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PRACTICAL GUIDANCE ON DISPERSION MODELLING

Determining the need for industrial PM10 offsets under the National Environmental Standards for air quality

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REPORT

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Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

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ABBREVIATIONS AND UNITS

AENV	Alberta Environment and Sustainable Resource Development
BPIP	Building Profile Input Programme
EPA	Environment Protection Authority (if Victoria, Australia)
EPA	Environmental Protection Agency (if United States)
GLC	Ground-level concentration
GPG	Good-practice guide
g/s	grams per second
HBRC	Hawke's Bay Regional Council
ISCST	Industrial Source Complex – Short Term
kW	kilowatt
MW	megawatt
MCR	Maximum Continuous Rating
MfE	Ministry for the Environment (New Zealand)
MoE	Ministry of the Environment (Ontario)
$\mu g/m^3$	micrograms per cubic metre
m/s	metres per second
NAQWG	National Air Quality Working Group
NES	National Environmental Standards (for air quality)
NSWDEC	New South Wales Department of Environment and Conservation
NZTM	New Zealand Transverse Mercator
PG	Pasquill-Gifford
PM_{10}	Respirable particles with an aerodynamic diameter less than 10 µm
PRIME	Plume Rise Model Enhancements
USEPA	United States Environmental Protection Agency
UTM	Universal Transverse Mercator

1.0 INTRODUCTION

1.1 Background to the Project

Since 1 September 2012, the National Environment Standards for air quality (NES) have required that “substantial” PM_{10} discharges from an industry in a polluted airshed should be offset by an equivalent reduction in emissions elsewhere in the airshed. The NES define a substantial discharge as one which would lead to off-site 24-hour average ground-level concentrations (GLCs) of PM_{10} greater than 2.5 µg/m^3.

The most common way to predict off-site GLCs is to use dispersion modelling. However, dispersion models typically have a large number of parameters that need to be specified, each of which can affect the output of the model, and in some cases alter the model’s prediction of whether or not the 2.5 µg/m^3 criterion is exceeded.

The National Air Quality Working Group (NAQWG) has identified the need for guidance to ensure that a nationally consistent, robust and transparent method is used to determine whether PM_{10} emissions offsets need to be implemented by the resource consent applicant. Without such guidance, there is a risk that the best choice of model configuration parameters are argued over repeatedly in every regional council across New Zealand, causing unnecessary expense, delay, and uncertainty for consent applicants. There is also a risk that different conclusions will be reached in different regions.

This project aims to provide comprehensive and specific guidance on how the dispersion modelling of two common examples of air discharge permit applications should be undertaken to provide a robust and transparent result which can be confidently compared to the 2.5 µg/m^3 offset criterion. Many of this study’s findings will be applicable to other discharge activities which require modelling as part of a resource consent application.

The following section outlines the NES regulations which pertain to the offsetting of industrial PM_{10} emissions.

1.2 NES Provisions Relating to Emissions Offsets

The Resource Management (National Environmental Standards for Air Quality) Regulations 2004 (the NES) include regulations regarding resource consents for discharges of PM_{10}. In particular, Regulation 17 requires that certain applications must be declined unless other PM_{10} discharges are reduced. Regulation 17 may be summarized as follows:

- Regulation 17(1) requires that a new application for the discharge of PM_{10} must be declined if it would be likely at any time to increase the 24-hour average ground-level concentration (GLC) of PM_{10} by more than 2.5 micrograms per cubic metre (µg/m^3), at any location within a “polluted airshed” other than the site on which the consent would be exercised.
- Regulation 17(2) states that 17(1) does not apply if:
  - The proposed consent is a replacement for one held by the applicant for the same activity at the same site; and
  - The amount and rate of PM_{10} discharged under the new consent are the same or less than under the existing one; and
  - Discharges under the new consent would only occur when they no longer occur under the existing consent.
- Regulation 17(3) states that 17(1) also does not apply if:

- The applicant can reduce the amount of PM_{10} discharged from other sources into the relevant polluted airshed “by the same or a greater amount than the amount likely to be discharged into the relevant airshed by the discharge to be expressly allowed by the proposed consent”; and
- That reduction takes effect within 12 months of granting, and has effect throughout the life of the consent.

In the context of these NES regulations, the word “offset” is commonly used to mean the reduction of PM_{10} emissions from other sources to account for discharges from the site in question. However, the word “reduce” is used in the regulations.

1.3 Structure of the Report

Section 2.0 introduces the dispersion modelling guidance that is already in existence and applicable to dispersion modelling in general. Later sections focus on specific guidance applicable to the emissions offset criterion through the use of two case studies involving industrial combustion sources to which the AUSPLUME dispersion model is applied. Section 3.0 introduces the case studies. Subsequent sections provide guidance on several aspects of dispersion model configuration, each starting with general recommendations, followed by their application to the case studies. Thus Section 4.0 discusses model domains and receptor locations, Section 5.0 discusses stack parameters and PM_{10} emission parameters, Section 6.0 discusses meteorological inputs, and Section 7.0 discusses pollution-dispersion parameter options. Then, Section 8.0 presents the results from the case studies. Section 9.0 summarizes the case-study results and provides some general recommendation regarding modelling practice. Concluding remarks are contained in Section 10.0. Section 11.0 introduces Golder’s report limitations statement. Section 12.0 contains a list of references. Combustion calculations are attached as Appendix A, further meteorological discussion is attached as Appendix B, and the report limitations statement in full is contained in Appendix C.

1.4 Acknowledgements

This report presents the findings from a joint project carried out by the University of Canterbury (UC) and Golder.

The project was funded through the Envirolink Funding Scheme (Ministry of Business, Innovation and Employment) under medium advice grant 1285-HBRC184, applied for by the Hawke’s Bay Regional Council, with funding awarded to UC. Golder was engaged as a subcontractor to carry out a number of the project tasks, and this report has been written in the Golder format, as a deliverable to UC. The report includes work by UC itself (Appendix B), and each of Golder and UC has provided input to the other’s work.

2.0 DISPERSION MODELLING GUIDANCE

2.1 Ministry for the Environment Good-Practice Guides

The Ministry for the Environment (MfE) has produced two good-practice guides (GPGs) that are particularly relevant to this study. These are the *Good Practice Guide for Atmospheric Dispersion Modelling* (MfE 2004), and the *Good Practice Guide for Assessing Discharges to Air from Industry* (MfE 2008).

The aim of the dispersion modelling GPG is to improve consistency and accuracy in modelling in New Zealand. Guidance is provided through a series of recommended protocols which, if followed, should lead to robust and defensible modelling results. The industrial discharges GPG provides guidance on the interpretation of modelling results in relation to the NES. This guide promotes a three-tiered approach to assessments, from simple to complex, and covers all elements of environmental assessment. In doing so it provides comprehensive guidance on the methods available for assessing how air quality can impact both human health and the environment.

The modelling undertaken for this study is based on the guidance provided in both these GPGs (guidance from jurisdictions outside New Zealand has also been consulted, to check consistency of advice, for instance Alberta (AENV 2009, 2012), Ontario (Ontario MoE 2009), New South Wales (NSWDEC 2005) and USEPA Appendix W (EPA 2005)).

The guidance provided in this report is as far as practical consistent with New Zealand and international practice. However, it is important to note that this report focusses on issues specifically related to the PM_{10} criterion for industrial offsets. For instance, as the criterion concentration for individual industries is small (just 5% of the airshed-total NES for PM_{10} of 50 µg/m^3 on the 24-hour average), an initially conservative modelling approach may need to be refined using more realistic emission factors, site details or other parameters.

2.2 Choice of Dispersion Model

In New Zealand there are a number of dispersion models that are commonly used for assessing the impacts of discharges to air from industrial sources. These include AUSPLUME (Lorimer 1990; EPA 2000), CALPUFF (Scire, Strimaitis & Yamartino 1999; TRC 2011), TAPM (Hurley, Physick & Luhar 2005; Luhar & Hurley 2003) and AERMOD (Cimorelli et al. 2004; Venkatram et al. 2001).

The case studies presented for this project use the AUSPLUME dispersion model. Recommendation 3 of the dispersion modelling GPG (MfE 2004) provides guidance on whether a Gaussian-plume model such as AUSPLUME is the most appropriate tool for a specific air-quality assessment. Gaussian-plume models are considered appropriate to use under the following conditions:

- Significant air quality impacts are likely to occur in the “near field”, within around 10 km of the industrial site.
- “Causality” issues are unimportant (this essentially means that pollution plume behaviour can be approximated as “steady-state”, with GLCs at each instant being dependent on conditions at that instant, but independent of GLCs at previous times).
- The terrain within around the source is not complex – that is, surrounding hills are lower than the stack height, and the meteorology can be considered spatially uniform.
- The site is away from the coast (and the meteorology can be considered spatially uniform in this case also).
- Neither atmospheric chemistry nor deposition need to be considered.
- Fumigation due to boundary layer growth and calm-wind conditions are unlikely to be important.

AUSPLUME has been selected for this project because it is widely used and easy to apply. It is often the model of choice for small industries, whose impacts are confined to short ranges, and detailed studies using more complex models are not warranted. Also, the assumptions, uncertainties and limitations of Gaussian-plume models are generally well understood. Finally, the meteorological information needed to drive AUSPLUME is relatively simple, and less expensive to generate than for more complex models.

3.0 INTRODUCTION TO THE CASE STUDIES

This report provides guidance on a number of aspects of the dispersion modelling process. To ensure that it is of practical use to reviewers of modelling assessments in regional councils, the guidance is applied to two hypothetical case studies of industrial facilities for which dispersion modelling is required to determine whether PM_{10} emissions offsets may be required.

The case studies have been chosen as activities that require resource consents in most jurisdictions and for which the applications are reasonably common, so that the examples are of direct use to council staff. To ensure that the activities are captured by the Section 17 2.5 μgm^{-3} offset criteria, it has been assumed that the applications are new activities (i.e., not a renewal of an existing consent).

The sources considered in the case studies have been given stack diameter, efflux velocities, efflux temperatures and emission rates which are considered representative of the activities. The stack height was set in each case to give a modelled 24-hour-average PM_{10} GLC of approximately 2.5 $\mu g/m^3$ near to the site.

Aspects of dispersion-model configuration are discussed in Section 4.0 onwards, including their application to each case study. The case studies themselves are introduced in the remainder of this section.

3.1 Case Study 1: 900 kW Diesel-fired Generator

Case Study 1 is a 900 kilowatt (kW) diesel-fired generator, located in the Hornby industrial area of Christchurch. The generator has New Zealand Transverse Mercator (NZTM) co-ordinates (1562250, 5179050). The location of the site boundary and generator are shown in Figure 1. The stack location is indicated by the red dot and the site boundary by the red square. The stack is assumed attached to a single building. The terrain around the site is flat.

Figure 1: Aerial view of the location of the diesel-fired generator in Hornby, Christchurch.

The duration and daily pattern of emissions of PM_{10} from the stack represent typical load-shedding operations, where the generator contributes electricity to the national grid. The source parameters have been determined for a 900 kW diesel-fired generator, and are shown in Table 1 and Table 2.

The meteorological data set used to run the model was the Christchurch 1997-98 data set developed for Environment Canterbury (Fisher & Bluett 1999). This data set has been used for a large number of modelling investigations which have been run to support resource consent applications in Christchurch.

Table 1: Stack parameters for the 900 kW diesel-fired generator.

Stack height	Stack diameter	Efflux velocity	Efflux temperature	Building dimensions
9.5 m	0.3 m	45 m/s	500 °C	Height 4.5 m Width and length 15 m

Table 2: Emission parameters for the 900 kW diesel-fired generator.

Output	Thermal efficiency (%)	Moisture content of fuel	Ash content of fuel	PM_{10} emission rate
900 kW (100% MCR)*	37 %	zero	zero	0.06 g/s from 6:00 to 10:00 and from 16:00 to 19:00.

*MCR maximum continuous rating.

3.2 Case Study 2: 1 MW Wood-fired Boiler

Case Study 2 is a 1 megawatt (MW) wood-fired boiler. The boiler is located close to the Onekawa industrial area of Napier. The location chosen is approximately 100 m southwest of Hospital Hill, a significant terrain feature in the area. A map of the location is shown in Figure 2. The stack location is indicated by the red dot and the site boundary by the 6-sided polygon. The stack is assumed attached to a single building.

Figure 2: Aerial view of the location of the wood-fired boiler, Onekawa industrial area, Napier. Axes are in metres, in NZTM coordinates.

Stack and emission parameters are shown in Table 3 and Table 4, respectively. These parameters are representative of a 1 MW boiler.

Table 3: Stack parameters for the 1 MW wood-fired boiler.

Stack height	Stack diameter	Efflux velocity	Efflux temperature	Building dimensions
29 m	0.3 m	15.7 m/s	250 °C	Height 12 m Width and length 18 m

Table 4: Emission parameters for the 1 MW wood-fired boiler.

Output	Thermal efficiency	Moisture content of fuel	Ash content of fuel	PM_{10} emission rate
1 MW (100% MCR)*	75 %	25 %	0.7 %	0.17 g/s (continuous)

*MCR maximum continuous rating.

Meteorological data for 2006 were input to AUSPLUME. The data set was created as part of a project for Hawke's Bay Regional Council (HBRC), and are derived from CALMET model outputs (Golder 2012). CALMET was based on prognostic modelling from TAPM, and observations from meteorological monitoring stations in Napier – including one at Marewa Park, close to Onekawa.

Further details on emissions and meteorology are provided in Sections 5.0 and 6.0, respectively. The next section provides guidance on modelling domain and receptor locations.

4.0 DOMAIN AND RECEPTORS

4.1 Introduction – General Guidance

This section provides guidance on the configuration of the modelling domain. This is the area impacted by the emissions of PM_{10} from the industrial source, and should be large enough to cover areas of elevated GLCs, and of sufficient spatial resolution to capture the peak off-site GLC with sufficient precision.

Range of impacts – A commonly used rule of thumb is that the model domain should have horizontal dimensions 50 times the stack height. This is thought to be sufficient to capture plumes hitting the ground under most emissions scenarios and atmospheric conditions. If there are a number of stacks, the maximum stack height would be used. For instance, the presence of a 30 m stack then implies a modelling domain of 1.5 km x 1.5 km. Plots of peak GLCs over the area of the domain should readily indicate whether the locations of peak impact have been included in the model domain. Care should be taken in complex terrain (where the terrain height is greater than the stack height). Complex terrain should be included in the model domain and the modelled plumes examined to ensure that plumes impinging on hillsides are captured by the model.

Receptor locations – Some guidance states that steady-state plume models are applicable for receptors between 100 m and 10 km from the source (possibly down to 50 m). Below this range, the plume concentration may not fit the Gaussian model, and above this range the meteorology may no longer be represented by the single-location data set. Also, there is uncertainty in modelled GLCs close to area sources and buildings, such that receptors should not be placed within a range smaller than the source or building size itself. For example if an area source has dimension 100 m, there should be no receptors within 100 m of its perimeter.

Gridded receptors – AUSPLUME allows specification of a regular grid of receptors. This essentially defines the model domain and the locations at which the PM_{10} GLCs are calculated by the model. The set of gridded receptors needs to be detailed enough to capture the peak PM_{10} concentration with sufficient precision. For small-scale sources with expected short-range effects, the resolution should be 50 m or better. It is recommended that a method of 'grid convergence' is used, whereby the resolution doubles until the maximum-modelled GLC increases by less than 10%. As the number of receptors is limited in AUSPLUME[1], it is recommended that the range of impacts be determined on a 50 m grid, which – provided this captures all areas of impact – can be cropped to the required size before a finer-resolution grid of receptors is implemented.

Note that as the receptor-grid resolution increases, the maximum PM_{10} GLC over the grid increases or remains the same. The resolution must also be high enough so as not to miss a modelled GLC that exceeds 2.5 $\mu g/m^3$. If the aim of the assessment is purely to determine whether the GLC exceeds this target anywhere, then the grid resolution need not increase beyond the stage at which the exceedence appears.

Specification of receptors on a polar grid is not recommended. As distance from the central point increases, the receptors become sparser and peak GLCs may be missed by the model.

Discrete receptors (sensitive locations) – Specific receptors at chosen individual locations are generally chosen to supplement the gridded receptors and provide estimates of PM_{10} at sensitive locations such as residences, schools or hospitals. For comparison with NES-related targets, whether the offset-triggering concentration of 2.5 $\mu g/m^3$ or the NES compliance target of 50 $\mu g/m^3$, the gridded receptors should give a sufficiently precise estimate of the PM_{10} GLC at sensitive locations. However, GLCs at sensitive locations would be modelled and presented for completeness.

Discrete receptors (site fence line) – The NES applies at and beyond the site fence line. An examination of the spatial patterns of PM_{10} GLC may reveal that the peak GLC for NES purposes occurs along the fence line itself. Again, GLCs on the receptor grid should be sufficiently precise, but discrete receptors along the fence line would also be specified as part of the modelling process for completeness. Their spacing would be the same as the eventual gridded receptor spacing.

Extended range of impacts – For higher stack exit temperatures and velocities, air quality impacts may extend further and the initial model domain may be too small. There is a limit to the number of receptors allowable in AUSPLUME and the model run time is proportional to the number of receptors, so for efficiency a larger initial grid with a coarser set of receptors may be used to find the locations of maximum impact. If some impacts are found at greater distances, receptors may not need to be so closely spaced to capture the impacts in the model. This means that the receptors will not form a regular grid. Guidance from Alberta (AENV 2009, 2012) prescribes receptor spacing increasing with distance from the source – that guidance is consistent with the approach described in this section.

Summary of Guidance on the Model Domain and Receptors

- An initial estimate of the model domain size should be 50 times the stack height in each direction, to be adjusted once the extent of modelled impacts are better known.
- An initial regular rectangular grid of receptors should be defined with 50 m horizontal resolution. The resolution should be halved until the peak modelled 24-hour PM_{10} GLC changes by less than 10 %. If the model domain size is large, making the number of gridded receptors too high at 50 m spacing, start with a coarser resolution and reduce the receptor spacing only in the most impacted regions (this may result in an irregular grid).
- Specify discrete receptors to represent sensitive locations.

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[1] AUSPLUME allows a maximum number of gridded receptors of 200 in each direction, but 10000 in total. The maximum number of discrete receptors is 100.

- Specify fence-line receptors at the same horizontal resolution as the gridded receptors.
- Care should be taken that receptors are not too close to area and volume sources.

The next sections show the model domains and receptor grids used for the case studies.

4.2 Modelling Domain and Receptors for Case Study 1 (Diesel-Fired Generator)

Figure 3 shows the model domain and the receptor-grid spacing for the diesel-fired generator case study. The model domain size of 500 m by 500 m was based on the stack height of 10 m. The grid spacing was initially chosen to be 50 m, but was reduced to 25 m and finally to 10 m to ensure grid convergence. The 10 m grid spacing used for this model run is very fine. A fine receptor grid is required in this case study as the maximum GLCs occur on or very close to the property boundary, where the plumes of PM_{10} are narrow. A separate set of discrete receptors was set up around the site boundary. Their locations coincide with points on the 10 m receptor grid, but it is convenient to identify them separately in the AUSPLUME results, as the highest off-site impacts actually occur along the boundary.

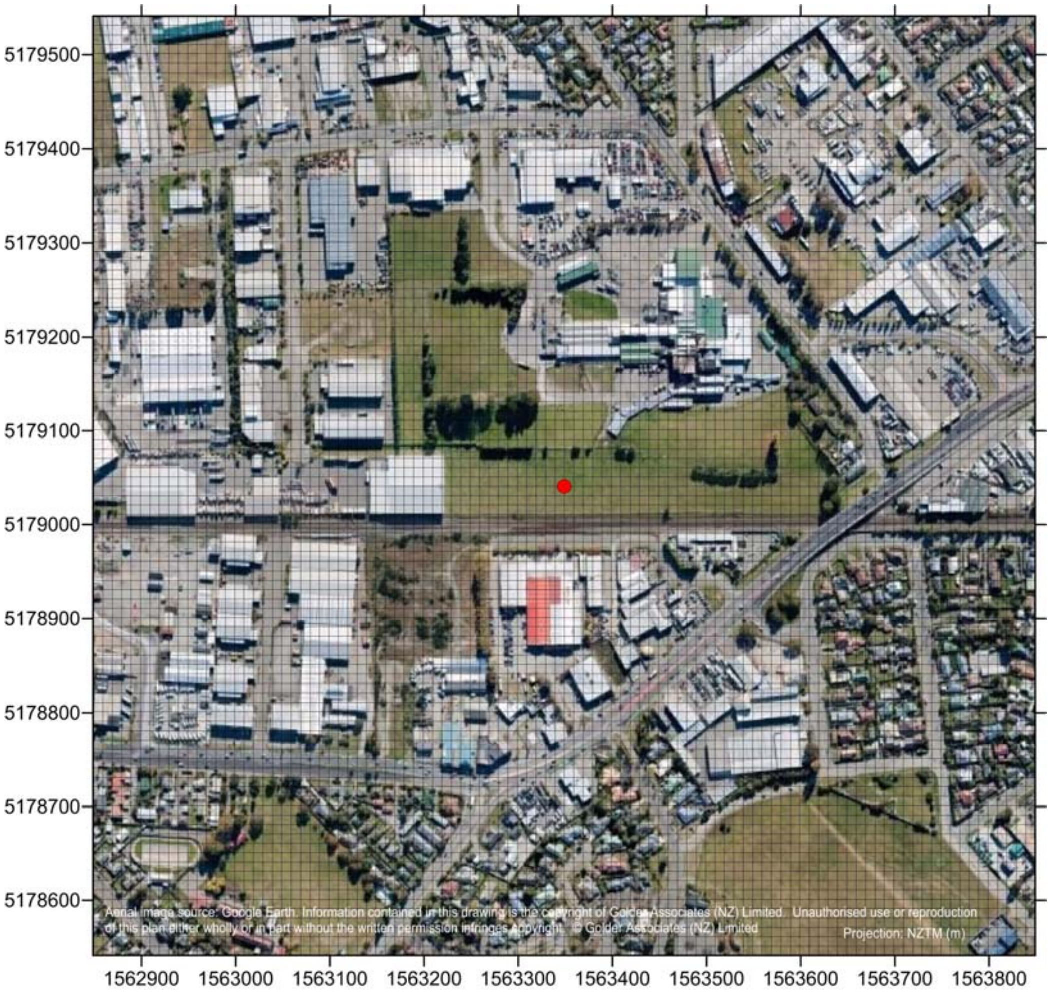

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Figure 3: Modelling domain and gridded receptor spacing for the diesel-fired generator. Axes are in metres, in NZTM coordinates.

4.3 Modelling Domain and Receptors for Case Study 2 (Wood-Fired Boiler)

Figure 4 shows the final model domain and the receptor-grid spacing for the wood-fired boiler case study. The 29 m stack height indicates that the domain should have dimensions around 1.5 km by 1.5 km. However, the proximity of the terrain required an extension of the domain to include much of Hospital Hill and Bluff Hill. The model was initially run with a 50 m grid spacing to determine the range of PM_{10} impacts. The final domain comprised a receptor grid with dimensions 2.1 km by 1.6 km, at resolution 25 m. Peak GLCs changed by less than 10 % between the two grids.

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Projection: NZTM (m)

Figure 4: Modelling domain and gridded receptor spacing for the wood-fired boiler.

5.0 DISCHARGE PARAMETERS

5.1 Introduction

The two case studies considered in this study are both point-source discharges, defined as being from a small opening such as a stack or vent. Modelling the discharge of contaminants from point sources with AUSPLUME requires the specification of the following discharge parameters:

- Stack height and diameter,
- Exhaust gas efflux velocity and temperature,
- Pollutant emission rate, and
- Dimensions of any buildings in close proximity to the stack.

The remainder of this section describes each of these variables and the sources of data that were used for the case studies.

5.2 Guidance on Stack and Emission Parameters

Stack height and diameter – These source characteristics are usually well defined and the information easily available either from engineering specifications or source emission testing programmes. If there is any doubt about the data on stack height and diameter, these dimensions can be confirmed by on-site measurements. Stacks often have a cone fitted to their top which reduces the diameter from that of the main body of the stack, with the aim of increasing the gas efflux velocity. The stack diameter should be the diameter at the point of exit from the stack.

Stack testing data typically cite a stack diameter. However, the diameter reported will be for the diameter of the stack at the point of sampling and may not relate to the exit of the stack in situations where there is a cone fitted.

Most councils require that rain exclusion hoods are not fitted to stacks, as they may affect the vertical flow of the exhaust gases. However, if a hood is proposed, it is necessary to take account of how this might affect the dispersion of gases from a stack. This complicates the dispersion modelling and specific advice on how this might be handled is provided in the modelling GPG (MfE 2004).

For the two case studies the stack height and diameter were selected as being “typical” of the activities being considered. The stack height and diameter for the diesel-fired generator were set at 9.5 m and 0.3 m, respectively; the stack height and diameter for the wood-fired boiler were set at 29 m and 0.3 m, respectively (see Table 1 and Table 3).

It was assumed that neither stack has a rain exclusion hood. To maximize the relevance of the results to this study, the modelled stack heights were fine-tuned to result in 24-hour average PM_{10} GLCs around 2.5 μgm^{-3}.

Exhaust gas efflux velocity and temperature – The temperature and velocity of the exhaust gases determine how buoyant the plume is and how much upward momentum the plume initially has. Together with the physical stack height they define the effective plume height (the height at which the plume stops rising). Therefore the exhaust gas characteristics are important inputs to the model.

Good sources of exhaust gas efflux velocity and temperature data include stack testing measurements, manufacturer’s specifications or theoretical combustion calculations. It is important to note that exhaust gas efflux velocity and temperature vary considerably with the output of the device in question. Unless otherwise stated, the exhaust gas efflux velocity and temperature input data should be based on the device operating at 100 % Maximum Continuous Rating (MCR) output.

The exhaust gas efflux velocity and temperature for the 900 kW diesel-fired generator scenario were taken from manufacturer’s specifications and set at 45 m/s and 500 °C respectively. Depending on the size of the generator, the output load and the diameter of the stack the efflux velocity of exhaust gases from a diesel-fired generator typically range from 35 m/s to 55 m/s and the temperature range from 400 °C to 600 °C.

The exhaust gas efflux velocity and temperature for the 1 MW wood-fired boiler operating at 100% MCR were taken from theoretical combustion calculations. Based on a stack diameter of 0.3 m, the efflux velocity was set at 16 m/s with an efflux temperature of 250 °C. These data were checked against stack testing data from other similar sources to demonstrate that they were realistic estimates. The values were found to be consistent with measurements from devices of this type. Depending on the quality of the fuel, the amount of excess air and the diameter of the stack the efflux velocity of exhaust gases from a boiler of this type may range between 10 m/s and 20 m/s. The temperature may range between 200 °C and 300 °C, depending on the use of economizers (these recover heat to improve the performance of the boiler and therefore result in a lower exhaust temperature).

PM_{10} emission rate – Good sources of PM_{10} emission rate data include stack testing measurements, manufacturer's specifications and emission rate calculations based on published emission factors. It is important to note that the PM_{10} emission rate will vary considerably depending on the type of emission control equipment fitted and output may vary with the hours of operation. Unless otherwise stated, the PM_{10} emission rate should be based on the device operating at 100 % Maximum Continuous Rated (MCR) output.

Two sources of PM_{10} emission rate data were considered for the 900 kW diesel-fired generator. Emission rates were calculated from the manufacturer's specifications and from USEPA emission factors. These two methods gave emission PM_{10} rates of 0.05 g/s and 0.07 g/s respectively. In the case study modelling, a base-case emission rate of 0.06 g/s was used, with sensitivity tests using 0.05 g/s and 0.07 g/s as reasonable bounds for the variation of this parameter. The hours of emission were chosen to reflect what typically may be expected of a generator being operated for load shedding (06:00 to 9:00 and 16:00 to 20:00). The generator was assumed to be operating at 100% of MCR for those hours.

A summary of the combustion calculations for diesel-fired generator is included in Appendix A.

The PM_{10} emission rate for the 1 MW wood-fired boiler operating at 100% MRC was taken from theoretical combustion calculations based on USEPA emission factors and assuming that multi-cyclone control equipment was fitted. The calculated emission rate was 0.17 g/s. The data were checked against stack testing data from other similar sources to demonstrate that they were realistic estimates. These values were found to be consistent with typical measurements from devices of this type. The boiler was assumed to be operating at 100% of MCR for 24 hours a day (i.e. constant emissions).

5.3 Building Downwash

Airflow around buildings is often very complicated and may create zones of strong turbulence and downward mixing on the lee side. This effect is known as building downwash. In such cases, the entrainment of exhaust gases released by short stacks or rooftop vents in the wake of a building can result in much higher ground-level concentrations close to the source than the model would otherwise predict. A well-designed stack can minimise building downwash effects. Building downwash should be modelled to account for the effect of buildings that are close enough and tall enough to influence a plume. The combination of stack height, plume buoyancy and close-by building dimensions determines whether building downwash will affect ground level concentrations close by. The modelling GPG provides a detailed discussion on the building downwash effect.

To specify building dimensions, AUSPLUME has a utility labelled Building Profile Input Programme (BPIP). Other models have the same utility. This requires the co-ordinates of the building corners and building height to be entered. BPIP creates an effective building profile for the source being considered, depending on wind direction at 10° intervals. This building profile information is used by the building downwash algorithm to determine whether and to what degree the upwind building influences the dispersion of the plume. The building downwash algorithms available in AUSPLUME are:

- Huber-Snyder
- Schulman-Scire
- Hybrid Huber-Snyder Schulman-Scire
- PRIME (Plume Rise Model Enhancements)

These are described in the AUSPLUME technical user manual (EPA 2000). The modelling GPG recommends the use of the PRIME algorithm and this has been employed for the case studies. This is consistent with guidance in many overseas jurisdictions (the USA, Canada and Australian State EPAs). A building of width 15 m, length 15 m and height 4.5 m has been used in the diesel-fired generator case study. A building of width 18 m, length 18 m and height 12 m has been used in the wood-fired boiler case study.

These building dimensions have been selected so that building downwash algorithm should be used in the two case studies.

Discharge parameters used for the case studies are shown in Tables 1 to 4.

6.0 METEOROLOGY

6.1 Introduction

In addition to the stack and emission parameters, the important input to any dispersion model is the meteorological data. The production of meteorological data sets from climate-site data and meteorological models is discussed in detail in the modelling GPG (MfE 2004). AUSPLUME requires a time series of meteorological parameters from a single site. The time series should be one (or more) complete years long, with data at hourly intervals. The minimum set of parameters includes temperature, wind speed and direction, Pasquill-Gifford (PG) stability class and mixing height. Other parameters such as the wind direction standard deviation (σ_θ, a measure of plume fluctuations) may also be included. AUSPLUME's meteorological requirements are discussed further in the technical user manual (EPA 2000). The AUSPLUME meteorological files used in the case studies have been supplied along with this report.

6.2 Meteorological Data for Case Study 1 (Diesel-Fired Generator)

For Case Study 1, a meteorological data set for 1997-1998 was input to AUSPLUME. This was developed for Environment Canterbury (Fisher & Bluett 1999), and has been used in a large number of modelling investigations for resource consent applications in Christchurch. This meteorological data set is based on measurements made in Hornby over the period 1 September 1997 to 31 August 1998. Wind speed was measured using a Vector A101M photo electronic anemometer. Wind direction was measured using a Vector W200P potentiometer wind vane. Temperature was measured at two heights above ground level using a Vector T302 temperature sensor. Mixing heights were measured by a Doppler acoustic sounder. Stability classes were determined from incoming solar radiation during the day (also measured at the Hornby site) and vertical temperature gradient at night.

6.3 Meteorological Data for Case Study 2 (Wood-Fired Boiler)

Meteorological data sets have been produced for the Hawke's Bay area, for use by consultants running the dispersion models CALPUFF and AUSPLUME. The data sets consist of CALMET outputs for CALPUFF, and meteorological files extracted at several locations from the CALMET results and converted for input to AUSPLUME. This makes use of CALMET's calculations of mixing height and stability class. Full details are contained in the report by Golder (2012). As the model domain for Case Study 2 is close to the Onekawa, Napier industrial area, the AUSPLUME meteorological file for Onekawa has been used. The modelled year is 2006. Note that at the locations of climate stations, the CALMET and AUSPLUME outputs for wind, temperature and humidity match the site data. Although there is no climate station at Onekawa, the Hawke's Bay Regional Council (HBRC) station at Marewa Park is close by, and the meteorological outputs for Onekawa are very similar to those at Marewa.

6.4 Further Guidance on Meteorological Inputs

Appendix B contains guidance on the following aspects of the meteorological inputs to the AUSPLUME model:

- The proximity of the meteorological site to terrain features.

- The representativeness of AUSPLUME input data of prevailing regional flow patterns.
- The appropriateness of single-point AUSPLUME meteorological data sets (as opposed to three-dimensional meteorological data sets) in complex terrain.
- Spatial variation in meteorological parameters.

7.0 OTHER MODEL-CONFIGURATION PARAMETERS

7.1 Introduction

In addition to the configuration of emissions and meteorological inputs, there are further parameters which need to be chosen in AUSPLUME. These options relate to the way the model disperses and removes air pollution and therefore have an effect on the resulting GLCs. Example parameters deal with surface roughness, plume rise options, wind profile assumptions, building and stack-tip downwash, dispersion curves, terrain adjustment, and wet and dry deposition. These are discussed in more detail in the dispersion modelling GPG (MfE 2004; see Chapter 4, recommendations 26 to 38). Guidance on dispersion parameters used in AUSPLUME is given in this section, which also details the parameters as they were set in the two case studies. The parameters are usually given ‘default’ settings. The sensitivity of the model results to non-default parameter settings is examined in Section 8.0. Detailed guidance specific to AUSPLUME may also be found in the AUSPLUME technical user manual (EPA 2000).

The remainder of this section provides guidance on choices for the remaining parameters in AUSPLUME.

7.2 Parameters and Switches in AUSPLUME

Surface roughness – Surface roughness affects turbulence and the vertical mixing of a pollutant plume. The roughness length is given a default value in AUSPLUME according to the majority land cover type around the industrial site. A range of values is possible for any land cover type, but the AUSPLUME defaults give roughness lengths at the lower end of the accepted ranges. A lower roughness length leads to higher GLCs, so it is appropriate to use the defaults.

Plume-rise options – To be consistent with the defaults in the AUSPLUME technical user manual, gradual plume rise should be used, stack-tip downwash should be used, and partial penetration of elevated plumes should *not* be included.

Wind-profile exponents – Calculation of plume rise is based on the variation of wind speed above the stack tip. The wind speed profile is approximated by a power-law function depending on height. The Irwin urban or Irwin rural exponents for the power law should be chosen to determine the wind speed profile. The Irwin urban exponents should be chosen for urban areas with a high density of buildings within a 3 km radius of the industrial source. These assume a higher heat flux from the surface and higher roughness length than the Irwin rural option.

Building downwash – The PRIME algorithm should be used, as this is considered to produce superior results to the other options. Its use is described above, in Section 5.0. Note that there is some uncertainty in GLCs for receptors within the building wake (say, within three building heights or widths).

Dispersion curves – These are empirically-determined measures of horizontal and vertical spread of pollution plumes, which increase with distance downwind. It is recommended that the Pasquill-Gifford curves are used for stack heights less than 100 m, and the Briggs rural curves are used for stack heights greater than 100 m. The same scheme should be used for both the horizontal and vertical plume spread. A number of options are available to adjust the selected dispersion curves. There should be no adjustment of the curves for wind direction shear, but they should be adjusted for surface roughness and the buoyancy enhancement option should be taken. Stability class adjustments in urban areas should not be made.

Terrain adjustment – AUSPLUME models the uplifting of plumes by broad terrain features. The default scheme uses the Egan half-height approach, and this option should generally be chosen.

Dry and wet deposition and resulting plume depletion – Removal and deposition processes decrease ambient concentrations. The effect increases with distance. For more realistic PM_{10} GLCs, these processes should be modelled. However, there is much uncertainty over removal rates, as they are sensitive to the pollutant properties (especially particle size), the turbulent properties of the atmosphere and the properties of the ground surface. Also, plume models run much more slowly with depletion and deposition switched on. Therefore, for short-range air-quality impacts, these processes are usually not modelled, and will give slightly conservative results for ambient GLCs.

The two case studies have been configured according to the default and/or recommended parameter choices described in this section. The basic configuration for each case study uses the same parameters, summarized in Table 5, with the exception of the terrain-adjustment parameter. The diesel-fired generator is situated in flat terrain, and a terrain-adjustment scheme has not been used. Sensitivity tests to the dispersion parameters have been carried out as variations on the basic configuration for each case study, and the results of those are presented in Section 8.0.

Table 5: Summary of case study parameter choices. These apply to both cases, unless indicated otherwise.

Parameter	Base case choice
Land use category	Residential, with surface roughness 0.4 m
Plume rise	Gradual plume rise – on
	Stack-tip downwash – on
Wind profile exponents	Irwin urban
Building downwash	PRIME
Dispersion curves	PG curves chosen in the vertical and horizontal, as the stacks are less than 100 m tall
	Adjustment for wind-direction shear – off (default)
	Adjustment for surface roughness – on (default)
	Enhancement for plume buoyancy – on (default)
Terrain adjustment	No terrain for Case Study 1 Egan half-height approach for Case Study 2
Wet and dry deposition; plume depletion	Off
Miscellaneous	Stability-class adjustments in urban areas – off
	Smooth stability class changes – off
	Convective plume rise – off

8.0 CASE STUDY RESULTS

8.1 Introduction

For each case study, a contour plot containing the maximum modelled 24-hour average PM_{10} GLC at each gridded receptor for the base case is shown (Sections 8.2 and 8.3). In addition, sensitivity tests have been carried out using variations to the base case model configurations. Variations have been applied to five aspects of model-configurations. These are (i) source variables, (ii) land use category, (iii) dispersion parameters, (iv) wind-profile exponents and (v) other model settings. The resulting maximum-modelled 24-hour average PM_{10} GLCs outside the site boundary are presented. The sensitivity of the model results to the tested variables is rated as follows:

- Not sensitive (no change in peak PM_{10} GLC)
- Low sensitivity (less than 10% change in peak PM_{10} GLC)
- Sensitive (between 10% and 50% change in peak PM_{10} GLC)
- Highly sensitive (greater than 50% change in peak PM_{10} GLC)

The percentage change in peak PM_{10} GLC depends on the percentage change in the tested variable, so that the tested variable is changed within reasonable limits of certainty. Also, percentage changes in peak PM_{10} GLC normalized by the percentage change in the tested variable are presented where appropriate to provide an additional measure of model sensitivity.

8.2 Case Study 1: Diesel Generator

Figure 5 shows a spatial map of the maximum-modelled PM_{10} 24-hour average GLC from the diesel-fired generator emissions. The peak GLC is 2.4 µg/m^3, southwest of the stack. Concentrations are just under the emissions-offset criterion of 2.5 µg/m^3 and emissions offsets would not need to be implemented. The model domain is large enough to have captured the modelled air-quality impacts of the generator. Tables 6 to 10 present the results of the sensitivity tests, and show the maximum off-site GLCs. For most of the tests, the maximum GLCs occur within 10 m of the location of the base-case maximum.

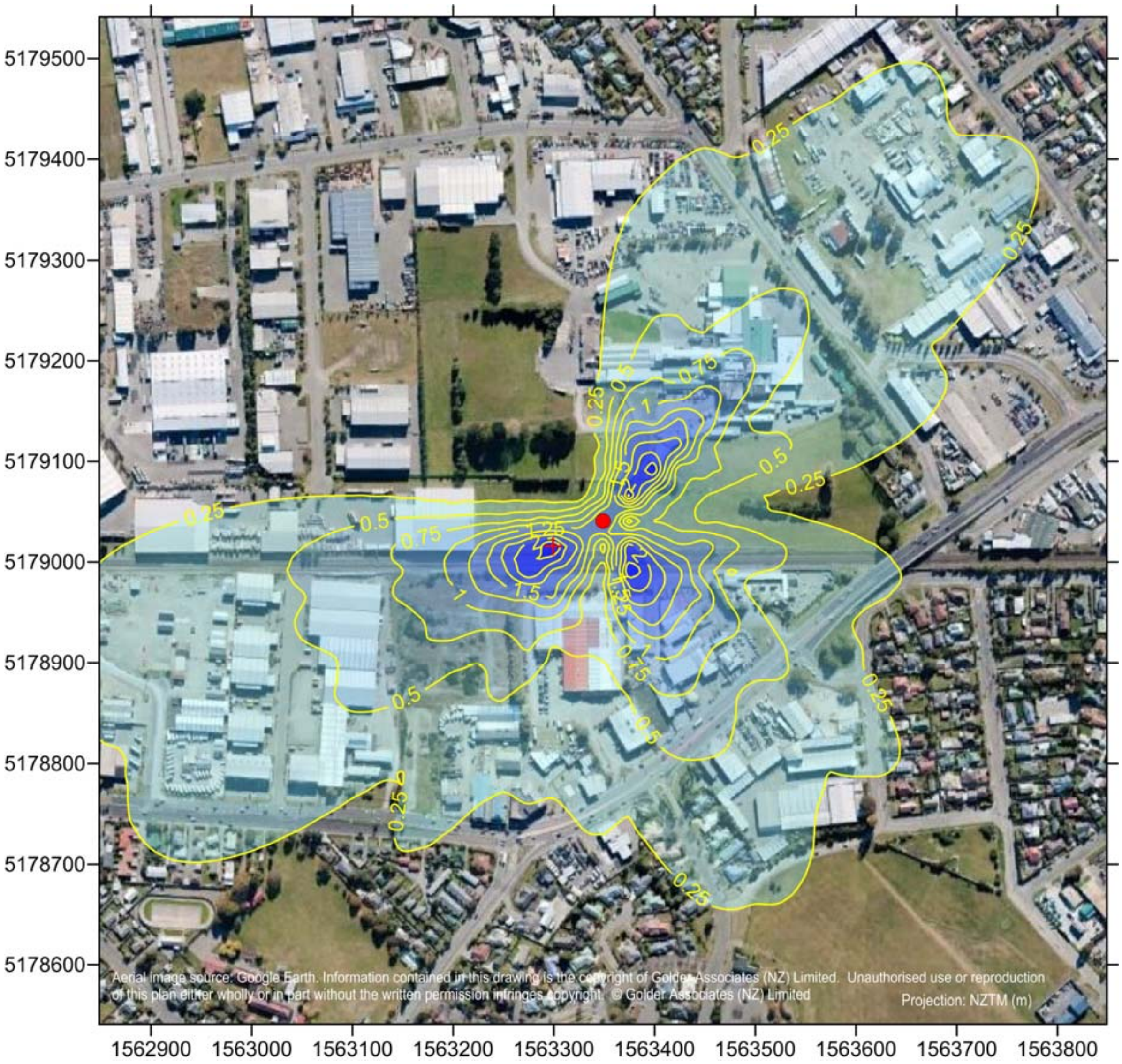

Figure 5: Contour plot of maximum PM_{10} 24-hour average GLC: Diesel fired generator base case. The red circle shows the location of the generator stack. The cross indicates the location of the maximum-modelled GLC.

Table 6: Case Study 1 results of model sensitivity to source parameters.

Parameter	Value	24-hour average PM_{10} GLC ($\mu g/m^3$)	% variation (from base case GLC)	Model sensitivity
Stack height (SH)	8.5 m	3.6	+ 54 %	Highly sensitive
	9.5 m (base case)	2.4		
	10.5 m	0.8	- 66 %	
Efflux velocity (EV)	35 m/s	3.3	+ 39 %	Sensitive
	45 m/s (base case)	2.4		
	55 m/s	1.5	- 35 %	
Efflux temp (ET)	400 °C	2.0	- 13 %	Sensitive
	500 °C (base case)	2.4		
	600 °C	2.6	+ 12 %	
Emission rate (ER)	0.05 g/s	2.0	- 17 %	Sensitive
	0.06 g/s (base case)	2.4		
	0.07 g/s	2.7	+ 17 %	
Operating hours	08:00 to 15:00	3.2	+ 35 %	Sensitive
	06:00 to 10:00 and 16:00 to 20:00 (base case)	2.4		
	22:00 to 0:500	1.9	- 18 %	

Table 7: Case Study 1 results of model sensitivity to land-use category.

Land use category	Surface roughness (m)	24-hour average PM_{10} GLC ($\mu g/m^3$)	% variation	Model sensitivity
Flat rural	0.1	2.3	± 1 %	Low sensitivity
Residential	0.4 (base case)	2.4		
Commercial	0.8	2.4		

Table 8: Case Study 1 results of model sensitivity to dispersion parameters.

Parameter	**Option**	**24-hour average PM_{10} GLC ($\mu g/m^3$)**	**% variation**	**Model sensitivity**
Dispersion curves	PG - vertical and horizontal (base case)	2.4	2 %	Low sensitivity
	Briggs Rural - vertical and horizontal	2.3		
	Sigma-theta	2.4		
	PG - Adjustment for surface roughness – on (base case)	2.4	2 %	Low sensitivity
	PG - Adjustment for surface roughness - off	2.3		
	PG - Enhance for plume buoyancy – on (base case)	2.4	0 %	Not sensitive
	PG - Enhance for plume buoyancy - off	2.4		
Plume rise	Gradual plume rise - on (base case)	2.4	98 %	Highly sensitive
	Gradual plume rise - off (building wake effects ignored)	0.045		
	Stack tip downwash – on (base case)	2.4	0 %	Not sensitive
	Stack tip downwash – off	2.4		

Table 9: Case Study 1 results of model sensitivity to wind-profile exponent scheme.

Wind-profile exponent	**24-hour average PM_{10} GLC ($\mu g/m^3$)**	**% variation from base case**	**Model sensitivity**
Irwin urban (base case)	2.3	± 3 % (less than 0.1 $\mu g/m^3$)	Low sensitivity
Irwin rural	2.3		
ISCST model	2.3		

Table 10: Case Study 1 results of model sensitivity to other parameters.

Parameter	Option	24-hour average PM_{10} GLC ($\mu g/m^3$)	% variation from base case	Model sensitivity
Building downwash	Building downwash off	0.14	94 %	Highly sensitive
	PRIME (base case)	2.34		
	Huber Snyder (HS)	0.14		
	Schulman Scire (SS)	0.14		
	Hybrid HS/SS	0.14		
Stability class changes for urban land cover	Off (base case)	2.34	1 %	Low sensitivity
	On - Urban 1	2.34		
	On - Urban 2	2.32		
Plume pdf in convective conditions	Off (base case)	2.34	93 %	Highly sensitive
	On	0.16		

Table 11 gives a summary of the model's response to the parameters and switches tested for the diesel-fired generator case study. In Table 11 the parameters are listed in ranked order from most sensitive parameter to the least. In addition to summarizing results presented above, the table shows for numerical parameters a 'sensitivity factor', which is the percentage change in maximum-modelled PM_{10} GLC per percentage change in parameter value, and a required 'parameter accuracy'. The required parameter accuracy aims to prevent the variation in modelled PM_{10} GLC from exceeding 10 %.

The ordered list must be treated with some caution as (i) some switches – such as the 'top three' in the table are fixed according to accepted good practice, and (ii) the order only applies to this case study and within the perturbations of the base-case parameter values actually tested. However, the ranked order shown in Table 11 is likely to apply in other cases, and should provide a good indication of the parameters which need to be known with most certainty.

From Case Study 1, Table 11 provides the following indications regarding model configuration and sensitivity:

1) The model results are most sensitive to choices of plume rise and building downwash options. They are also sensitive to switch of the plume dispersion formula in convective conditions. However, these options are generally chosen according to accepted good practice, so model sensitivity to them is less important.

2) The parameters to which the model results are most sensitive, *whose numerical values can be chosen by the user*, are source parameters, particularly the stack height and efflux velocity. There is also some sensitivity to emission rate and efflux temperature.

3) In addition, results are sensitive to the hours of operation. The same daily-total emission of PM_{10} has different impacts depending on the time of day or night of release, due to differing meteorological conditions.

4) In this case study, the influence of efflux temperature is counter-intuitive, as modelled concentrations increase as the temperature increases. This is worthy of further investigation.

5) The remaining model configuration options considered had relatively little effect on the peak modelled PM_{10} GLCs. Nonetheless, parameters should be given as realistic values as possible.

Table 11: Summary of results from the diesel-fired generator parameter sensitivity tests.

Parameter (or switch)	Model sensitivity	Ranked sensitivity	Indicative variation	Sensitivity factor (% change in GLC per % change in parameter)	Required parameter accuracy (to keep GLC sensitivity to around 10 %)
Gradual plume rise	Highly sensitive	1	98 %		
Building downwash	Highly sensitive	2	94 %		
Plume pdf in convective conditions	Highly sensitive	3	93 %		
Stack height	Highly sensitive	4	66 %	5	<0.2 m
Efflux velocity	Sensitive	5	40 %	2	<3 m/s
Operating hours	Sensitive	6	40 %		
Emission rate	Sensitive	7	17 %	1	<0.01 g/s
Efflux temp	Sensitive	8	13 %	0.6	~80 °C
Wind profile exponent	Low sensitivity	9	3 %		
Land use category (roughness length)	Low sensitivity	10	2 %	0.02	~2 m
Dispersion curves	Low sensitivity	11	2 %		
Urban stability class changes	Low sensitivity	12	1 %		
Stack tip downwash	No sensitivity	13	0 %		

The following section discusses the results of Case Study 2, a wood-fired boiler located near complex terrain.

8.3 Case Study 2: Wood-fired Boiler

Figure 6 shows a spatial map of the maximum-modelled PM_{10} 24-hour average GLC from the wood-fired boiler emissions. The peak PM_{10} is 7.73 µg/m^3, on the nearest slope of Hospital Hill (the terrain height is 42 m at this location). As this GLC exceeds the 2.5 µg/m^3, emissions offsets would need to be implemented. Tables 12 to 16 present the results of the sensitivity tests, and show the maximum off-site GLCs in the complex terrain of Hospital Hill approximately 600 m northeast of the site. Note that the peak GLC generally decreases to the northeast, to around 1 µg/m^3, indicating that the domain is sufficiently large for the model to have captured the impacts of the boiler. Also note from Table 14 that although the modelled GLC is enhanced by the presence of complex terrain, the GLC would still exceed 2.5 µg/m^3 in its absence.

Figure 6: Contour plot of maximum PM_{10} 24-hour average concentration: Wood fired boiler base case. The red circle shows the location of the boiler stack.

Table 12: Case Study 2 results of model sensitivity to source parameters.

Parameter	Value	24-hour average PM$_{10}$ GLC (μg/m^3)	e% variation (from base case GLC)	Model sensitivity
Stack height (SH)	28 m	8.53	+ 10 %	Sensitive
	29 m (base case)	7.73		
	30 m	6.93	- 10 %	
Efflux velocity (EV)	10.65 m/s	10.48	+ 36 %	Sensitive
	15.65 m/s (base case)	7.73		
	20.65 m/s	6.42	- 17 %	
Efflux temp (ET)	200 °C	8.54	+ 10 %	Low to sensitive
	250 °C (base case)	7.73		
	300 °C	7.09	- 8 %	
Emission rate (ER)	0.15 g/s	6.82	- 12 %	Sensitive
	0.17 g/s (base case)	7.73		
	0.19 g/s	8.64	+ 12 %	

Table 13: Case Study 2 results of model sensitivity to land-use category.

Land use category	Surface roughness (m)	24-hour average PM$_{10}$ GLC (μg/m^3)	% variation	Model sensitivity
Flat rural	0.1	7.91	± 2 %	Low Sensitivity
Residential	0.4	7.73		
Commercial	0.8	7.60		

Table 14: Case Study 2 results of model sensitivity to dispersion parameters.

Parameter	Option	24-hour average PM$_{10}$ GLC (μg/m^3)	% variation (from base case GLC)	Model sensitivity
Dispersion curves	PG - vertical and horizontal (base case)	7.73	8 %	Low sensitivity
	Briggs Rural - vertical and horizontal	8.35		
	PG - Adjustment for surface roughness – on (base case)	7.73	0 %	Not sensitive
	PG - Adjustment for surface	7.73		

Parameter	Option	24-hour average PM_{10} GLC ($\mu g/m^3$)	% variation (from base case GLC)	Model sensitivity
	roughness - off			
	PG - Enhance for plume buoyancy – on (base case)	7.73	12 %	Sensitive
	PG - Enhance for plume buoyancy - off	8.64		
Plume rise	Gradual plume rise - on (base case)	7.73	47 %	Highly sensitive
	Gradual plume rise - off (building wake effects ignored)	4.09		
	Stack tip downwash – on (base case)	7.73	0 %	Not sensitive
	Stack tip downwash – off	7.73		
Terrain effects	Ignore terrain	3.03	61 %	Highly sensitive
	Egan half height (base case)	7.73		
	Modified Egan	7.73		

Table 15: Case Study 2 results of model sensitivity to wind-profile exponent scheme.

Wind-profile exponent	24-hour average PM_{10} GLC ($\mu g/m^3$)	% variation from base case	Model sensitivity
Irwin urban (base case)	7.73	± 4 %	Low sensitivity
Irwin rural	7.49		
ISCST model	8.05		

Table 16: Case Study 2 results of model sensitivity to other parameters.

Parameter	**Option**	**24-hour average PM_{10} GLC ($\mu g/m^3$)**	**% variation**	**Model sensitivity**
Building downwash	Building downwash off	4.09	400 %	Highly sensitive
	PRIME (base case)	7.73		
	Huber Snyder (HS)	4.09		
	Schulman Scire (SS)	4.09		
	Hybrid HS/SS	38.39		
Stability class changes for urban land cover	Off (base case)	7.73	32 %	Sensitive
	On - Urban 1	5.23		
	On - Urban 2	7.37		
Plume pdf in convective conditions	Off (base case)	7.73	47 %	Highly sensitive
	On	4.09		

Table 17 gives a summary of the model's response to the parameters and switches tested for the wood-fired boiler case study. This is the equivalent of Table 11.

Table 17: Summary of results from the wood fired boiler parameter sensitivity tests.

Parameter (or switch)	**Model sensitivity**	**Ranked sensitivity**	**Indicative variation**	**Sensitivity factor (% change in GLC per % change in parameter)**	**Required parameter accuracy (to keep GLC sensitivity to around 10 %)**
Building downwash	Highly sensitive	1	400 %		
Terrain effects	Highly sensitive	2	61 %		
Plume pdf in convective conditions	Highly sensitive	3	47 %		
Gradual plume rise	Highly sensitive	3	47 %		
Urban stability class changes	Sensitive	5	32 %		
Efflux velocity	Sensitive	6	~30 %	~1	<2 m/s
Emission rate	Sensitive	7	12 %	1	0.017 g/s
Stack height	Sensitive	8	10 %	3	1 m

Efflux temp	Low to sensitive	9	9 %	0.5	50 °C
Dispersion curves	Low sensitivity	10	8 %		
Wind profile exponent	Low sensitivity	11	4 %		
Land use category (roughness length)	Low sensitivity	12	2 %		
Stack tip downwash	Not sensitive	13	0 %		

From Case Study 2, Table 17 provides the following indications regarding model configuration and sensitivity:

1) Model results are most sensitive to the building downwash scheme, terrain adjustment scheme and plume-rise and plume-pdf switches. Results may actually be less sensitive to the plume-pdf switch, but if this option is taken, building downwash must be switched off. It is important to note that accepted good practice fixes these choices to be PRIME for building downwash; Egan half-height for terrain adjustment, gradual plume rise switched on and the pdf formulation for plumes in convective conditions switched off.

2) Model results are also sensitive to changes to urban stability classes. These options shift some stability classes to be more unstable in urban areas. Model results for peak PM_{10} GLCs may change if the peak occurs under one of the stability classes which the scheme changes. However, the AUSPLUME technical manual recommends that these options are not used.

3) As with Case Study 1, the model results are sensitive to the source parameters, namely, efflux velocity, stack height, emission rate, and efflux temperature. The user needs to know these with sufficient certainty. Uncertainty in the efflux velocity of more than 2 m/s, uncertainty in the stack height of more than 1 m, or uncertainty in the efflux temperature of more than 50 °C, each lead to uncertainty in the resulting peak PM_{10} concentration of 10 %. As the PM_{10} concentration is proportional to emission rate, a 10 % uncertainty in emissions leads to a 10 % uncertainty in modelled GLCs. Note that these estimates are case-specific.

It is interesting to compare the model sensitivities between the two case studies. The peak GLC in Case Study 2 occurs at a greater distance from the source than in Case Study 1. Model results in Case Study 2 are less sensitive to source-related parameters (such as stack height, efflux velocity and efflux temperature) or options which affect dispersion around the source (such as plume rise and plume buoyancy enhancements), though these are still important.

9.0 SUMMARY AND RECOMMENDATIONS

9.1 Summary of Results

This project has aimed to provide comprehensive and specific guidance on how the dispersion modelling of two common examples of air discharge permit applications should be undertaken to provide a robust and transparent result that can be confidently compared to the 2.5 µg/m^3 emissions offset criterion. The project has focused on the AUSPLUME model.

The two case studies undertaken were a 900 kW diesel-fired generator operating over a limited number of hours each day and a 1 MW wood-fired boiler operating continuously.

Key elements of a dispersion modelling assessment have been considered in detail for each of the case studies. These were the modelling domain and receptor grid, source discharge parameters, meteorological data sets, and other model-configuration settings.

To provide an indication of how sensitive the model results are to each of these elements, both case studies were run with a number of options for each of the parameters and switches. The key findings of both case studies were similar, as follows:

1) Model results are sensitive to the chosen building downwash scheme, terrain adjustment scheme, plume-rise and plume-pdf switches, and can be sensitive to stability-class adjustments if applied. However, these choices are fixed by accepted good practice in the air quality modelling community and model developers.
2) Model results are sensitive to the source parameters, namely, efflux velocity, stack height, emission rate, and efflux temperature. The user needs to know these with certainty in order to produce modelled GLCs with sufficient precision.
3) Many model configuration options had little effect on the peak modelled PM_{10} GLCs, although they affect the hour-by-hour trends and spatial details of PM_{10} patterns.

9.2 Recommendations for Dispersion Modelling Good Practice

The following recommendations are made for carrying out a dispersion modelling exercise as part of an air discharge permit application. They are also provided so that regional council staff may check that consultants have followed good practice.

1) Follow the dispersion modelling GPG recommendations, or provide justification for any alternative approach followed.
2) Create a clear audit trail so that the modelling may be easily reviewed, supplying a full set of electronic input and output files.
3) Use the best available input data for source discharge parameters and meteorological files, including emission rates, efflux velocities and efflux temperatures.
4) Take particular care with building downwash aspects, using the correct locations, building dimensions and stack heights.
5) Run sensitivity tests if there is ambiguity or uncertainty over configuration options. Also run sensitivity tests to get a measure of certainty in the model results.
6) If a source is intended to have time-varying emissions, then these should be specified in the consent conditions. Otherwise, the source could operate constantly. In that case the modelling should assume constant maximum emissions.

10.0 CONCLUSIONS

This report provides guidance on how to run AUSPLUME for regulatory air quality assessments in New Zealand, and is the first time specific guidance has been produced for this model (although as noted above much of the guidance is applicable to other models). The guidance aims to be sufficiently well-defined and specific to enable robust and defensible assessments under the new NES regulation for industrial PM_{10} emissions offsets in polluted airsheds. These include determining whether emissions offsets are required to be implemented by the applicant, according to whether modelled 24-hour average PM_{10} GLCs exceed 2.5 µg/m^3 beyond the site boundary.

11.0 LIMITATIONS

Your attention is drawn to the document, “Report Limitations”, in Appendix C. The statements presented in that document are intended to advise you of what your realistic expectations of this report should be, and to present you with recommendations on how to minimise the risks to which this report relates which are associated with this project. The document is not intended to exclude or otherwise limit the obligations necessarily imposed by law on Golder Associates (NZ) Limited, but rather to ensure that all parties who may rely on this report are aware of the responsibilities each assumes in so doing.

12.0 REFERENCES

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APPENDIX A

Combustion Calculations for Case Studies

COMBUSTION CALCULATIONS

28 May 2013

Diesel Engine 900 kW output

Operating conditions

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS			
Carbon:	88.56	%wt (DAF basis)	
Hydrogen:	11.44	%wt (DAF basis)	
Oxygen:	0.00	%wt (DAF basis)	
Nitrogen:	0.00	%wt (DAF basis)	
Sulphur:	0.001	%wt (DAF basis)	
Fuel moisture content:	0.00	%wt (as received basis)	
Ash content:	0.00	%wt (as received basis)	
DAF portion:	1.000	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	102.40	moles/kg (DAF basis)	
Excess air:	5.00	%	
Total O_2 required:	107.52	moles/kg (DAF basis)	
Flue gas CO_2 content:	15.19	%vol dry	
Flue gas O_2 content:	1.05	%vol dry	
APPLIANCE DETAILS			
Power Output:	900	kW	
Percentage of MCR:	100.00	%	
Effective power output:	900	kW	
Efficiency:	30.00	%	
As rcvd fuel CV:	43000	kJ/kg	
Equivalent Stack diameter:	0.300	m	
Heat produced by combustion:	3000	kW	
Heat loss:	2100	kW	
Liquid density	0.83	kg/L	
Maximum fuel burning rate:	0.07	kg/s (as received basis)	
	0.25	t/h (as received basis)	
	0.08	L/s (as received basis)	
STACK PROPERTIES			
Temperature:	823	K	509 oC (872 K) from Manufactures Specs
WET flow rate (POC sheet):	36.67	m^3/kg DAF fuel	Catepillar STANDBY 880 ekW 1100 kVA
Actual volumetric flow rate:	2.56	m^3/s	
Stack x-sectional area:	0.07	m^2	
Efflux velocity:	36.19	m/s	45 m/s from Manufactures' specfications
DRY flow rate @ STP (POC sheet):	10.89	Nm^3/kg DAF fuel	
	0.76	Nm^3/sec	
	2,735	Nm^3/hour	
WET flow rate @ STP (POC sheet):	12.17	Nm^3/kg DAF fuel	
	0.85	Nm^3/sec	
	3,057	Nm^3/hour	
EMISSION CALCULATIONS			
TSP emission factor	0.00	g/L	
PM_{10} emission factor:	0.8794	g/L	US-EPA AP42 Table 3.4-2 uncontrolled diesel engine
TSP emissions rate:	0.000	g/s	
PM_{10} emission rate:	0.0739	g/s	0.05 g/s from Manufacture specs

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

22 Apr 2013

1278104_926: 1 MW wood fired boiler

Operating conditions 5% O_2

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS			
Carbon:	52.30	%wt (DAF basis)	Typical CHONS for wood
Hydrogen:	6.00	%wt (DAF basis)	
Oxygen:	41.50	%wt (DAF basis)	
Nitrogen:	0.20	%wt (DAF basis)	
Sulphur:	0.03	%wt (DAF basis)	
Fuel moisture content:	25.00	%wt (as received basis)	
Ash content:	0.70	%wt (as received basis)	
DAF portion:	0.743	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	45.77	moles/kg (DAF basis)	
Excess air:	31.14	%	
Total O_2 required:	60.02	moles/kg (DAF basis)	
Flue gas CO_2 content:	15.29	%vol dry	
Flue gas O_2 content:	5.00	%vol dry	
APPLIANCE DETAILS			
Power Output:	1000	kW	Based on example advice from HBRC
Percentage of MCR:	100.00	%	
Effective power output:	1000	kW	
Efficiency:	75.00	%	
As rcvd fuel CV:	13550	kJ/kg	EECA Calorific value calculator - wood with 25% moisture
Equivalent Stack diameter:	0.30	m	Based on example advice from HBRC
Heat produced by combustion:	1333	kW	
Heat loss:	333	kW	
Maximum fuel burning rate:	0.10	kg/s (as received basis)	
	0.35	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	523.15	K	Based on example advice from HBRC
WET flow rate (POC sheet):	15.13	m^3/kg DAF fuel	
Actual volumetric flow rate:	1.11	m^3/s	
Stack x-sectional area:	0.07	m^2	
Efflux velocity:	15.65	m/s	HBRC advises 6 m/s To achieve 6 m/s suggest boiler operating at 39%MCR
DRY flow rate @ STP (POC sheet):	6.39	Nm^3/kg DAF fuel	
	0.47	Nm^3/sec	
	1,681	Nm^3/hour	
WET flow rate @ STP (POC sheet):	7.90	Nm^3/kg DAF fuel	
	0.58	Nm^3/sec	
	2,079	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

Golder Associates

COMBUSTION CALCULATIONS

22 Apr 2013

1278104_926: 1 MW wood fired boiler

Standard conditions 12% CO_2

Parameter	Value	Unit	Comment / source of data
FUEL ULTIMATE ANALYSIS			
Carbon:	52.30	%wt (DAF basis)	Typical CHONS for wood
Hydrogen:	6.00	%wt (DAF basis)	
Oxygen:	41.50	%wt (DAF basis)	
Nitrogen:	0.20	%wt (DAF basis)	
Sulphur:	0.03	%wt (DAF basis)	
Fuel moisture content:	25.00	%wt (as received basis)	
Ash content:	0.70	%wt (as received basis)	
DAF portion:	0.743	kg/kg fuel (as received basis)	
AIR REQUIREMENTS			
Theoretical O_2 required:	45.77	moles/kg (DAF basis)	
Excess air:	66.82	%	
Total O_2 required:	76.35	moles/kg (DAF basis)	
Flue gas CO_2 content:	12.00	%vol dry	
Flue gas O_2 content:	8.42	%vol dry	
APPLIANCE DETAILS			
Power Output:	1000	kW	Based on example advice from HBRC
Percentage of MCR:	100.00	%	
Effective power output:	1000	kW	
Efficiency:	75.00	%	
As rcvd fuel CV:	13550	kJ/kg	EECA Calorific value calculator - wood with 25% moisture
Equivalent Stack diameter:	0.30	m	Based on example advice from HBRC
Heat produced by combustion:	1333	kW	
Heat loss:	333	kW	
Maximum fuel burning rate:	0.10	kg/s (as received basis)	
	0.35	t/h (as received basis)	
STACK PROPERTIES			
Temperature:	523.15	K	Based on example advice from HBRC
WET flow rate (POC sheet):	18.48	m^3/kg DAF fuel	
Actual volumetric flow rate:	1.35	m^3/s	
Stack x-sectional area:	0.07	m^2	
Efflux velocity:	19.1	m/s	Not used for modelling - velocity under operating conditions rather than standardised conditions is used for modelling'
DRY flow rate @ STP (POC sheet):	8.14	Nm^3/kg DAF fuel	
	0.60	Nm^3/sec	
	2,142	Nm^3/hour	
WET flow rate @ STP (POC sheet):	9.65	Nm^3/kg DAF fuel	
	0.71	Nm^3/sec	
	2,540	Nm^3/hour	
EMISSION CALCULATIONS			
TSP emission factor:	350	mg/m^3 dry STP 12% CO_2	
PM_{10} emission factor:	280	mg/m^3 dry STP 12% CO_2	Assumes 80% PM10 for multicyclone
TSP emissions rate:	0.21	g/s	
PM_{10} emission rate:	0.17	g/s	
PM_{10} emission rate:	0.60	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

APPENDIX B

Meteorological Aspects of AUSPLUME Modelling

Introduction

The air pollution dispersion modelling of Case Studies 1 and 2 deals with two types of meteorological inputs that AUSPLUME uses. Data as described in Sections 6.2 and 6.3 of the main report, can come from either an *in-situ* meteorological station sampling for at least one year (as in Case Study 1), or from a numerical weather prediction model (whose outputs are used by the diagnostic model CALMET in Case Study 2).

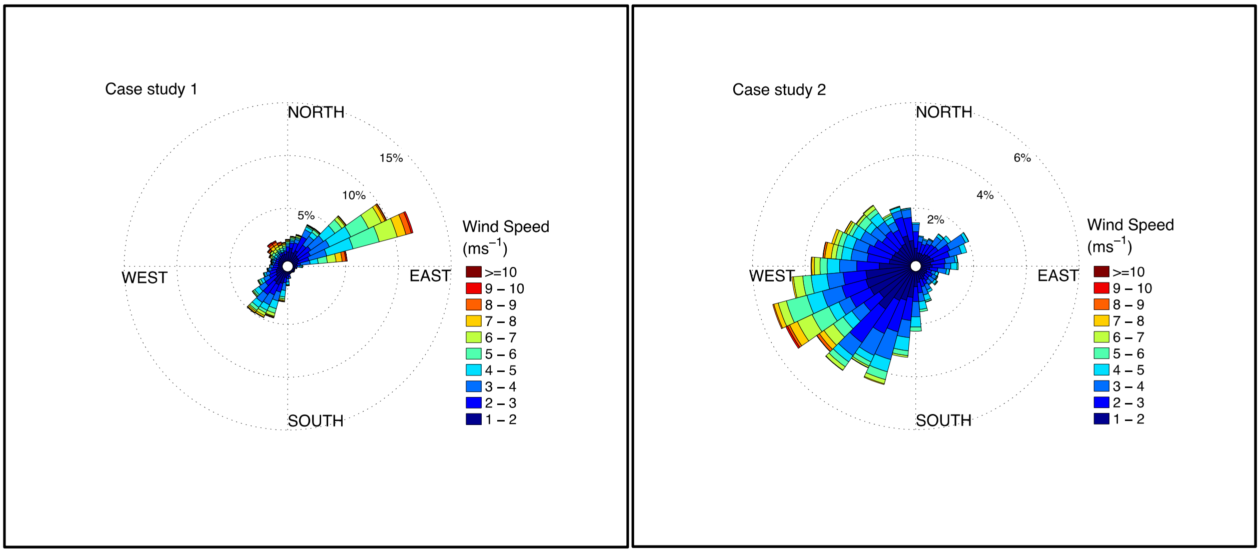
The approach used in Case Study 2 is less expensive than the approach in Case Study 1, which requires operating and servicing a set of meteorological instruments for at least one year. Nevertheless, care should be taken when extracting the time series data from the CALMET gridded data set for use in AUSPLUME. Usually the CALMET domain resolution is an order of magnitude greater than the one used for the dispersion modelling, in this case the CALMET grid resolution is 100 m while the AUSPLUME receptor-grid resolution is 25 m. This scale of resolution mismatch should not create a problem, but it is advisable to compare the data from the CALMET location to a nearby weather station if available, and more importantly to check for the geographic location with a site-specific geographic map for matching with the pollution source. The additional further meteorological guidance contained in this Appendix will be given for Case Study 2 since this is around an area of complex terrain with Hospital Hill in the vicinity of the modelled stack, and the coast only 2.5 km away. Case Study 1 is in an area of flat terrain (the nearest terrain, including the coast, is 10 km away). Given this contrast in the topographic setting between the two cases one can assume that the regional meteorology (on the 10 to 50 km scale) is represented with higher confidence by the observed meteorological data at Case Study 1 with minimal influence from localized flows (such as the effects from nearby hills or the coast) relative to Case Study 2.

Although AUSPLUME has its own limitations (discussed in Section 2.2 of the main report), one still needs to check that the single-location meteorological input data (either from observations or a diagnostic gridded data set) represent the expected local flow, as this is the most important factor in small-scale air pollution dispersion modelling. The following sections discuss some of the important factors related to meteorological inputs. The sections address the relevance of the meteorological inputs to the dispersion model configuration, an examination of some meteorological time series, and the likely impacts on GLCs of difference choices of meteorological inputs.

The Proximity of the Meteorological Site to Terrain Features

Using a high-resolution topographic digital map is essential when dealing with emission sources close to terrain. Micro-scale dispersion modelling (at spatial grid scales of less than 100 m) resolves more of the dispersion dynamics related to flow stagnation (either the flow is blocked by terrain or opposing flows converge in one location), and also flow divergence (in a topographically confined area). These aspects of the flow are all related to how well the terrain is represented in the model and how well the topographically-forced flows are resolved.

To check whether the dispersion model resolves the effects of surrounding terrain, an examination of the contour plot of the mean GLC over the modelled period is necessary. Indications of contours shaped by the underlying terrain should be evident. An example can be seen by comparing the peak GLC contours of Figure 5 (Case Study 1) and Figure 6 (Case Study 2) of the main report. The peak GLC contours of Case Study 1 reflect the wind speed and direction distribution shown in the wind-rose diagram (Figure B1(a)). In contrast, the peak GLC contours of Case Study 2 are affected by the undulating surrounding terrain in addition to the wind speed and direction distribution shown in Figure B1(b).



(a) (b)

Figure B1: Wind speed and direction distribution plotted as a wind-rose frequency diagram for the Case Study 1 and 2 stack locations.

The impact on GLCs of the proximity of the site to terrain is as follows:

- The terrain can alter the GLC spatial pattern by creating convergence (high GLC) and divergence (low GLC) zones related to topography shape.
- Locations of maximum GLC for stack heights similar to the height of the downwind terrain, but above the surface-based inversion layer, would be on adjacent terrain. This is because winds above the surface based inversion are relatively strong, and horizontal transport of pollutants is rapid enough that the plume remains coherent and affects GLCs on adjacent terrain (that is, there is not enough time for vertical dispersion of pollution through the mixed-layer).

To ensure that the dispersion modelling has resolved nearby topographic features the following should be considered:

- In relatively simple, flat terrain, as in Case Study 1, check that the GLC contour patterns are consistent with the wind rose.
- In complex terrain, as in Case Study 2, check that the GLC contour patterns are consistent with the underlying terrain undulations downwind of the emission source.

The Representativeness of AUSPLUME Input Data of Prevailing Regional Flow Patterns

The representativeness of the input data becomes more relevant for calm regional flow conditions that are associated with cold air pooling near the surface accompanied by limited vertical mixing or low mixing heights. There should be no problem with correctly-placed weather stations to capture the regional flow signal. Weather stations for the purpose of dispersion modelling should be placed as close as possible to the expected emission source but also not adjacent to any building or terrain obstacle. Diagnostic gridded meteorological data sets usually represent the regional flow especially if they are driven by larger scale mesoscale modelled data, as is the case with the CALMET derived data set. Nevertheless, it is advisable to check for this by comparing wind speed, direction and atmospheric pressure time series extracted from the CALMET grid with data from a weather station in the region of interest (whose data were not input to CALMET). If the meteorological input data underestimates the pressure gradients and resulting wind speeds, then GLCs may be more conservative, and conversely.

A further consideration of the meteorological input data to AUSPLUME relates to the character of the regional and local flows. If they are different, the meteorology that the plume experiences away from the source is different from the near-field meteorology. This usually occurs in areas of complex terrain, or when the local meteorology is decoupled from the regional flow pattern. Such conditions are examined in the following section, and these may be reasons for not using AUSPLUME.

The Appropriateness of Single-point AUSPLUME Meteorological Data Sets in Complex Terrain

If the dispersion model is applied to an area within a valley, if ridges are higher than the stack height, or if there are obvious terrain features (such as saddles, terrain gaps, or even large water bodies) within 1 to 2 km of the emission source, it is advisable not to use a dispersion model based on a single-point meteorological data set. Otherwise, care should be taken in interpreting the results.

For Case Study 2, meteorological fields (wind speed, direction, and mixing height) can be extracted from several locations on the CALMET grid within a 1 to 2 km radius of the emission source, and variability in the meteorological fields can be examined. Plume patterns and GLCs may be resolved differently by the model, according to the location at which the meteorological driver is chosen from an area of spatially heterogeneous meteorological fields. This latter point will be discussed thoroughly in the following section. However, it is irrelevant if the meteorological driver for AUSPLUME is from weather-station data, as there is a more limited choice of weather station locations – there may only be one in the vicinity.

Spatial Variation in Meteorological Parameters

In this section the relationships between wind speed and direction and mixing height are explored based on data extracted from three different locations from the CALMET gridded data set for Case Study 2. This analysis is then put into the context of the previous discussion. The locations used for this comparison are the Onekawa meteorological site, used in the main report, and two further locations, labelled Marewa-NE and Marewa-E. Marewa-NE is in the southeastern foothills of Hospital Hill, around 1.5 km northeast of Marewa Park. Marewa-E is located around 2 km to the east of Marewa Park. The locations are shown in Figure B2. The two further sites are close to the Onekawa site, but also represent areas potentially affected by topographic and coastal atmospheric boundary layer processes. All sites are similar distances from the modelled industrial site in Onekawa.

Figure B2: A topographic map of Case Study 2 with the locations of the Onekawa, Marewa-NE and Marewa-E sites marked.

The Marewa-NE and Marewa-E sites were chosen as alternative sites to the Onekawa site as they represent locations in proximity to (i) terrain (Marewa-NE) that might be affected by topographically induced modifications to the meteorology, and (ii) the coast (Marewa-E) that might be affected by coastal boundary layer processes or sea breeze intrusions. Figure B3 summarizes the important meteorological fields in dispersion modelling that would lead to spatial and magnitude variations in GLCs. The three sites show two main meteorological regimes, which are also depicted in the wind-rose diagram of Figure B1(b) for Case Study 2. The first regime is a synoptically driven pressure gradient creating the northwest and southwest prevailing wind flows in the area, which are associated with higher surface wind speeds; the second regime results from local pressure gradients created by the thermal circulation of the easterly and northeasterly sea breezes, associated with lower surface wind speeds.

The main feature in Figure B3 is the direct relationship between surface wind speed and mixing layer height. All three locations exhibit the same relationship that indicates an increase in mixing layer height (or more vertical dispersion of ground-level air pollution) with an increase in wind speed. Low mixing heights (less than 500 m) occur at wind speeds less than 4 m/s. At this mixing layer height, or less, the atmospheric dynamics start to favour less vertical mixing and higher GLCs.

The effect of proximity to terrain is depicted in site Marewa-NE, located on the southeastern foothill of Hospital Hill. Figure B3(b) (Marewa-NE) shows far fewer southeasterly winds, which is a result of topographic blocking and re-alignment of flow along the topographic northeast to southwest line.

A feature that distinguishes Marewa-E and Marewa-NE from the inland site (Onekawa) is the higher wind speeds from the easterly and northeasterly sectors. These two sites are closer to the coast and are influenced by the sea breeze and coastal pressure gradient regimes. This does not necessarily indicate that the coastal sites will have higher GLCs if the emission source was placed in that region or if those sites were used as the meteorological drivers to the dispersion modelling. The GLCs are also determined by the mixing height. The Marewa-E site has more mixing heights lower than 500 m (seen by the green, yellow and black points in Figure B3(c)). This feature is a result of the sea breeze dynamics in this coastal site. The sea breeze is usually a shallow stream of cool air that creates an internal boundary layer over the land and limits the mixing layer heights to low levels, usually to a maximum depth of 500 m. This process is clearly reflected at the coastal site (Marewa-E), where easterly winds between 2 m/s and 5 m/s are associated with lower mixing heights.

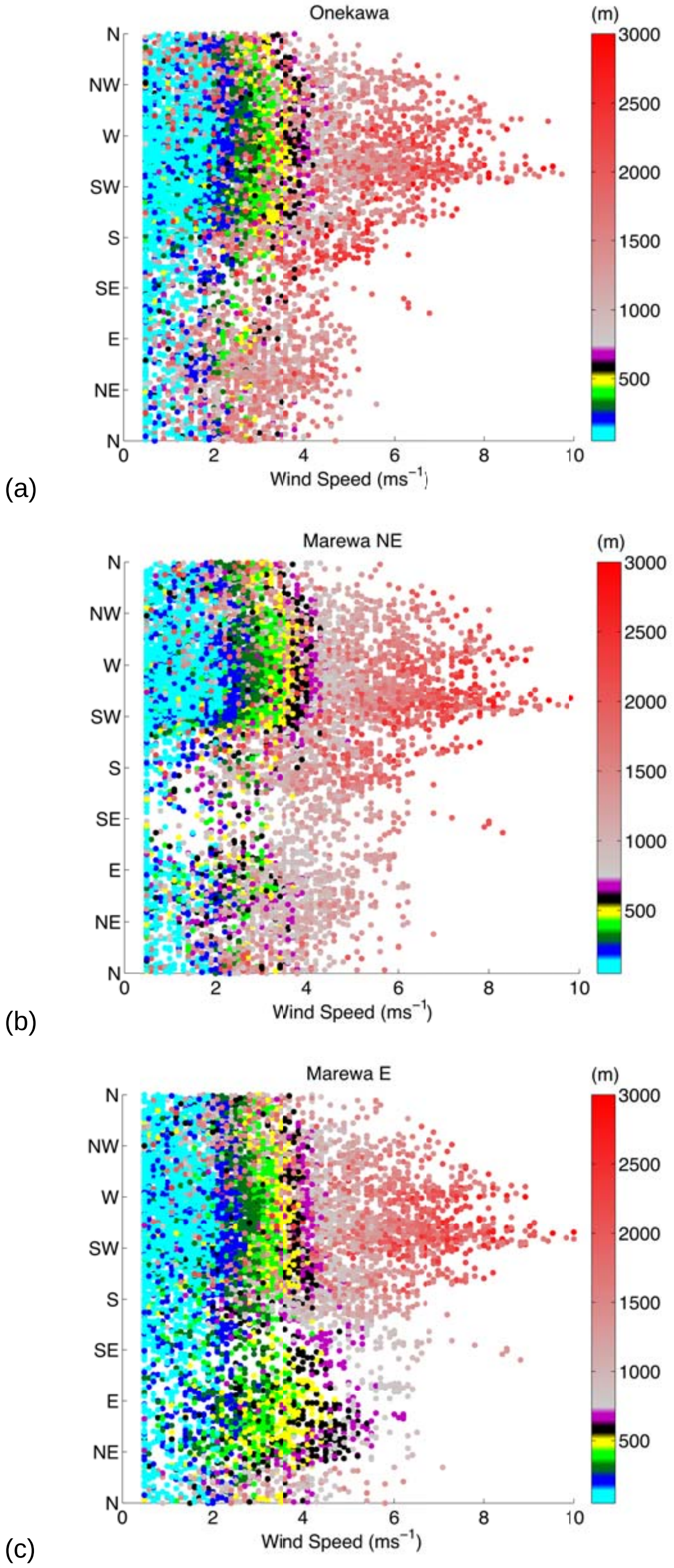


Figure B3: Scatter plot of wind speed and direction coloured by mixing layer height from the three meteorological sites (Onekawa, Marewa-NE, and Marewa-E). Data are from the CALMET gridded meteorological data set used in Case Study 2

APPENDIX C

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Report Limitations

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