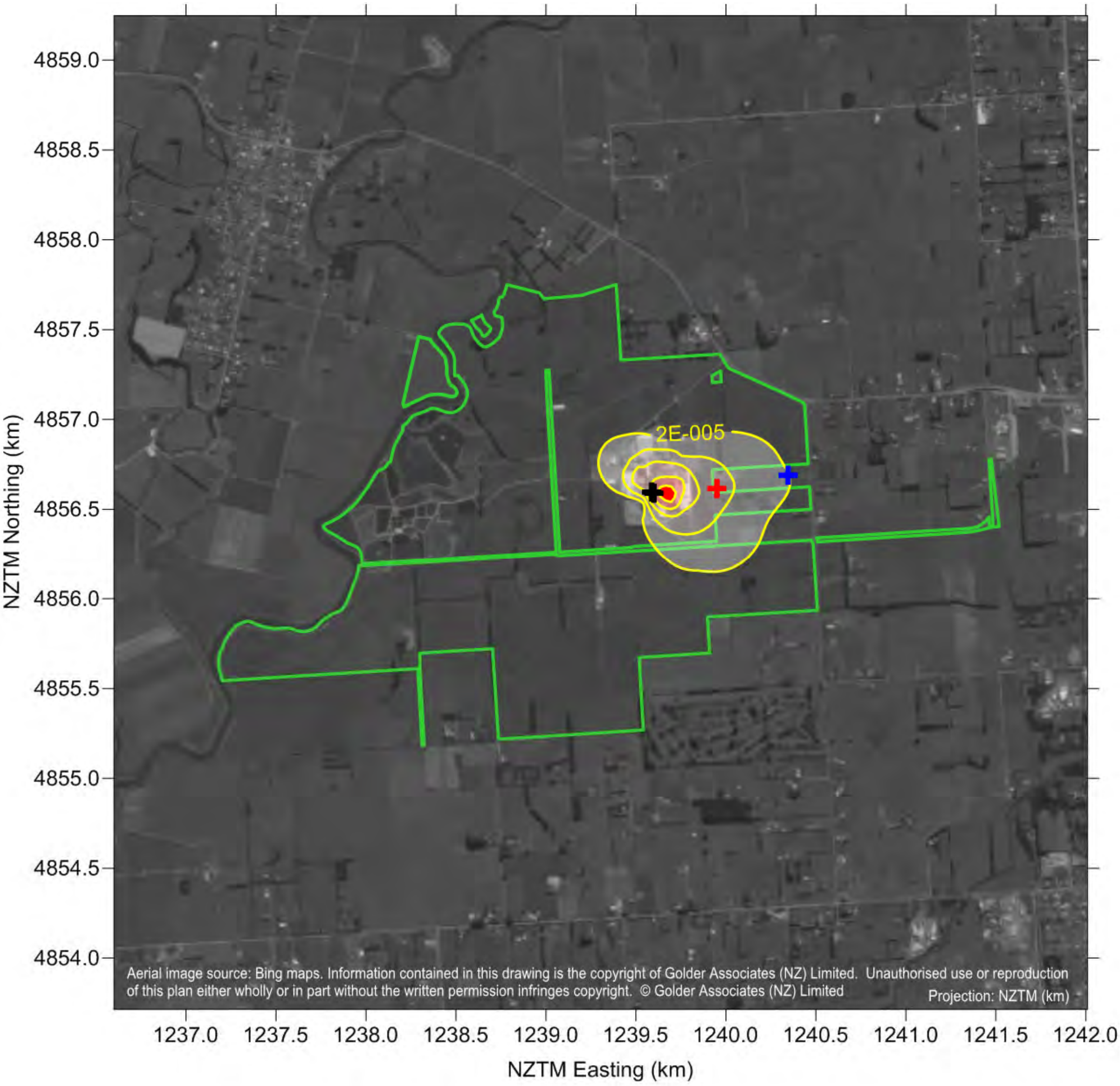

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Figure 16: Predicted annual average cadmium (Cd) ground level concentrations based on the hourly varying emissions file. Contour intervals: $2x10^{-5}$, $4x10^{-5}$, $8x10^{-5}$, $1.6x10^{-4}$, $3.2x10^{-4}$ µg/m³. The assessment criterion is 0.02µg/m^3

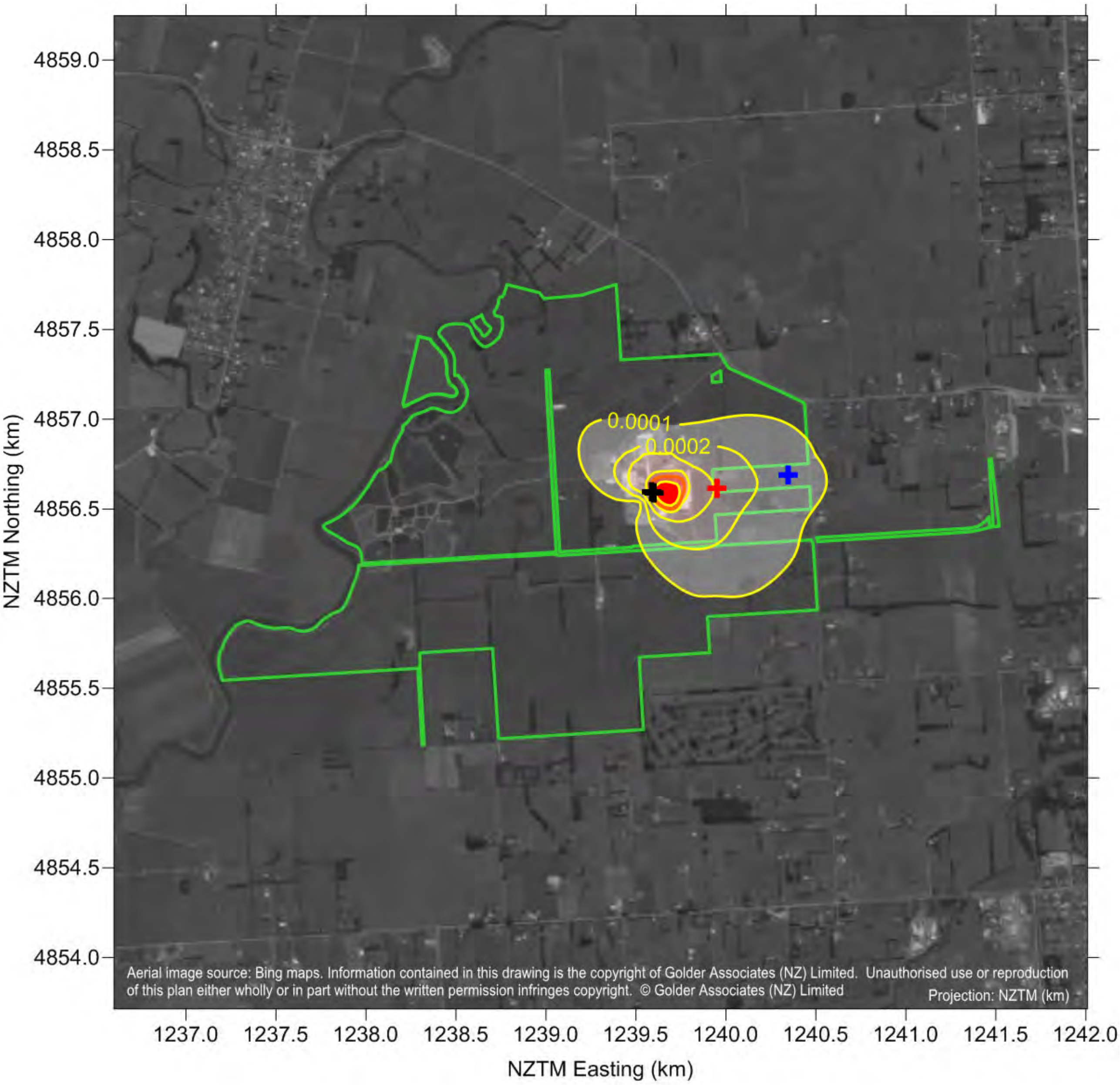

Figure 17: Predicted annual average Chromium (Cr) ground level concentrations based on the hourly varying emissions file. Contour intervals: 0.0001, 0.0002, 0.0004, 0.0008, 0.0016 µg/m³. The assessment criterion is 0.0011µg/m³.

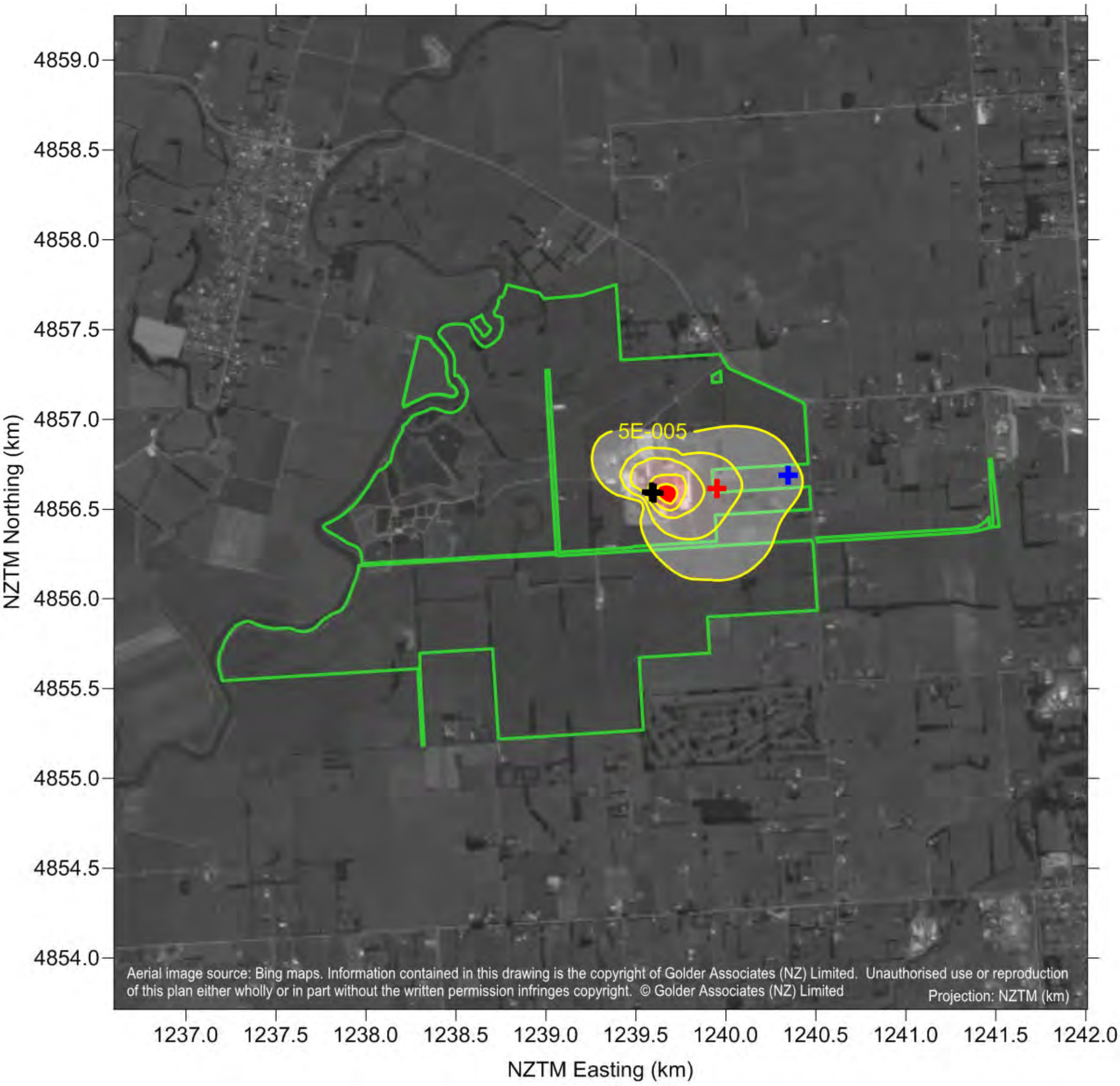

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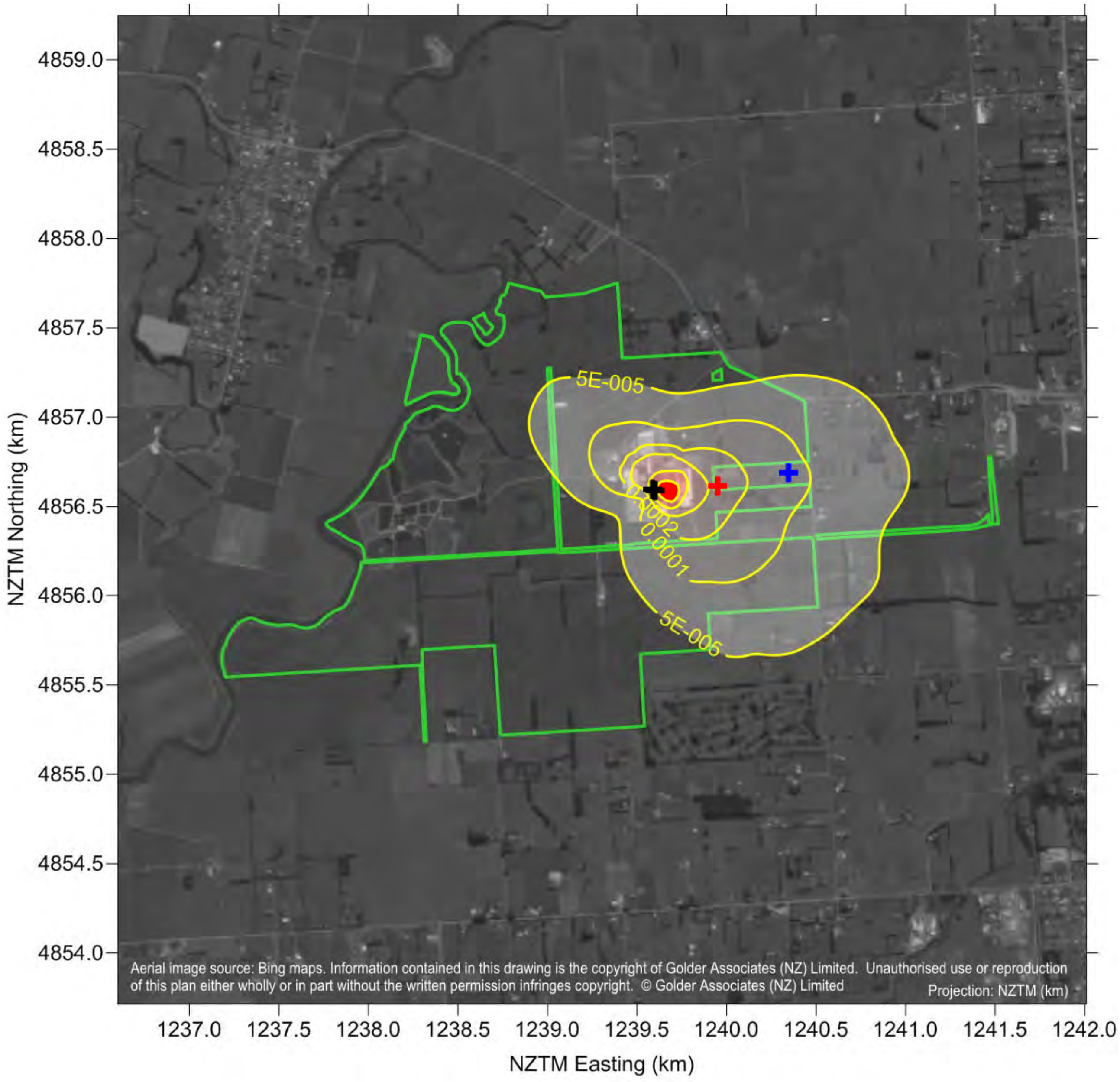
Figure 18: Predicted annual average mercury (Hg) ground level concentrations based on the hourly varying emissions file. Contour intervals: $5x10^{-5}$, $1x10^{-4}$, $2x10^{-4}$, $4x10^{-4}$, $8x10^{-4}$ µg/m³. The assessment criterion is 0.33µg/m³.



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Projection: NZTM (km)

Figure 19: Predicted annual average dioxin ground level concentrations (pg/m³), excluding background.

8.0 SOIL METAL ANALYSIS

8.1 Introduction

An assessment of heavy metals in soils was carried out by Soilwork Limited in September 2014 (Greenwood 2014). The metals chosen for analysis were based on the metals detailed in Table 3. A copy of this assessment is provided in APPENDIX J. Six sampling sites were chosen. Guided by Golder's modelling of ambient air quality impacts, three of these were located near the coal-fired boiler, at points potentially most affected by long-term deposition of heavy metals (labelled 'affected' sites). The other three were located at points upwind of the boiler under prevailing wind conditions, where predicted impacts were much lower (labelled 'control' sites). Soil cores from the surface down to a depth of 7.5 cm, and from 7.5 cm down to 15 cm were collected by Soilwork Limited and analysed for arsenic, cadmium, chromium, copper, lead, nickel and zinc by Hill Laboratories.

A full set of results of the soil heavy metal analyses are contained in Table 3.1 of Greenwood (2014). Average soil concentrations over the full depth to 15 cm over the control sites and affected sites taken from that table are shown here in Table 12. It can be seen that all concentrations are well within the guidelines used.

For chromium, copper, lead, nickel and zinc, concentrations at the affected sites are only marginally higher than at the control sites. However, arsenic and cadmium are slightly smaller. A transect of 25 samples was taken at each site and the mean concentration at each site presented by Greenwood (2014).

Table 12: Summary of soil heavy metal analyses (averages from Table 3.1 of Greenwood (2014)).

	Total recoverable soil concentrations (mg/kg dry weight)						
	Arsenic	**Cadmium**	**Chromium**	**Copper**	**Lead**	**Nickel**	**Zinc**
Mean of control sites	4	0.24	20	12	8.4	10	49
Mean of affected sites	3	0.21	26	16	11.2	13	65
Guidelines#	20	1	600	100	300	60	300

Note: #Guidelines quoted by Greenwood taken from New Zealand Water & Wastes Association report (NZWWA 2003).

8.2 Analysis

8.2.1 Overview

The following sections (8.2.2 and 8.2.3) consider the results of the soil metal assessment, relating them to the dispersion modelling of long term contaminant concentrations. In particular the following issues are considered:

- Consistency of soil metal concentrations at the affected sites with modelled annual average GLCs of CFB contaminant emissions.
- Estimated soil metal changes over a further hundred years of CFB operation.

8.2.2 Soil concentrations versus modelling results

The affected sites are labelled by Greenwood (2014) as Site 1, Site 2 and Site 3 in order of increasing distance from the coal-fired boiler. The modelled annual-average ambient concentrations are in the approximate ratio 12:10:5 at Sites 1, 2 and 3, respectively. Subtracting the mean concentration at the control site – treating it as a baseline level – leaves concentrations of chromium, nickel and zinc at the affected sites in a similar ratio. Copper and lead are more uniform between Sites 1 and 2, but higher than at the control sites. Arsenic and cadmium are lower at the affected sites, but cadmium is higher at Site 1 than at Site 2.

In summary, changes in soil metal concentrations in the vicinity of the CFBs are consistent with the modelled long term ambient concentrations of CFB contaminants. Note that this assumes the long-term pattern of soil deposition would be the same as the long-term average ambient concentration. This may be a reasonable assumption for the long term.

8.2.3 Projection of soil metal concentrations

The assessment found soil metal concentrations that were 20 %, 24 %, 5 %, 17 %, 4 %, 23 % and 24 % of relevant guidelines, respectively for arsenic, cadmium, chromium, copper, lead, nickel, and zinc. In one hundred years' time, the soil concentrations of (chromium, copper, lead, nickel, zinc), respectively, may reach 7 %, 26 %, 6 %, 36 % and 37 %, respectively, of their associated guideline. The percentages have been calculated under the following assumptions:

- The baseline concentrations are represented by the mean of the control sites, and do not change.
- The excess affected-site soil concentration over the baseline is due to boiler operation over the last 55 years.
- The soil metal impacts due to CFB operation occurs at the same rate for the next 100 years, so the excess affected-site soil metal concentration can be scaled up by a factor 155/55.
- The baseline concentration can then be added back into the affected-site soil concentration and compared with the NZWWA (2003) guidelines.

The arsenic and cadmium concentrations cannot be projected using this method, as there is no excess concentration over the baseline of these metals.

8.2.4 Summary

In summary, an examination of dispersion-model results in relation to measured soil metal concentrations near to the Alliance Lorneville coal-fired boiler indicates the following:

1) Most metal concentrations in soil are elevated in the region of the most elevated modelled ambient air quality impacts due to the CFB.
2) The spatial variation in most soil metal concentrations is consistent with the spatial pattern of modelled ambient impacts.
3) The spatial variation in soil metal concentration is consistent with the metals being emitted from the coal-fired boiler.
4) Metal concentrations are significantly below guideline levels. The majority of the concentrations have been taken to be baseline levels which would be present in the absence of boiler impacts.
5) With continued input from the boiler over the next century at the same rate as the last 55 years, metal concentrations will still be significantly below guideline levels.

9.0 EVALUATION OF MODEL RESULTS

9.1 Introduction

The dispersion modelling provides estimates of GLCs resulting from the contaminant emissions discharged from the boiler stacks. To evaluate the model results against the relevant assessment criteria, background concentrations of contaminants must also be considered. This section of the report takes the modelled GLCs of contaminant emissions discharged from the boiler stacks, combines these with the estimated background level and then evaluates the cumulative effect against the relevant assessment criteria.

The key potential effects of concern are human health effects due to the discharge of PM$_{10,}$ NO$_{2,}$ SO$_2$, metals and dioxins. Potential health effects of PM$_{10,}$ NO$_{2,}$ SO$_2$ vary in degree but can include mortality, morbidity, hospitalisation, work-affected days, increased use of medication, emergency room attendances for respiratory and cardiovascular disease, increases in respiratory symptoms and decreases in lung function (such as asthma).

9.2 Particulate Matter

Table 13 presents the modelled, background and cumulative PM$_{10}$ GLCs. The cumulative PM$_{10}$ GLC is compared to the assessment criterion to evaluate the potential impacts of the PM$_{10}$ discharged from the boilers.

Table 13: Cumulative concentrations of PM$_{10.}$

Averaging period	**Maximum off-site GLC**			**GLC at highest impacted off-site dwelling**			**Assessment criterion (µg/m^3)**
	Modelled GLC (µg/m^3)	**Back-ground GLC (µg/m^3)**	**Cumulative GLC (µg/m^3)**	**Modelled GLC (µg/m^3)**	**Back-ground GLC (µg/m^3)**	**Cumulative GLC (µg/m^3)**	
24-hour	40	15	55	17	15	32	50
Annual	5	10	15	1.7	10	12	20

9.2.1 Impacts adjacent to the site boundary

The maximum cumulative 24-hour PM$_{10}$ GLC of 55 µg/m^3 is predicted to occur at the nearest point of the site boundary (i.e., approximately 370 metres east of the boiler stacks). Only one exceedance above 50 µg/m^3 is predicted to occur at this location over a 2 year period (i.e., only one modelled GLC above 35 µg/m^3, before adding background), indicating compliance with the NES for PM$_{10}$ can be met. However given the level of uncertainty in the modelling and analysis it is possible that the NES could be breached at this uninhabited location. Nevertheless, this is not a location where people are likely to be exposed for a substantial time with respect to a 24-hour period and it is considered that the NES would therefore not apply. The area is adjacent to the Alliance site boundary and is open rural land.

From the above analysis, it concluded that the potential for adverse health effects due to cumulative PM$_{10}$ exposure adjacent to Alliance's site boundary and beyond is minor.

9.2.2 The most impacted residential dwelling

The most impacted off-site residential dwelling is approximately 770 metres east from the boiler stacks and the predicted exposure information for this location indicates a maximum cumulative 24-hour PM_{10} GLC of 32 µg/m³ (64 % of the NES limit).

The predicted impact of cumulative PM_{10} concentrations (modelled + background GLCs) at the most impacted residential dwelling is shown as a 24-hour average time series from January 2010 to December 2011 in Figure 20. Figure 21 shows the cumulative frequency plot of predicted 24-hour average PM_{10} concentrations at this dwelling, excluding background.

The information displayed on Figure 20 shows that the predicted 24-hour average cumulative PM_{10} concentrations at the most impacted residential dwelling is above 25 µg/m³ only in five occasions during the period of two years. Figure 21 shows that, for modelled GLCs (i.e., before adding background) a concentration above 5 µg/m³ is predicted for less than 8 % of days at this receptor, and a concentration above 15 µg/m³ is predicted only one day during the two year period.

The maximum off-site cumulative annual average PM_{10} GLC is predicted to be 12 µg/m³ (60 % of the MfE criterion) at the nearest residential off-site dwelling.

From the above analysis, it concluded that the potential for adverse health effects due to cumulative PM_{10} exposure at the nearest residential dwelling to Alliance's site boundary is also minor.

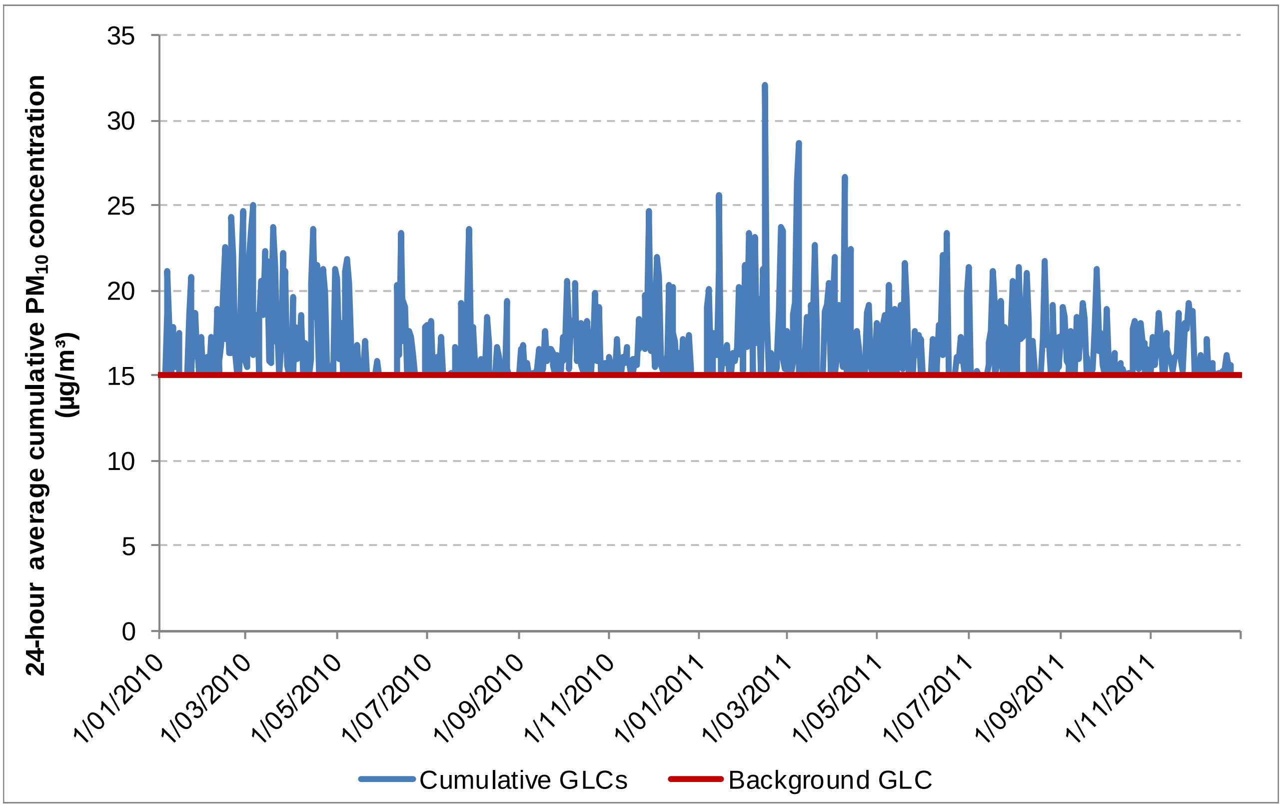

Figure 20: Predicted 24-hour average cumulative PM_{10} concentrations at the most impacted off-site dwelling.

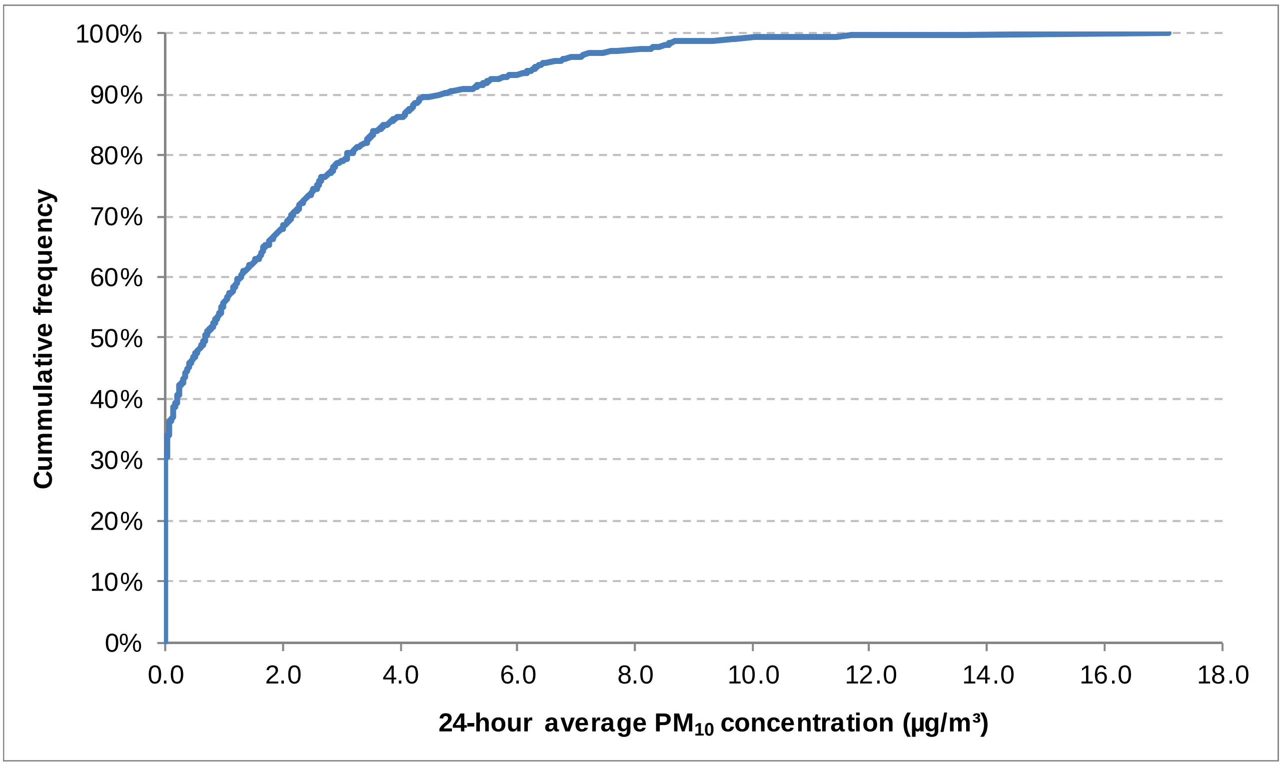

Figure 21: Cumulative frequency plot of predicted 24-hour average PM_{10} concentrations at the most impacted off-site dwelling, excluding background.

9.2.3 Impacts in urban areas

It is important to consider the impact of the PM_{10} boiler emissions on the areas that are in relatively close proximity to the plant and that have relatively high populations (Wallacetown and Invercargill airsheds).

The modelled impact of the PM_{10} discharged from the boilers on the centre of Wallacetown is shown as a 24-hour average time series from January 2010 to December 2011 in Figure 22. Figure 23 shows the cumulative frequency plot of predicted PM_{10} concentrations from the boiler discharges in the centre of Wallacetown.

The modelled impact of the PM_{10} discharged from the boilers on the northern edge of the Invercargill airshed is shown as a 24-hour average time series from January 2010 to December 2011 in Figure 24. Figure 25 shows the cumulative frequency plot of predicted PM_{10} concentrations from the boiler discharges boilers on the northern edge of the Invercargill airshed.

The information displayed in Figure 22 to Figure 25 shows that the increase in 24-hour average PM_{10} concentrations due to the boiler discharges is predicted in to be below 5.0 µg/m³ in Wallacetown and below 4.0 µg/m³ in the Invercargill airshed. An increase of above 1 µg/m³ is experienced approximately 6 % of days in both Wallacetown and in the Invercargill airshed. An increase of above 2 µg/m³ is experienced approximately 2 % of days in Wallacetown and 1 % of days in the Invercargill airshed.

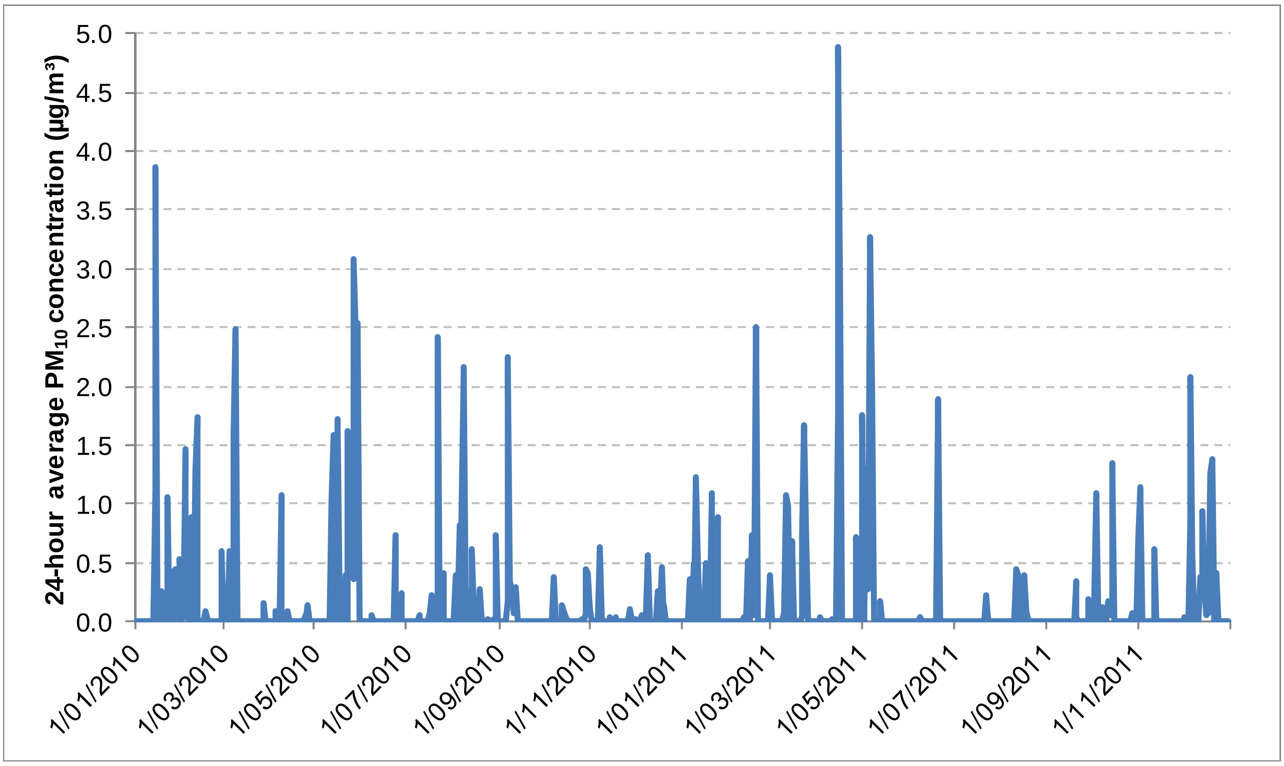

Figure 22: Predicted 24-hour average PM_{10} concentrations from the boiler discharges in the centre of Wallacetown.

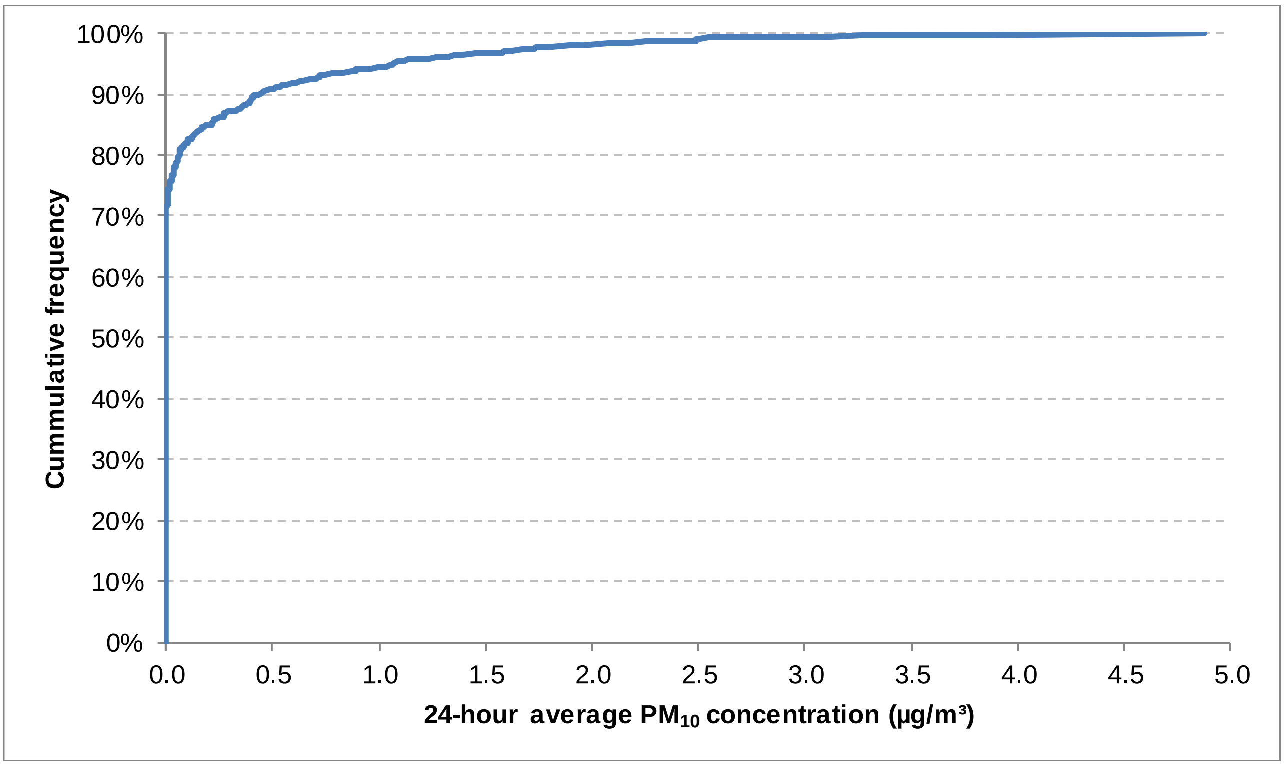

Figure 23: Cumulative frequency plot of predicted PM10 concentrations from the boiler discharges in the centre of Wallace town.

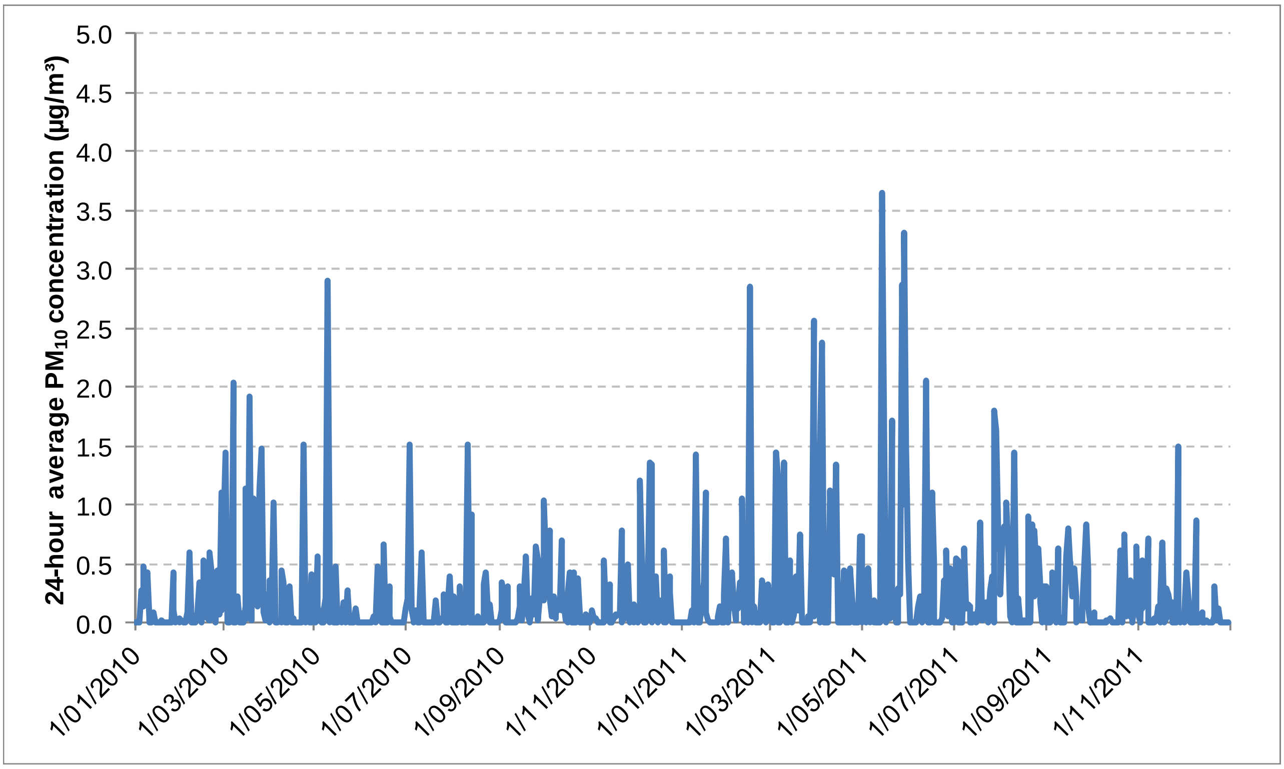

Figure 24: Predicted 24-hour average PM_{10} concentrations from the boiler discharges on the northern edge of the Invercargill airshed.

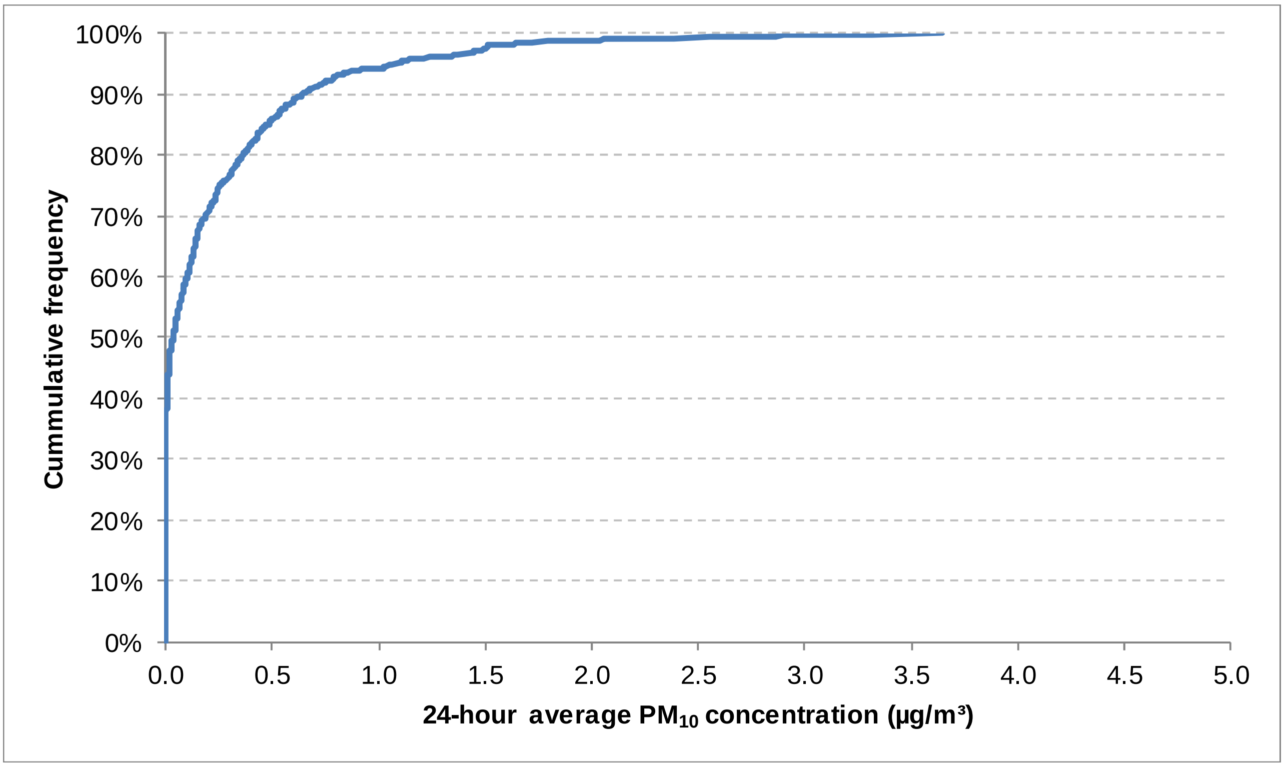

Figure 25: Cumulative frequency plot of predicted PM_{10} concentrations from the boiler discharges on the northern edge of the Invercargill airshed.

Figure 25 above indicates that the influence of the Alliance CFBs on the Invercargill airshed's 24-hour PM_{10} levels will be below detection for at least 95 % of days in a year (i.e. below 1 µg/m^3). On worst case winter days for high urban ambient PM_{10}, Golder expects the interaction of Alliance emissions with the Invercargill airshed would be minimal. Furthermore, the highest 5 % of predicted 24-hour PM_{10} impacts from the Alliance CFBs, as shown in Figure 25 for Invercargill, are not expected to occur on cold still winter days when the background levels are high. Consequently, our view is that the level of 24-hour PM_{10} impacts from the Alliance CFBs on the residential dwellings surrounding the site is most relevant to the assessment of boiler emissions mitigation.

In summary, the analysis contained in this section indicates that the boilers have a negligible impact on Wallacetown and the Invercargill airshed.

9.3 Nitrogen Dioxide

Table 14 presents the modelled, background and cumulative NO_2 GLCs. The cumulative NO_2 GLC is compared to the assessment criterion to evaluate the potential impacts of the primary NO_2 discharged from the boilers and the secondary NO_2 produced by atmospheric chemistry processes which convert NO to NO_2.

Table 14: Cumulative concentrations of NO_2.

Averaging period	Maximum off-site GLC			GLC at highest impacted off-site dwelling			Assessment criterion (µg/m³)
	Modelled GLC (µg/m³)	Back-ground GLC (µg/m³)	Cumulative GLC (µg/m³)	Modelled GLC (µg/m³)	Back-ground GLC (µg/m³)	Cumulative GLC (µg/m³)	
1-hour (99.8th percentile‡)	16	15	31	13	15	28	200
24-hour	9	15	24	6	15	21	100

The maximum off-site cumulative 1-hour average NO_2 GLC is predicted to be 31 µg/m³ (16 % of the assessment criterion). The cumulative 1-hour average NO_2 GLC at the highest impacted off-site dwelling is predicted to be 28 µg/m³ (14 % of the assessment criterion).

The maximum off-site cumulative 24-hour average NO_2 GLC is predicted to be 24 µg/m³ (24 % of the assessment criterion). The maximum cumulative annual average PM_{10} GLC at an off-site dwelling is predicted to be 21 µg/m³ (21 % of the assessment criterion).

In summary, the cumulative concentrations of NO_2 at the maximum off-site and highest impacted off-site dwelling locations are predicted to be well below the respective 1-hour and 24-hour average assessment criteria

9.4 Sulfur Dioxide

Table 15 presents the modelled, background and cumulative SO_2 GLCs. The cumulative SO_2 GLC is compared to the assessment criterion to evaluate the potential impacts of the SO_2 discharged from the boilers.

Table 15: Cumulative concentrations of SO_2.

Averaging period	Maximum off-site GLC			GLC at highest impacted off site dwelling			Assessment criterion (µg/m³)
	Modelled GLC (µg/m³)	Back-ground GLC (µg/m³)	Cumulative GLC (µg/m³)	Modelled GLC (µg/m³)	Back-ground GLC (µg/m³)	Cumulative GLC (µg/m³)	
1-hour maximum (99.9 percentile†)	290	5	295	169	5	174	570
1-hour 99.9th Percentile (99.8th percentile‡)	260	5	265	143	5	148	350
24-hour	140	5	145	62	5	67	120
Annual	18	3	21	7	3	10	30

Notes: † Based on the modelled 99.9th percentile in accordance with MfE guidance for predicted 1-hour concentrations.

‡ Based on the modelled 99.8th percentile.

The 1-hour maximum cumulative off-site and highest impacted off-site dwelling SO_2 GLCs are predicted to be 295 µg/m³, (52 % of assessment criterion) and 174 µg/m³, (31 % of assessment criterion) respectively.

The 1-hour 99.9th percentile cumulative off-site and highest impacted off-site dwelling SO_2 GLCs are predicted to be 265 µg/m (76 % of assessment criterion) and 148 µg/m³, (42 % of assessment criterion) respectively.

In summary, the maximum and 99.9th percentile 1-hour average SO_2 impacts are below the applicable health standards and typical levels would be well within these.

The maximum 24-hour average cumulative off-site SO_2 GLC is predicted to be 145 µg/m³ (120 % of the assessment criterion). The maximum 24-hour average cumulative SO_2 GLC at the highest impacted off-site dwelling is predicted to be 67 µg/m³ (56 % of the assessment criterion).

Because the maximum off-site cumulative 24-hour SO_2 concentration is predicted to be above the relevant assessment criterion it is important to understand the spatial extent and frequency of that predicted exceedance. The off-site area which is predicted to experience exceedances of the 24-hour average SO_2 assessment criterion is limited to the western ends of the two fingers of land that extend into the site boundary from the eastern side. The area impacted by 24-hour average SO_2 concentrations greater than 120 µg/m³ is estimated to be less than 2 hectares (see Figure 13).

The modelled impact of the SO_2 discharged from the boilers at the maximum impacted off-site gridded receptor is shown as a 24-hour average time series from January 2010 to December 2011 in Figure 26. Figure 27 shows the ranked predicted 24-hour average SO_2 ground level concentrations at the maximum impacted off-site gridded receptor. Figure 28 shows the cumulative frequency plot of predicted SO_2 concentrations from the boiler discharges at the maximum impacted off-site gridded receptor.

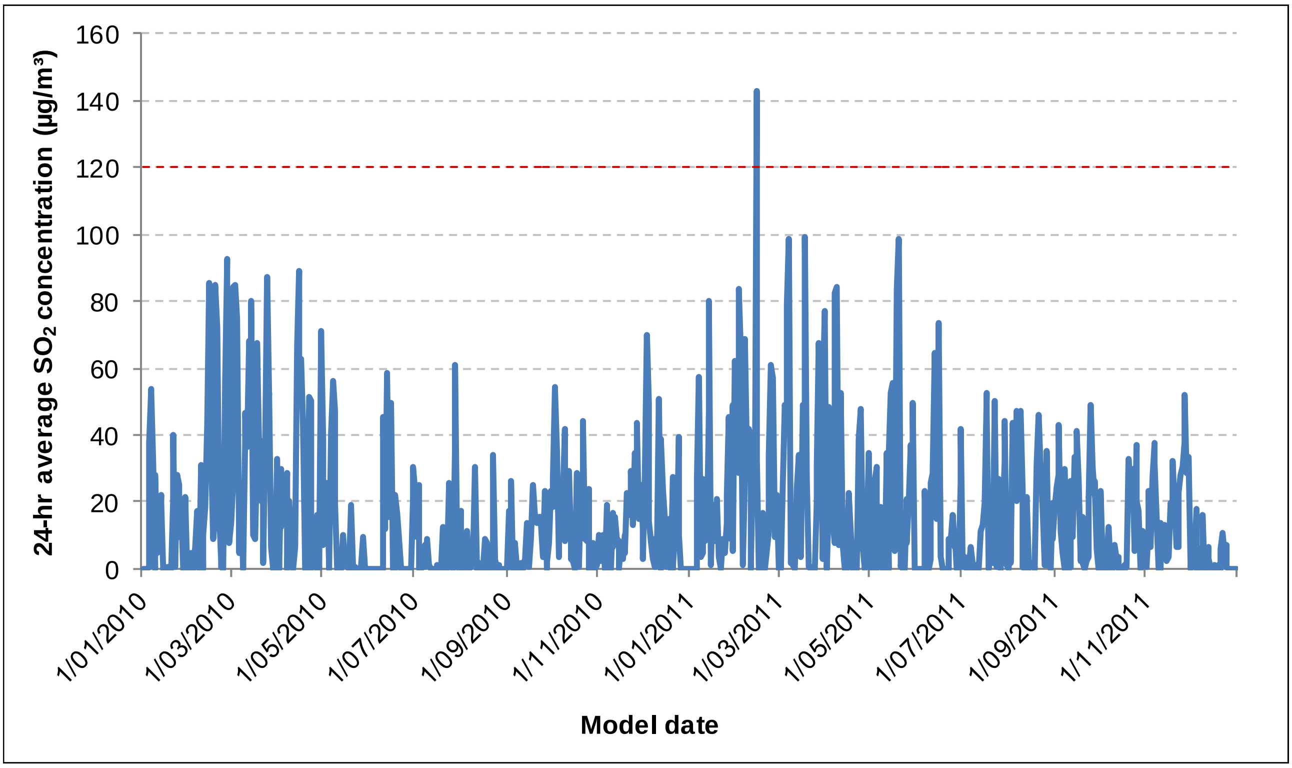

Figure 26: Predicted 24-hour average SO_2 ground level concentrations based on the hourly varying emissions file at the maximum impacted off-site gridded receptor. The 24-hour average SO_2 assessment criterion is indicated by the red dashed line.

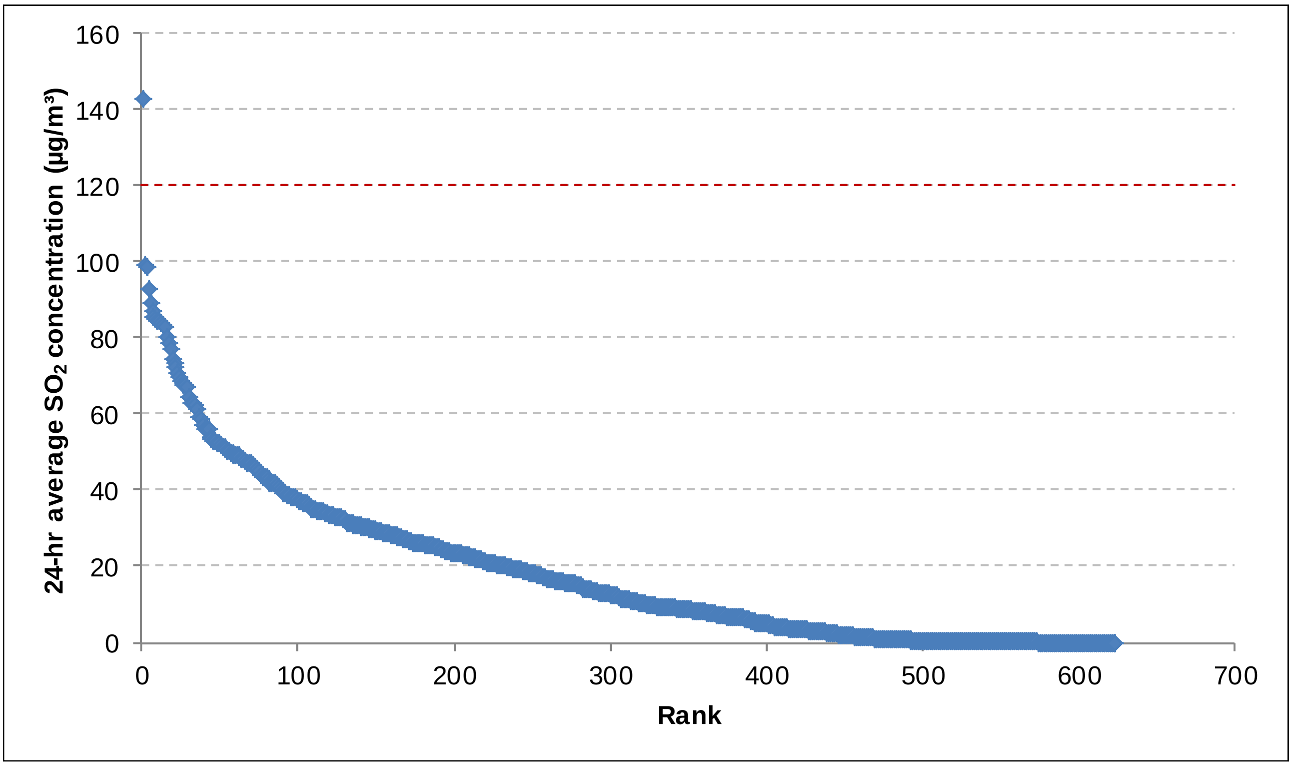

Figure 27: Ranked predicted 24-hour average SO_2 ground level concentrations based on the hourly varying emissions file at the maximum impacted off-site gridded receptor. The 24-hour average SO_2 assessment criterion is indicated by the red dashed line.

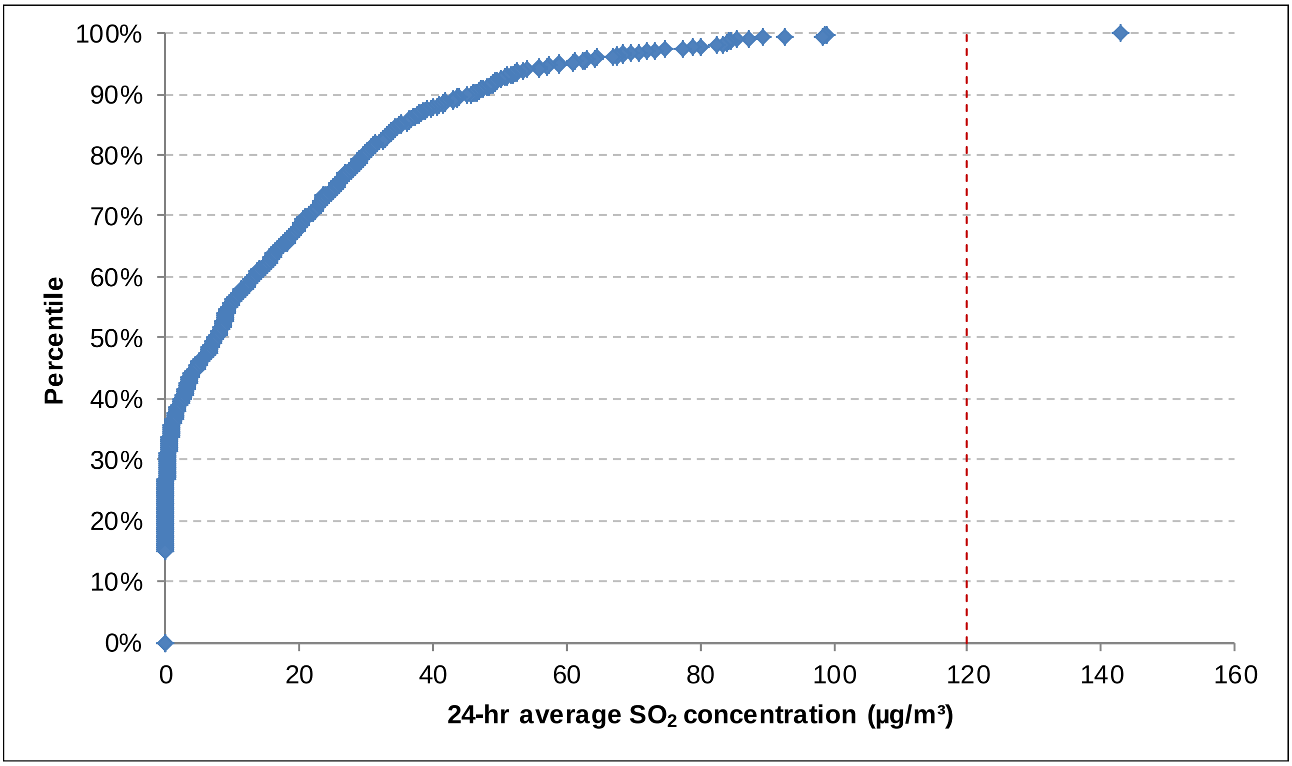

Figure 28: Percentiles for the predicted 24-hour average SO_2 ground level concentrations based on the hourly varying emissions file at the maximum impacted off-site gridded receptor. The 24-hour average SO_2 assessment criterion is indicated by the red dashed line.

Figure 26 and Figure 27 show that only a single exceedance of the 24-hour average SO_2 assessment criterion is predicted to occur at the maximum impacted off-site gridded receptor. Figure 28 shows that concentrations above 80 µg/m³ (75 % of the 24-hour average SO_2 assessment criterion) are predicted to occur for approximately 2 % of the time.

In summary, while an exceedance of the 24-hour average SO_2 assessment criterion is predicted to occur, the spatial extent and frequency of this event is likely to be very limited and any adverse effect that does occur will be minor.

The maximum off-site cumulative annual average SO_2 GLC is predicted to be 21 µg/m³ (70 % of the assessment criterion). The maximum cumulative annual average SO_2 GLC at an off-site dwelling is predicted to be 10 µg/m³ (33 % of the assessment criterion), which is considered to be much more representative of wider scale SO_2 impacts than the maximum off-site value. In summary, the maximum annual average SO_2 impact is below the applicable health standards and typical levels would be well within these.

9.5 Metals

Table 16 presents the modelled, background and cumulative metal GLCs. The cumulative metal GLC is compared to the assessment criterion to evaluate the potential impacts of the metals discharged from the boilers.

Table 16: Cumulative concentrations of metals.

Metal	Maximum Off-site GLC (annual average)			GLC at a highest impacted off-site dwelling (annual average)			Assessment criterion (µg/m^3)
	Modelled GLC (µg/m^3)	Back-ground GLC (µg/m^3)	Cumulative GLC (µg/m^3)	Modelled GLC (µg/m^3)	Back-ground GLC (µg/m^3)	Cumulative GLC (µg/m^3)	
Arsenic	8.6 x 10^{-4}	0	8.6 x 10^{-4}	3.1 x 10^{-4}	0	3.1 x 10^{-4}	5.5 x 10^{-3}
Cadmium	5.6 x 10^{-5}	0	5.6 x 10^{-5}	2.0 x 10^{-5}	0	2.0 x 10^{-5}	2 x 10^{-2}
Chromium	3.8 x 10^{-4}	0	3.8 x 10^{-4}	1.4 x 10^{-4}	0	1.4 x 10^{-4}	1.1 x 10^{-3} (Cr VI) 1.1 x 10^{-1} (Cr metal and Cr III)
Mercury	1.6 x 10^{-4}	0	1.6 x 10^{-4}	5.7 x 10^{-5}	0	5.7 x 10^{-5}	3.3 x 10^{-1}
Lead*	3.0 x 10^{-4}*	0	3.0 x 10^{-4}*	1.2 x 10^{-4}*	0	1.2 x 10^{-4}*	2 x 10^{-1}*

Note: *3 month rolling average.

The maximum off-site cumulative annual average concentrations for the following metals are predicted to be:

- Arsenic 8.6 x 10^{-4} µg/m^3 which is 16 % of the assessment criterion
- Cadmium 5.6 x 10^{-5} µg/m^3 which is 0.28 % of the assessment criterion
- Chromium 3.8 x 10^{-4} µg/m^3 which is 35 % of the assessment criterion
- Mercury 1.6 x 10^{-4} µg/m^3 which is 0.05 % of the assessment criterion

The maximum off-site cumulative three month rolling average concentrations for copper is 3.0 x 10^{-4} µg/m^3 which is 0.15 % of the assessment criterion.

In summary, the maximum annual average GLCs of arsenic, cadmium, chromium and mercury are all well below the applicable health standards and unlikely to cause any adverse effects. The three month rolling average of copper is well below the applicable health standard and unlikely to cause any adverse effects.

9.6 Dioxins

Table 17 presents the modelled, background and cumulative dioxin GLCs. The cumulative dioxin GLC is compared to the assessment criterion to evaluate the potential impacts of the dioxins discharged from the boilers.

The modelled maximum annual exposure concentration of I-TEQ is predicted to be 3 x 10^{-10} µg/m^3. This equates to 0.0003 pg I-TEQ/m^3 (nb: pg is a picogram) as listed below in Table 17. Given this exposure concentration and the above values for average body weight, inhalation rate (13 m^3/day), contact time and exposure time over 70 years then a LADD value of 1.74 x 10^{-5} pg I-TEQ/kg/day. This is also an estimate of the maximum TDI value that is predicted for this proposal.

From the above LADD value, the incremental cancer risk is calculated as 1.74 x 10^{-5} pg/kg/day x 1.4 * 10^{-3} kg-day/pg (i.e., LADD * Risk Factor), which results in a predicted incremental cancer risk that is equal to 2.4 x 10^{-8}. This is level of incremental risk is well below the probability of 10^{-6} that usually assumed internationally as an acceptable level of risk. It is also over 400 times lower than the MfE guideline for cancer risk of 1 x 10^{-5}.

The potential for non-cancer effects due to inhalation is also extremely low when comparing the estimated TDI value of 1.74 x 10^{-5} pg/kg/day to the guideline value of 1.0 pg/kg/day, as the health guideline TDI value is 57,000 times above the estimated worst case value.

Table 17: Cumulative concentrations of Dioxin.

	Maximum Off-site GLC (annual average)			**Maximum Off-site GLC (annual average)**			**Assessment criterion (pg/kg/day)**
	Modelled GLC (pg I-TEQ/m^3)	**Back-ground GLC** (fg I-TEQ /m^3)	**Cumulative GLC** (pg I-TEQ/m^3)	**Modelled GLC** (pg I-TEQ/m^3)	**Back-ground GLC** (fg I-TEQ/m^3)	**Cumulative GLC** (pg I-TEQ/m^3)	
Dioxin	0.0003	16	0.0163	0.0001	16	0.0161	1.0

10.0 MITIGATION

10.1 Overview

This section discusses existing measures for mitigation of the ambient concentrations of respirable particulate (including PM_{10} and $PM_{2.5}$). From the modelling and monitoring assessments, it is clear that the ambient concentrations of SO_2, NO_2 and other contaminants that are discharged from the CFB stacks are well below health effect thresholds. Therefore these contaminant discharges from the CFBs have only minor or, in many cases, a less than minor potential to cause any adverse effects. Furthermore, the effective mitigation of nuisance effects due to TSP emissions is effectively mitigated by the relatively large separation distances between the Alliance CFBs and the property boundary.

With the exception of incremental ambient PM_{10} concentrations due to the CFB emissions, it is concluded that the existing restrictions on coal sulfur levels, the CFBs output capacity (MW) and existing CFBs stack heights provide adequate and effective mitigation of potential environmental effects.

Regarding ambient PM_{10} concentrations, compliance with the MfE's NES for PM_{10} in all areas surrounding the site boundary is achieved, however this does not ensure only minor, or a less than minor potential for adverse effects. This is because PM_{10} (especially that derived from combustion) does not have an established threshold concentration below which there are only minor or else no observable adverse health effects on humans. Therefore while MfE's NES for PM_{10} is expected to be met at all residential dwellings surrounding the Alliance property boundary (including the most impacted dwelling that is 650 m to the east of the CFBs), it is important for Alliance to ensure that a good level of performance is achieved by the CFBs with respect to PM_{10} emission control. From Golder's experience, for CFBs operating with multi-clone systems, a good level of performance would equate to a maximum PM_{10} discharge concentration of 250 mg/Nm^3 (corrected to 12 vol.% CO_2).

10.2 Existing Particulate Control Measures

The existing measures for mitigating air contaminant emissions from the CFBs (which includes PM_{10}) includes the CFBs existing automatic controls for ensuring steady coal combustion, the primary treatment of boiler exhaust air via multi-clones (for TSP and PM discharges) and discharge of these pre-treated emissions via tall discharge stacks in order to minimise ground level contaminant concentrations. In association with these engineering and process control measures, Alliance undertakes annual stack emissions testing and boiler tuning programmes. This provides a one-off annual check upon the particulate emission rates and associated combustion conditions.

Alliance requires various specifications for the coal that is supplied to the site, including specifying and controlling the maximum level of coal fines. This is important, as excessive fines within the coal supply can cause partial blockages within the grates, inducing uneven airflows and increased backpressures across the burning coal bed. This causes less even combustion conditions and an associated increase in respirable particulate emissions. Therefore managing coal fine levels within the supplied coal blend is a practical measure that allows for the maintenance of optimal oxygen conditions within the primary and secondary firing zones of the CFBs.

In the last two years, a number of initiatives by Alliance have been implemented to reduce PM_{10} emissions from the two CFBs. This has included trialling an alternative coal grade, an investigation of the CFBs' operating efficiency, review of combustion control measures, boiler combustion air settings and engineering upgrades to ash handling and multi-clone equipment on CFB 2. Historically CFB 2 had performed significantly worse than CFB1. The replacement of the existing multi-clone equipment in CFB2 reduced the concentration of PM10 within this boiler's discharge within the order of 40%.

The result has been a significant reduction in the flow weighted average PM_{10} discharge concentration from the CFBs which now appear to operate within a normalised concentration of 300 mg/Nm^3 (corrected to 12 vol.% CO_2). Prior to this upgrade the flow weighted average PM_{10} discharge concentration from the two CFBs was estimated to be closer to 400 mg/Nm^3.

With regards to dust control of coal storage, the lignite coal supply does arrive at the site in a relatively wet state and is unloaded into a partially covered tall load-in building. The potential for off-site dust from this operation is considered very low due the nature of the coal and the large distances to the site boundary – that is over 500 metres away in all directions.

10.3 Mitigation Options

10.3.1 Overview

There are a range of technologies available for controlling particulate emissions from the CFBs and therefore minimising the potential for adverse effects on the environment. The options include the following:

- Up-graded boiler operational controls
- Improved multi-clone (grit arrestor) performance
- Fractionating Bag House (FBH)
- Full Bag House (BH)
- Electrostatic Precipitators (ESPs)
- Increasing existing stack heights
- Combining the discharge of boiler exhausts into a common stack

Further details on these various control measures are provided in Section 10.3.2 below.

10.3.2 Description of options

Up-graded operational controls: The very fine $PM_{2.5}$ (the finer fraction of PM_{10}) is formed by two processes – firstly as a result of condensed products of incomplete combustion (PICs) within the coal-fired boiler exhaust and secondly from very fine soot (unburnt carbon) and a minor source from non-combustible minerals. Therefore optimising combustion chamber conditions (indicated by lower carbon monoxide (CO) levels in the boiler exhaust) is an effective mitigation measure.

Excessive combustion air supply can be overcome by the automation of combustion oxygen control and CO monitoring. Primary and secondary combustion air flows can be modified to help minimise CO and PIC levels in the exhaust air for optimal exhaust oxygen content. This requires oxygen and carbon monoxide monitoring within the exhaust stack and a sophisticated control strategy for automatic adjustment of primary and secondary air flows to minimise CO production. The costs for such systems are moderate (in the order of $100,000), but help reduce fuel usage as well as particulate discharge rates and are therefore considered to be cost effective.

Up-grading operational controls that are applied to the existing CFBs is considered to provide the most cost effective option for minimising coal use and respirable particulate emissions per unit mass of coal burnt. This option is considered to be the most cost effective means for minimising PM_{10} emissions from the CFBs.

Multi-clone systems: Multi-clones are inertial devices that utilise cyclonic forces to separate particulates from the CFBs exhaust air streams. These systems are more effective at removing larger particulate sizes and are therefore very effective with particles of approximately 20 µm in size and larger. They are less effective at removing particulates below 10 µm (i.e., PM_{10}) and should in theory have very little impact upon $PM_{2.5}$ emission rates. However in practice, modern multi-clone systems should achieve normalised PM_{10} concentrations below 250 mg/Nm^3 (corrected to 12 vol.% CO_2), which is consistent with recent tests performed on the CFB 2 stack (See Appendix H). Achieving a PM_{10} concentration of 250 mg/Nm^3 (corrected to 12 vol.% CO_2) in the final boiler discharge to air is therefore considered to be the appropriate target for the CFBs to achieve.

Currently it is estimated that the PM_{10} emissions from the two CFBs achieve a flow weighted average concentration of 300 mg/Nm^3 (equating to 21.6 kg/hr) and are therefore approaching good performance in terms of PM_{10} control (i.e., 250 mg/Nm^3 corrected to 12 vol.% CO_2) via standard multi-clone technology and combustion management. If necessary to achieve good multi-clone performance (i.e., 250 mg/Nm^3 corrected to 12 vol.% CO_2) an additional new multi-clone would cost an additional $250,000 over and above the cost for the upgraded CFB controls.

Fractionating bag-house filters: These bag-house filter systems treat a minor proportion of the total boiler exhaust air flow. This portion is the underflow that is drawn from the base of the multi-clone system (i.e., about 15 % of the total exhaust air flow). Therefore rather than having a rotary valve, a continual air flow is drawn from the base of the multi-clones, which enhances their overall efficiency. The solids rich air stream that is drawn off from the base of the multi-clones is then passed through a bag-house filter system. The filtered air stream is then recombined with the main exhaust flow that is discharged from the top of the multi-clones. These systems appear to have variable success in practice, and typically provide a moderate enhancement of multi-clone performance and their reliability. Fractionating bag-house filters are expected to impose moderately high capital (about $2 million) and operational costs ($60,000/annum) to the site for relatively low benefit.

Full bag-house filters (FBHFs): These filter systems treat the total boiler exhaust air flow post the multi-cyclones and sometimes allow the pre-treatment via multi-clones to be eliminated. They create additional pressure drop and fan power costs, while achieving a high level of filterable particulate removal. A disadvantage of this technology is that the finer fraction of particulates (i.e., $PM_{2.5}$) may not be efficiently captured by existing bag-house filter technology. To be effective, filter bags may need to have different surface coatings and / or material to be effective at removing $PM_{2.5}$, alternative bag cleaning technologies (other than pulse jet) may also need to be implemented So while FBHFs are known to be efficient at removing filterable particulates including PM_{10}, a future requirement to focus control upon $PM_{2.5}$ emissions may well point to other technologies (e.g., Electrostatic Precipitators) as being more cost effective at controlling this finer size fraction of particulate. The use of FBHFs would impose a relatively high capital (approximately $6 million) and ongoing annual operating costs (approximately $0.2 million). Despite this, these systems are often used for controlling particulate emissions from medium to large scale coal-fired boiler plants. However, for the above reasons, it is concluded that FBHFs may not be the most cost-effective technology in the future for controlling $PM_{2.5}$ emissions from the CFBs.

Electrostatic precipitators (ESPs): This technology uses electrically charged plates to attract and remove fine particulate from the total boiler exhaust flow. The capital cost of ESPs is also high (approximately $3.2 million) although less than for a FBHF installation. Particulates are ionized when they pass the ESP plates, causing migration and collection on oppositely charged surfaces. Compared to FBHFs, they are more efficient at removing some $PM_{2.5}$ particles and can treat large volumes of gas with low pressure drops. Therefore ESPs may have lower operating costs compared to FBHF systems – depending on electricity prices. Whilst ESPs are most effective on fine particulates, they are less efficient on larger particles and are especially inefficient on large particulate with high electrical resistivity – the reverse is true for FBHF systems. Therefore, while ESPs may be most effective at reducing the potential health effects of boiler particulate emissions (by efficient removal of fine and ultra-fine particulate), they may discharge a higher mass concentration of suspended particulate. Therefore whether or not this technology is more cost-effective than conventional FBHF systems in the future is likely to depend upon the reduced potential for health effects from $PM_{2.5}$ rather than a simple consideration of the particulate mass emission rate. Finally, an increased extent of exhaust cooling prior to the ESP should improve its overall performance, as more $PM_{2.5}$ would have formed due to condensation and be available for removal.

Discharge stack design: The consideration of mitigation options include increasing the boilers existing discharge stack heights (currently 31 m and 34 m for CFB 1 and 2 respectively) or replacing these with a new common discharge stack (costing in the order of $0.5 million). This does not reduce the rate of contaminant emission, but reduces the intensity of exposure at the most impacted locations that surround the boiler stacks. The costs for reduction of PM_{10} exposure ($ per % ambient PM_{10} reduction) due to stack height increase are typically low compared to the costs for end-of-pipe treatment options.

Preliminary modelling has found that an increase in boiler stack heights to 45 m would be necessary to make a useful reduction to peak off-site ambient PM_{10} and $PM_{2.5}$ (and other contaminant concentrations). The costs for this increase are likely to be expensive (although low compared to end-of-pipe technologies in absolute terms and $ per % ambient PM_{10} reduction). However this could be considered as a useful interim step before more costly end-of-pipe mitigation treatment systems are contemplated.

10.3.3 Recommended mitigation option

For the CFBs it is recommended that Alliance commits to achieving a flow weighted average PM_{10} discharge concentration limit of 250 mg/Nm^3 (corrected to 12 vol.% CO_2) within 5 years. To achieve this limit Alliance should implement the use of modern boiler combustion control and may also need to undertake other measures such as a multi-clone upgrade to CFB 1. It may well be that, during the term of any long consent period, new ambient standards and/or evolving science indicates that a significant investment in further mitigation via end-of-pipe treatment of the CFBs exhaust air is justified. Depending on the details of any new PM_{10} or $PM_{2.5}$ regulations that may be imposed at a national or regional level, the most cost-effective option for further reducing particulate emissions could be an ESP, or some other technology instead of a FBHF. The latter when combined with a multi-clone, would represent the current Best Practice for CFB particulate emission controls in New Zealand.

The Alliance CFBs currently operate within a discharge limit of approximately 300 mg/Nm^3 (corrected to 12 vol.% CO_2) and therefore are approaching a good level of performance. It would be reasonable for Alliance to pursue a flow weighted average limit of 250 mg/Nm^3 within a five year period.

Golder concludes that the current best practicable option (BPO) of control of boiler particulate matter (PM) emissions is to achieve the 250 mg/Nm^3 in-stack discharge limit via the use of state-of-the-art instrumentation (oxygen and carbon monoxide), associated automation of boiler operation and achieve good performance from the multi-cyclone systems. Golder considers that the use of FBHF, ESP or similar end-of-pipe treatments represents the current best practice for PM emission controls.

11.0 COMPLIANCE MONITORING

11.1 General

Monitoring of air quality effects and/or compliance with discharge limits are standard approaches that are applied to coal-fired boilers. This section discusses the proposed regimes for monitoring the main CFB emissions including PM_{10}, discharge opacity and SO_2. This includes discussions and recommendations regarding consent conditions for these contaminants.

11.2 Particulate Discharges

11.2.1 General Approach

Given the importance of both PM_{10} and $PM_{2.5}$ with respect to potential health effects then annual stack monitoring is normally applied as a condition of consent. However the existing TSP testing methods provide a gross value for all particulate (including those larger than 10 microns). These methods are being superseded by US EPA methods for both measuring stack concentrations of PM_{10}, $PM_{2.5}$ and condensables (i.e., a fraction of $PM_{2.5}$ that can form post the stack from condensation of unburnt heavy organic compounds)[2]. The costs of correctly implementing these newer US EPA methods via certified agency are relatively high and comparable to (if not more expensive than) operating short ambient monitoring campaigns. The latter provides vastly more robust information regarding actual impacts, background concentrations and the potential cumulative effects of the CFBs discharges to air.

While stack PM_{10} limits of 300 mg/m^3 and eventually 250 mg/m^3 would be specified within a resource consent for the CFB discharges to air, it is recommended that ambient PM_{10} monitoring is used to confirm the off-site actual ambient concentrations that the in-stack limits seek to control. For both the proposed in-stack PM_{10} concentration limits, an associated average and peak ambient PM_{10} concentration due to the CFBs plus the ambient background can be established from the existing ambient monitoring and modelling presented in this report. Exceedance of a specified ambient PM_{10} concentration limit can then provide a trigger for undertaking stack emission testing rather than requiring this testing to be undertaken annually and reported.

It is considered that annual stack testing information does not provide a robust assessment of the actual ambient impacts for the CFBs. It is also considered that the accurate and continuous measurement of particulate matter (PM) emissions is very difficult, expensive and is generally only undertaken for much larger coal-fired power plant facilities or thermal plants.

The ambient PM_{10} monitoring regime that is proposed would be undertaken at a location that is one of the most impacted in terms of both frequency and magnitude as a result of the CFBs stack emissions – other locations do not require ambient monitor or would they be as effective for monitoring the CFBs emission control performance. Additionally, if the plant was to expand and the CFBs operated at a significantly higher rate on average, then the percentile PM_{10} trigger values would start to be routinely exceeded irrespective of compliance with in-stack limits.

Under the proposed ambient monitoring regime, the direct testing of stack emissions can be used at the discretion of Alliance to help tune the CFBs operation, unless ambient limits are exceeded and triggers the justification for stack testing.

In summary, the proposed monitoring strategy is designed to provide far greater certainty about actual PM_{10} emissions from the CFBs than would otherwise be achieved by the currently accepted practice of periodic stack discharge testing. More specific details regarding this monitoring regime for CFBs PM_{10} emissions is discussed below.

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[2] .. The combined use of US EPA Methods 201A and 202 enables sampling both filterable (201A) and condensable particulate (202). This will capture filterable PM10 as well as the fraction of $PM_{2.5}$ formed on exhaust cooling. These particulate partially escape the filter based sampling methods that are commonly used in New Zealand.

11.2.2 Ambient particulate and wind monitoring

A continuation of the 10 minute average beta gauge method at the approximate location of the dwelling predicted to be the most impacted by respirable particulate emissions from the CFBs (as detailed in Appendix H) is recommended for the ambient monitoring. The 1-hour ambient PM_{10} levels concentrations would be continuously monitored at this location, providing a more effective scrutiny of actual PM_{10} emissions effects from the CFBs over time. The measured percentile ambient concentrations would be very sensitive to the variation in real PM_{10} emissions from the CFBs, as well as the average discharge rate of PM_{10}.

Regarding the heights of the PM_{10} sampling and of the wind monitoring equipment, these should be different, at 3 m and 6 m high respectively. This is because the PM_{10} monitoring is related to height above ground level where people are likely to be exposed. Whereas the wind monitoring height is set higher above ground level to indicate the direction of wind within the lower boundary layer. This is more relevant for the elevated CFBs stack emissions.

11.2.3 Development of ambient particulate consent limits

This section provides a summary of the approach followed by Golder Associates to develop percentile hourly concentration limits to apply to continuously monitored *ambient* respirable particulate data. These limits and associated monitoring are proposed as part of the new air discharge consent that would authorise the continued operation of the site coal-fired boilers at Alliance Lorneville.

The proposed operation of a continuous ambient monitor for PM_{10} and wind monitoring station is considered to offer a significantly more robust compliance monitoring-regime than current in-stack PM_{10} measurement practices. This is especially given the location is near the nearest off site private dwelling that happens to also be downwind of the coal-fired boilers (CFBs) during most prevalent wind conditions that occur at the site. Not only does the use of percentile ambient limits provide a restriction on the maximum PM_{10} discharge rates from the CFB stacks, they also require the CFB operational rates to be consistent with the distribution of varying rates during the peak season that was assumed by the original modelling assessment. This is something stack emissions testing for PM_{10} has no ability to achieve.

The ambient percentile concentration limits are restricted to those times when the CFBs are directly upwind of the monitoring site and they account for the varying level of background ambient PM_{10} that is already present prior to the influence of the CFBs emissions. While ambient standards for PM_{10} are based on a 24-hour time frame, the use of hourly PM_{10} and wind monitoring data is necessary to confirm compliance with in-stack PM_{10} discharge concentration limits as this allows for more simplified reverse dispersion modelling to infer emission levels.

Methodology

The method for setting appropriate ambient limits utilised the cumulative ambient PM_{10} data obtained from the ambient monitoring site (i.e. most impacted off-site location to the east of the CFB air discharges), which was operated for two to three months in the summer of 2014 and 2015 (described by Golder (2014)). From this data set the distribution of existing background PM_{10} concentrations could be reliably established. This was necessary to enable the distribution of cumulative ambient PM_{10} impacts at the monitoring site (CFB emissions + background) to be predicted. For the monitoring period (January, February and March), dispersion model predictions of the distribution of CFB generated PM_{10} concentrations at the monitoring site were established. These were based on the CFBs operating for a distribution of steam outputs that was typical for these peak season months, and when assuming the in-stack discharge PM_{10} concentration limits of 300 mg/Nm^3 and 250 mg/Nm^3 respectively. Some details on the derivation of these 1-hour PM_{10} distributions and setting the limits are given as follows:

1) **Background PM_{10} distribution.** Ambient monitoring data obtained in the 2014 and 2015 seasons was used, including only the times when the wind direction had an easterly component (bearing between 0 degrees and 180 degrees from true north). The monitoring site is not downwind of the Alliance CFBs for this range, so the PM_{10} may be considered solely 'background'.

2) **CFB PM_{10} distribution.** Hourly PM_{10} is extracted from the dispersion model, for times when the wind direction is between 245 degrees and 270 degrees. In this narrow range, the monitoring site is almost directly downwind of the CFBs, and captures the main impacts from the coal-fired boilers. The modelling was carried out assuming CFB in-stack PM_{10} concentrations of 300 mg/Nm^3 and 250 mg/Nm^3 at 12 vol.% CO_2 in separate runs.

3) **Cumulative Ambient Impacts:** The distributions of existing background and CFB derived PM_{10} impacts at the monitoring site were added together as they are independent. This produced an estimate of the cumulative PM_{10} distribution that is expected to occur at the monitoring site when the CFBs operate at the in-stack concentration limits for PM_{10}. From this data, the percentile concentrations were then calculated for the monitoring site (see Tables 1 and 2 – columns headed “Consent Limits”). The consent limits for percentile PM_{10} concentrations were established from the predicted values with the addition of 2 µg/m^3, which allows for a ‘truncation error’ in the percentile values that are calculated from each season’s monitoring data.

Proposed Percentile Concentrations

The proposed percentile ambient concentrations trigger values for 1-hour PM_{10} are shown in Table 18 and Table 19 for both 300 mg/Nm^3 and 250 mg/Nm^3 in-stack PM_{10} concentrations limits. The last column in Table 18 displays the measured percentiles from the actual ambient 1-hour PM_{10} monitoring data for February 2014. These ambient monitoring data relate to the downwind directions from the CFBs stacks. It can be seen these data did not comply with the proposed limits based on 250 mg/Nm^3 or 300 mg/Nm^3. This was to be expected as the actual CFBs in-stack concentrations were assessed by Golder as being above 350 mg/Nm^3 prior to 2015.

Table 18: Proposed Ambient Trigger Levels compared to 2014 monitoring results for PM_{10}.

Number of hours monitoring site downwind of plant 130			**1-hour PM_{10} Percentile Concentrations (µg/m^3)**		
Hourly PM_{10} Percentile Concentrations	**Percentile**	**Rank**	**Ambient Consent Limits equivalent to In-stack PM_{10} of 300 mg/Nm^3**	**Ambient Consent Limits equivalent to In-stack PM_{10} of 250 mg/Nm^3**	**Monitored hourly ambient PM_{10}, downwind conditions (Jan- March, 2014)**
	100%	1	122	117	*93*
	95%	7	37	35	*61*
	75%	33	25	23	*25*
	50%	66	18	17	*15*

The above proposed percentile concentrations limits in Table 18 for 1-hour PM_{10} are repeated in Table 19. The last column in Table 19 contains the equivalent percentiles of the ambient 1-hour PM_{10} monitoring data for January 2015. It can be seen that these percentiles comply with the proposed limits for 300 mg/Nm^3. This can be expected as the actual CFBs in-stack concentrations were assessed by Golder meets the 300 mg/Nm^3 prior post 2015. Compliance with the percentiles for the in-stack concentration limit of 250 mg/Nm^3 is just met except for the average percentile, which is consistent with the CFB discharging slightly above the 250 mg/Nm^3 based limits. This indicates the CFBs are probably close to achieving the average discharge concentration of 250 mg/Nm^3 during summer of 2015.

Table 19 Proposed Ambient Trigger Levels compared to 2015 monitoring results for PM_{10}.

Number of hours monitoring site downwind of plant 209			1-hour PM_{10} Percentile Concentrations (µg/m^3)		
Hourly PM_{10} Percentile Concentrations	**Percentile**	**Rank**	**Ambient Consent Limits equivalent to In-stack PM_{10} of 300 mg/Nm^3**	**Ambient Consent Limits equivalent to In-stack PM_{10} of 250 mg/Nm^3**	**Monitored hourly ambient PM_{10}, downwind conditions (Jan- March, 2015)**
	100%	1	122	117	*69*
	95%	11	37	35	*33*
	75%	53	25	23	*22*
	50%	105	18	17	*18*

Proposed Ambient (1-hour) PM_{10} Concentration Percentiles

The use of the 95th and 100th percentile ambient concentration trigger limits allows for some limited and theoretical exceedance of 300 mg/Nm^3 in-stack conc. limit for up to 5% of the time, but limited in magnitude by the 100th ambient percentile limit. This is considered to be good practice for conditions that are applied to continuous monitoring data as it allows for measurement outliers while capping the magnitude.

In addition, the use of percentile limits is required in this instance because measured values are a result of both CFBs PM_{10} emissions plus the existing background. Therefore the percentile values helps in the assessment of compliance levels over extended periods of time. For example the maximum one-off hourly concentration (100 percentile) that can occur during the monitoring period results from a combination of the CFBs operating at their in-stack discharge limit combined with worst case meteorology and background PM_{10} levels. If the CFB discharges are highly variable but on average achieve the discharge limit (say over a day), or else they operate consistently above the in-stack discharge limit, then this is likely to lead to the measured 1-hour maximum ambient concentration exceeding the 100 percentile limit.

Having an additional 95 percentile ambient concentration limit adds further robustness to the compliance monitoring as this specifies the ambient concentration that should be met for 95 % of time if the CFBs operate at their in-stack discharge limit, while accounting for variations in background PM_{10} over time – the latter has been established accurately from site monitoring.

In summary, having percentile limits for maximum and 95 percentile ambient concentrations allows for background ambient variations to be accounted for in the monitoring data, while ensuring that the need for stack testing is only triggered when there is a reasonable prospect that the in-stack CFBs limits are not being routinely complied with. The limits also allow for some short term exceedances of the in-stack PM_{10} limits which is reasonable given the ambient target for PM_{10} is a 24-hour average.

11.2.4 Consent conditions for particulate emissions

Opacity of smoke discharged from CFBs

Monitoring of opacity of smoke discharged from the CFBs is only proposed in response to a complaint and the decision by ES to investigate. It is considered that having conditions with emission limits on discharges does not predispose the need for routine monitoring (e.g. discharge opacity, efflux velocity etc.). Such limits can be checked for compliance in response to complaints or concerns that they may not be in compliance. For example in this case, if the CFB stack discharge is excessively visible.

In-stack monitors of exhaust obscuration cannot be used to provide reliable information regarding the discharge opacity and while the Ringelmann Chart approach is manual and requires trained staff, it remains the only credible method for taking enforcement action with respect to discharge plume's being excessively opaque. To clarify the standard method used for measuring opacity according to the Ringelmann Chart, it is proposed to have the introduction to this condition worded as follows:

> *"The opacity of smoke discharged from any boiler shall not exceed Ringelmann Shade 1 as described in New Zealand Standard 5201:1973 except:"*

Ambient particulate monitoring

It is proposed to have a condition regarding the preparation of a Particulate Discharge Management Plan worded as follows:

"The consent holder shall undertake an annual campaign of continuous monitoring and logging of ambient 1-hour and 24-hourly average respirable particulate (PM_{10}) concentrations in conjunction with wind speed and direction. The monitoring location shall be as close as practical to New Zealand Transverse Mercator coordinates (NZTM) 1240.240, 4856.670 (Eastings and Northings in kilometres (km)). The period of each monitoring campaign shall commence either before or by 1 December and operate at least to 1 April for each calendar year. Specific features of the methodology shall include:"

Ambient particulate and wind monitoring and limits

With regards to monitoring of ambient particulate and wind monitoring, the following condition is proposed:

"The consent holder shall undertake an annual campaign of continuous monitoring and logging of ambient 1-hour and 24-hourly average respirable particulate (PM_{10}) concentrations in conjunction with wind speed and direction. The monitoring location shall be as close as practical to New Zealand Transverse Mercator coordinates (NZTM) 1240.240, 4856.670 (Eastings and Northings in kilometres (km)). The period of each monitoring campaign shall commence either before or by 1 December and operate at least to 1 April for each calendar year. Specific features of the methodology shall include:

(a) The ambient PM_{10} monitoring shall be by Beta Attenuation Monitor (BAM in accordance with AS/NZ 3580.9.11:2008 'Determination of suspended particulate matter - PM_{10} beta attenuation monitors' or equivalent semi-continuous method. The sampling height shall be 3 metres above ground level.

(b) Concurrent monitoring of wind speed and direction at the monitoring site and logging of 10 minute and hourly averaged data at the same site as the PM_{10} monitoring. Wind speed and direction shall be monitored using industry standard meteorological monitoring instrumentation that is attached to a mast at a height of 6 metres above ground level. Specifically the wind direction and speed monitoring equipment shall meet the following specifications:

Wind Speed Instrumentation:
Range: 0 to ≥ 30m/s
Accuracy: ≤ ±5% @ 3 m/s
Resolution: ≤ 0.1 m/s
Response Time: ≤ 1 second
Wind Speed Threshold: ≤ 0.5 m/s

Wind Direction Instrumentation:
Range: 0-359º
Accuracy: ≤ ±5% @ 3 m/s
Resolution: 1º
Response Time: ≤ 1 second
Wind Speed Threshold: ≤ 0.5 m/s

(c) Ambient PM_{10} concentrations in micrograms per cubic metre shall be recorded in electronic form as 1-hour and 24-hour averages (mid night to mid night). Wind speed in metres per second, and wind direction in degrees clockwise of true north, shall be recorded in electronic form as 1-hour and 10 minute averages.

(d) *The consent holder shall report the hourly PM_{10} concentration measurements that occur when the monitoring site is downwind of the boiler stacks. This includes 1-hour average wind directions that are between 245 and 270 degrees from true north (or whichever directions are within 13 degrees of the direction bearing between the monitor sample point and the boiler stacks).*

(e) *From the downwind ambient 1-hour PM_{10} results, report the maximum, 95th and 50th percentile values (ie. X, Y, Z indicated in Table 1, respectively). The maximum and 95th percentiles (X & Y) shall meet their respective PM_{10} concentration percentile limits listed in Table X. These are appropriate limits that relate to the applicable coal-fired boiler stack PM_{10} discharge limits of 300 mg/m^3 and 250 mg/m^3 (at 12 vol.% CO_2 and dry STP condition). The applicable stack discharge limit for PM_{10} is defined in Condition X.*

Table X: Ambient PM_{10} percentile limits for off-site monitoring.

Hourly Downwind PM_{10} Percentile	***Monitored hourly PM_{10} ($\mu g/m^3$), downwind conditions***	***Expected Ambient PM_{10} ($\mu g/m^3$) for stack concentration of 300 mg/m^3***	***Expected Ambient PM_{10} ($\mu g/m^3$) for stack concentration of 250 mg/m^3***
100%	*x*	*122*	*117*
95%	*y*	*37*	*35*
50%	*z*	*18*	*17*

The concentration limits specified above translate into maximum PM_{10} mass emission limits (kg/hr) from the discharge stacks when operating the CFBs at maximum capacity. For the proposed stack discharge concentration limits of 300 mg/Nm^3 (at 12 vol.% CO_2) and then reducing to 250 mg/Nm^3 (at 12 vol.% CO_2), the maximum PM_{10} mass rates for the combined CFBs are respectively 21.4 kg/hr and 17.8 kg/hr.

The above mass emission limits are recommended as conditions in addition to their corresponding stack concentration limits. Although the use of in-stack PM_{10} concentration limits is considered to be sufficient, the imposition of these and especially the ambient concentration limits provide a tight restriction over the CFBs mass discharge rate of PM_{10} (kg/hr) which is more robust than what mass based limits would achieve. This is because the combination of in-stack and ambient concentration limits impose a restriction on PM_{10} mass emissions that applies to all CFB operating rates as well as the CFB output (MW) distribution over time. By comparison, the imposition of maximum allowable mass emission limits only provides control over instantaneous emission rates when operating near or at full CFB output capacity.

The level of predicted PM_{10} impact would not ordinarily justify more than the standard stack testing practice. However Alliance is proposing a vastly more comprehensive and robust method for monitoring the actual CFB emission control performance – this provides clear information on the actual cumulative impacts that are strongly influenced by the CFBs emissions as well as a growing data base of background levels. The additional value of routine stack testing over and above this monitoring is very low and therefore we firmly believe that this should only be required when ambient monitoring data indicates that in-stack concentration may be breaching consent limits. Additionally, Golder's view is that while in-stack instrument is available for online opacity measurement, that these systems are not sufficiently accurate or reliable to be used for compliance monitoring.

Regarding PM_{10} emissions, this report details overall maximum rates for the CFBs. In principal these can also be defined within the consent as maximum instantaneous discharge rates and directly measured alongside the concentration limits if stack testing is triggered via ambient monitoring results.

Best Practicable Option

Golder's view is that in the interim term at least, the BPO is the efficient operation of the existing systems – this does not include full bag-house filters or similar technology. However it is reasonable to review this in the future in light of evolving science, engineering and environmental regulations. To reflect this, the following consent condition is proposed:

"Within ten years of the commencement of this consent and five yearly intervals thereafter, the consent holder shall conduct a review of:

- *(a) The results of the monitoring required by the conditions of this consent;*
- *(b) Relevant guidelines or standards for discharges to air; and*
- *(c) Technology for the control of emissions to air from the site.*

As part of this review, the consent holder shall identify if there is a need for further mitigation and if so, what is the most appropriate technology to further reduce any adverse effects as a result of air discharges from the combined boilers on the environment. The results of this review shall be provided to the consent authority within one month of the report being completed and the consent holder shall be required to implement any practicable actions set out within the review in agreement with the consent authority."

11.2.5 Implementation of particulate conditions

The ambient PM_{10} monitoring data would be continuously logged and an alarm to CFB control room operators should be triggered if the maximum percentile limit is exceeded. The 95 percentile ambient concentration can be routinely checked by Alliance environmental staff via spreadsheet analysis of the current logged-to-date hourly ambient PM_{10} concentration data. Additionally it may be practically for the site PLC system to log hourly PM_{10} concentration data and provide hourly up-dates of the to-date maximum and 95 percentile values to CFB operators, as well as displaying the most recent hourly average ambient PM_{10} concentration (which could be up-dated every 10 minutes).

When the trigger condition for stack testing (percentile concentration limits) is reached, it is clear this cannot be undertaken immediately, however this is not important. If there are routine non compliances of the in-stack emission limits for PM_{10} as would be indicated by ambient trigger levels being reached, then follow up stack testing (within approximately several weeks, or more) is likely to highlight such non-compliance. If the ambient triggers were reached for other reasons, for example an untypically high background PM_{10} event, then the follow up testing will also be useful.

In summary, same day testing would be ideal, however follow-up testing in response to ambient trigger levels being breached would also be very useful to confirm whether or not the CFBs are operating within the in-stack discharge limits for PM_{10}. This approach would be a vastly more effective use of in-stack testing than occurs under the current standard practice. The current practice typically entails prearranged stack testing at times that suit the testing agency or else the consent holder.

With regards to the preparation of a monitoring report to the consent authority, it is noted that there is a significant amount of data proposed under the consent conditions that will need to be summarised and reported upon. Therefore a period of two months following the end of the monitoring period is proposed for this to occur. However, it would be reasonably expected that, should the ambient monitoring trigger levels be exceeded during the monitoring period, the consent authority should be informed and kept up-dated with any measures/actions that Alliance implements in response.

11.3 Sulfur Dioxide Emissions

11.3.1 General

The use of coal sulphur content limit, the limitation on maximum coal-fired boiler (CFB) output (i.e. coal use or steam output), provides adequate control on SO_2 emissions given the scale of measured and modelled impacts from the Alliance CFB stack emissions. The short and long term boiler operating rate profile (output versus frequency) is also restricted to that required during the 2013/2014 operation season as a result of the percentile ambient PM_{10} limits that are proposed.

Continuous in-stack SO_2 monitoring produces real-time discharge concentration data, but this requires parallel collection and processing of steam production data (tonnes/hr) to calculate the instantaneous SO_2 emission rate (kg/hr). This is standard practice for much larger industrial dischargers of SO_2 into the atmosphere such as sulphuric acid plants (Ravensdown), the NZ Aluminium Smelters and much larger coal-fired boiler systems that are operated by Fonterra Co-operative Group Limited. However these facilities produce a much larger scale of SO_2 discharge to atmosphere and associated air quality impact compared to Alliance. The latter therefore justifies a less expensive and mass balance type approach for monitoring their CFB SO_2 discharges.

11.3.2 Coal sulfur monitoring

The following condition is proposed for coal sulfur monitoring:

"The sulfur content of fuel used for the boilers shall not exceed 0.5 wt% (as-received), based on the results of the following testing:

- a. *A grab sample of the supplied coal for the boilers shall be collected at least once per week and sent to an IANZ accredited laboratory for analysis for sulfur as combustible sulfur as percent by weight of coal both on an as-received and dry basis.*
- b. *If the coal blend changes then a representative analysis of the sulfur content shall be carried out as soon as practicable and within not less than five working days of beginning to burn the new coal.*
- c. *If the coal source changes then a representative analysis of the sulfur content shall be carried out to confirm compliance with the 0.5 wt% limit before the new coal source is accepted.*
- d. *The annual monitoring report required by condition X, shall summarise grab sample test results including a comparison with the limit specified in this condition."*

11.3.3 Consent conditions for sulfur dioxide emissions

Regarding SO_2, the predicted ambient impacts off-site as well as the measured impacts to date indicates a minor potential for any health effects. Neither ambient or stack testing is considered necessary in addition to the proposed weekly monitoring of coal sulphur levels and control over coal combustion rates that the ambient PM_{10} concentration limits (proposed for consent conditions) will effectively impose. However stack testing is justified if coal sulfur is non-compliant.

This report details the overall maximum SO_2 and emission rate of 78 kg/hr for the CFB operation. This value can be listed in the consent conditions as a maximum. As with PM_{10}, the need to directly monitor in-stack SO_2 emissions can be triggered by other proposed monitoring – in this instance the non-compliance with maximum sulfur coal limits. The following condition is proposed to reflect this:

"The combined maximum sulfur dioxide (SO_2) emission rate from the two coal fired boilers shall not exceed 78 kg/hr. Direct measurement of in-stack emissions using a standard wet chemistry method shall be undertaken as soon as practical should the coal sulphur content not comply with requirements of Condition X."

11.4 Conclusions

It is concluded that an initial stack limit for the flow weighted average CFBs PM_{10} discharge concentration of 300 mg/Nm^3 (corrected to 12 vol.% CO_2), followed by a reduction to 250 mg/Nm^3 to achieve good multi-clone performance within 5 years, would be appropriate. A TSP in-stack concentration limit is not proposed, as this will be effectively controlled by the PM_{10} limits. Further to the PM_{10} limits proposed, it is considered that Alliance could also implement the installation of improved boiler operation controls and automatic combustion oxygen control within the medium term.

It is concluded that annual or even six monthly direct testing of stack emissions provides only a snapshot of actual emission control performance. It is concluded that annual ambient PM_{10} and wind monitoring campaigns close to the same strategic site that Alliance has used to support this assessment of effects report, would provide vastly more useful and robust information on the actual impacts of particulate discharges (PM_{10} and $PM_{2.5}$) from the Alliance CFBs. It is proposed that collation of continuous ambient particulate and wind direction, speed data occurs annually for a minimum period of one month during peak operating seasons. If this indicates an exceedance of a specified ambient concentration limits, then this would trigger a formal stack test for PM_{10} emission and concentration.

With regards to the longer term, it would be reasonable for Alliance to periodically review the current environmental regulations and should these tighten in the future, Alliance should be required to review technologies for controlling PM_{10} and $PM_{2.5}$ emissions. These reviews would place Alliance in a well-informed position as to the need for further mitigation and the current BPO for controlling $PM_{2.5}$ as well as PM_{10} emissions to atmosphere.

12.0 SUMMARY & CONCLUSIONS

12.1 Overview

This report presents the results of an assessment of the air contaminants discharged from the two CFBs operated at the Alliance plant at Lorneville, Southland. The assessment was based on modelled air quality impacts supported by direct measurement of key air contaminants at a key off-site location. The objective of this assessment was to predict the future potential effects of ambient contaminants on the surrounding environment due to the CFB discharges to air and given their continued operation under a new long-term consent.

The receiving environment immediately surrounding the plant predominantly consists of rural blocks with isolated residential dwellings. There are two areas of higher density population within 3 km of the plant, Wallacetown and the northern suburbs of Invercargill. In summary, the receiving environment is of moderate sensitivity to the CFB discharges because of the significant buffer distance between residential dwellings and the CFBs.

The assessment of air quality impacts from the CFBs involved predicting the increased air contaminant ground level concentration (GLCs) using a complex atmospheric dispersion and meteorological modelling methods. An important feature of this assessment was the use of hourly varying steam output data for the two CFBs that enabled the development of a realistic hourly-varying contaminant emissions profile to be established. This emission profile was modelled for a two year period using a 3D hourly varying meteorological data set that was developed for the site. Ambient air contaminant monitoring data was collected over three time periods (involving two locations) to provide accurate information on actual air quality impacts due to the CFBs, as well as to confirm existing background air quality. The ambient monitoring also enabled the accuracy of assumed contaminant emissions to be confirmed and revised.

For the above reasons, the modelling based assessment of potential air quality effects presented in this report is considered to provide a reliable and realistic assessment of the cumulative air quality effects resulting from the CFB operation and existing background levels of air contaminants.

In addition to the assessment of air quality effects, this report reviews air emission mitigation options – both existing and options available for future reductions in contaminant emissions as may be necessary.

12.2 Key Findings

12.2.1 Localised air quality effects

The key findings of the assessment of CFB discharges are that all cumulative ambient contaminant concentrations readily meet compliance with all relevant national standards and guidelines for air quality beyond the site boundary and at locations where people are likely to be exposed. It is only at one localised area of limited extent, close to the Alliance site boundary where the ambient SO_2 and PM_{10} could infrequently exceed their respective ambient criteria. However this is a small area of uninhabited rural land where people are not likely to be exposed. In this location, the national standards and guidelines are not considered to apply.

The key areas to assess are those off site locations where people may live or work (for extended hours), as well as where the highest cumulative air contaminant concentrations occur that result primarily from CFBs discharges. In this case, for all assessed contaminants other than NO_2, this location was a residential dwelling that is located approximately 650 metres to the east of the CFB discharge stacks - referred to as the most impacted off site residential dwelling location (MIRD). For NO_2 this occurred at a residential dwelling approximately one kilometre to the northeast of the CFB stacks.

The assessment of SO_2 concentrations at the MIRD indicated that these were all below relevant standards and guideline values and were 76 % of these or less. Therefore it is concluded that all off site locations are subjected to a minor potential, or less for adverse effects of existing SO_2 discharges from the CFBs. Likewise, the assessment of impacts of NO_2, metals (both ambient and deposited) and dioxins indicated that the maximum predicted concentration of all these contaminants are well below the respective assessment criteria (including health risk criteria for dioxins) and therefore these contaminants also create a minor or less potential for any health effects on people.

12.2.2 Airshed ambient particulate effects

The increased ambient concentrations of the PM_{10} resulting from the CFBs discharges to air upon Wallacetown and Invercargill have been assessed. The results indicate that the increase in PM_{10} would be up to 5 $\mu g/m^3$ (24 hour average) and most often less than 1 $\mu g/m^3$ (24 hour average) at the fringes of these urban areas.

12.2.3 Boiler particulate emission limits

For the MIRD the NES for PM_{10} is readily complied with, the maximum cumulative concentration is expected to be approximately 64 % of the NES criterion. For the vast majority of time, the cumulative concentrations are expected to be less than 40 % of the criterion value. This level of effect is associated with existing CFB discharges of PM_{10} (i.e., at flow weighted average discharge concentration of 300 mg/Nm^3 corrected to 12 vol.% CO_2). Because PM_{10} ambient exposures have the potential to cause adverse health effects even below the NES target for ambient PM_{10}, then a maximum PM_{10} limit of 250 mg/Nm^3 (corrected to 12 vol.% CO_2) should eventually be achieved in the CFB exhaust discharge as this is an good level of performance that the existing boiler emission control technology should be able to achieve. It is recommended that this level of performance be achieved with 5 years of a consent being granted.

12.2.4 Future boiler particulate controls

In addition to the above, it is also recommended that Alliance undertakes periodic technology reviews so to be well informed of the best practical option in the future for minimising PM_{10} and $PM_{2.5}$ emissions from the CFBs. This will also enable Alliance to respond to future regulations, policies and advances in health effects science related to air quality. This is likely to entail some form of end-of-pipe type treatment (EOP) system. It is concluded that the specific type of EOP would be best established in the future when it is more clear as to what technology would be most effective at reducing $PM_{2.5}$ discharges. It is concluded that use of FBHF technology will not necessary represent the BPO given that $PM_{2.5}$ emissions from the CFBs become the key driver requiring further control on air emissions. This is what recent air quality health research is strongly suggesting (WHO, 2013). It is noted that the existing ambient levels of $PM_{2.5}$ (based on some limited monitoring data) indicates these to readily comply with the current WHO guideline for this contaminant at the MIRD.

12.2.5 Compliance monitoring for particulate impacts

With respect to compliance monitoring, our key recommendation is to move away from stack testing and to instead rely on more comprehensive ambient monitoring data. The use of annual ambient PM_{10} and wind monitoring campaigns close to the same strategic site that Alliance has used would provide vastly more useful and robust information on the actual impacts of particulate discharges (PM_{10} and $PM_{2.5}$) from the Alliance CFBs. Stack testing would only be undertaken for compliance purposes if the ambient monitoring resulted in an exceedance of specified ambient concentration limits. This compliance monitoring approach is considered to be substantial improvement over the reliance on conventional stack emissions testing.

12.3 Overall Conclusion

The overall conclusion from this assessment is that none of the key air pollutants that are discharged from the Alliance CFBs are likely to cause exceedances of relevant national and international air quality standards and guidelines at off-site locations where people are likely to be exposed. However some further reduction in PM_{10} emissions is recommended with the next five years to achieve a good level of performance. The need for further mitigation should be assessed in the future to ensure that compliance with relevant regulations is maintained, that BPO is maintained and potential health effects of respirable particulate exposure to people are minimised to a reasonable level.

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APPENDIX A

Report Limitations

Report Limitations

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APPENDIX B

Combustion Calculations

Golder Associates

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Babcock & Wilcox Boiler No. 1

Operating conditions - stack test match up 73% MCR

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.51	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.77	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.43	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.60	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.70	%wt (DAF basis)	Coal testing Newvale Dec 2012
Fuel moisture content:	40.6	%wt (as received basis)	Coal testing Newvale Dec 2012
Ash content:	3.4	%wt (as received basis)	Coal testing Newvale Dec 2012
DAF portion:	0.560	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.85	moles/kg (DAF basis)	
Excess air:	77.45	%	Set based on O2 content from stack testing Dec 2012
Total O_2 required:	111.53	moles/kg (DAF basis)	
Flue gas CO_2 content:	10.95	%vol dry	Average of stack testing from Dec 2012 - 10.7%vol dry
Flue gas O_2 content:	9.20	%vol dry	Average of stack testing from Dec 2012 - 9.2%vol dry
APPLIANCE DETAILS			
Power Output:	18000	kW	Stack testing Dec 2012
Percentage of MCR:	73	%	Stack testing Dec 2012
Effective power output:	13140	kW	
Efficiency:	69.58	%	Set efficiency to match up efflux velocities
As rcvd fuel CV:	12975	kJ/kg	Coal testing Newvale Dec 2012
Equivalent Stack diameter:	1.21	m	Stack testing Dec 2012
Heat produced by combustion:	18884	kW	
Heat loss:	5744	kW	
Maximum fuel burning rate:	1.46	kg/s (as received basis)	
	5.24	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	481.15	K	Average of stack testing from Dec 2012 - 208℃
WET flow rate (POC sheet):	25.01	m^3/kg DAF fuel	
Actual volumetric flow rate:	20.38	m^3/s	
Stack x-sectional area:	1.15	m^2	
Efflux velocity:	17.73	m/s	Average of stack testing from Dec 2012 - 16.7m/s
DRY flow rate @ STP (POC sheet):	11.86	Nm^3/kg DAF fuel	
	9.67	Nm^3/sec	
	34,794	Nm^3/hour	Average of stack testing from Dec 2012 - 34,794 Nm^3/h
WET flow rate @ STP (POC sheet):	14.20	Nm^3/kg DAF fuel	
	11.57	Nm^3/sec	
	41,658	Nm^3/hour	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Babcock & Wilcox Boiler No. 1

100% MCR 12% CO2 emission calculations

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	61.95	%	
Total O_2 required:	101.69	moles/kg (DAF basis)	
Flue gas CO_2 content:	12.00	%vol dry	Set to 12% CO2
Flue gas O_2 content:	8.07	%vol dry	
APPLIANCE DETAILS			
Power Output:	18000	kW	
Percentage of MCR:	100	%	
Effective power output:	18000	kW	
Efficiency:	69.58	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	1.21	m	assume no cone
Heat produced by combustion:	25868	kW	
Heat loss:	7868	kW	
Maximum fuel burning rate:	2.01	kg/s (as received basis)	
	7.23	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	21.29	m³/kg DAF fuel	
Actual volumetric flow rate:	23.98	m³/s	
Stack x-sectional area:	1.15	m²	
Efflux velocity:	20.86	m/s	
DRY flow rate @ STP (POC sheet):	10.80	Nm³/kg DAF fuel	
	12.17	Nm³/sec	
	43,802	Nm³/hour	
WET flow rate @ STP (POC sheet):	13.12	Nm³/kg DAF fuel	
	14.78	Nm³/sec	
	53,216	Nm³/hour	
EMISSION CALCULATIONS			
SO_2 emission rate (no ash retention):	20.1	g/s	
SO_2 emission rate (5% ash retention):	19.1	g/s	
Modellled SO_2 emission rate:	13.4	g/s	Based on 30% lower due to monitoring analysis
NO_X emission factor:	2.9	kg/tonne	Spreader stoker lignite
NO_X emission rate:	5.8	g/s	US-EPA AP42 Table 1.7-1 (5.8 lb/ton)
TSP emission factor:	450.0	mg/m³ dry STP 12% CO2	Set to 450 mg/Nm³
PM_{10} emission factor:	300.0	mg/m³ dry STP 12% CO_2	Set to 300 mg/Nm³
TSP emissions rate:	5.5	g/s	
TSP emissions rate:	19.7	kg/hr	
PM_{10} emission rate:	3.7	g/s	
PM_{10} emission rate:	13.1	kg/hr	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Babcock & Wilcox Boiler No. 1

100% MCR 5% O_2 velocity calculation

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	30.96	%	
Total O_2 required:	82.23	moles/kg (DAF basis)	
Flue gas CO_2 content:	14.87	%vol dry	
Flue gas O_2 content:	5.00	%vol dry	Set based on lowest O_2 expected for well tuned boiler
APPLIANCE DETAILS			
Power Output:	18000	kW	
Percentage of MCR:	100	%	
Effective power output:	18000	kW	
Efficiency:	69.58	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	1.21	m	assume no cone
Heat produced by combustion:	25868	kW	
Heat loss:	7868	kW	
Maximum fuel burning rate:	2.01	kg/s (as received basis)	
	7.23	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	17.91	m³/kg DAF fuel	
Actual volumetric flow rate:	20.17	m³/s	
Stack x-sectional area:	1.15	m²	
Efflux velocity:	17.54	m/s	
DRY flow rate @ STP (POC sheet):	8.72	Nm³/kg DAF fuel	
	9.82	Nm³/sec	
	35,343	Nm³/hour	
WET flow rate @ STP (POC sheet):	11.04	Nm³/kg DAF fuel	
	12.43	Nm³/sec	
	44,757	Nm³/hour	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Babcock & Wilcox Boiler No. 1

50% MCR 8% O_2 velocity calculation

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	61.03	%	
Total O_2 required:	101.11	moles/kg (DAF basis)	
Flue gas CO_2 content:	12.07	%vol dry	
Flue gas O_2 content:	8.00	%vol dry	Set based on lowest O_2 during last 10 years of testing
APPLIANCE DETAILS			
Power Output:	18000	kW	
Percentage of MCR:	50	%	
Effective power output:	9000	kW	
Efficiency:	69.58	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	1.21	m	assume no cone
Heat produced by combustion:	12934	kW	
Heat loss:	3934	kW	
Maximum fuel burning rate:	1.00	kg/s (as received basis)	
	3.61	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	21.19	m^3/kg DAF fuel	
Actual volumetric flow rate:	11.93	m^3/s	
Stack x-sectional area:	1.15	m^2	
Efflux velocity:	10.38	m/s	
DRY flow rate @ STP (POC sheet):	10.74	Nm^3/kg DAF fuel	
	6.05	Nm^3/sec	
	21,776	Nm^3/hour	
WET flow rate @ STP (POC sheet):	13.06	Nm^3/kg DAF fuel	
	7.36	Nm^3/sec	
	26,483	Nm^3/hour	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Babcock & Wilcox Boiler No. 1

25% MCR 10% O_2 velocity calculation

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	90.29	%	
Total O_2 required:	119.48	moles/kg (DAF basis)	
Flue gas CO_2 content:	10.20	%vol dry	
Flue gas O_2 content:	10.00	%vol dry	
APPLIANCE DETAILS			
Power Output:	18000	kW	
Percentage of MCR:	25	%	
Effective power output:	4500	kW	
Efficiency:	69.58	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	1.21	m	assume no cone
Heat produced by combustion:	6467	kW	
Heat loss:	1967	kW	
Maximum fuel burning rate:	0.50	kg/s (as received basis)	
	1.81	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	24.39	m^3/kg DAF fuel	
Actual volumetric flow rate:	6.87	m^3/s	
Stack x-sectional area:	1.15	m^2	
Efflux velocity:	5.97	m/s	
DRY flow rate @ STP (POC sheet):	12.71	Nm^3/kg DAF fuel	
	3.58	Nm^3/sec	
	12,885	Nm^3/hour	
WET flow rate @ STP (POC sheet):	15.03	Nm^3/kg DAF fuel	
	4.23	Nm^3/sec	
	15,238	Nm^3/hour	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Foster Wheeler Boiler No. 2

Operating conditions - stack test match up 79% MCR

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.51	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.77	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.43	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.60	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.70	%wt (DAF basis)	Coal testing Newvale Dec 2012
Fuel moisture content:	40.6	%wt (as received basis)	Coal testing Newvale Dec 2012
Ash content:	3.4	%wt (as received basis)	Coal testing Newvale Dec 2012
DAF portion:	0.560	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.85	moles/kg (DAF basis)	
Excess air:	70.20	%	Set based on O2 content from stack testing Dec 2012
Total O_2 required:	106.98	moles/kg (DAF basis)	
Flue gas CO_2 content:	11.42	%vol dry	Average of stack testing from Dec 2012 - 11.1%vol dry
Flue gas O_2 content:	8.70	%vol dry	Average of stack testing from Dec 2012 - 8.7%vol dry
APPLIANCE DETAILS			
Power Output:	12700	kW	Email F Wise, Aug 2013
Percentage of MCR:	79	%	Stack testing Dec 2012
Effective power output:	10033	kW	
Efficiency:	77.67	%	Set efficiency to match up dry flow rate
As rcvd fuel CV:	12975	kJ/kg	Coal testing Newvale Dec 2012
Equivalent Stack diameter:	0.93	m	Stack testing Dec 2012
Heat produced by combustion:	12917	kW	
Heat loss:	2884	kW	
Maximum fuel burning rate:	1.00	kg/s (as received basis)	
	3.58	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	461.15	K	Average of stack testing from Dec 2012 - 188°C
WET flow rate (POC sheet):	23.14	m^3/kg DAF fuel	
Actual volumetric flow rate:	12.90	m^3/s	
Stack x-sectional area:	0.68	m^2	
Efflux velocity:	18.99	m/s	Average of stack testing from Dec 2012 - 17.3m/s
DRY flow rate @ STP (POC sheet):	11.37	Nm^3/kg DAF fuel	
	6.34	Nm^3/sec	
	22,819	Nm^3/hour	Average of stack testing from Dec 2012 - 22,819 Nm^3/h
WET flow rate @ STP (POC sheet):	13.71	Nm^3/kg DAF fuel	
	7.64	Nm^3/sec	
	27,514	Nm^3/hour	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Foster Wheeler Boiler No. 2

100% MCR 12% CO_2 emission calculations

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	61.95	%	
Total O_2 required:	101.69	moles/kg (DAF basis)	
Flue gas CO_2 content:	12.00	%vol dry	Set to 12%
Flue gas O_2 content:	8.07	%vol dry	
APPLIANCE DETAILS			
Power Output:	12700	kW	
Percentage of MCR:	100	%	
Effective power output:	12700	kW	
Efficiency:	77.67	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	0.93	m	assume no cone
Heat produced by combustion:	16351	kW	
Heat loss:	3651	kW	
Maximum fuel burning rate:	1.27	kg/s (as received basis)	
	4.57	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	21.29	m^3/kg DAF fuel	
Actual volumetric flow rate:	15.16	m^3/s	
Stack x-sectional area:	0.68	m^2	
Efflux velocity:	22.31	m/s	
DRY flow rate @ STP (POC sheet):	10.80	Nm^3/kg DAF fuel	
	7.69	Nm^3/sec	
	27,685	Nm^3/hour	
WET flow rate @ STP (POC sheet):	13.12	Nm^3/kg DAF fuel	
	9.34	Nm^3/sec	
	33,636	Nm^3/hour	
EMISSION CALCULATIONS			
SO_2 emission rate (no ash retention):	12.7	g/s	
SO_2 emission rate (5% ash retention):	12.1	g/s	
Modellled SO_2 emission rate:	8.4	g/s	Based on 30% lower due to monitoring analysis
NO_X emission factor:	2.9	kg/tonne	US-EPA AP42 Table 1.7-1 (5.8 lb/ton)
NO_X emission rate:	3.7	g/s	
TSP emission factor:	450	mg/m^3 dry STP 12% CO2	Set to 450 mg/Nm^3
PM_{10} emission factor:	300	mg/m^3 dry STP 12% CO_2	Set to 300 mg/Nm^3
TSP emissions rate:	3.5	g/s	
TSP emissions rate:	12.5	kg/hr	
PM_{10} emission rate:	2.3	g/s	
PM_{10} emission rate:	8.3	kg/hr	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

Golder Associates

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Foster Wheeler Boiler No. 2

100% MCR 5% O2 velocity calculation

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	30.96	%	
Total O_2 required:	82.23	moles/kg (DAF basis)	
Flue gas CO_2 content:	14.87	%vol dry	
Flue gas O_2 content:	5.00	%vol dry	Set based on lowest O_2 expected for well tuned boiler
APPLIANCE DETAILS			
Power Output:	12700	kW	
Percentage of MCR:	100	%	
Effective power output:	12700	kW	
Efficiency:	77.67	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	0.93	m	assume no cone
Heat produced by combustion:	16351	kW	
Heat loss:	3651	kW	
Maximum fuel burning rate:	1.27	kg/s (as received basis)	
	4.57	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	17.91	m^3/kg DAF fuel	
Actual volumetric flow rate:	12.75	m^3/s	
Stack x-sectional area:	0.68	m^2	
Efflux velocity:	18.77	m/s	
DRY flow rate @ STP (POC sheet):	8.72	Nm^3/kg DAF fuel	
	6.21	Nm^3/sec	
	22,339	Nm^3/hour	
WET flow rate @ STP (POC sheet):	11.04	Nm^3/kg DAF fuel	
	7.86	Nm^3/sec	
	28,289	Nm^3/hour	

NOTES:

N = Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity

STP = Standard temperature (0 °C) and pressure (1 atmosphere)

DAF = Dry, ash free

MCR = Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Foster Wheeler Boiler No. 2

50% MCR 8% O2 velocity calculation

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	61.03	%	
Total O_2 required:	101.11	moles/kg (DAF basis)	
Flue gas CO_2 content:	12.07	%vol dry	
Flue gas O_2 content:	8.00	%vol dry	Set based on lowest O_2 during last 10 years of testing
APPLIANCE DETAILS			
Power Output:	12700	kW	
Percentage of MCR:	50	%	
Effective power output:	6350	kW	
Efficiency:	77.67	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	0.93	m	assume no cone
Heat produced by combustion:	8175	kW	
Heat loss:	1825	kW	
Maximum fuel burning rate:	0.63	kg/s (as received basis)	
	2.28	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	21.19	m^3/kg DAF fuel	
Actual volumetric flow rate:	7.54	m^3/s	
Stack x-sectional area:	0.68	m^2	
Efflux velocity:	11.11	m/s	
DRY flow rate @ STP (POC sheet):	10.74	Nm^3/kg DAF fuel	
	3.82	Nm^3/sec	
	13,764	Nm^3/hour	
WET flow rate @ STP (POC sheet):	13.06	Nm^3/kg DAF fuel	
	4.65	Nm^3/sec	
	16,739	Nm^3/hour	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

COMBUSTION CALCULATIONS

10 Mar 2015

1378104044 - Foster Wheeler Boiler No. 2

25% MCR 10% O2 velocity calculation

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS	New Vale		
Carbon:	69.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Hydrogen:	4.76	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Oxygen:	24.38	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Nitrogen:	0.59	%wt (DAF basis)	Steam from Coal, Coal Research Ass of NZ, 1978
Sulphur:	0.89	%wt (DAF basis)	Assume max 0.5% wt as received.
Fuel moisture content:	40.3	%wt (as received basis)	Average of testings from July 2012 to February 2015
Ash content:	3.6	%wt (as received basis)	Average of testings from July 2012 to February 2015
DAF portion:	0.561	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	62.79	moles/kg (DAF basis)	
Excess air:	90.29	%	
Total O_2 required:	119.48	moles/kg (DAF basis)	
Flue gas CO_2 content:	10.20	%vol dry	
Flue gas O_2 content:	10.00	%vol dry	Set based on lowest O_2 during last 10 years of testing
APPLIANCE DETAILS			
Power Output:	12700	kW	
Percentage of MCR:	25	%	
Effective power output:	3175	kW	
Efficiency:	77.67	%	based on stack testing matchup
As rcvd fuel CV:	12885	kJ/kg	Average Gross Cv. 15.0 MJ/kg (July 2012 to February 2015)
Equivalent Stack diameter:	0.93	m	assume no cone
Heat produced by combustion:	4088	kW	
Heat loss:	913	kW	
Maximum fuel burning rate:	0.32	kg/s (as received basis)	
	1.14	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	443.15	K	set at 170℃
WET flow rate (POC sheet):	24.39	m^3/kg DAF fuel	
Actual volumetric flow rate:	4.34	m^3/s	
Stack x-sectional area:	0.68	m^2	
Efflux velocity:	6.39	m/s	
DRY flow rate @ STP (POC sheet):	12.71	Nm^3/kg DAF fuel	
	2.26	Nm^3/sec	
	8,144	Nm^3/hour	
WET flow rate @ STP (POC sheet):	15.03	Nm^3/kg DAF fuel	
	2.68	Nm^3/sec	
	9,631	Nm^3/hour	

NOTES:

N =	Standard atmospheric conditions (0 °C, 1 atmosphere) and zero humidity	DAF =	Dry, ash free
STP =	Standard temperature (0 °C) and pressure (1 atmosphere)	MCR =	Maximum combustion rate

APPENDIX C

NO to NO_2 Conversion

1.0 INTRODUCTION

One of the important primary pollutants from combustion activities is NO_X. NO_X refers to the sum of the two most common oxides of nitrogen, namely nitric oxide (NO) and nitrogen dioxide (NO_2). The contaminant of concern for potential human health effects is NO_2. However, the relative proportions of NO and NO_2 in a discharge plume change from their original amounts with distance downstream. This Appendix describes a method for diagnosing NO_2 from the total NO_X, as a post-processing step, to provide modelled ground-level concentrations (GLCs) of NO_2.

2.0 METHOD

The modelled NO_X has been post-processed using a method described by Janssen et al. (1988), which gives the ratio of NO_2 to NO_X as a function of distance from the source. The function was derived empirically from measurements of NO, NO_2 and ozone (O_3) in stack plumes of Dutch power plants over a period of 10 years. Janssen et al. (1988) found that NO to NO_2 oxidation in power plant plumes could be described approximately by the relationship given in Equation 1.

$$[NO_2] \big/ [NO_X] = A(1-\exp(-\alpha x)) \quad \text{.......... Equation 1}$$

In Equation 1, $[NO_2]$ and $[NO_X]$ are the volume mixing ratios, or concentrations (as NO_2), of NO_2 and NO_X. The non-dimensional parameter, *A*, is referred to as the 'ozone' parameter, and α is the 'wind' parameter. The downwind distance is denoted by *x*.

Encapsulated in *A* is the oxidation of NO to NO_2 in the presence of O_3 and the photolysis of NO_2 by sunlight (to re-form NO). The wind parameter,α, also depends on $[O_3]$, and it implicitly converts reaction rates to a downwind distance scale, using the wind speed at the plume height. If *x* is in km, α is in units of 1/km.

The Janssen et al. method has been used for NO_X plumes from Alliance Lorneville for the following reasons:

a) Close to the plant, chemical equilibrium is will not have been reached. Alternative methods such as the ozone-limiting method would assume that oxidation from NO to NO_2 was complete, and would over-estimate the NO_2 near to the source. Also, the availability of O_3 would be reduced, due to the time required for atmospheric mixing processes to replace O_3 consumed by the oxidation reaction.

b) The method has been developed specifically for power plant plumes, with the effects in (a) accounted for empirically.

Janssen et al. (1988) placed no lower limit on the downwind distance, and Equation (1) gives zero $[NO_2]$ at the source (where *x*=0). This is not realistic, as measurements of $[NO_2]/[NO_X]$ in boilers indicate the fraction may be up to 10 %. A value of 10 % has been assumed for the Alliance Lorneville site. Then, a reasonable variation of Equation 1 is that given in Equation 2.

$$[NO_2] \big/ [NO_X] = 0.10 + 0.90A(1-\exp(-\alpha x)) \quad \text{.......... Equation 2}$$

The values of *A* and α depend on ambient ozone levels, incoming solar radiation and wind speed. These empirical relationships, originally developed in the Netherlands, are shown in Table 1, Table 2 and Table 3. It has been assumed that the relationships also apply in New Zealand. The following section describes the use of ambient measurements to determine values of *A* and α suitable for the Lorneville boilers. These have been used in the main body of the report to post-process modelled NO_X to provide estimates of NO_2 ground-level concentrations around the plant.

Table 1: Values for *A* and α in winter (solar radiation up to 400 W/m^2).

Ozone background concentration	Wind speed at plume height < 5 m/s	Wind speed at plume height 5 m/s to 15 m/s	Wind speed at plume height > 15 m/s
120 – 200 ppb			
60 – 120 ppb			
40 – 60 ppb			
30 – 40 ppb	A = 0.87; α = 0.07	A = 0.87; α = 0.07	A = 0.87; α = 0.15
20 – 30 ppb	A = 0.83; α = 0.07	A = 0.83; α = 0.07	A = 0.83; α = 0.10
10 – 20 ppb	A = 0.74; α = 0.07	A = 0.74; α = 0.07	A = 0.74; α = 0.07
0 – 10 ppb	A = 0.49; α = 0.05	A = 0.49; α = 0.05	A = 0.49; α = 0.05

Table 2: Values for *A* and α in spring or autumn (solar radiation up to 1200 W/m^2).

Ozone background concentration	Wind speed at plume height < 5 m/s	Wind speed at plume height 5 m/s to 15 m/s	Wind speed at plume height > 15 m/s
120 – 200 ppb			
60 – 120 ppb			
40 – 60 ppb	A = 0.85; α = 0.10	A = 0.85; α = 0.15	A = 0.85; α = 0.30
30 – 40 ppb	A = 0.80; α = 0.10	A = 0.80; α = 0.10	A = 0.80; α = 0.25
20 – 30 ppb	A = 0.74; α = 0.10	A = 0.74; α = 0.10	A = 0.74; α = 0.15
10 – 20 ppb	A = 0.635; α = 0.10	A = 0.635; α = 0.10	A = 0.635; α = 0.10
0 – 10 ppb			

Table 3: Values for *A* and α in summer (solar radiation up to 1800 W/m^2).

Ozone background concentration	Wind speed at plume height < 5 m/s	Wind speed at plume height 5 m/s to 15 m/s	Wind speed at plume height > 15 m/s
120 – 200 ppb	A = 0.93; α = 0.40	A = 0.93; α = 0.65	A = 0.93; α = 0.80
60 – 120 ppb	A = 0.88; α = 0.20	A = 0.88; α = 0.35	A = 0.88; α = 0.45
40 – 60 ppb	A = 0.81; α = 0.15	A = 0.81; α = 0.25	A = 0.81; α = 0.35
30 – 40 ppb	A = 0.74; α = 0.10	A = 0.74; α = 0.15	A = 0.74; α = 0.25
20 – 30 ppb	A = 0.67; α = 0.10	A = 0.67; α = 0.10	A = 0.67; α = 0.10
10 – 20 ppb			
0 – 10 ppb			

3.0 DETERMINATION OF THE OZONE AND WIND PARAMETERS

As described above, the ozone and wind parameters, *A* and α, depend on ambient ozone, wind speed and solar radiation. They are determined from measurements presented in the following sections.

Ambient Ozone Concentrations

Baseline surface O_3 concentrations in New Zealand have been monitored at Baring Head, near Wellington, since 1991. Figure 1 shows hourly ozone concentrations at that site in 2008-2010, under baseline conditions (wind direction from the sea, direction between 150° and 210°, and speed greater than 5 m/s). There is a marked seasonal cycle, with minimum values of 10-20 ppb during the summer (days 335 to 365, and days 1 to 59) and maximum values of 25-35 ppb in the winter (days 152 to 243). Spring and autumn values are about 20-30 ppb. Under baseline conditions there is a relatively narrow range of ozone concentrations; the southerly winds are from the ocean, where the ozone destruction processes are slow.

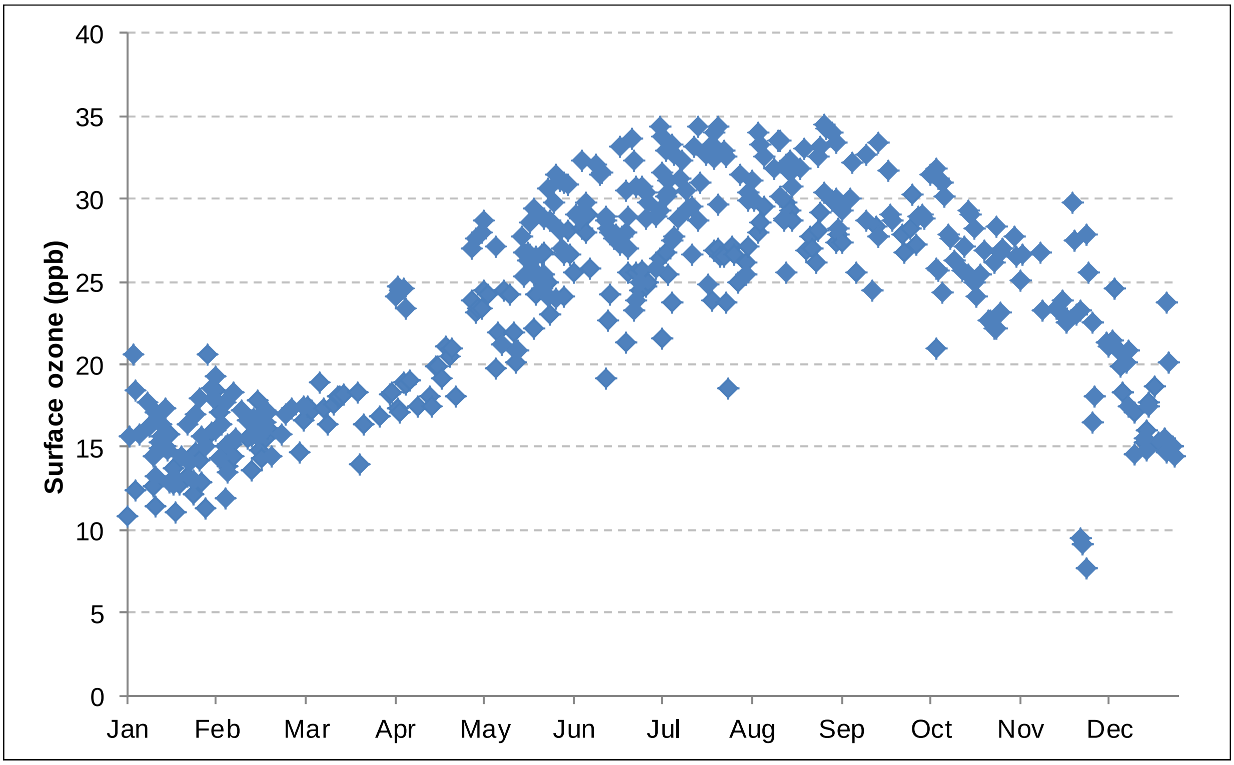


Figure 1: Daily average of surface ozone at Baring Head for 1 Jan 2008 to 1 Jan 2011 (NIWA).

Based on the ambient O_3 data, concentrations of 20 ppb in summer, 30 ppb in spring and autumn, and 35 ppb in winter have been used to look up parameter values in Table 1, Table 2 and Table 3.

Solar Radiation Data

Table 1, Table 2 and Table 3 provide seasonally-varying parameter values under incoming solar radiation rates of 400 W/m^2, 1200 W/m^2 and 1800 W/m^2 respectively. The ultraviolet solar radiation alters the chemical equilibrium between NO and NO_2 by dissociation of NO_2 molecules to re-form NO, and (through sensible heating at the surface) affects atmospheric mixing and dispersion. Parameters *A* and α have been used based on solar radiation levels experienced in Invercargill.

Figure 2 shows the maximum solar radiation rate at Invercargill Airport for each day in 2010 to 2012 (data were obtained from the National Climate Database and supplied by NIWA). The solar flux rates show a variation over the year, from about 1,000 W/m^2 in summer to 300 W/m^2 in winter.

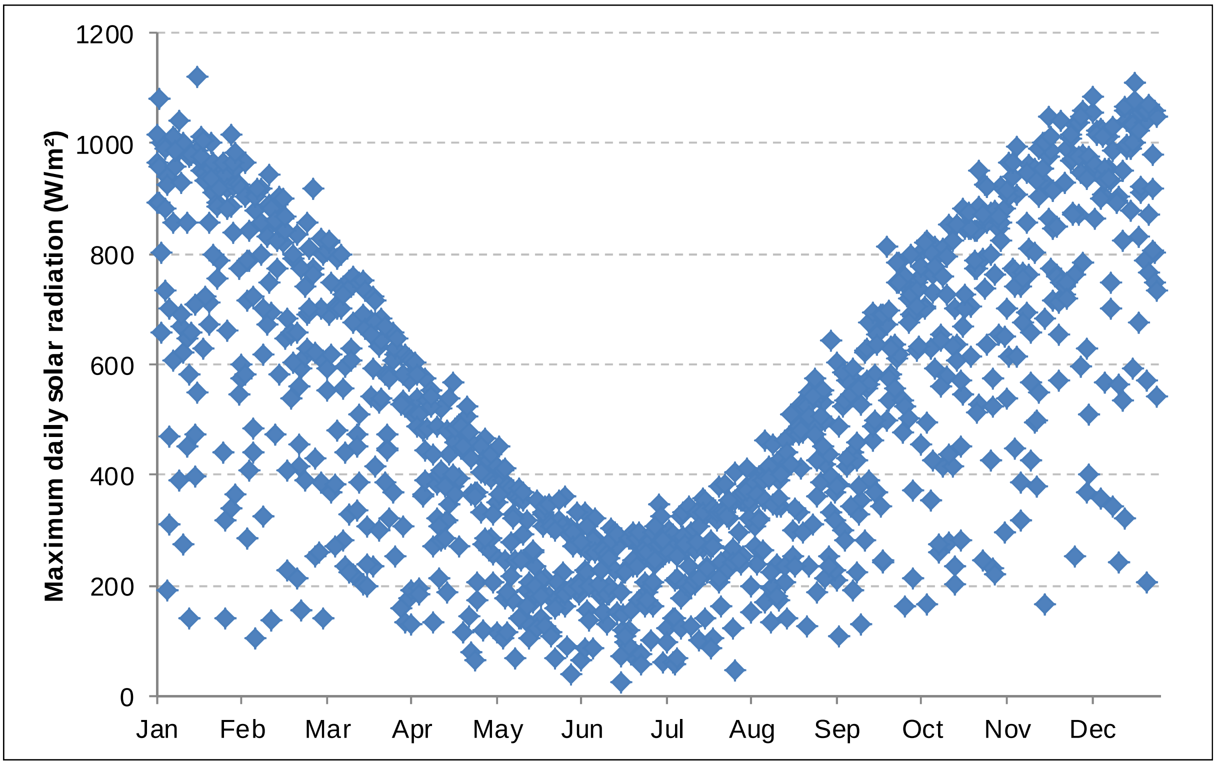


Figure 2: Maximum daily solar radiation at Invercargill Airport for 1 Jan 2010 to 1 Jan 2013.

4.0 CONCLUSION

Suitable values of *A* and α have been selected from the Table 1, Table 2 and Table 3, based on observed incoming solar radiation in Invercargill and baseline O_3. These are shown in Table 4.

Table 4: Values of parameters *A* and α from the Janssen et al. method.

Season	**O_3 (ppb)**	**Solar radiation (W/m^2)**	**Ozone parameter (*A*)**	**Wind parameter (α, 1/km)**	**Table number**
Summer	20	1,000	0.635	0.1	Table 2
Autumn/Spring	30	600	0.83	0.07 – 0.1	Table 1
Winter	35	300	0.87	0.07 – 0.15	Table 1

For a conservative prediction of NO_2, the highest value of *A* and the highest value of α in Table 4 have been used in the dispersion modelling. These are 0.87 and 0.15, respectively. The ratio of $[NO_2]$ to $[NO_X]$ is then given in Equation 3:

$$[NO_2]/[NO_X] = 0.10 + 0.783(1 - \exp(-0.15x)) \quad \text{Equation 3}$$

5.0 REFERENCES

Janssen L H J M, Van Wakeren J H A, Van Duren H and Elshout A J 1988. A Classification of NO Oxidation Rates in Power Plant Plumes Based on Atmospheric Conditions. *Atmospheric Environment.* 22, No 1, 1988, pp 43-53.

NIWA 2013. Baring Head Atmospheric Ozone data. Sylvia Nichol, Gordon Brailsford, and Mike Harvey. http://www.niwa.co.nz/atmosphere/our-data/trace-gases. Accessed Aug 2013.

APPENDIX D

CALMET Model Configuration

1.0 OVERVIEW OF METEOROLOGICAL MODELLING

The modelling of exposure to airborne pollutants requires a detailed meteorological data set that accounts for spatial variation in wind speed, direction and other atmospheric parameters on an hourly basis and as a function of height above ground level. This hourly three-dimensional (3D) meteorological data set allows for more accurate and defensible predictions of air pollution dispersion, and deposition of contaminants to the ground.

The 3D meteorological data set has been developed using the CALMET model (Scire et al. 1999; TRC 2011) with input developed using the meteorological component of The Air Pollution Model (TAPM) (Hurley, Physick & Luhar 2005; Hurley 2000; Hurley et al. 2003), data from local weather stations and terrain and land-use information.

The weather model TAPM has been used to simulate the large-scale weather patterns and their modification by the coasts and terrain of New Zealand. The TAPM model outputs (including vertical wind profiles) assist in providing the synoptic (large) scale air flows to the regional meteorological model, CALMET. The CALMET model then uses the large scale weather patterns in combination with local weather stations to determine wind patterns of the Invercargill area.

To ensure local winds are accounted for, inputs to CALMET also incorporate data from local weather stations usually run by MetService or NIWA. Automatic weather stations in the vicinity are located at Invercargill Airport, Tiwai Point, and Gore. Rainfall information is available from gauges at several sites. Golder understands that a weather station has been in operation on the Alliance site, but that good-quality data have been available from this site only sporadically over the years. Therefore these data have not been used in the modelling. CALMET also requires upper-air information. Vertical profiles are available from Invercargill Airport, but soundings are taken every 12 hours. This low frequency of monitoring leaves large gaps in information on the varying atmospheric conditions throughout the day. However, TAPM provides hourly profiles and these have been used in preference in the meteorological modelling (see Section 4.3 below for an analysis and justification for this method). TAPM has also been used to fill gaps in the time series of cloud cover and cloud ceiling height from the Airport.

The CALMET 3D data set incorporates high-resolution terrain and land-use information (generated from the LINZ database), which allows it to account for wind flows driven by terrain features, such as slope and valley flows, and sea breezes.

CALMET was run for a two-year period, over a 12 km by 13 km area centred on the Alliance Lorneville site. This area covers part of the Invercargill urban area, and the Airport (so as to include the location of the airport weather station).

This Appendix describes the configuration of TAPM for Invercargill region (Section 2.0), and evaluates the model's performance using common statistical measures of performance (Section 3.0). The CALMET modelling is described and evaluated in Section 4.0. Summary remarks and a reference list may be found in Sections 5.0 and 6.0, respectively.

2.0 CONFIGURATION OF TAPM

The TAPM runs were set up according to the parameters listed in Table 1. The model domain was centred on chosen latitude/longitude coordinates (46° 21.5' S, 168° 33' E) relative to the WGS-84 geodetic datum, with New Zealand Transverse Mercator Grid (NZTM) coordinates assigned to the central point. The centre of the domain is roughly 10 km east of Invercargill. TAPM works with latitude / longitude grids, assuming the x-axis is along constant-latitude lines and the y-axis along meridians. The user is then able to use a rectangular coordinate system (here, NZTM), with sources, receptors, terrain and land cover located correctly relative to each other.

The start and end dates of the model run cover the complete years 2010 and 2011. These two years were chosen after an examination of a series of annual wind roses constructed from Invercargill Airport data. The wind roses are very similar for each year, but 2010 and 2011 were selected for their better data coverage. The two-year modelling period should include the full range of meteorological conditions likely to occur in the area.

TAPM employs grid nesting. Each grid has the same centre and the same number of points, so the higher resolution grids cover successively smaller areas. The vertical levels 'telescope' up from the surface, with lower levels closer together and the distance between levels increasing with height. Grid 4 has the finest horizontal resolution (1 km grid cell size). The grid nesting is 'one-way', in that each grid is influenced by its next-coarsest neighbour; there is no feedback from fine to coarse grids.

TAPM is driven at its outer boundaries by synoptic meteorology, which is generated by Australian forecast models and supplied by TAPM's developer, CSIRO. Data for the years 2010 and 2011 are used to drive the model runs described in this report. Local meteorological features, such as sea breezes and slope flows, are produced by the model's internal dynamics.

TAPM can assimilate wind data from surface-based climate stations, and nudges the modelled wind components towards their observed values in the vicinity of the climate station. This improves the modelled conditions at the climate station, whilst producing outputs which realistically capture the vertical structure of the atmosphere. Wind-data assimilation has been done at the three sites listed in Table 2. Surface meteorological data have been incorporated over the lowest two model levels (10 m and 25 m above ground level), with a radius of influence of 5 km (the minimum recommended in the TAPM documentation).

TAPM configuration parameters not mentioned in this Appendix or listed in the tables should be assumed to take default values, or they relate to a particular feature of the model which is not used.

Table 1: TAPM configuration parameters.

Parameter	Value
Start and end dates	1 January 2010 to 31 December 2011
Grid centre (Lat / Long, WGS84)	46° 21.5' S 168° 33' E
Grid centre (NZTM)	(1257673, 4856508) (m)
No. of grids; no. of grid cells in horizontal	4; 65 x 75
Horizontal grid-cell spacing (one value per grid)	20 km, 8 km, 2.5 km, 1 km
No. of levels in the vertical; level heights	25; heights 10 m, 25 m, 50 m, 100 m, 150 m, 200 m, 250 m, 300 m, 400 m, 500 m, 600 m, 750 m, 1000 m, 1250 m, 1500 m, 1750 m, 2000 m, 2500 m, 3000 m, 3500 m, 4000 m, 5000 m, 6000 m, 7000 m, 8000 m

Table 2: List of meteorological stations whose wind data are assimilated into the TAPM runs. Data obtained from the National Climate Database (CliDb).

Site name	Easting (NZTM, m)	Northing (NZTM, m)	Grid 4 i-coordinate.	Grid 4 j-coordinate.
Invercargill Aero AWS	1240111	4849399	15	31
Tiwai Point EWS	1245779	4830335	20	12
Gore AWS	1282192	4884947	58	66

3.0 EVALUATION OF TAPM MODEL PERFORMANCE

3.1 Introduction

Time series of TAPM meteorological outputs have been compared with observations at the monitoring sites listed in Table 2 for the years 2010 and 2011 combined, using common statistical measures. Model performance measures are described by Willmott (1981; 1982). Their formulas are given by Golder (2007), for example. Note that as wind data have been assimilated into the model runs, the model performance for the wind will be improved at the site locations.

3.2 Index of Agreement

The index of agreement (IOA) is a measure of the overall agreement between modelled and observed time series. It ranges between zero for no agreement and 1 if the two time series are identical. The IOA shows no agreement if the time series are different orders of magnitude, even if they happen to be correlated, and hence is a more stringent measure of performance than the correlation coefficient. IOAs of 0.7-0.8 would be considered to indicate good model performance. Higher values should be expected for meteorological models than dispersion models, particularly if observations have been assimilated.

Table 3 shows the IOA for the wind speed (labelled WS), the westerly and southerly wind-velocity components (labelled U and V, respectively), and temperature and relative humidity (labelled T and RH, respectively).

Table 3: IOA between TAPM outputs and meteorological observations.

Site	Year	WS	U	V	T	RH
Invercargill	2010/11	0.97	0.98	0.98	0.91	0.76
Tiwai Point	2010/11	0.96	0.98	0.95	Not Measured	Not Measured
Gore	2010/11	0.94	0.95	0.94	0.93	0.70

At each site, the IOAs for wind components (WS, U and V) are 0.94 or more, indicating a close match to surface observations. As mentioned above, this should be expected, as wind observations have been assimilated into the runs. The IOAs between observations at Invercargill Airport and TAPM outputs for a location near to Invercargill have also been calculated (but not shown in the table). The location is outside the specified 5 km radius of influence of the input data, but still close to Invercargill, and is thus a measure of how the model would perform if wind data had not been assimilated. The values of IOA for WS, U and V are 0.80, 0.87 and 0.85, respectively. This indicates that the model performance would still be reasonable without data assimilation, and is improved if data are assimilated.

IOAs for temperature are all above 0.90, which indicates good model performance. IOAs for relative humidity are lower, but still adequate.

3.3 Model Skill Scores

The model skill scores relate the variability in the meteorological parameters simulated by the model to the observed variability, for the whole time series of paired observed/modelled concentrations. The time series standard deviations (Std_O for observations and Std_P for modelled variables) are measures of the variability. They should be similar, and the root-mean-square model error (RMSE) should be smaller than the observed variability. The skill scores can be defined as follows:

- Skill_R = RMSE/Std_O – the total model error as a fraction of the observed variability.
- Skill_V = Std_P/Std_O – the model variability as a fraction of the observed variability.

Skill_R should be less than 1, and Skill_V should be close to 1. Values of Skill_R and Skill_V are presented in Table 4 and Table 5, respectively. Values of Skill_R for WS, U, V and T are substantially less than 1 at each site, meaning the model error is well within the observed variability of those meteorological parameters. This is not so for the relative humidity, indicating some model error in the water vapour content of the atmosphere. This is not surprising, as TAPM does not include detailed microphysical schemes. The skill score Skill_V is less than, but sufficiently close to, 1 in most cases (Table 5).

Table 4: Skill score Skill_R for the TAPM meteorological runs.

Site	Year	WS	U	V	T	RH
Invercargill	2010/11	0.33	0.25	0.29	0.54	0.96
Tiwai Point	2010/11	0.35	0.25	0.41	Not Measured	Not Measured
Gore	2010/11	0.46	0.38	0.46	0.51	1.15

Table 5: Skill score Skill_V for the TAPM meteorological runs.

Site	Year	WS	U	V	T	RH
Invercargill	2010/11	0.85	0.85	0.88	0.74	0.97
Tiwai Point	2010/11	0.81	0.85	0.96	Not Measured	Not Measured
Gore	2010/11	0.91	0.93	0.88	0.93	1.10

The IOA, Skill_R and Skill_V are measures of performance of the whole two-year period. An inspection of the time series of modelled and observed parameters shows a reasonable trend of wind components hour by hour, capturing most of the day and night extremes, and the transitions in between. There is a slight under-prediction of daytime maximum wind speed. Night-time minimum temperatures can be over-predicted (that is, the model does not reach cold enough temperatures).

It is important to note that despite the shortcomings of TAPM hour by hour mentioned in the previous paragraph, these issues are common to most models of this type and TAPM still performs adequately well in regions where there are no meteorological data. However, meteorological data *are* available close to the Lorneville site and the CALMET modelling described in Section 4.0 uses wind, temperature and humidity observations from the three monitoring sites to provide more realistic meteorology close to the surface.

3.4 Incorporation of TAPM Outputs into CALMET

The previous sections (3.2 and 3.3) show that TAPM generally performs well, both with and without wind data assimilation. The performance measures are statistical in nature and provide a measure for the whole model run. This does not mean that TAPM outputs match climate station observations hour by hour, although when wind data are assimilated, they are close. Outside the radius of influence of the climate-station data, the TAPM wind fields may sometimes differ from those observed, leading to unrealistic spatial wind patterns. It is possible to incorporate TAPM's 3D wind patterns into CALMET, but due to such spatial patterns, we have decided not to do this. Instead, we have extracted hourly vertical profiles from TAPM at the Airport location and have incorporated these into CALMET. This revised procedure brings in the modelled vertical structure of the atmosphere from TAPM on an hourly basis. It does not bring in the horizontal structure of the wind patterns as would be provided by the 3D TAPM outputs, but as the terrain is almost flat for a few km around Invercargill and Lorneville, there would be little variation expected over the small area of interest covered by CALMET. Variation due to terrain effects would be modelled within CALMET. Note that as surface-wind data have been assimilated into TAPM, the extracted profile matches the surface data closely and any discontinuity in the vertical is minimised.

4.0 CALMET MODELLING

4.1 Introduction

CALMET is a diagnostic meteorological model that blends surface-based data and vertical profiles from nearby climate stations and / or prognostic model data, and accounts for the effects of high-resolution terrain and land use on the wind flow.

CALMET version 6.334 has been used to provide hourly, three-dimensional meteorological fields for input to the CALPUFF dispersion model. The CALMET domain covers an area of 12 km from east to west and 13 km from north to south, with the southwest corner of the domain located at coordinates (1232.5, 4848.6) (km, NZTM). The Alliance Lorneville site is located in fairly flat terrain at the centre of the CALMET domain. The terrain is shown in Figure 1, and land-cover classifications are shown in Figure 2.

4.2 CALMET Model Parameters

This section contains information describing the CALMET configurations, with input parameters shown in Tables 6 to 11. The table captions correspond to the Input Group headings in the CALMET input parameter file. These tables provide details of user-specified parameters for generating an hourly, three-dimensional meteorological dataset with CALMET. Parameters not mentioned here should be assumed to take default values, or they relate to a particular feature of the model that is not used.

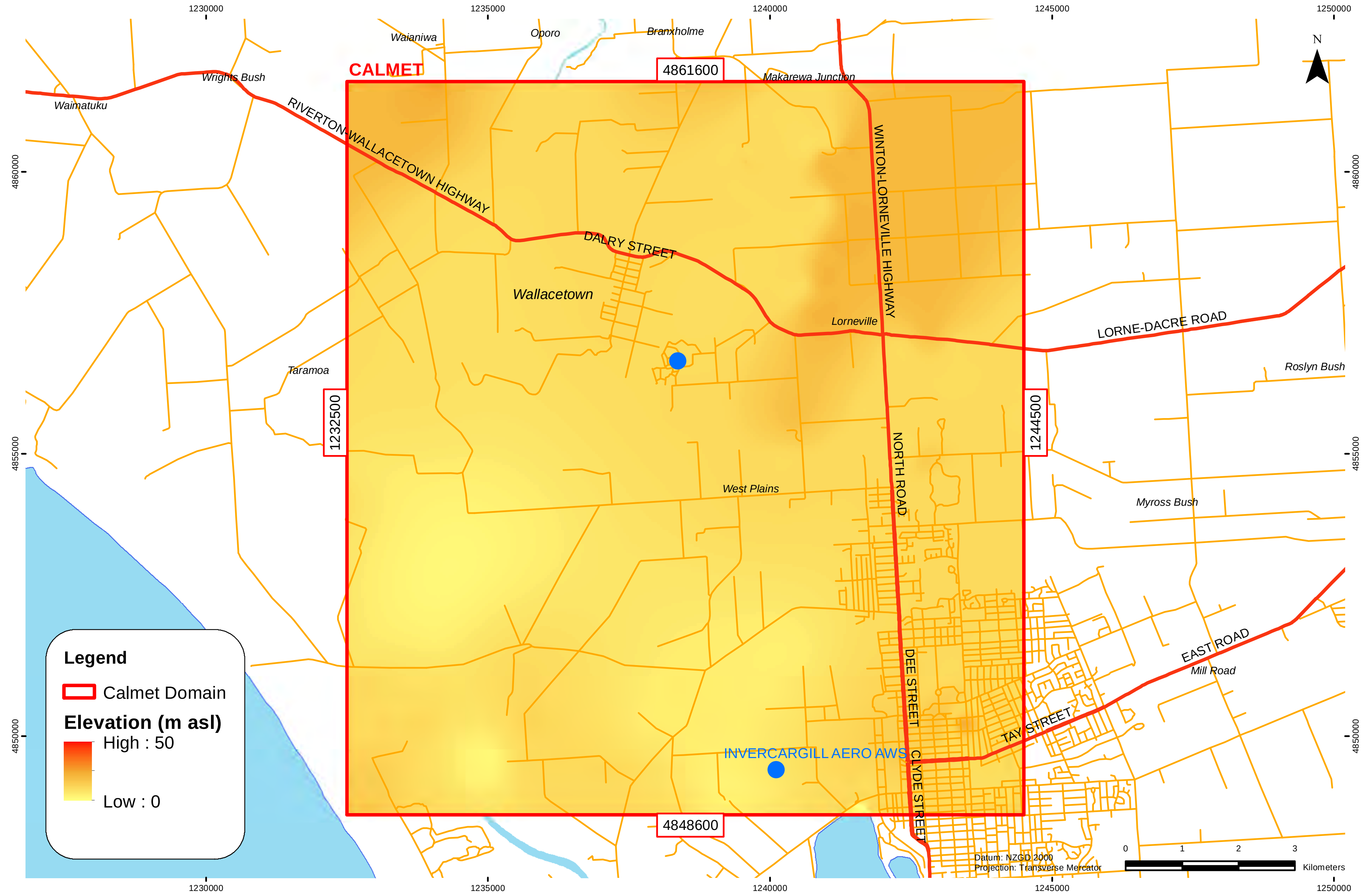
The upper-air site in Table 11 is co-located with the surface site in Table 10, so CALMET is based on a consistent hourly profile from the surface upwards. The upper-air information is composed of TAPM outputs over Invercargill Airport. Cloud height and sky cover data are mainly obtained from the Airport. Gaps in the record are filled by extrapolation of the data in time (if no more than two hours), or by cloud parameters diagnosed from the relative humidity profiles from TAPM.

Table 6: Run control.

Parameter	Value
Start date/time	1 January 2010 00:00
Finish date/time	1 January 2012 00:00
Time zone	UTC+1200
Time step	3600 s

Table 7: Map projection.

Parameter	Value
Map projection	Tangential Transverse Mercator (TTM)
Datum region	WGS-84
Projection origin	46.3333 S, 168.3000 E
False origin *(NZTM coordinates)*	(1238.278, 4858.172) km



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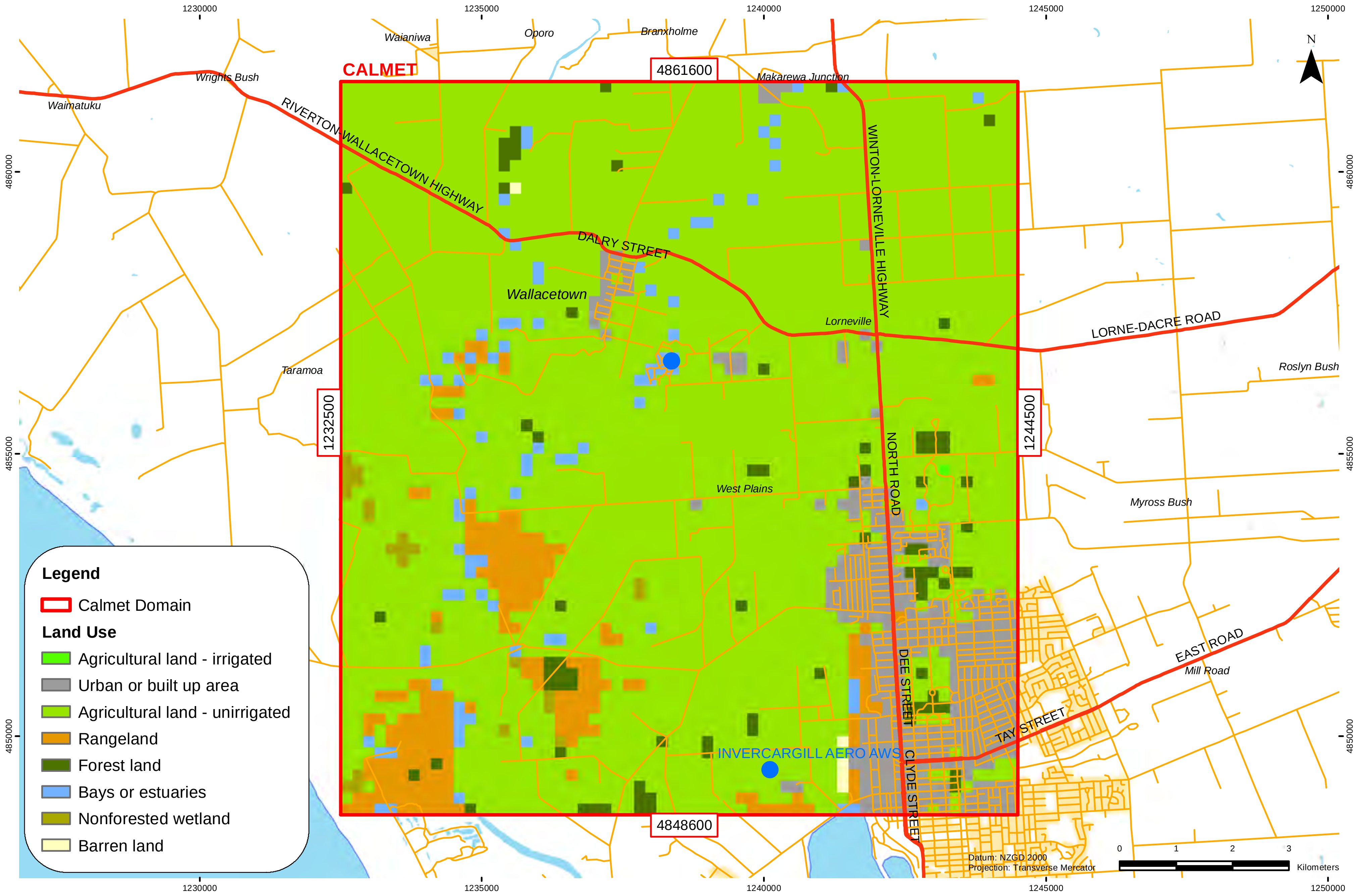

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Table 8: Grid control.

Parameter	Value
SW corner of grid cell (1,1)	(1232.5, 4848.6) km (NZTM)
Grid dimensions	60 x 65 grid cells at spacing 0.2 km
Vertical grid, number of layers	12
Cell-face heights for vertical grid (m)	0, 20, 45, 80, 130, 195, 275, 385, 540, 740, 1000, 1700, 3000

Table 9: Wind field options.

Parameter	Value
Extrapolation of surface wind observations	1; No extrapolation is done (hourly modelled profiles are used to provide vertical structure)
Layer-dependent biases	0
Maximum radius of influence of met. data	5 km
Relative weighting of first-guess field and observations (distance from site at which the weightings are equal)	1 km
Radius of influence of terrain features	1 km

Table 10: Surface meteorological stations.

Name	Source and ID	NZTM X (m)	NZTM Y (m)	Time zone	Anem. ht. (m)
Invercargill Aero AWS	CliDb (11104)	1240111	4849399	-12	10
Tiwai Point EWS	CliDb (5823)	1245779	4830335	-12	10
Gore AWS	CliDb (5778)	1282192	4884947	-12	10

Table 11: Upper-air meteorological information.

Location	Source	NZTM X (m)	NZTM Y (m)	Time zone
Invercargill Aero	Prognostic Model (TAPM)	1240111	4849399	-12

4.3 CALMET Model Performance at Upper Levels

The meteorological fields from CALMET are driven by surface observations from the three sites listed in Table 10 and modelled vertical profiles extracted from TAPM at the location of Invercargill Airport. As mentioned in the introduction, it was considered that the modelled hourly vertical profiles would provide a better meteorological basis to the dispersion modelling than radio-soundings which are carried out through weather-balloon ascents three times per day. The modelled vertical profiles should constitute a realistic, physically-based representation of the dynamics of the atmospheric boundary layer. The alternative is for CALMET to simply interpolate between the twice-daily temperature and thrice-daily wind profiles (temperature is not measured during the 6 am ascent). As there are measured profiles available, CALMET's performance in simulating the vertical structure of the atmosphere at the measurement times should be evaluated to give confidence in its performance at the in-between times.

A radio-sounding is carried out from Invercargill Airport twice a day, at approximately midday and midnight, which measures pressure, dry-bulb temperature and dew-point temperature, with height, wind speed and wind direction determined from the motion of the radiosonde as it ascends. A third sounding is taken at 6 am, which measures wind speed and wind direction only. Although measurements are transmitted continuously throughout the ascent, data are retained – and disseminated for public use – at 'standard' and 'significant' levels. Standard levels for wind data include 300 m, 600 m, 900 m, 1500 m, 2100 m, 2700 m, 4200 m and 7200 m above sea level. Standard levels for temperature data include 1000 mb, 925 mb, 850 mb, 700 mb and 500 mb. Thus the standard data levels for wind and temperature do not usually coincide. All parameters are retained at significant levels, defined by a sharp change in dry-bulb or dew-point temperature.

Model-performance statistics have been calculated for CALMET's upper-level outputs, including wind speed and direction at 300 m, 600 m and 1500 m, and temperature at 925 mb and 850 mb. The statistics are summarised in Table 12. The IOA values can be seen to be comparable with the values for surface-variables in TAPM shown in Table 3, and the same is true of the skill score Skill-V. Skill_R values (which should be small) are higher than those in Table 4. In summary, CALMET performs well in simulating upper-level meteorological parameters. Note that as the upper-level information used in CALMET is modelled using TAPM, the statistics are also a reflection of the performance of TAPM at upper levels.

Table 12: CALMET model-performance statistics at upper levels.

Parameter	Level	IOA	Skill_R	Skill_V
Wind speed	300 m	0.87	0.67	0.90
Wind U-component	300 m	0.92	0.52	0.97
Wind V-component	300 m	0.88	0.64	0.93
Wind speed	600 m	0.88	0.65	0.99
Wind U-component	600 m	0.92	0.55	0.97
Wind V-component	600 m	0.90	0.61	0.98
Wind speed	1500 m	0.90	0.58	0.90
Wind U-component	1500 m	0.93	0.50	0.88
Wind V-component	1500 m	0.91	0.57	0.93
Temperature	925 mb	0.96	0.38	0.93
Temperature	850 mb	0.97	0.35	0.97

The following figures show examples observed and modelled vertical profiles of wind speed, wind direction and temperature for selected conditions that occur in the area. The conditions are those of strong southwesterly wind, moderate northerly and weak northeasterly, and are shown in Figure 3, Figure 4 and Figure 5, respectively. These each occur for a significant amount of time. The model reproduces the observed profiles well, for at least the lowest kilometre of the atmosphere, so should be considered a good basis for air dispersion modelling. The upper-air wind speed, above the boundary layer, is underestimated under the stronger wind conditions, but this has not been investigated further. The winds within the boundary layer – which have lower speeds – are the more important for dispersion of pollutants. It is also important also to get their direction right, and the model does this well. The weaker wind conditions are likely to lead to higher ground-level concentrations, and may occur under drainage-flow conditions at night. Figure 5 shows an example of this; the surface wind is from the northeast at a speed of 1 m/s, in a shallow, stable inversion layer where the temperature increases with height for around 200 m.

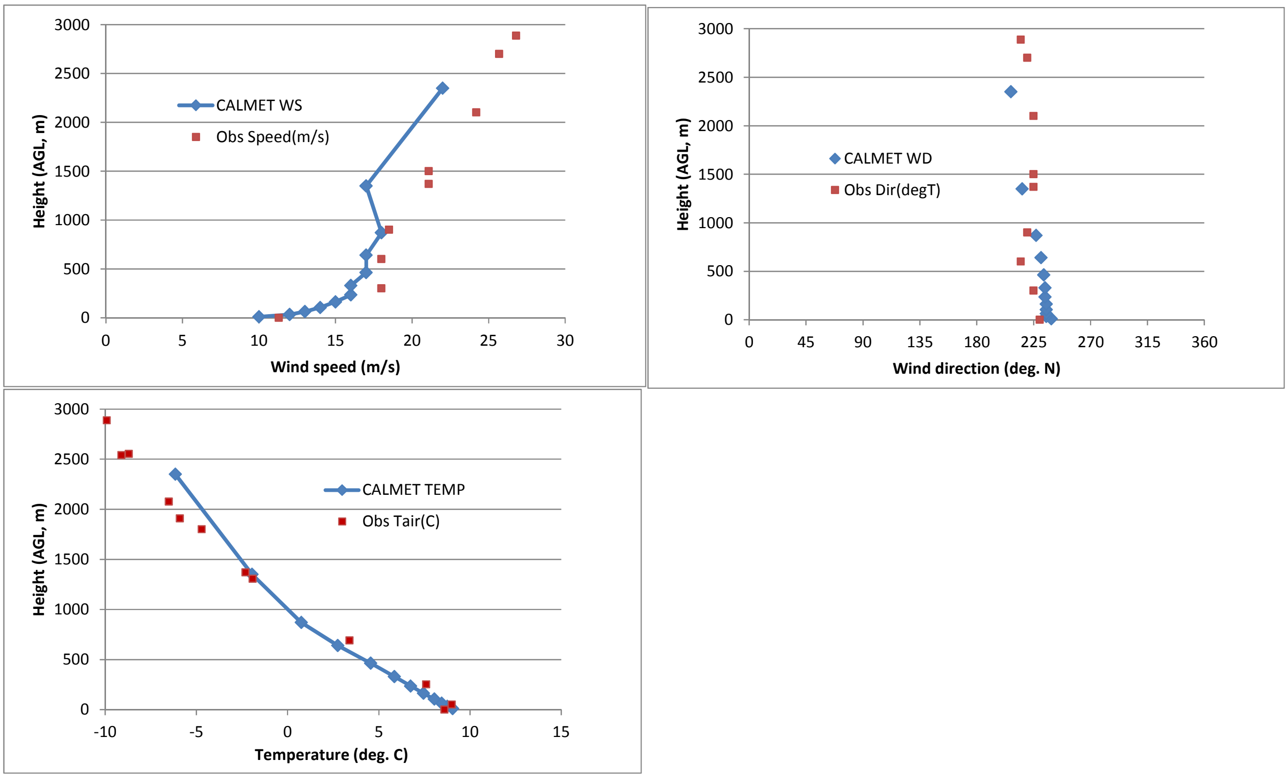

Figure 3: Vertical profiles, observed and modelled - strong southwesterly (12:00 pm, 14 June 2010).

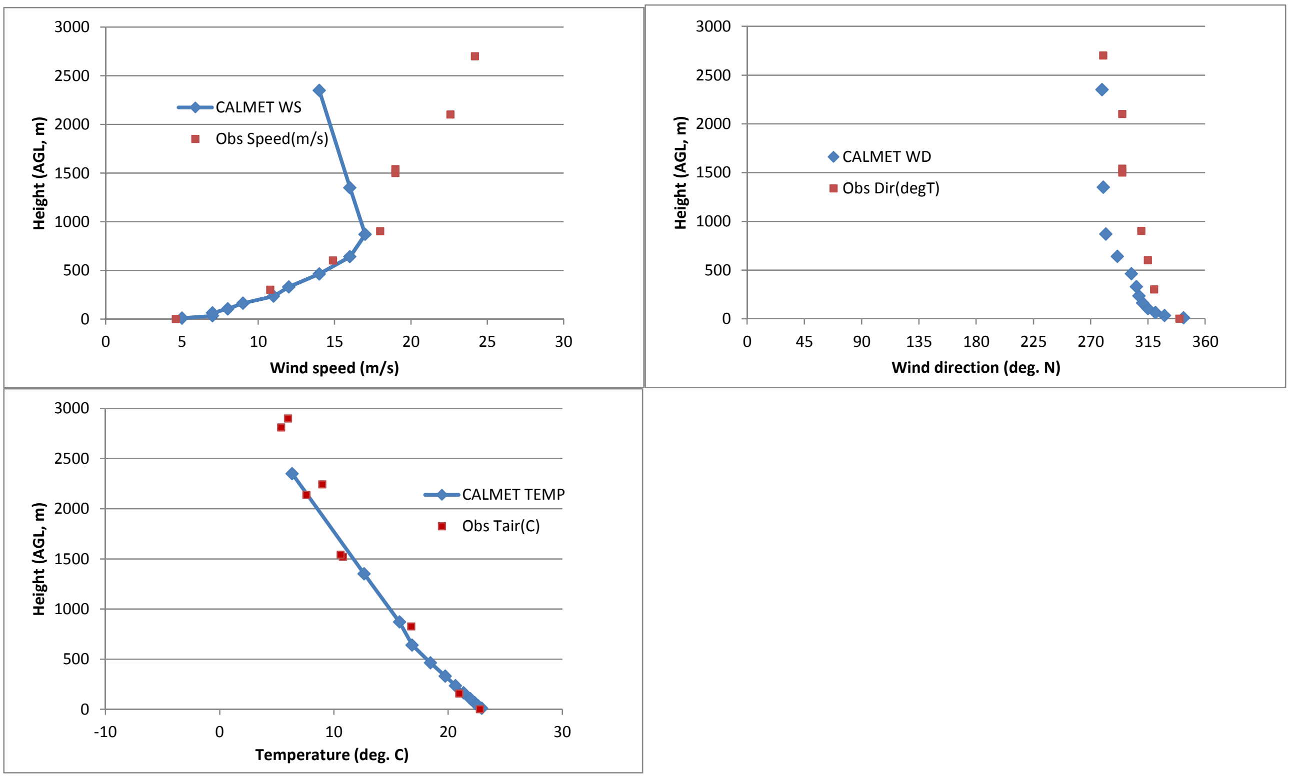

Figure 4: Vertical profiles, observed and modelled - moderate northerly (12:00 pm, 22 February 2010).

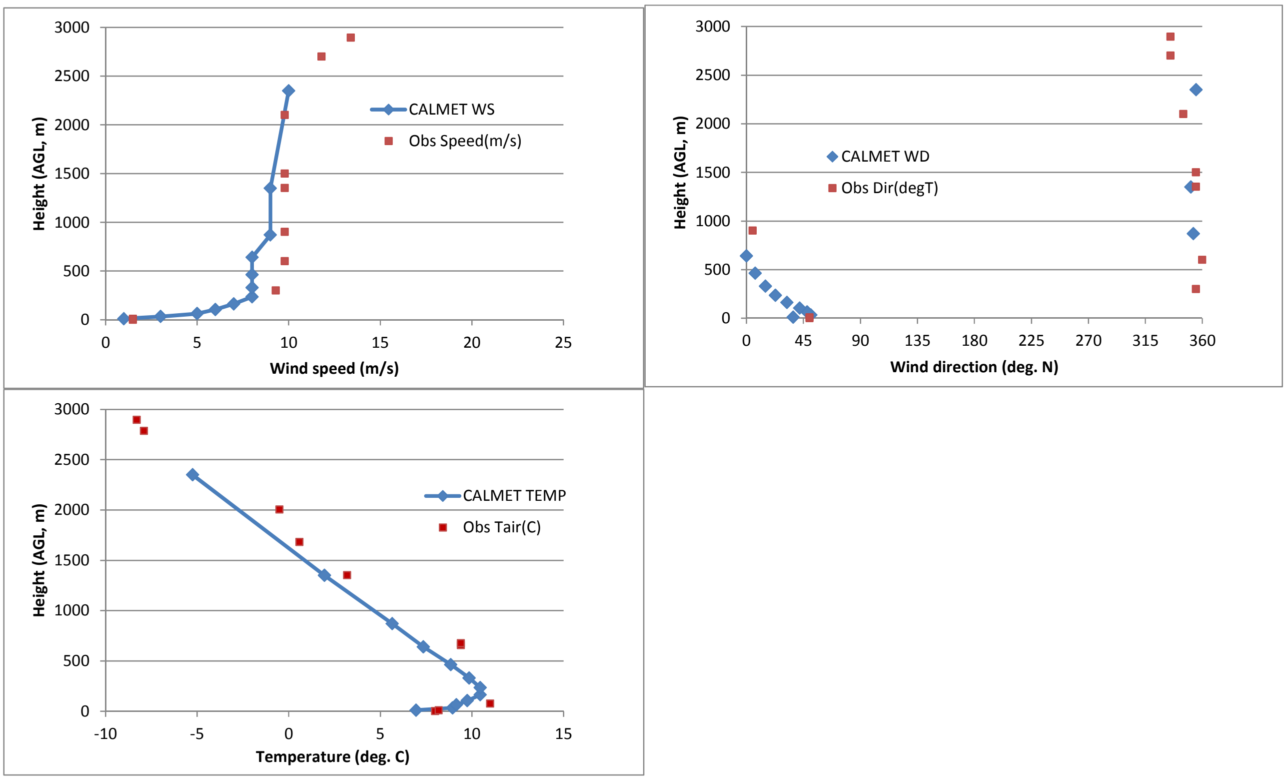

Figure 5: Vertical profiles, observed and modelled – weak northeasterly (12:00 am, 28 August 2010).

5.0 SUMMARY

Meteorological modelling focusing on the Southland area, around Invercargill and Lorneville, has been carried out for the years 2010 and 2011. TAPM was used to provide hourly modelled vertical profiles of meteorological parameters which were combined with surface-based observations in CALMET. The outputs from TAPM and CALMET, at the surface and aloft, have been compared with observations of surface meteorology and twice- or thrice-daily observed profiles. The models have been shown to perform reasonably well in the atmospheric boundary layer and provide a realistic basis for dispersion modelling of emissions from the Alliance Lorneville plant using CALPUFF.

6.0 REFERENCES

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APPENDIX E

CALPUFF Model Configuration

1.0 INTRODUCTION

CALPUFF version 6.42 was run from 1 January 2010 to 1 January 2012. Most standard options were used, including the PRIME building-wake algorithm and the ‘pdf’ formulation for dispersion under convective conditions. Concentrations of SO_2, NO_X and PM_{10} and metals were calculated at a number of discrete receptors, and on a grid with 50 m spacing.

2.0 GENERIC CALPUFF PARAMETERS

A fuller list of parameters used in the CALPUFF runs is given in the following tables. Parameters not mentioned below should be assumed to take default values, or they relate to a particular feature of the model that is not used.

Table 1: CALPUFF start and end times.

Parameter		Value	
Start date / time		00:00	1 January 2010
End date / time		00:00	1 January 2012
Base time zone	XBTZ	-12 (NZST)	
Time step	NSECDT	3600 s	

Table 2: Pollutant specifications.

Parameter		Value	
Number of chemical species	NSPEC	6	
Number of emitted species	NSE	6	
Species;	modelled; emitted; deposited?	SO_2 NO_x PM_{10} $PM_{2.5}$ TSP Metals, dioxins, furans	Yes; Yes; No Yes; Yes; No Yes; Yes; No Yes; Yes; No Yes; Yes; No Yes; Yes; No
Chemical mechanism	MCHEM	0	(No chemistry)
Dry deposition	MDRY	0	(No dry deposition)
Wet deposition	MWET	0	(No wet deposition)

Table 3: Technical options.

Parameter		Value
Dispersion coefficient calculation	MDISP	2 use micrometeorological variables
Back-up calculation	MDISP2	3 PG for rural; MP for urban
PDF for dispersion under convective conditions	MPDF	1 (On)
Building downwash	MBDW	2 PRIME algorithm
Check parameters for regulatory settings		No (they are USEPA-specific)
Minimum σv over land (default 0.5 m/s)		0.5 m/s

Table 4: Map projection (parameters should match CALMET).

Parameter	Value
Map projection	Tangential Transverse Mercator (TTM)
Datum region	WGS-84
Projection origin	46.3333 S, 168.3000 E
False origin (*NZTM coordinates*)	(1238.278, 4858.172) km

Table 5: Grid control.

Parameter		Value
SW corner of grid cell (1,1)		(1232.5, 4848.6) km (NZTM)
Grid dimensions	NX x NY; DGRIDKM	60 x 65 grid cells at spacing 0.2 km
Vertical grid, number of layers		12
Cell-face heights for vertical grid (m)		0, 20, 45, 80, 130, 195, 275, 385, 540, 740, 1000, 1700, 3000

Table 6: Grid control (subset of CALMET grid points used by CALPUFF).

Parameter		Value
CALPUFF computational grid range E-W		21 to 50 out of NX=60
CALPUFF computational grid range S-N		25 to 57 out of NY=65
Use of gridded receptors?		Yes
Receptor grid range E-W		21 to 50
Receptor grid range S-N		25 to 57
Receptor grid nesting	MESHDN	4 (grid spacing 50 m)

Table 7: Discrete receptors. Total of 102 discrete receptors are modelled.

ID	NZTM easting (km)	NZTM northing (km)	Ground Elev. (m)*
1	1241.006	4856.992	18
2	1241.377	4856.845	15
3	1240.825	4855.628	15
4	1241.147	4855.487	11
5	1241.401	4856.461	13
6	1241.481	4857.123	17
7	1241.365	4857.119	17
8	1241.329	4857.118	17
9	1241.294	4857.117	18
10	1241.257	4857.117	18
11	1241.218	4857.115	18
12	1241.154	4856.967	17
13	1241.171	4856.916	17
14	1241.148	4857.11	18
15	1240.92	4856.907	18
16	1241.272	4857.339	19
17	1241.142	4857.24	19
18	1241.091	4857.176	19
19	1240.966	4857.162	19
20	1240.831	4856.932	18
21	1240.796	4857.212	20
22	1240.747	4857.087	19
23	1241.077	4855.651	13
24	1240.813	4855.527	14
25	1240.732	4856.197	16
26	1240.317	4854.725	10
27	1240	4854.91	10
28	1240.151	4854.921	10
29	1240.148	4854.815	10
30	1240.662	4857.084	19
31	1240.548	4857.019	19
32	1240.467	4857.068	16
33	1240.614	4857.57	18
34	1240.316	4857.484	13
35	1239.956	4857.241	11
36	1240.263	4857.483	10
37	1239.798	4857.387	10
38	1239.955	4857.435	10
39	1239.944	4857.452	10
40	1239.931	4857.472	10
41	1239.897	4857.456	10

ID	NZTM easting (km)	NZTM northing (km)	Ground Elev. (m)*
42	1239.921	4857.492	10
43	1239.908	4857.515	10
44	1239.893	4857.542	10
45	1239.846	4857.538	10
46	1239.864	4857.595	10
47	1239.812	4857.597	10
48	1239.911	4857.619	9
49	1240.572	4855.571	15
50	1240.715	4855.595	14
51	1240.619	4855.863	16
52	1240.745	4855.524	14
53	1240.354	4855.746	17
54	1240.616	4855.107	12
55	1240.258	4856.55	15
56	1240.359	4854.969	10
57	1238.783	4854.897	9
58	1238.664	4855.156	9
59	1239.491	4854.728	10
60	1239.018	4855.199	10
61	1239.402	4858.429	9
62	1239.307	4858.463	9
63	1239.434	4858.126	9
64	1239.349	4857.988	9
65	1239.292	4858.035	9
66	1239.15	4858.125	9
67	1239.039	4858.19	9
68	1239.124	4858.235	9
69	1239.375	4856.295	11
70	1239.349	4856.297	11
71	1239.332	4856.287	11
72	1239.614	4854.789	10
73	1239.279	4854.941	10
74	1239.431	4855.009	10
75	1239.278	4854.909	10
76	1239.425	4854.829	10
77	1239.504	4855.097	11
78	1238.662	4855.025	9
79	1238.779	4855.034	9
80	1240.489	4856.791	16
81	1240.593	4855.764	16
82	1240.907	4855.59	12
83	1240.222	4855.609	17

ID	NZTM easting (km)	NZTM northing (km)	Ground Elev. (m)*
84	1238.768	4855.162	9
85	1240.384	4855.051	12
86	1239.408	4855.099	10
87	1240.536	4856.615	17
88	1240.518	4856.483	17
89	1240.523	4856.446	17
90	1240.814	4856.077	16
91	1241.399	4856.636	14
92	1239.799	4854.904	10
93	1240.65	4854.973	10
94	1239.611	4854.883	10
95	1241.216	4855.548	11
96	1240.342	4856.689	16
97	1238.492	4855.268	9
98	1238.623	4855.276	9
99	1240.438	4856.474	16
100	1240.236	4855.035	12
101	1240.487	4854.827	10
102	1239.425	4854.71	10

Note: * Above mean sea level – height shown is that of the CALMET grid cell containing the receptor point.

3.0 STACK SOURCE PARAMETERS

Table 8: Emission parameters.

Point source ID	NZTM Easting (km)	NZTM Northing (km)	Stack height (m)	Base elevation (m)	Stack Diameter (m)	Efflux velocity (m/s)	Temp. (K)
Babcock and Wilcox boiler, B1	1239.587	4856.596	30.9	11	1.21	Based on MCR	443
Foster Wheeler boiler, B2	1239.600	4856.590	34.1	11	0.93	Based on MCR	443

Table 9: Maximum emission rates.

Contaminant	Emission rate (g/s)	
	Boiler 1	Boiler 2
SO_2	13.35	8.44
NO_x	5.82	3.68
PM_{10}	3.66	2.31
TSP	5.48	3.47
Lead	1.45×10^{-4}	9.14×10^{-5}
Arsenic	6.56×10^{-4}	4.14×10^{-4}
Cadmium (Cd)	4.31×10^{-5}	2.72×10^{-5}
Chromium (Cr)	2.97×10^{-4}	1.88×10^{-4}
Mercury (Hg)	1.21×10^{-4}	7.62×10^{-5}
Dioxin and Furans	259 pg I-TEQ/s	164 pg I-TEQ/s

```
'1378104-044 Alliance Lorneville'
'P'
'METERS'  1
'UTMN'  0
6
'Dry'  1 10.5
4  17.48
1239654  4856781
1239651  4856826
1239676  4856827
1239678  4856782
'Process'  1 11
4  17
1239607  4856777
1239639  4856779
1239653  4856548
1239621  4856546
'Slaughter1'  1 11
9  16.5
1239552  4856763
1239552  4856755
1239579  4856756
1239580  4856736
1239581  4856726
1239596  4856727
1239601  4856648
1239554  4856645
1239547  4856763
'Slaughter2'  1 11
5  18.8
1239596  4856737
1239580  4856736
1239579  4856756
1239579  4856765
1239594  4856766
'Slaughter3'  1 11
4  17.7
1239579  4856765
1239579  4856756
1239552  4856755
1239552  4856763
'Slaughter4'  1 11
4  19.5
1239596  4856737
1239596  4856727
1239581  4856726
1239580  4856736
2  1
'B1'  11  30.9  1239587  4856596
'B2'  11  34.1  1239600  4856590
```

Figure 1: Building parameter (BPIP) input file.

APPENDIX F

Coal Composition Data

COAL TESTING – JULY 2012 TO FEBRUARY 2015

Table 1: Coal testing for Newvale Industrial Coal. All values as received.

Testing date	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Sulphur (%)	Swell Cv (MJ/kg)
July 2012	39.4	3.8	30.5	26.4	0.40	14.82
August 2012	39.9	3.6	30.6	25.9	0.37	14.77
September 2012	40.0	3.7	31.0	25.3	0.35	14.77
October 2012	40.5	3.5	30.9	25.0	0.37	14.91
November 2012	40.5	3.6	29.8	26.0	0.41	14.90
December 2012	40.6	3.4	30.2	25.8	0.39	15.00
January 2013	40.1	3.5	30.5	25.8	0.41	15.14
February 2013	39.6	3.4	31.2	26.8	0.41	15.23
March 2013	40.4	3.6	30.3	25.6	0.44	15.02
April 2013	40.3	3.5	30.5	24.7	0.44	14.96
May 2013	40.6	3.8	30.3	25.3	0.44	14.82
July 2013	38.9	3.5	31.2	26.3	0.45	15.42
August 2013	39.10	3.61	31.24	26.10	0.42	15.29
September 2013	40.6675	3.516	30.2376	25.6	0.42	15.00
October 2013	40.3	3.6	30.2	25.8	0.42	15.07
November 2013	39.7	3.7	32.2	24.4	0.43	15.14
December 2013	40.3	3.8	30.1	25.8	0.43	15.07
January 2014	41.4	3.9	29.9	24.7	0.43	14.82
February 2014	40.4	3.7	30.3	25.5	0.41	15.13
March 2014	40.2	3.5	30.7	25.6	0.41	15.15
April 2014	41.3	3.3	30.1	25.3	0.42	14.95
May 2014	41.2	3.6	29.7	25.5	0.39	14.95
July 2014	40.8	3.4	30.2	25.6	0.37	15.01
September 2014	40.4	3.6	30.3	25.7	0.38	15.05
October 2014	41.4	3.1	29.8	25.7	0.41	14.99
November 2014	40.7	3.3	30.3	25.8	0.37	15.09
January 2015	39.4	3.4	31.2	26.0	0.39	15.29
AVERAGE	40.3	3.6	30.5	25.6	0.41	15.0

Note: Data provided to Alliance and Golder from Solid Energy. Personal communications (emails) between Duncan MacKenzie (Solid Energy) and Frank Wilson (Alliance), 15 July 2013, and between Duncan MacKenzie (Solid Energy) and Cathy Nieuwenhuijsen (Golder), 17 February 2015.

Table 2: Trace element analysis based on drill-core testing. Recommended “guide” values for Newvale coal are shaded grey.

Trace element	Newvale estimated average	Newvale arithmetic average	Lower 90% confidence figure	Upper 90% confidence figure	Newvale geometric average	World coal range (1)	USA coal range (1)	Australian coal average (2)
Antimony (ppm)		0.049	0.045	0.054	0.047	0.05 – 10	<0.1 – 7.4	0.46
Arsenic (ppm)		2.33	2.06	2.61	2.15	0.5 – 80	<1 – 170	0.93
Barium (ppm)		22.8	21.0	24.6	22	20 – 1000	4 – 570	
Beryllium (ppm)	<0.2					0.1 – 15	0.2 – 14	0.82
Boron (ppm)		26.2	24.2	28.3	25.2	5 – 400	<0.6 – 160	21
Cadmium (ppm)	<0.10					0.1 – 3	<0.004 – 9	0.09
Chlorine (%)		0.03	0.02	0.03	0.02	0.005 – 0.2	0.013 – 0.24	0.032
Chromium (ppm)		2.2	2.0	2.5	2	0.5 – 60	2 – 84	9
Cobalt (ppm)		1.25	0.84	1.19	1.00	0.5 – 30	0.8 – 90	3.7
Copper (ppm)		1.85	0.80	1.22	0.99	0.5 – 50	3 – 160	14
Fluorine (ppm)	<20	All BDL			All BDL	20 – 500	<13 – 1900	98
Lead (ppm)		0.49	0.32	0.47	0.39	2 – 80	<1 – 62	5.8
Manganese (ppm)		128.61	112.5	134.3	122.91	50 – 70	1 – 1400	99
Mercury (ppm)		0.06	0.053	0.061	0.05	0.02 – 1	0.01 – 1.8	0.021
Molybdenum (ppm)	0.05 - 0.21	0.22	0.179	0.263	0.21	0.1 – 10	<0.1 – 16	0.85
Nickel (ppm)		2.67	1.83	2.56	2.17	0.5 – 50	1.4 – 130	8.6
Phosphorous (%)		0.00058	0.00050	0.00065	0.00052	0.001 – 0.3	0.0001 – 0.12	
Selenium (ppm)	0.1 – 0.35	0.37	0.334	0.399	0.35	0.2 – 10	<0.6 – 20	0.47
Thorium (ppm)		0.24	0.2	0.27	0.2	0.5 – 10	<3 – 26	2.6
Thallium (ppm)	<0.5					<0.2 – 1	<0.3 – 13	
Tin (ppm)	<1					1 – 10	<0.3 – 3	
Uranium (ppm)	0.01-0.10	0.10	0.082	0.108	0.09	0.5 – 10	<0.1 – 15	0.93
Vanadium (ppm)		2.25	1.67	2.27	1.95	2 – 100	2 – 120	23
Zinc (ppm)		11.3	6	12	8.5	5 – 300	~25	14

Notes: Data provided by Duncan MacKenzie (Solid Energy) to Cathy Nieuwenhuijsen (Golder Associates (NZ) Ltd), 30 August 2013. (1) Source: Swaine (1990, 1995). (2) Source: Dale (2006).

APPENDIX G

CALPUFF Variable Emissions

1.0 INTRODUCTION

This appendix outlines the process used to develop hourly varying contaminant emissions files for the Alliance Lorneville coal-fired boilers (i.e., the 18 MW Babcock and Wilcox and a 12.7 MW Foster Wheeler). These contaminant emission files were used as input to the CALPUFF dispersion model. These emission profiles are based on the steam production of the processing period from 23/11/2013 to 22/11/2014. This period was chosen as the second new rendering line was operating and there was winter processing Alliance have confirmed that this period reflects the steam production rates for future seasons at the Lorneville plant.

Two boiler stack emission scenarios were established. The first and main scenario was based on the hourly varying measured steam flows and associated boiler stack emissions. The modelling of this emissions profile was used for the assessment of 24-hour and longer average ground level concentrations (GLCs). The second emission scenario based on a conservative emissions envelope which would overstate long term impacts, while ensuring that the potential short term impacts of air contaminants are captured by the modelling assessment.

Firstly the current steam loading is discussed (Section 2.0). Then Sections 3.0 and 4.0 provide information on how the projected steam use is applied to the modelling setup and Section 5.0 provides a summary. The general CALPUFF configuration parameters are given in Appendix E.

2.0 STEAM PRODUCTION RATES FOR 2013/2014 SEASON

The steam produced by each of the boilers is measured and the steam flow and pressure are recorded at 1 minute intervals. Steam records have been provided between 23 November 2013 through to 22 November 2014. This time frame was used as it after the second rendering line was commissioned and includes Winter processing.

One hour average steam flow was been calculated from the 1-minute data and corrected to 8 bar steam. For the most part, the 8 bar steam correction only changes the steam measurements by a small amount, but this correction ensures that steam flows are converted to an accurate equivalent energy demand.

The 1-hour average steam flows are presented in Figure 1 for CFB No. 1 (18 MW Babcock & Wilcox) and Figure 2 for CFB No.2 (12.7 MW Foster Wheeler). It can be observed that each of the two boilers have three different operation periods, namely a shutdown period, a shoulder season and the peak season. During the shoulder seasons, the production is either gradually increasing or decreasing. A shutdown or lower operation period over Christmas / New Year and Easter can also be observed in the steam profiles. During parts of the shoulder season and earlier part of the peak season, CFB No. 1 is often shut down over part of the weekend, whereas later in the peak season, it is operated at a lower rate (rather than shutdown) during the weekend. In comparison, CFB No. 2 is more frequently shutdown over part of the weekend across the whole season.

The boilers generally operate below their maximum steam production capacity, as shown in the two figures below. The maximum combined operation is 99 % of the maximum capacity rating (MCR), with the operation rate below 70 % MCR approximately 80 % of the time. Note that CFB No. 2 has several short periods where the measured steam flow at 8 Bar goes slightly above the MCR for this boiler.

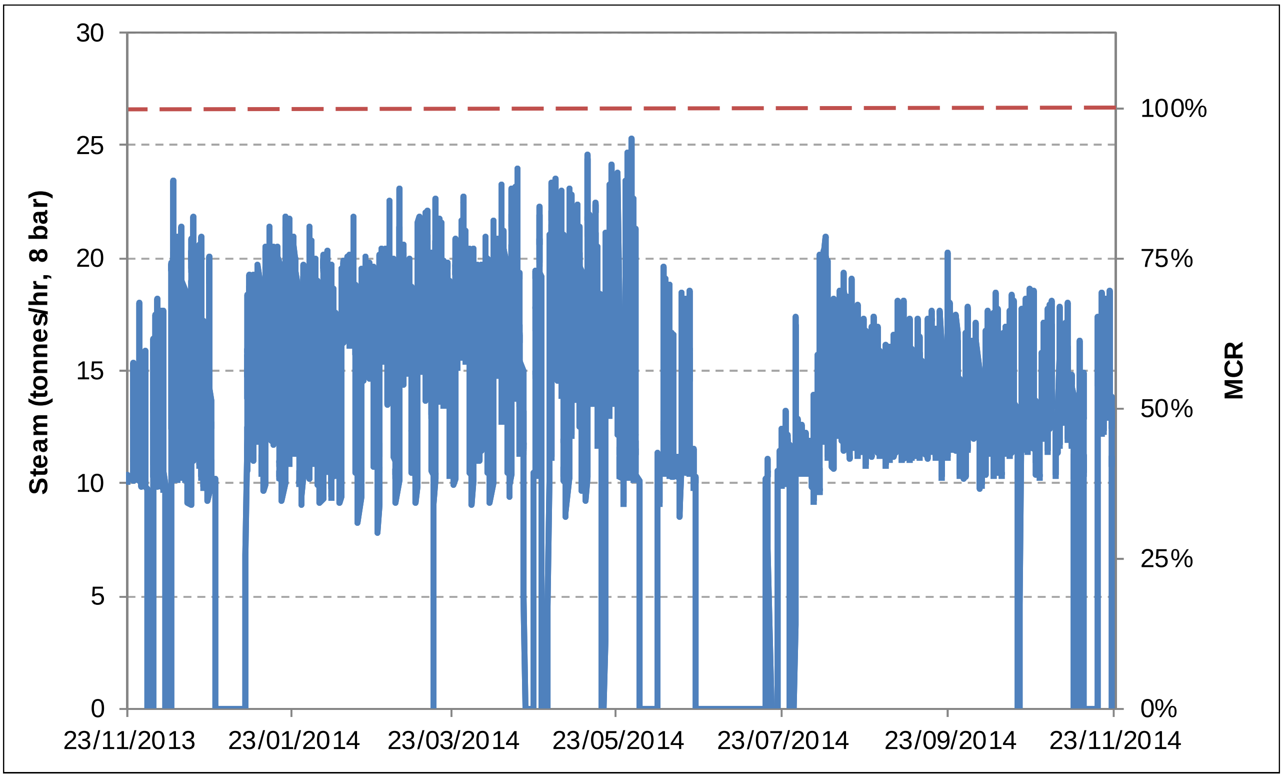

Figure 1: Measured steam (8 bar) for CFB No.1 during the 2013/14 processing season. Red dashed line shows the maximum steam rating (corrected to 8 bar).

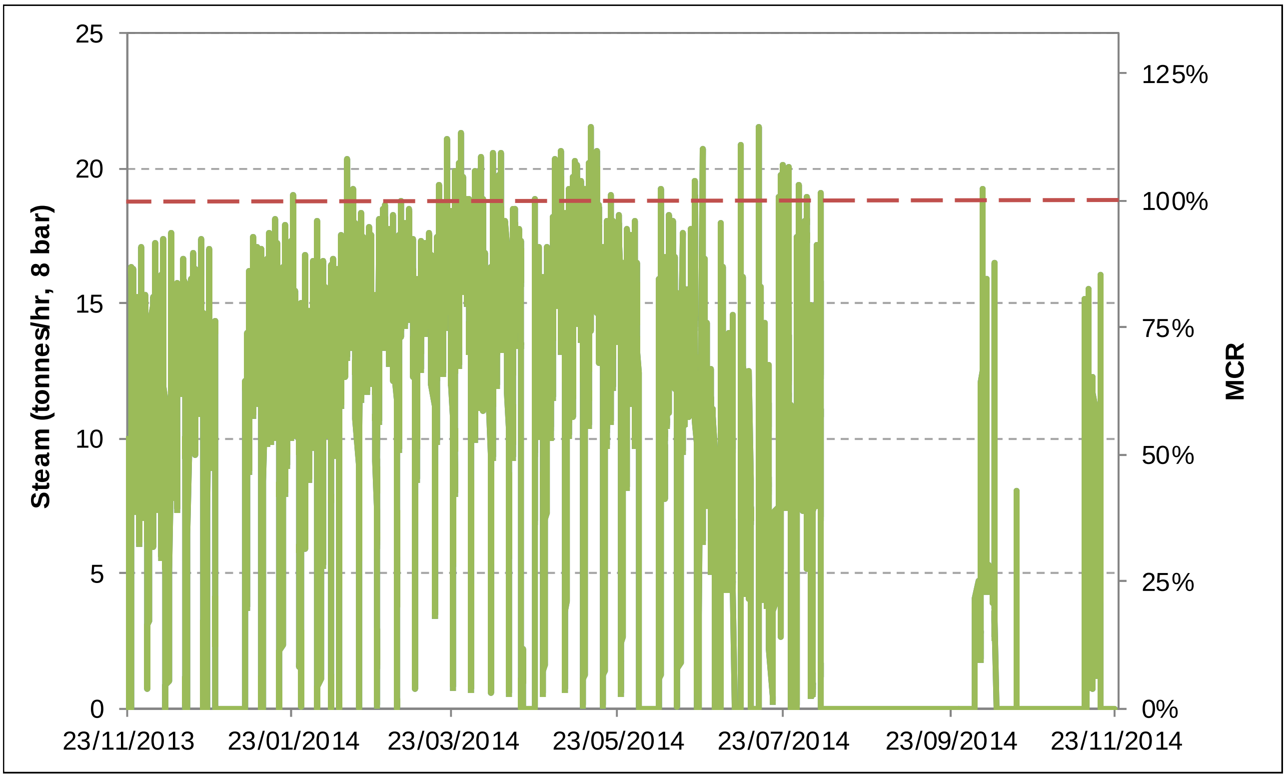

Figure 2: Measured steam (8 bar) for CFB No. 2 during the 2013/14 processing season. Red dashed line shows the maximum steam rating (corrected to 8 bar).

2.1 Modelling and Measured Period Match Up

Two years of meteorological data (2010 and 2011) have been used as input to the dispersion model, while the latter assumed contaminant emissions based on measured 2013/14 process steam production. The two year modelling period had the contaminant emissions based on measured data distributed in time as shown in Table 1.

Table 1: Matched up periods for modelled and measured data.

Modelled period	Measured steam data period
1 Jan 2010 to 22 Nov 2010	1 Jan 2014 to 22 Nov 2014
23 Nov 2010 to 22 Nov 2011	23 Nov 2013 to 22 Nov 2014
23 Nov 2011 to 1 Jan 2012	23 Nov 2013 to 1 Jan 2014

3.0 MODELLED OPERATIONAL PROFILES

3.1 Hourly Varying Emissions

The hourly varying boiler output operational profiles based on the process outlined above are presented in Figure 3 and Figure 4. Only one of the modelled years is shown as the second modelled year has the same operations profile. These profiles are used to calculate the modelled efflux velocities and contaminant emission rates as discussed in Section 4.0.

There are a few points when CFB No.2 goes above 100 % MCR. This already occurs in the 2013/14 measured steam profiles (see Figure 4).

The Christmas/New Year shutdown period and a lower operation rate over the Easter period are included in the hourly varying emissions profiles. While these do not necessarily occur at the actual days of these holidays this is unlikely to make any material difference to the modelling results. The timing of Christmas / New Year with regards to the working week varies each year. Likewise the timing of Easter varies each year. These shutdown or low operation periods are not included in the conservative envelope modelling described in Section 3.2.

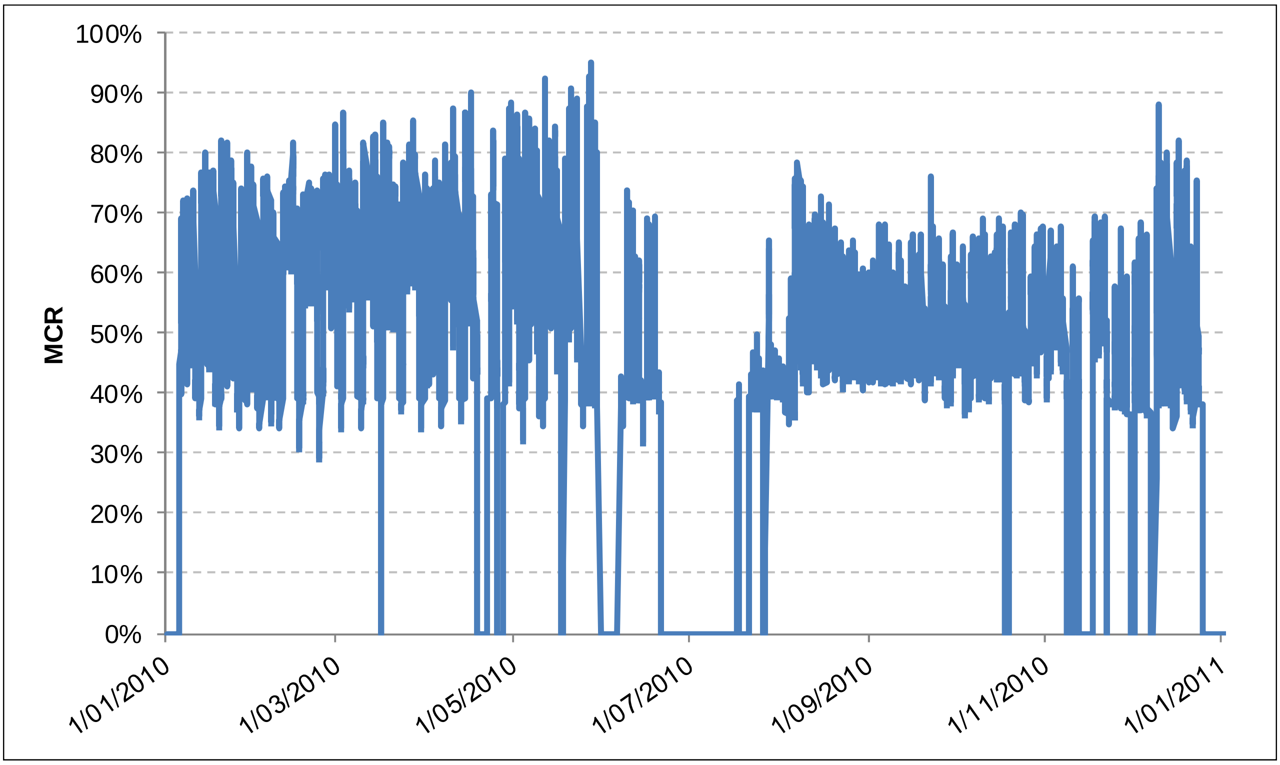

Figure 3: Modelled hourly varying CFB No .1 operations profile. Note that the same operations profile is repeated for the 2011 modelling year.

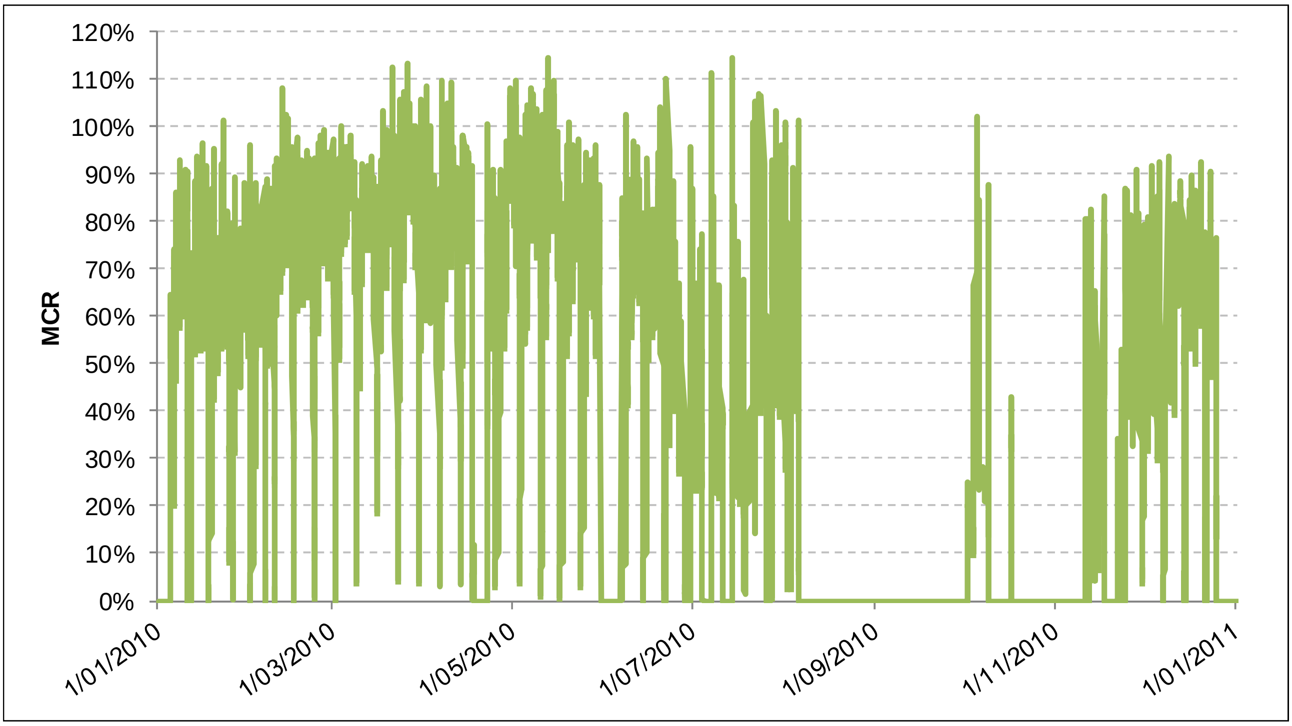

Figure 4: Modelled hourly varying CFB No.2 operations profile. Note that the same operations profile is repeated for the 2011 modelling year.

3.2 Envelope Emissions

The envelope MCR profile was developed to cover the approximate maximum range in the hourly varying emissions. Figure 5 shows the envelope emissions profile with the step changes in operation for each of the boilers. These profiles were developed to encompass most of the short term peaks in the operation of each boiler and reflect the actual operating profiles without overstating the cumulative operation. The combined boiler's operation is shown in Figure 6 with the combined envelope of operation also shown. Winter processing and the shoulder seasons have reduced operation with each boiler assumed to have a different shut down period as occurred during the 2013/14 season. From Figure 6 it can be seen that the emissions envelope covers the broad operation peaks of both boilers.

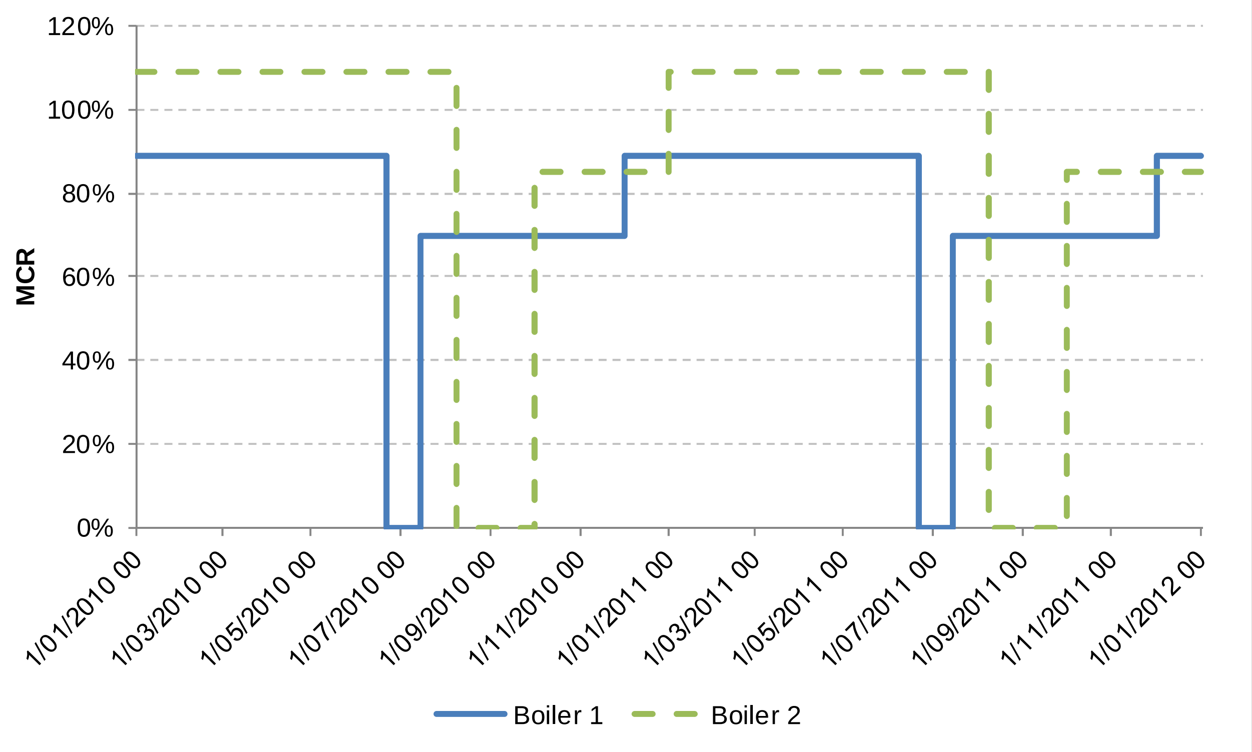

Figure 5: Envelope operations profile for each boiler over the whole modelling period.

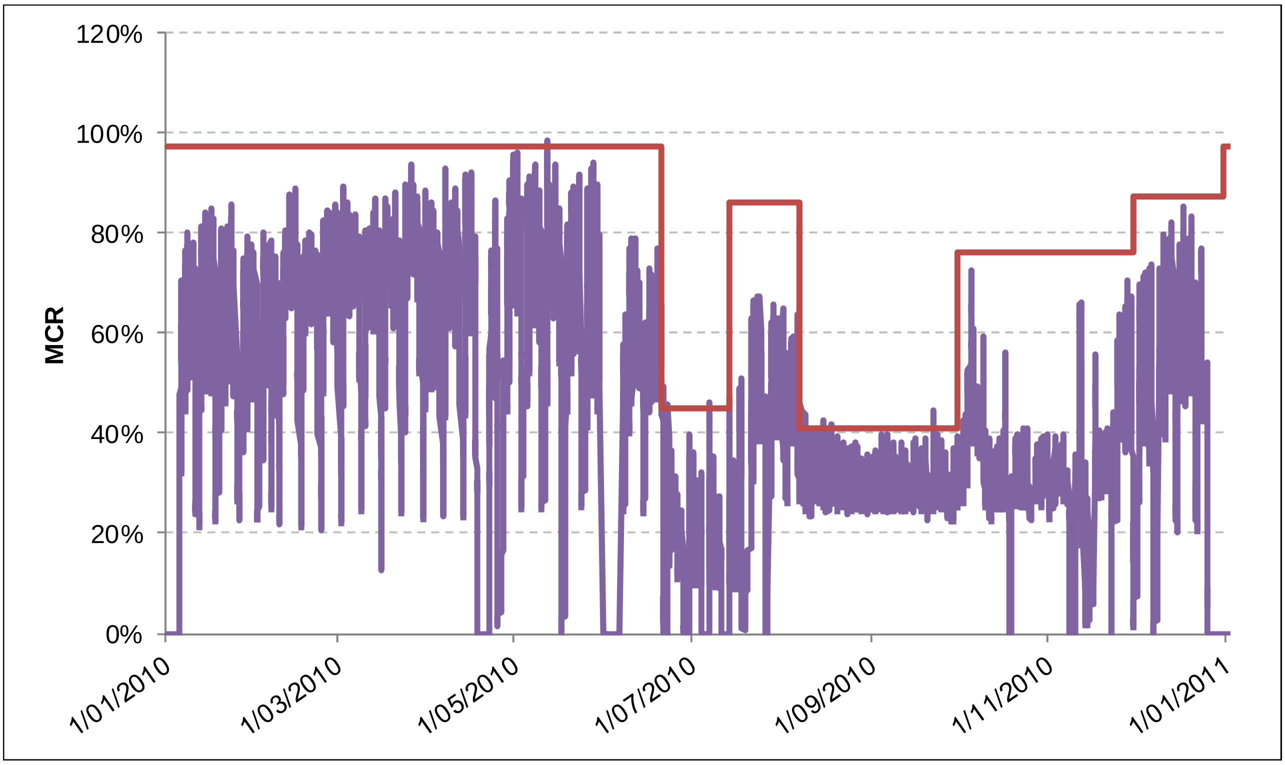

Figure 6: Modelled envelope operations profile (redline) for combined boilers in comparison to the combined hourly varying operations profile. Note that the same profile is repeated for the 2011 modelling year.

4.0 DISCHARGE PARAMETERS

Of the boiler discharge parameters required as dispersion model input, the efflux velocity and contaminant emission rates were to be adjusted each hour to take account of the varying operations rate. Fixed discharge parameters such as stack height and diameter are provided in the main body of the report.

4.1 Efflux Velocity

Efflux velocity is based on the operating rate of the plant and the amount of excess combustion air. Three combustion calculations were carried out for each of the boilers (six in total) at 25 %, 50 % and 100 % MCR (Appendix B). The excess oxygen was set at 5 vol. % for 100 % MCR, 8 vol. % for 50 % MCR and 10 vol. % for 25 % MCR and are based on the experience of typical variation in excess air as a function of MCR. Stack testing at Alliance Lorneville indicate that the excess oxygen is usually higher. However these lower values (which give lower efflux velocities) cover the future operation of the boilers.

Based on the combustion calculations, a relationship curve is developed between the operational MCR and the resultant efflux velocity. This relationship is based on a power curve of the form:

$$y=Ax^b$$

where y is the efflux velocity in metres per second (m/s), x is the MCR as a percentage. The power curve is shown in Figure 7 with the coefficients given in Table 2. This equation and coefficients are used to calculate the efflux velocity for each hour for the hourly varying emissions file and the envelope emissions file.

Table 2: Coefficients for calculating the efflux velocity from the operating MCR.

	A	b
CFB No. 1	0.4925	0.777
CFB No. 2	0.5281	0.7765

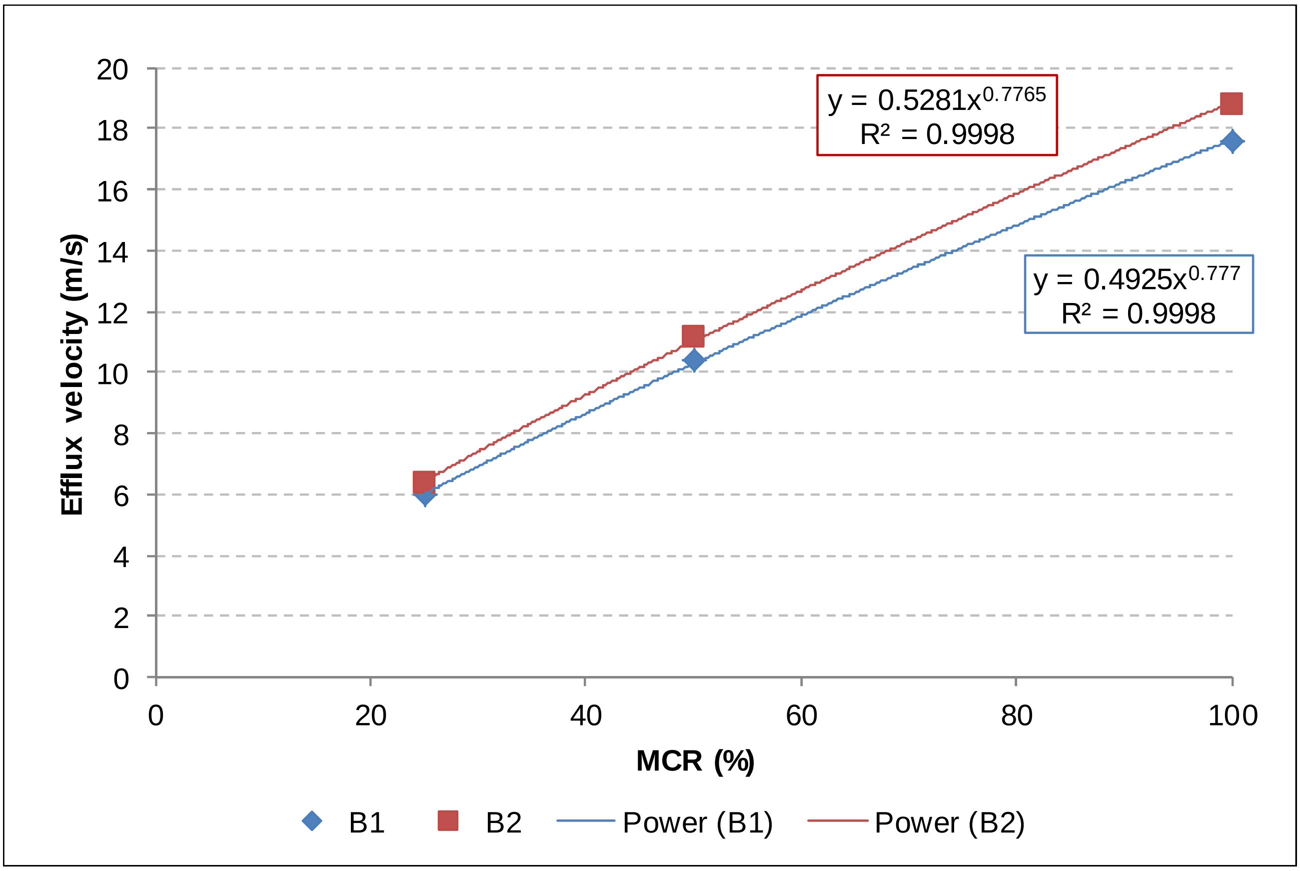

Figure 7: Relationship between MCR and efflux velocity for CFB No.1 (B1) and CFB No. 2 (B2).

4.2 Emission Rates

The emission rates for each of the boilers is based on directly scaling the maximum emission rate by the operational rate. For example, if the boiler is operating at 75 % MCR, then the emission rate will be 75 % of the maximum emission rate. The maximum emission rates are given in Table 3 and discussed in the main body of the report. These emission rates are scaled for each hour of the hourly varying emissions file and the envelope emissions.

Table 3: Summary of maximum emission rates for the boilers.

Contaminants	Emission rate (g/s)	
	CFB No.1 – B&W	**CFB No.2 - FW**
SO_2	13.35	8.44
NO_x	5.82	3.68
PM_{10}	3.66	2.31
TSP	5.48	3.47
Lead	1.45×10^{-4}	9.14×10^{-5}
Arsenic	6.56×10^{-4}	4.14×10^{-4}
Cadmium	4.31×10^{-5}	2.72×10^{-5}
Chromium VI	2.97×10^{-4}	1.88×10^{-4}
Chromium metal and Chromium III		
Mercury	1.21×10^{-4}	7.62×10^{-5}
Dioxin and Furans	259 pg I-TEQ/s	164 pg I-TEQ/s

5.0 SUMMARY

This appendix has outlined the development of the hourly varying and envelope emissions profiles for the CALPUFF modelling for the two coal-fired boilers located at Alliance Lorneville. Operational rate of the boilers is based on steam data measured from 23/11/2013 to 22/11/2014, which is expected to reflect future steam use at the plant. Emission rates and efflux velocities vary based on the operational rate of the boilers.

APPENDIX H

Ambient and stack test monitoring results

1.0 AMBIENT MONITORING

1.1 Overview

Two ambient monitoring programmes were carried out in the vicinity of the Alliance Lorneville site during the following periods:

- First ambient monitoring: from 31 January to 21 May 2014, including SO_2 and PM_{10} concentrations.
- Second ambient monitoring: from 19 December 2014 to 17 March 2015[1], including two sub-periods:
  - PM_{10} concentrations measured from 19 December 2014 to 16 February 2015; and
  - $PM_{2.5}$ concentrations measured from 17 February to 17 March 2015.

Both ambient monitoring programmes were carried out at the location shown in Figure 1. The monitoring site (orange cross) was located on the property of a private householder at 237 Steel Road, Lorneville, approximately 650 metres east of the Alliance boiler stacks (the house is marked by a blue cross). This location was chosen as it was predicted by the preliminary dispersion modelling to be the highest impacted dwelling with respect to PM_{10} and SO_2 concentrations.

The equipment was installed and operated by Watercare Services Limited (Watercare) for both programmes.

The first ambient monitoring programme used continuous SO_2 and PM_{10} analysers which were housed in an air-conditioned room, with the sampling height of pollutants being 3 m above ground. Ambient SO_2 was measured in accordance with AS 3580.4.1:2008 'Determination of sulfur dioxide - Direct reading instrumental method', using an Ecotech EC 9850 monitor. The PM_{10} was measured in accordance with AS/NZ 3580.9.11:2008 'Determination of suspended particulate matter - PM_{10} beta attenuation monitors' using a Thermo Series FH62-C14 Beta Attenuation Monitor (BAM). The monitoring programme also included the meteorological parameters of wind speed and direction (6 m above ground level), temperature and relative humidity.

The second ambient monitoring programme used the same type of continuous PM_{10} analyser and concentrations were measured in accordance with the same method as for the first programme. The second monitoring also included meteorological parameters of wind speed and direction, temperature and relative humidity. On 17 February 2015 the PM_{10} monitor was switched to a $PM_{2.5}$ head, providing ambient concentrations of $PM_{2.5}$ from then onwards.

A summary of the results from the ambient monitoring programmes is presented in the next section. A comparison of wind patterns and of steam outputs from Alliance Lorneville's coal fired boilers during the two monitoring periods is also provided below. The discussion of these results is provided in the main report.

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[1] The second ambient monitoring programme was still being carried out during the writing of this appendix, with the expected decommissioning date being the 24 March 2015. Additional ambient monitoring data to the one presented in this appendix (i.e. data from 17 to 24 March 2015) can later be supplied as an addendum upon request.

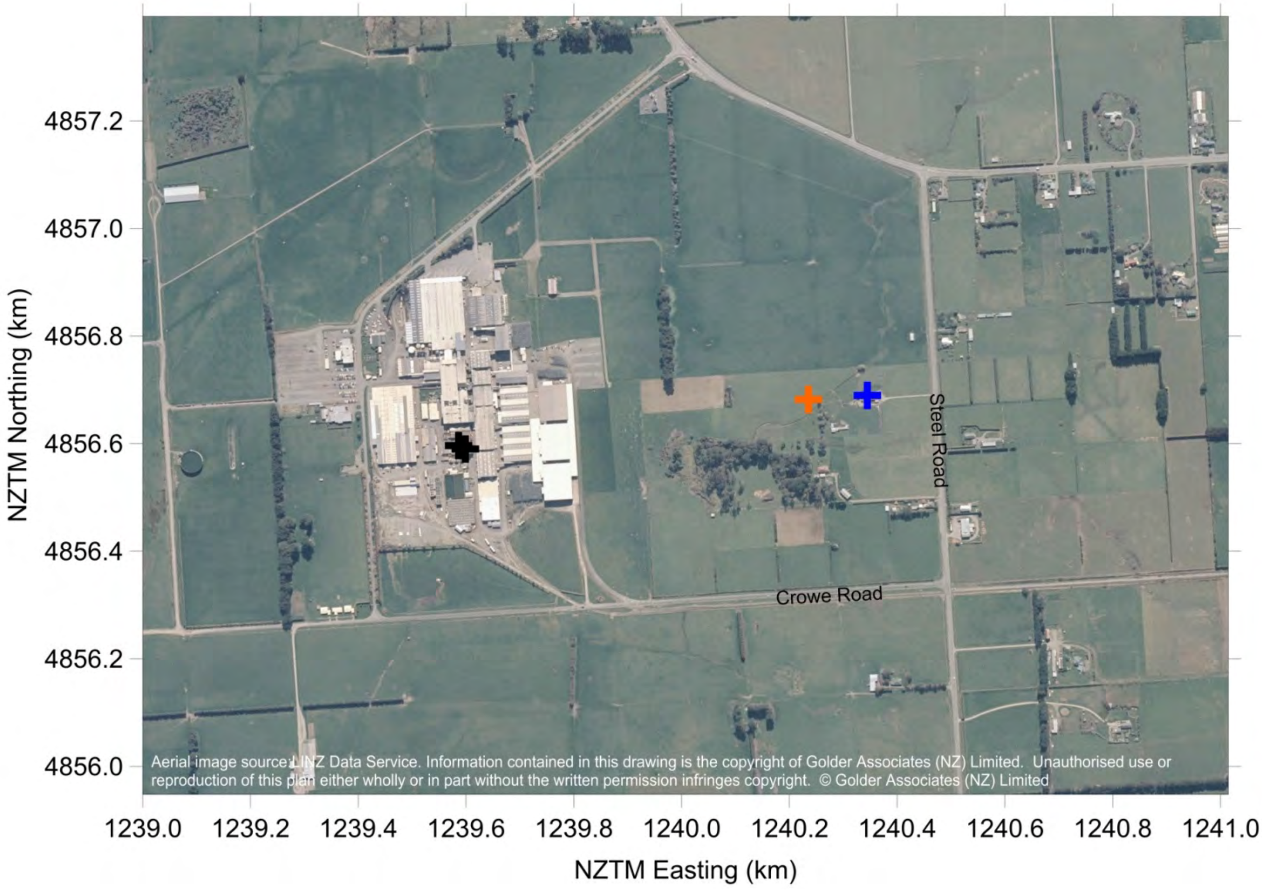


Figure 1: Location of the ambient monitoring site (orange cross), at 237 Steel Road (dwelling marked by a blue cross). The boiler stack locations are indicated by black crosses.

1.2 Results

Summaries of the results from the first ambient monitoring programme, carried from 31 January to 22 May 2014, are provided in Figure 2, Figure 3 and Figure 4. A summary of the results from the second ambient monitoring programme, carried from 19 December to 17 March 2015, is provided in Figure 5.

Scatter plots of the pollutants concentrations versus the measured wind direction (1-hour averages) are provided in Figure 6 and in Figure 7 for the first and second monitoring programmes, respectively.

A comparison of different percentiles of 10-minute averaged PM_{10} and $PM_{2.5}$ concentrations is provided in Table 2 with the respective ratios of $PM_{10}/PM_{2.5}$ for each range.

It is noted that, for the second ambient monitoring programme, the results presented in the graphs below up to 16 February 2015 are based on data that was quality assured by Watercare, while the results from 17 February 2015 onwards is based on raw data. Given the type of equipment and previous data sets of raw data versus quality assured data, it is not expected that raw data from 17 February 2015 onwards would have any significant changes as a result of the quality assurance process.

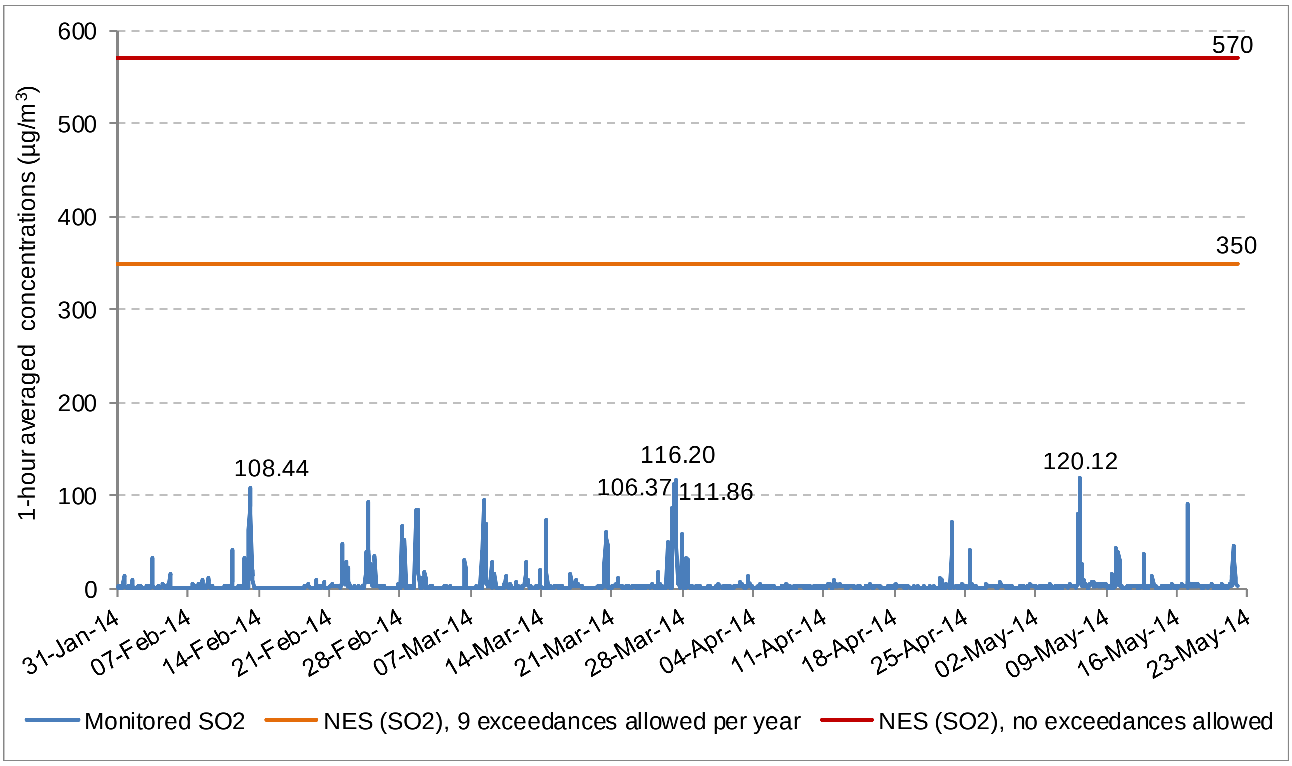


Figure 2: 1-hour averaged SO_2 concentrations monitored from 31/01/2014 to 21/05/2014.

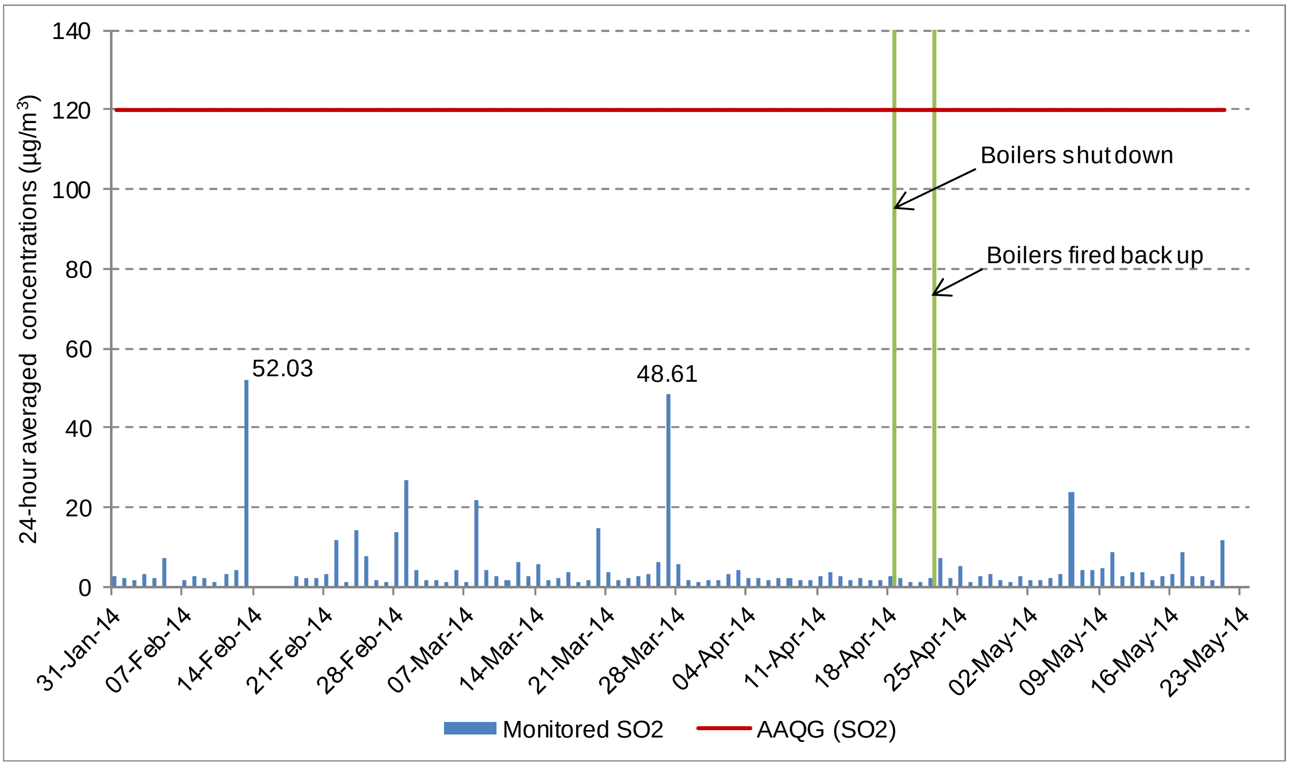


Figure 3: 24-hour averaged SO_2 concentrations monitored from 31/01/2014 to 21/05/2014.

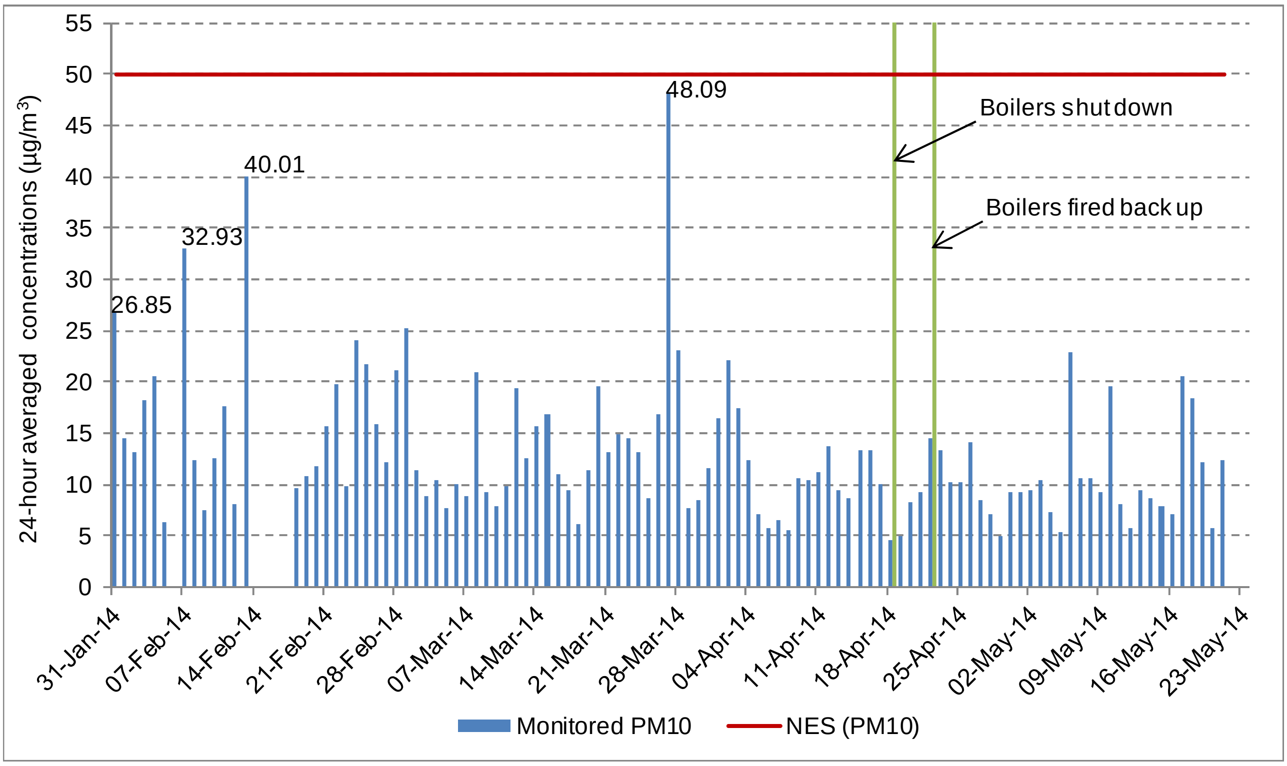


Figure 4: 24-hour averaged PM_{10} concentrations monitored from 31/01/2014 to 21/05/2014.

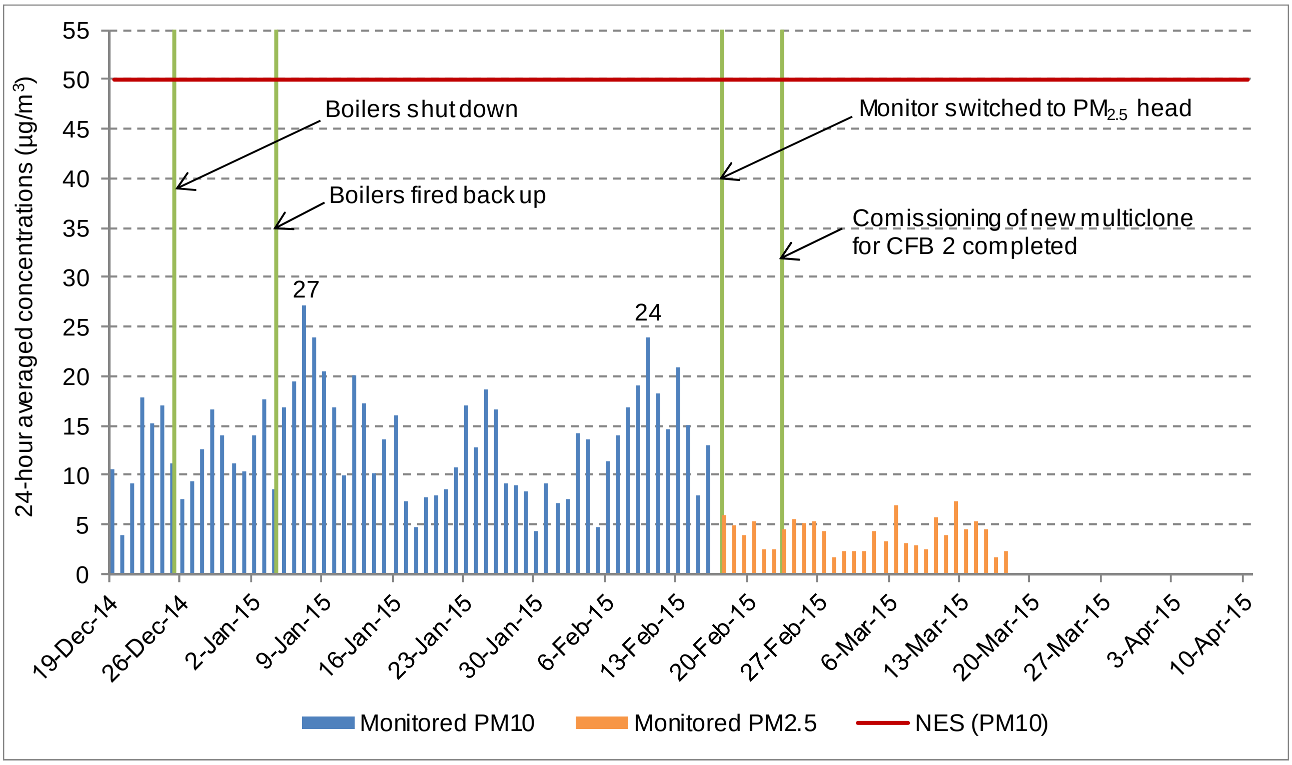


Figure 5: 24-hour averaged PM_{10} and $PM_{2.5}$ concentrations monitored from 19/12/2014 to 17/03/2015.

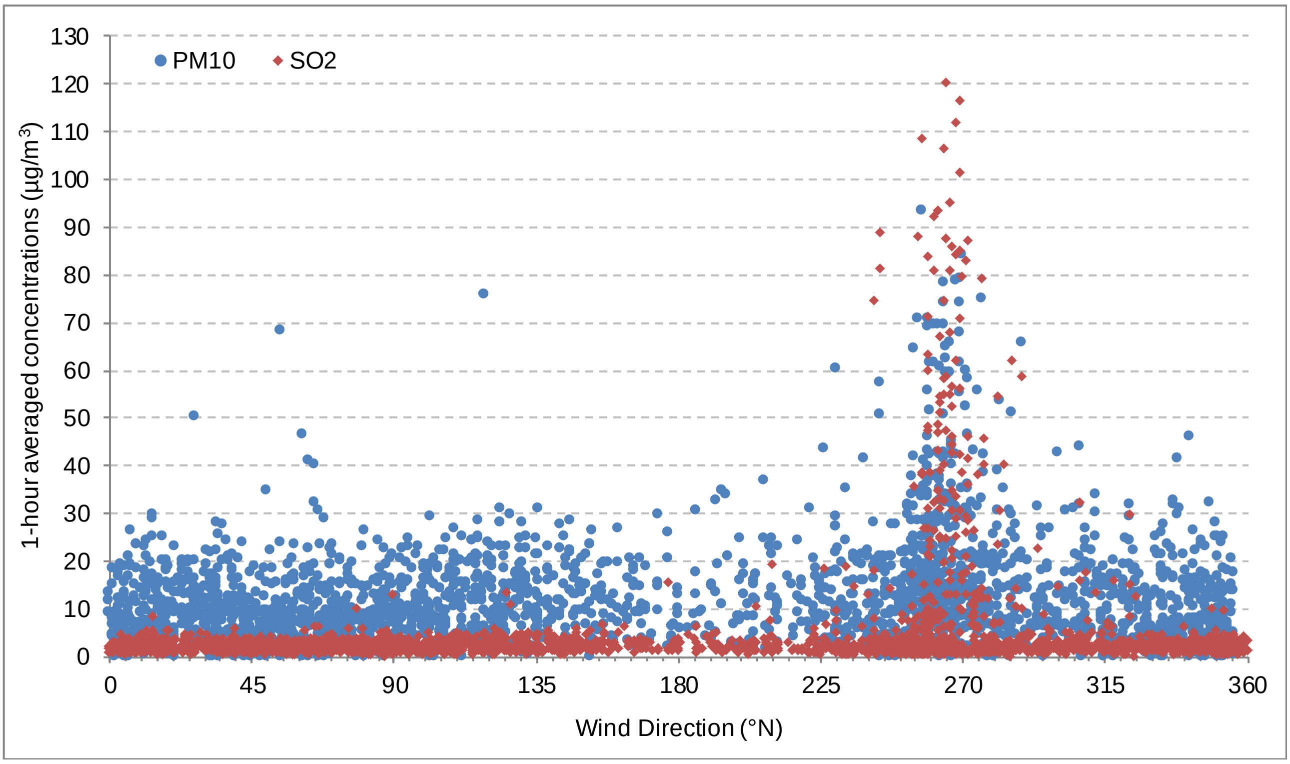


Figure 6: 1-hour averaged PM_{10} and SO_2 concentrations versus wind direction, monitored from 31/01/2014 to 21/05/2014.

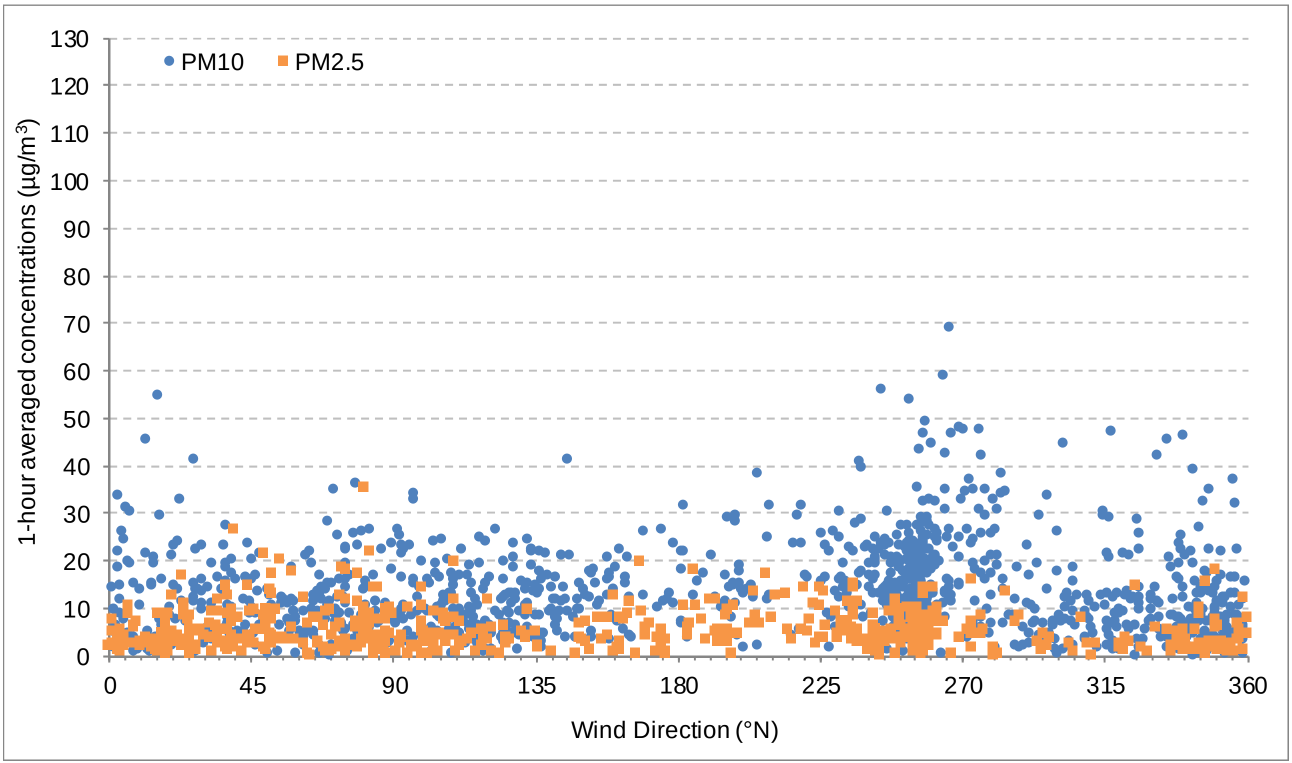


Figure 7: 1-hour averaged PM_{10} and $PM_{2.5}$ concentrations versus wind direction, monitored from 19/12/2014 to 17/03/2015.

Table 1: Statistical summary and ratios of 10-minute averaged PM_{10} and $PM_{2.5}$ concentrations monitored from 19/12/2014 to 17/03/2015.

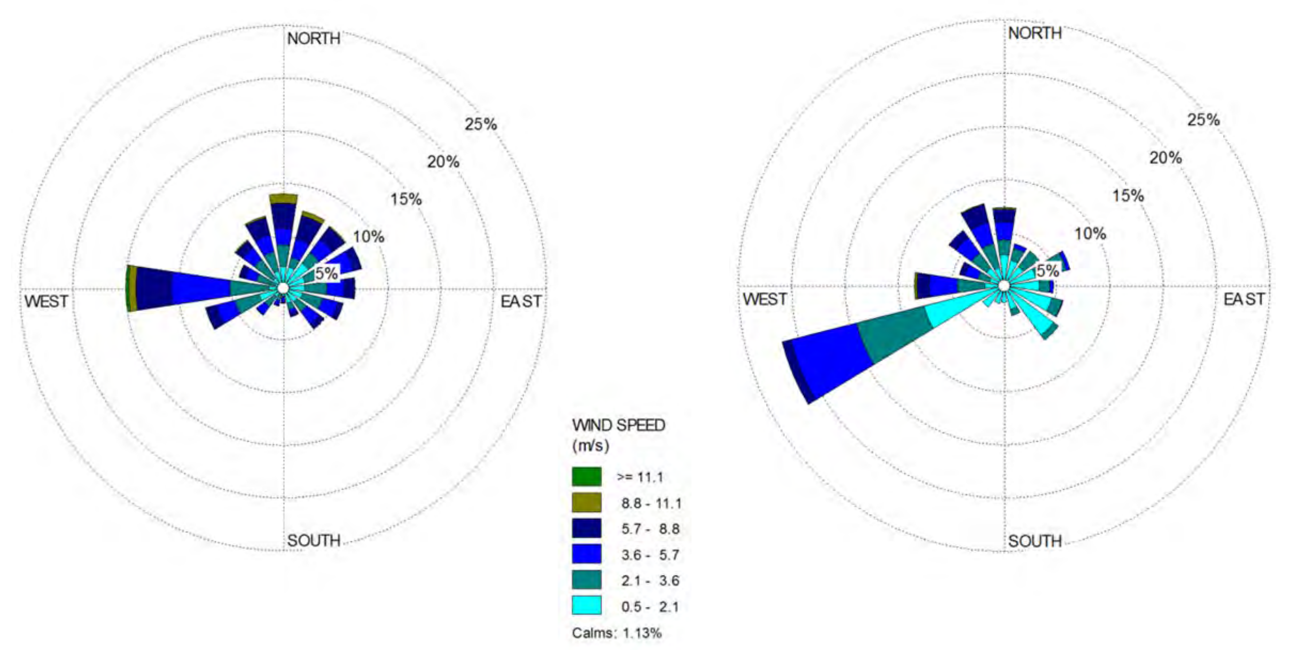
Statistical summary	10-minute averaged concentrations (µg/m^3)		Ratio $PM_{10}/PM_{2.5}$
	PM_{10}	$PM_{2.5}$	
Maximum	104.1	55.3	1.9
99th percentile	47.6	21.6	2.2
95th percentile	30.5	14.5	2.1
90th percentile	25.5	11.6	2.2
Average	13.1	4.0	3.3
40th percentile	9.9	2.2	4.5
30th percentile	7.6	0.8	9.1
20th percentile	5.2	0.0	

1.3 Comparison of wind patterns and steam outputs

Wind patterns and combined steam outputs from Alliance Lorneville's coal fired boilers (CFBs) during the two monitoring periods has been considered. These are intended to enable an analysis of possible factors that may or may not have influenced the PM_{10} concentrations measured during the two ambient monitoring programmes.

Windroses for both ambient monitoring periods are provided in Figure 8 and indicate that the percentage of winds blowing boiler emissions towards the monitoring location (i.e. westerly winds) was significantly higher in the first monitoring period. It is unclear whether this is due to the shorter timeframe and only earlier summer timeframe of the second monitoring period, or whether the wind direction measurements are offset by some degree. It is difficult to be certain without SO_2 concentration measurements, but when Figure 7 is compared to Figure 6 there appears to be a slight difference in the wind direction that the peak PM_{10} concentrations are associated with. Given the monitoring location hasn't changed, this would suggest that the wind direction measurements from the second monitoring period are slightly offset and in reality there may have been a similar level of westerlies as the previous monitoring period. This could be confirmed with Invercargill Airport meteorological data if necessary.

The different ranges (i.e. percentiles) of boilers steam output during each monitoring period are also provided in Table 2. This comparison indicates that, although steam outputs were slightly higher during the first ambient monitoring, they are generally consistent with steam outputs during the second ambient monitoring. The minor variances between these steam outputs are not likely to have had any significant influence in the differences between PM_{10} concentrations for these two periods.



(a) First ambient monitoring of PM$_{10}$, 31 January to 21 May 2014

(b) Second ambient monitoring of PM$_{10}$, 19 December 2014 to 17 February 2015

Figure 8: Wind Roses for the ambient monitoring site.

Table 2: Statistical summary of the CFBs combined steam outputs during the first and second periods of ambient monitoring of PM$_{10}$ concentrations.

Statistical summary	Combined steam output at 8bar (t/h)	
	31 January to 21 May 2014	19 December 2014 to 17 February 2015
Maximum	45	40
90th percentile	38	36
70th percentile	35	33
50th percentile	32	30
Average	28	24

2.0 STACK TEST MONITORING

A summary of the test results for TSP and PM$_{10}$ concentrations measured at the stacks of CFB 1 and CFB 2 in the last five years is provided in Table 3 and in Figure 9 below. Table 4 summarises the stack test results for condensable particulate matter that was carried out in March 2014.

Table 3: Summary of stack test Results for TSP and PM_{10} concentrations in the last five years.

Date	TSP[†] mg/dsm^3 @ 12% CO_2		PM_{10}[‡] mg/dsm^3 @ 12% CO_2	
	CFB 1	**CFB 1**	**CFB 1**	**CFB 2**
Feb-10	528	950		797
Jan-11	533	736		
Dec-11	322	626	240	232
Dec-12	437	694	385	588
Mar-14	382	579	286	362
Post commissioning of a new multi-clone grit arrestor on CFB 2:				
Feb-15	341	318	269	214

[†] Test methodology: ISO 9096:2003(E): Stationary source emissions - Determination of concentration and mass flow rate of particulate material in gas-carrying duct. Manual gravimetric method.

[‡] Test methodology: USEPA Method 201A – Determination of PM10 Emissions (Constant Sampling Rate Procedure).

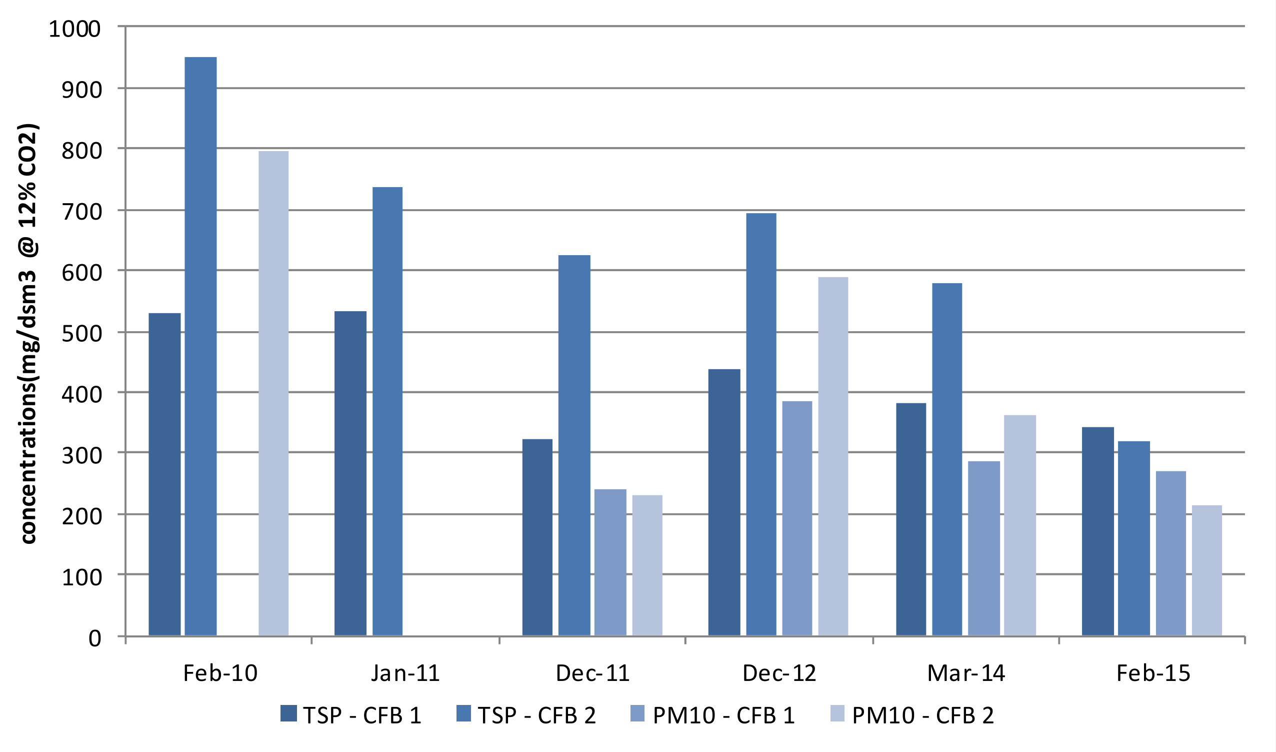


Figure 9: Summary of stack test results for TSP and PM_{10} concentrations measured in the last five years.

Table 4: Summary of stack test results for Condensable Particulate Matter in March 2014.

Results*	**CFB 1**	**CFB 2**
Concentration of filterable PM corrected to 12 % CO_2 (mg/dsm^3)	395	625
Concentration of condensable PM corrected to 12 % CO_2 (mg/dsm^3)	51	75
Percentage of total particulate that is condensable particulate matter (%)	11	11

* Test methodology: Modified USEPA Method 202 (Dry Impinger Method for Determining Condensable Particulate Emissions from Stationary Sources).

APPENDIX I

Back Calculation of SO_2 and PM_{10} emissions

1.0 INTRODUCTION

This appendix provides an independent assessment of actual sulfur dioxide (SO_2) and respirable particulate (PM_{10}) emissions from the coal-fired boilers that are operated at the Alliance Group Ltd's (Alliance) meat processing site at Lorneville, Invercargill. The dispersion modelling system described in the main body of this report was utilised in combination with summer/autumn 2014 ambient monitoring data that is discussed in the previous Appendix H.

An analysis of the monitored ambient concentrations versus the preliminary modelled SO_2 and PM_{10} concentrations was undertaken. This was used to estimate the actual SO_2 and PM_{10} emissions that occurred during the 2014 ambient monitoring period. This combined approach involved the following steps:

1) Atmospheric modelling was used to predict initial spatial patterns based on predicted site operation with plant changes (new rendering etc.). Estimates of emission assumptions were also used.
2) Ambient monitoring site was located to confirm predicted concentrations.
3) After analysis of modelling and monitoring data, assumptions of SO_2 and PM_{10} emissions were adjusted.

The sections below provide details about the ambient monitoring, the boiler discharge modelling and how data from each were analysed and compared in order to adjust assumptions of SO_2 and PM_{10} emissions.

2.0 AMBIENT MONITORING DATA

The summer/autumn 2014 ambient monitoring data was collected from 31 January 2014 to 21 May 2014 as described in Appendix H of the main report. The location of the site with respect to the boiler stacks is shown in Figure 1. The monitoring site was approximately 650 metres east of the Alliance boiler stacks (the house is marked by a blue cross). The off-site ambient monitoring location was situated within the general area where the dispersion modelling assessment predicted the occurrence of the highest off-site air quality impacts due to emissions into the atmosphere from Alliance's coal-fired boiler operations. The monitoring also included monitoring of wind speed and direction, with a resulting time series data set of 10 minute average values. This was undertaken in parallel with the collation of 10 minute average steam production data for the two site coal-fired boilers.

3.0 BOILER DISCHARGE MODELLING

3.1 Boiler stack emissions

Boiler stack SO_2 and PM_{10} discharges to air were modelled as detailed in the main report to which this appendix is attached and referenced. The only differences were that for the preliminary modelling used in this assessment (back calculation of emissions) the nominal emission rates were assumed as presented in Table 1, and the boilers output profile was based on different steam data. Details about the boilers output information are provided in the next section.

Table 1: Preliminary boiler stack emission rate assumptions for SO_2 and PM_{10}.

Contaminant	Stack Concentration (mg/Nm³ 12vol% CO_2 dry)	Maximum Rate (g/s)	Maximum Rate (kg/hr)
SO_2	1375 (CFB1)	19.1	68.7
	1375 (CFB2)	12.1	43.4
PM_{10}	250 (CFB1)	3.1	11.2
	250 (CFB2)	1.9	6.8

3.2 Boilers output information

For the preliminary modelling used in this back calculation assessment, the time series set of steam data was obtained for the 2012/2013 season and was augmented to allow for projected increases in steam demand for rendering. This steam profile was used to vary boiler emission rates so to match a realistic daily and longer term boiler plant output pattern.

It is noted that the steam output profile used in the modelling presented in the main report is based on updated steam data that was measured from 23/Nov/2013 to 23/Nov/2015. However, the subsequent update of the steam output profile does not affect the comparisons that are made in this back calculation assessment.

The relevant steam output profiles for the back calculation, which involves comparison between monitored and modelled ambient concentrations, are the steam outputs that were actually measured during the monitoring period and the steam output considered in the preliminary model that is being compared. The comparison between these two steam output profiles is presented and discussed later in this document.

3.3 Meteorological data

The same meteorological data set that is used for the main boiler discharge assessment modelling was also used for this assessment.

Figure 1: Location of the ambient monitoring site (orange cross), at 237 Steel Road (dwelling marked by a blue cross). The boiler stack locations are indicated by black crosses.

4.0 ANALYSIS OF MONITORED AND MODELLED DATA

4.1 Overview

An analysis of the monitored ambient concentrations versus the modelled SO_2 and PM_{10} concentrations was undertaken when assuming the emission assumptions listed in Table 1 above. This was used to estimate the actual SO_2 and PM_{10} emissions that occurred during the 2014 ambient monitoring period.

The main characteristics of the data sets used for this analysis and for estimation of real contaminant emissions are described below:

- **Monitored data set**

  Period: 31 January 2014 – 21 May 2014.

  Location: (1240.240, 4856.670) (eastings and northings in kilometres (km), New Zealand Transverse Mercator coordinates (NZTM)).

  Parameters used: ambient SO_2 and PM_{10} concentrations (in µg/m^3) and wind direction (bearing in degrees from true north, (^{o}N)).

  Time averages used: 10-minute and 1-hour.

- **Modelled data set**

  Period (of model run, based on meteorological data input): 1 January 2010 – 31 December 2011.

  Location (of gridded receptor where data were extracted from model): (1240.250, 4856.700) (eastings and northings in km, NZTM).

  Parameters used: SO_2 and PM_{10} ground level concentrations (GLCs) (in µg/m^3) and wind direction (^{o}N).

  Time averages used: 1-hour.

4.2 Wind Direction Adjustments

The SO_2 and PM_{10} concentrations used correspond to the reported quality assured values however the raw wind direction data that was corrected by applying an offset to reported values so that the spike in measured SO_2 concentrations occurred for wind directions that placed the ambient monitoring site downwind of the boiler stacks. A plot of concentration against wind direction is shown in Figure 2, after the offset has been applied, which correlates with the well-defined spike in concentrations under westerly winds.

4.3 Construction of Downwind and Background Time Series

For the comparison of monitored and the modelled concentration data at the monitoring site location, were created when the monitoring site location for both monitored and modelled data was downwind of the boilers stacks. A “background” subset of monitoring data was also created for the opposite situation, that is, when the monitoring site was not downwind of the boiler stacks. The following steps were taken to create these subsets:

1) **Definition of “downwind” direction range**: Assess the direction of the monitoring site from the boiler stacks using the plots of PM_{10} and SO_2 concentrations versus wind direction (such as that shown in Figure 2), replicating the approach for both monitoring data and modelling data. The direction ranges were evaluated as follows:

Monitored data set downwind direction range: 261 °N – 271 °N.

Modelled data set downwind direction range: 253 °N – 263 °N.

The modelling data set indicated a slightly different downwind direction from the actual downwind direction. This is due to (i) the difference in locations between monitoring site and the nearest model grid point (around 30 m), and (ii) the difference between the true compass direction and the direction in NZTM (just over 3 degrees at Invercargill). For this reason it was important to select downwind direction ranges that best fitted the monitoring and modelling data spikes separately.

2) **Construction of downwind time series:** New time series were created for each data set (10-minute and 1-hour averaged monitored data, and 1-hour averaged modelled data) by filtering PM_{10} and SO_2 concentrations for when the wind direction was within the respective downwind direction range of each data set.

Following the initial filtering of the data set for direction, the modelling data set was further filtered to only retain modelling data for the same months of the year that the 2014 ambient monitoring was undertaken.

3) **Construction of "background" time series:** A time series of background PM_{10} and SO_2 monitoring data was established from observations of wind directions in the non-downwind ranges 0 °N – 254 °N or 278 °N – 360 °N. The monitored "background" time series was then created by filtering the concentrations when wind direction was in the non-downwind range of the monitored data set. For the purpose of a cross-check, a second "background" time series was created by filtering the monitored data set for wind within the downwind range, but at times when there was no steam production from the boilers (based on measured steam production from the same period). The statistics of this data set (the concentrations at a range of percentile levels) were similar to the first background time series.

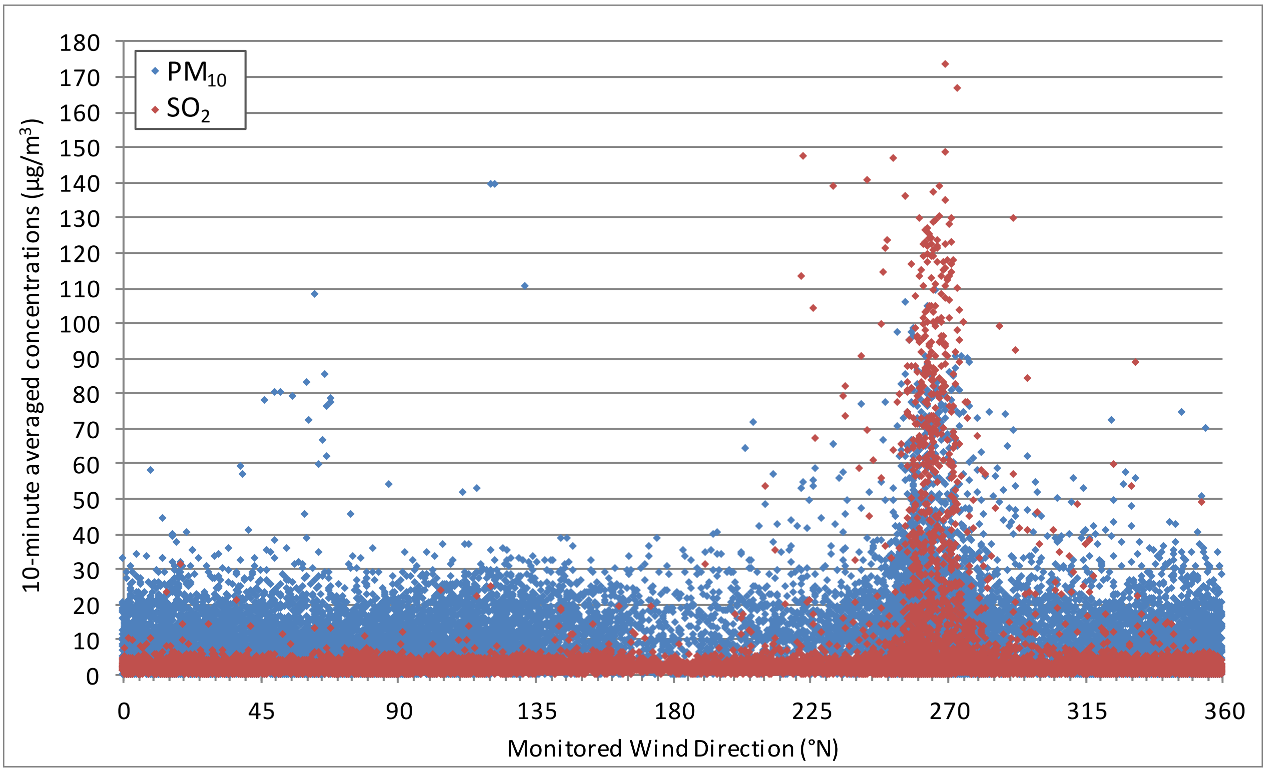


Figure 2: Monitored 10-minute averaged ambient concentrations versus wind direction, from 31 January to 21 May 2014.

4.4 Comparison of Steam Production during Monitoring and Modelling Periods

The steam production rates assumed for modelling predictions of contaminant impacts would differ from those which actually occurred during the monitoring period, and would bias the comparison of respective SO_2 and PM_{10} concentrations resulting from the modelling and monitoring exercises. To assess the effect the assumed and actual steam output distributions were compared. The resulting steam production histograms are shown in Figure 3, which exhibit a reasonable match, although there are some differences. These differences in steam production rates shown in Figure 3 will produce some error (estimated to add approximately 10%) for the assessment of actual SO_2 and PM_{10} emissions from the coal-fired boilers.

4.5 Comparison of Meteorology during Monitoring and Modelling Periods

An additional factor that could have biased the ratio of modelled to monitored concentrations is if there were a significant difference between the modelled meteorology from 2010 and 2011 and the monitored meteorology during 2014. In particular there may be differences in wind strength and other boundary-layer characteristics when the boiler stacks are upwind of the monitoring site.

A comparison of the wind roses from the Invercargill Airport meteorological station during the modelled meteorological period (2010-2011) and for the ambient monitoring period (in 2014) are shown in Figure 4. Westerly wind speed frequencies are further highlighted in Figure 5. The graphs indicate that the distribution of speeds for winds blowing boiler emissions towards the monitoring location (i.e. westerly winds) were very consistent between the modelling and monitoring periods.

Given the above, then meteorology assumptions for the modelling and monitoring periods were not likely to cause significant bias between monitoring and modelling predictions of SO_2 and PM_{10} concentrations.

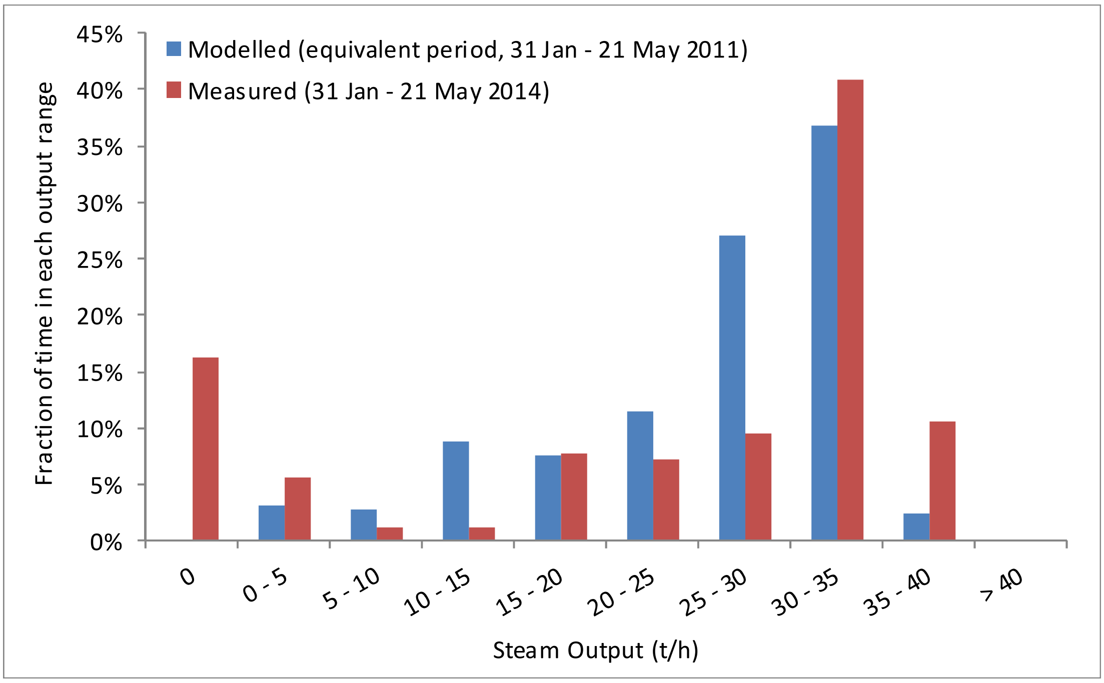
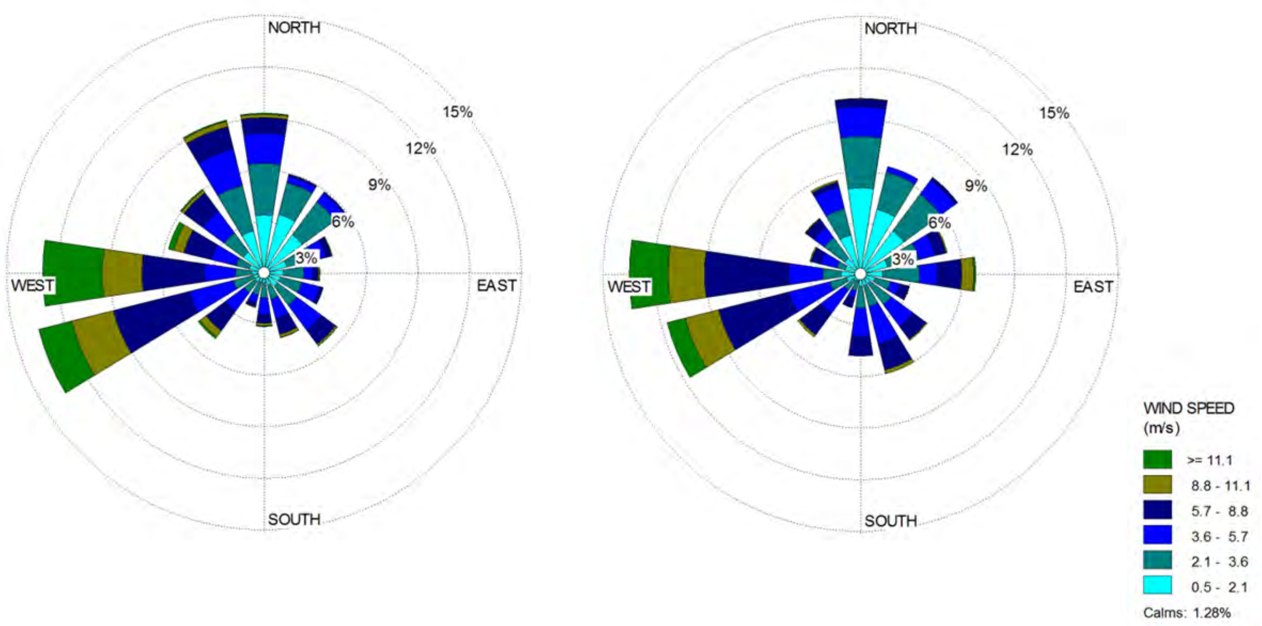


Figure 3: Combined steam output from Boilers 1 and 2 (for February-May) for monitored and modelled data sets, filtered for hours of wind direction in the downwind range.



(a) (b)

Figure 4: Wind roses for Invercargill Airport meteorological station. (a) Period from 1 January 2010 to 31 December 2011. (b) Period from 31 January 2014 to 21 May 2014.

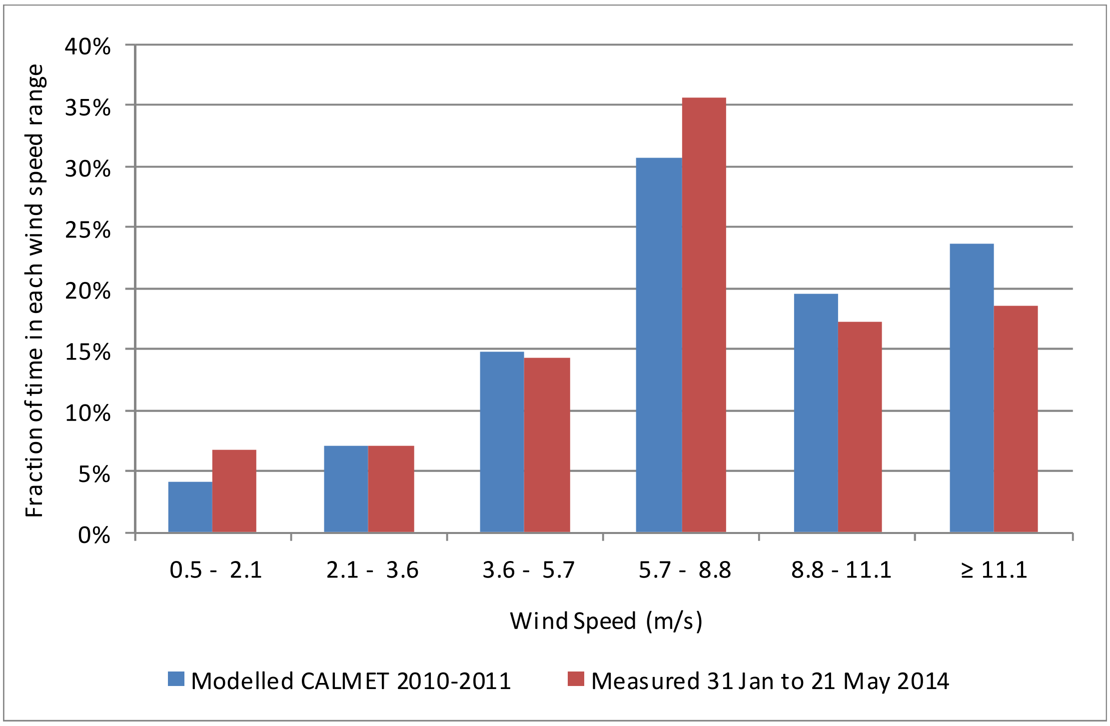


Figure 5: Distribution of wind speed categories for the Invercargill Airport location, filtered for wind directions within the downwind ranges defined for the monitored and modelled data sets.

4.6 Statistical Summaries of Monitored and Modelled Data in the Downwind Direction Range

Statistical summaries were completed for each set of modelled and monitored 1-hour average contaminant concentrations to compare impacts downwind of the operational boilers. The summaries are contained in Table 2, of which the final column [E] provides estimates of the ratio between measured concentrations due to the boiler emissions and those predicted. Note that the measured values in column [D] are estimates themselves as they are a result of the actual measured percentile downwind concentration minus the same percentile background concentration.

The subtraction of background monitoring results from downwind monitoring data (column [D] in Table 2) was undertaken to provide estimates of the actual boiler contaminant impact (in µg/m^3) for comparison with the modelled impact (µg/m^3) for a range of measured percentile concentrations at the monitoring site. This approach is considered most valid as it is anticipated that high measured values are more likely to be associated with higher background concentrations and vice versa. Conversely, it is clear that an estimate of the true impact from the boiler stacks by subtracting the average background concentration from a low percentile measured value (that is, using *different* percentile levels) would produce an erroneous result.

The upper percentile ratios of monitored to modelled SO_2 impacts in Table 2 (column [E]) for SO_2 indicate a closer match than similar ratios for PM_{10}. This is probably an artefact of the monitored SO_2 upper percentile values being less influenced by variable and high background levels, as in the case for PM_{10}. As the ratio for SO_2 estimated from the 75th, 85th and 95th percentiles is around 0.7, a 30 % over prediction of SO_2 is inferred, due to a 30 % over-estimate of emission rates in the modelling.

The lower to mid-range percentile ratios of in Table 2 for PM_{10} indicate a close match between modelled and monitored concentrations. The 95th percentile monitored values may well be overstated by a higher frequency of the maximum operating capacity associated with the monitoring results (see Figure 3). On average, the ratios for PM_{10} (apart from the 85th and 95th percentiles) equates to 1.5. Therefore a 50% under-estimate of PM_{10} emission rates is inferred.

Table 2: Statistical summaries of monitored (1-hour average) and modelled (1-hour average) contaminant concentrations (in µg/m^3). The downwind monitored data minus non-downwind background monitored data estimates the contribution from the stacks for comparison with model results.

Contaminant	Percentile	Downwind monitored data [A]	Non-downwind background monitored data [B]	Model results [C]	Downwind minus non-downwind background monitored data [D] = [A] – [B]	Ratio of monitored to modelled impacts [E] = [D]/[C]
PM_{10} (µg/m^3)	20th	9.2	4.6	2.5	4.6	1.8
	30th	11.7	6.2	3.7	5.5	1.5
	50th	15.6	9.5	5.7	6.1	1.1
	75th	31.0	15.3	9.6	15.7	1.6
	85th	42.2	18.8	10.8	23.4	2.2
	95th	66.4	24.8	15.2	41.6	2.7
SO_2 (µg/m^3)	20th	1.2	1.2	15.8	0	0
	30th	1.5	1.5	22.9	0	0
	50th	1.5	2.0	35.0	0.5	0
	75th	31.6	2.9	59.1	29	0.5
	85th	52.6	3.4	66.6	49	0.7
	95th	85.3	4.7	93.9	80.6	0.9

4.7 Estimation of Actual Contaminant Emissions

The difference between the modelled and monitored SO_2 and PM_{10} concentrations as summarised in Table 2 are considered to have been mainly of the bias between the actual emission SO_2 and PM_{10} and those assumed by the dispersion model set-up. There will be some errors inherent in the model itself, but they are likely to be minimised by the consideration of concentration statistics and therefore should only make a small contribution to biases in predictions that model emission rate assumptions cause.

The following key points summarise the modelling and monitoring comparison:

- Actual boiler PM_{10} emissions during the 2014 monitoring programme were approximately 50 % higher than that assumed (total of 18 kg/hr) for the preliminary modelling (see Table 1) and equating to stack concentrations of 250 mg/Nm^3 (corrected to 12 vol. % CO_2 and dry basis). Therefore the back-calculation assessment indicates the actual PM_{10} emissions to be 27 kg/hr and equating to a flow weight average concentration of 375 mg/Nm^3. The error associated with this estimate would be in the order of ± 20 %.

- Actual boiler SO_2 emissions during the 2014 monitoring programme were approximately 30 % lower than those assumed (total of 112 kg/hr) for the preliminary modelling (see Table 1). This equates to approximately 78 kg/hr. Because of the low background SO_2 levels and subsequently low influence of this upon the assessment error then the estimated error would be in the order of ± 10 % or less.

- The background ambient 24-hour average PM_{10} concentration was typically 15 $\mu g/m^3$.

- The annual average PM_{10} is estimated to be 10 $\mu g/m^3$ or less.

- The 1-hour and 24-hour average SO_2 were typically 5 $\mu g/m^3$ or less.

- An annual-average background SO_2 background concentration of 3.0 $\mu g/m^3$ was estimated.

APPENDIX J

Soil Metal Concentrations

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ALLIANCE GROUP LTD, LORNEVILLE PLANT

SOIL HEAVY METAL CONCENTRATIONS

Prepared for

Alliance Group Ltd, Lorneville Plant
Invercargill
New Zealand

By Dr P. B. Greenwood

October 2014

1 INTRODUCTION

To assist in current reconsenting of coal-fired boiler discharges to air, Alliance Group Ltd commissioned Soilwork to conduct a single assessment of concentrations of heavy metals in soils near the boiler and also in areas considered to have been unaffected by any boiler discharges. This brief report summarises that assessment conducted in September 2014.

2 METHODOLOGY

For this work, six individual soil sampling transects and two sampling depths were used. Three of the sampling sites (Sites 1-3) were located near the boiler and within areas reported by Golder Associates Ltd to be potentially most affected by long-term depositions of heavy metals. The remaining three sites (Sites 4-6) were located as far as possible upwind from the boiler but on the same farm and soil type (Waikiwi silt loam). Locations of the six sampling sites are shown in Figure 2.1.

Figure 2.1:
Map of relative boiler air discharge concentrations and soil sampling sites. (Map of site and boiler discharges is from Golder Associates Ltd).

In terms of potential historic depositions of heavy metals from the boiler, Site 1 is considered to be within an area potentially most affected, whilst Sites 2 and 3 are in areas progressively less affected. Sites 4-6 are considered to have been unaffected by previous boiler discharges.

For the soil sampling, soil cores were collected from the 0-7.5 cm and 7.5-15.0 cm soil depths on 28 September 2014 at regular distances along transects across each of the six sampling sites (individual paddocks). For each sample, approximately 25 soil cores were collected.

Heavy metal analyses were conducted by Hill Laboratories.

3 SOIL ANALYSES AND CONCLUSIONS

Results of the soil analyses are presented in Table 3.1, and this data shows that soil concentrations of arsenic at Sites 1-3 ('affected' sites) are not noticeably different from values recorded at the control sites (Sites 4-6) or from the average value for those latter sites. For cadmium, the average control soil concentration (0.24 mg/kg) is slightly higher than recorded for the 'affected' sites (0.20-0.22 mg/kg), and this is attributed to higher superphosphate inputs to the control sites.

For all of the other heavy metals tested, soil concentrations at the 'affected' sites, particularly Sites 1 and 2 that are closest to the boiler stack, are higher than average concentrations in the control areas. For chromium, copper, lead, nickel, and zinc, average values within the 0-15 cm soil depth at Sites 1-3 (with average values for the control sites in brackets) are 26 mg/kg (20 mg/kg), 16 mg/kg (12 mg/kg), 11.2 mg/kg (8.4 mg/kg), 13 mg/kg (10 mg/kg), and 65 mg/kg (49 mg/kg) respectively. Of the three paddocks considered to be potentially most affected by boiler discharges, Site 3 is located furthest from the boiler, and soil concentrations of some metals at that site are slightly lower than corresponding average values for Sites 1 and 2. Values for chromium, copper, lead, nickel, and zinc (with average values for Sites 1 and 2 in brackets) are 25 mg/kg (26 mg/kg), 13 mg/kg (17 mg/kg), 11.1 mg/kg (11.3 mg/kg), 12 mg/kg (13 mg/kg), and 57 mg/kg (69 mg/kg) respectively.

Thus, for chromium, copper, lead, nickel, and zinc, it appears that historic air discharges from the boiler over a period of approximately 55 years have resulted in minor increases in soil concentrations within the three sampling paddocks (Sites 1-3) that, based on emissions to air, are considered to be potentially most affected. For two of those metals (copper and zinc), most of the increase is very localised because values are noticeably lower, and close to control values, in the sampling paddock (Site 3) that is situated only slightly further from the boiler stack than the other two 'affected' sampling paddocks.

For the heavy metals tested in this assessment, however, soil concentrations at all of the Lorneville sampling sites, including sites that appear to have been affected by previous boiler discharges, remain very low. For the sampling site closest to the boiler (Site 1), concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc within the 0-15 cm soil depth are currently 3 mg/kg, 0.22 mg/kg, 27 mg/kg, 17 mg/kg, 11.2 mg/kg, 14 mg/kg, and 71 mg/kg, respectively. These are low values compared with corresponding Ministry for the Environment guidelines (2003) for maximum soil values (0-20 cm depth) of these metals under biosolids applications of 20 mg/kg, 1 mg/kg, 600 mg/kg, 100 mg/kg, 300 mg/kg, 60 mg/kg, and 300 mg/kg. Other guidelines for maximum values are similarly very high compared with current values at Lorneville. For example, in 2001 the Taiwan Environmental Protection Authority reviewed data from Germany, Canada, and Holland, before setting maximum soil concentrations of arsenic, cadmium, chromium, copper, lead, nickel, and zinc at 60 mg/kg, 5 mg/kg, 250 mg/kg, 200 mg/kg, 500 mg/kg, 200 mg/kg, and 600 mg/kg respectively.

Table 3.1:
Results of soil heavy metal analyses, September 2014.

		Total recoverable soil concentrations (mg/kg dry weight)						
Sampling site	**Sampling depth (cm)**	**Arsenic**	**Cadmium**	**Chromium**	**Copper**	**Lead**	**Nickel**	**Zinc**
1	0-7.5	3	0.22	26	17	11.1	13	71
	7.5-15	3	0.22	27	17	11.2	14	70
	Mean (0-15cm)	***3***	***0.22***	***27***	***17***	***11.2***	***14***	***71***
2	0-7.5	3	0.18	25	17	12.1	13	69
	7.5-15	3	0.22	26	17	10.6	12	67
	Mean (0-15cm)	***3***	***0.20***	***26***	***17***	***11.4***	***13***	***68***
3	0-7.5	3	0.20	25	12	11.3	11	55
	7.5-15	3	0.19	25	14	10.9	12	58
	Mean (0-15cm)	***3***	***0.20***	***25***	***13***	***11.1***	***12***	***57***
4	0-7.5	3	0.26	19	11	7.8	9	48
	7.5-15	4	0.26	23	12	9.7	12	51
	Mean (0-15cm)	***4***	***0.26***	***21***	***12***	***8.8***	***11***	***50***
5	0-7.5	3	0.24	18	10	7.1	9	45
	7.5-15	3	0.25	20	9	7.8	9	40
	Mean (0-15cm)	***3***	***0.25***	***19***	***10***	***7.5***	***9***	***43***
6	0-7.5	4	0.23	20	15	8.6	11	57
	7.5-15	4	0.19	19	14	9.1	10	50
	Mean (0-15cm)	***4***	***0.21***	***20***	***15***	***8.9***	***11***	***54***
Control mean (Sites 4-6) (0-15 cm depth)		***4***	***0.24***	***20***	***12***	***8.4***	***10***	***49***
Potentially affected sites mean (Sites 1-3) (0-15 cm depth)		***3***	***0.21***	***26***	***16***	***11.2***	***13***	***65***

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