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URBAN AIRSHED MODEL AND METEOROLOGICAL DATA SETS

Airshed Modelling of Exposure to Particulates in the Hawke's Bay Region

Prepared for

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REPORT

Golder Associates

Executive Summary

This report addresses several air quality management issues of importance to the Hawke's Bay Regional Council (HBRC), using meteorological and airshed dispersion modelling techniques. The report focuses on current and future levels of airborne fine particulate matter (PM_{10} – particles less than 10 micrometres in diameter) in the region, identification of peaks in PM_{10}, effects of emissions reduction scenarios, cross-boundary dispersion, and compliance with the National Environmental Standard (NES) for 24-hour-average PM_{10} and World Health Organization (WHO) guideline for 24-hour-average $PM_{2.5}$. It also gives a qualitative comparison of source apportionment and emissions inventory studies carried out in the region, and provides a suite of modelled meteorological data sets for use in dispersion modelling as part of industrial resource consent applications. Source-apportionment data were used to give an indication of naturally-occurring levels of PM_{10}. These have been combined with airshed modelling results for the dispersion of PM_{10} from sources such as domestic heating, motor vehicles and industry. This work thus gives estimates of total PM_{10}, from both anthropogenic and natural sources.

The airshed model, TAPM, performed well in simulating peak PM_{10} concentrations measured at the HBRC air quality monitoring sites at Marewa Park and St John's College. It identified other 'hot spots' of PM_{10} due to domestic heating during winter. These were at Pirimai in Napier, and in an area encircling central Hastings (including the St John's College site but not including Hastings Central itself). The modelling indicates levels of PM_{10} higher than 90 µg/m^3 are possible in locations in both Napier and Hastings other than the monitoring sites (this the 24-hour average PM_{10} based on 2010 emissions data), although the spatial extent of higher concentrations is larger in Hastings.

Reductions in emissions from domestic heating by 47% in Napier and 50% in Hastings (relative to current emission levels) were indicated by the model for compliance with the NES for PM_{10}. These percentages may be converted to numbers of wood burner removals or replacements, although the calculation is not done in this report. It is unclear whether emission reductions measures need to be taken in Havelock North, as the model indicates that this urban area is currently compliant with the NES by a small margin.

Dispersion between the urban areas was indicated by the model to be small in worst-case conditions, so that reduction measures applied to one area would have very little effect on air quality in the other. Significant dispersion between Census Area Units (CAUs) within the urban areas was found by the model in worst-case conditions, meaning that the results of CAU-specific reduction measures would be complex and difficult to predict.

The model indicated that all airsheds would be compliant with the NES for PM_{10} by 2020, based on projected emissions. However, there are some uncertainties in the emissions projections supplied to Golder, and these results should be treated with care.

Estimates of peak $PM_{2.5}$ (particles less than 2.5 micrometres in diameter) have been provided, based on a re-scaling of PM_{10} emissions, for comparison with the WHO 24-hour guideline $PM_{2.5}$ concentration. The domestic heating component of $PM_{2.5}$ was assumed to be 85% of PM_{10}, such that resulting peak modelled concentrations of $PM_{2.5}$ were close to those of PM_{10}. As the WHO $PM_{2.5}$ guideline concentration is one-half of the NES for PM_{10}, emissions reductions required for compliance with the $PM_{2.5}$ guideline would be more stringent than those required for compliance with the NES. The modelling indicated a required reduction in domestic heating emissions of 72%, in both Napier and Hastings.

High-resolution meteorological data sets have been produced, covering Napier, Hastings, Awatoto, Whirinaki and Wairoa, based on modelled meteorology and local climate-site data. These have been created using the meteorological model CALMET, and are intended for used by consultants running the pollution-dispersion model CALPUFF for industrial assessments. Additional meteorological files have been extracted from the CALMET data sets for use with the AUSPLUME dispersion model.

The report makes several suggestions for improvements in the modelling and associated data sets, and for further applications of the models to the management of air quality in the Hawke's Bay region.

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1.0 INTRODUCTION

This report describes the application of computational models to air quality issues in the Hawke's Bay region. The models comprise an urban airshed model of the Heretaunga Plains, and model-derived three-dimensional meteorological data sets for industrial resource-consent applications. The computational tools have been developed to support resource management decision-making of the Hawke's Bay Regional Council (HBRC). The urban airshed model has been used to address aspects of the dispersion of fine particulate material (PM) around Napier, Hastings, Flaxmere and Havelock North, focusing on compliance with the National Environmental Standards (NES) for air quality (MfE 2011) and the effects of emissions-reduction measures on future air quality. The meteorological data sets have been produced for distribution among air quality professionals for use in their assessments of air quality effects of industrial discharges.

The specific requirements of HBRC are listed in Table 1 with their corresponding report sections.

Table 1: Project task list and report sections.

Task	Description	Section
(a)	Identification and quantification of 'hot spots' of particulate matter with diameter less than 10 µm (PM_{10}) in the urban areas of Napier and Hastings due to domestic heating emissions.	4.3
(b)	Examination of dispersion of PM_{10} between airsheds, between HBRC's air zones, and between census area units (CAUs) within airsheds.	4.5
(c)	Assessment of emissions reductions required in the Napier and Hastings airsheds relative to present-day conditions, as reflected in the 2010 emissions inventory, to achieve the NES (24-hour average PM_{10} concentration 50 µg/m^3).	5.2
(d)	Determination of the number of wood-burner conversions represented by the required reduction in PM_{10} emissions in Task (c).	5.2
(e)	Assessment of PM_{10} levels in the airsheds relative to projected emissions for 2020 after the conversion or phase-out of domestic wood-burners and cessation of outdoor burning.	5.3
(f)	Assessment of $PM_{2.5}$ levels in relation to the WHO guideline for 24-hour average $PM_{2.5}$ (PM with diameter less than 2.5 µm; guideline value 25 µg/m^3).	6.0
(g)	Provision of meteorological data sets for industrial air quality assessments.	8.0

Golder Associates (NZ) Limited (Golder) has addressed these requirements in this report. This has required some model calibration, testing and evaluation, which is an intrinsic part of any modelling project. Model testing results have been included in this report. In addition to the above list, Golder has carried out a basic review of emissions inventory and source-apportionment studies to ensure that the main sources of particulate pollution are accounted for, and that they have been incorporated into the dispersion modelling[1]. This essentially has meant accounting for the observed natural component of PM from sea spray and soil, which is not included in emissions inventories.

For clarity, the geographical entities mentioned above are delineated in Figure 1. The gazetted airsheds of Napier, Hastings, Awatoto and Whirinaki are outlined in dark blue. The Hastings airshed contains the towns of Hastings, Flaxmere and Havelock North. The Napier and Hastings airsheds have each been divided into two Airzones. Airzone 1 refers to urban areas in each airshed, and Airzone 2 refers to surrounding rural areas still within the airshed boundary. Open fire and solid-fuel burner phase-out dates and wood burner emission limits differ between Airzone 1 and Airzone 2. The CAUs in the region are outlined in light blue (for Airzone 1) or red (all others).

[1] This was part of Golder's Scope of Services.

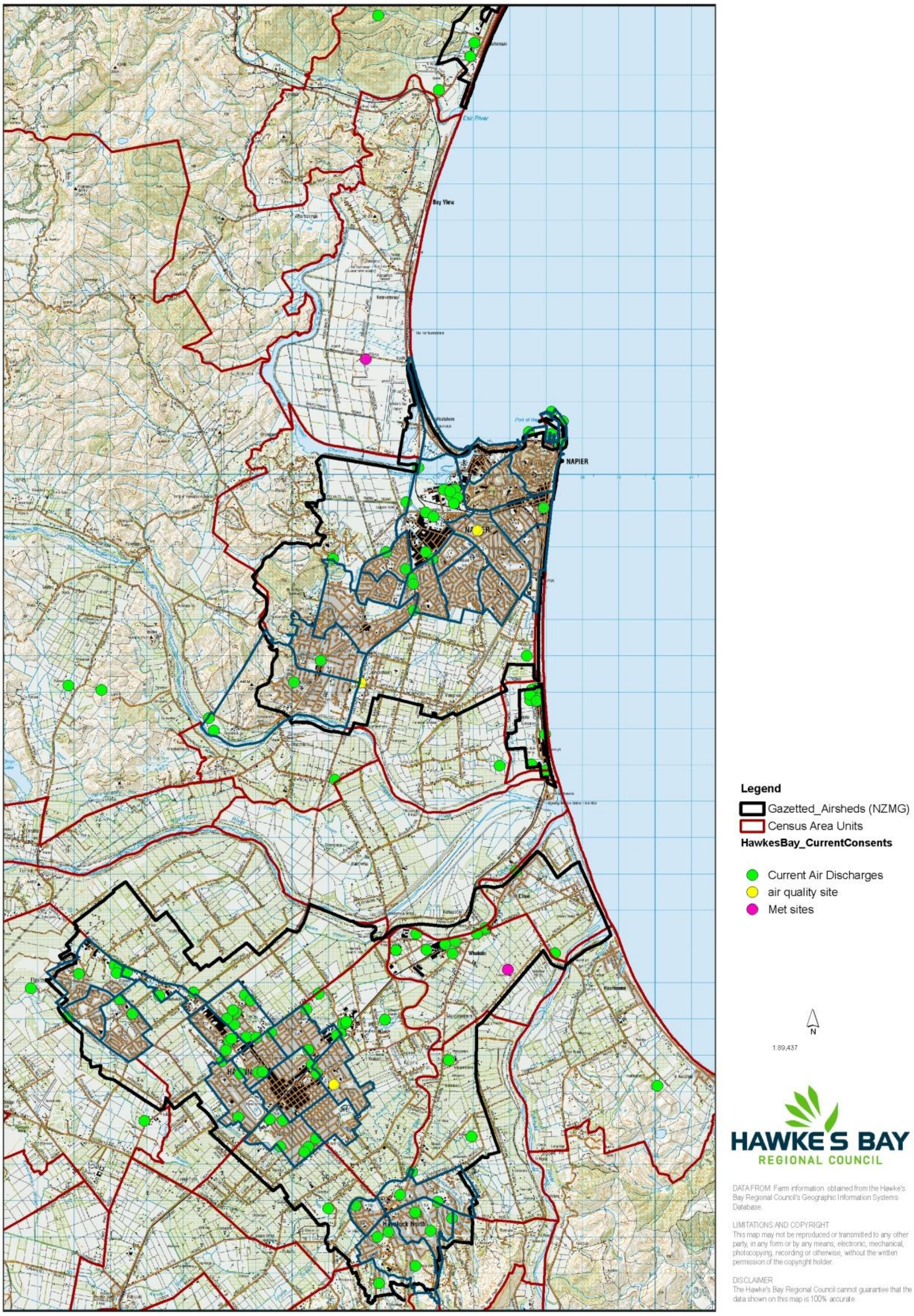


Figure 1: Airsheds (dark blue outlines) and CAUs (red) in the Hawke's Bay region (used with permission of HBRC).

List items (a) to (f) have been addressed using The Air Pollution Model (TAPM), developed in Australia by CSIRO (Hurley 1999; Hurley et al. 2005b), and used here to model air quality processes in the urban airshed. The airshed model may be used to aid characterization of air quality, identify and quantify pressures on air quality from sector emissions, predict future trends in air quality and compliance with the NES and ambient air quality guidelines (MfE 2002; MfE 2011), and to assess the effects of emissions management options. TAPM has been run for the Heretaunga Plains at high resolution (an area approximately matching that of Figure 1 at horizontal grid resolution 500 m), based on the meteorology of the five-year period 2006-2010 and on urban emissions from inventories of sources compiled for the years 2005 and 2010 (Wilton 2005; Wilton & Baynes 2010).

Regarding list item (g), meteorological data sets for four areas have been produced using the CALMET model. The CALMET outputs are used by the CALPUFF dispersion model. They can be provided to users of CALPUFF, who then need not run CALMET as part of their air quality assessments. The CALMET data sets contain hourly, three-dimensional meteorological fields, at 100 m or 200 m horizontal resolution as appropriate, for the years 2006 and 2010. These are based on TAPM model outputs and observations from climate stations run by HBRC, and cover Napier (centred on Onekawa), Hastings and Awatoto (combined into the same data set), Whirinaki and Wairoa. From these data sets, several single-point meteorological files have been extracted and converted for use by AUSPLUME.

Although Wairoa has not been gazetted by HBRC as an industrial airshed, meteorological data sets have been produced for this area. Levels of PM_{10} there are thought by HBRC to be significant enough so that it may be identified as a polluted airshed in the future, following further monitoring and modelling. Airshed modelling of Wairoa has not been carried out as part of the scope of the current project, although some has been carried out in previous years (Gimson 2006).

The models have been evaluated by comparison with observations of meteorology and ambient PM_{10} concentrations, to ensure that they give physically realistic results.

In the remainder of this report, Section 2.0 contains a brief review and comparison of emissions inventory information for the Hawke's Bay area and source apportionment studies carried out in Napier and Hastings. It also derives estimates of the natural component of PM_{10} from sea spray and soil dust for incorporation into the airshed modelling. Section 3.0 summarizes the configuration, calibration and evaluation of TAPM, whose details are contained in Appendices A, B and C. Section 4.0 presents airshed model results for present-day levels of PM_{10} at the HBRC air quality monitoring sites, indicates potential hot-spots of PM_{10}, and examines dispersion of PM_{10} between Airzone 1 areas and among CAUs. Section 5.0 discusses PM_{10} emissions reductions required to meet the NES for PM_{10}, and compares them with airshed model results for PM_{10} in the year 2020, which are based on predicted emissions. Section 6.0 provides modelled estimates of $PM_{2.5}$ in the region, based on estimated $PM_{2.5}/PM_{10}$ emission ratios, and compares them with the WHO guideline for 24-hour average $PM_{2.5}$. Section 7.0 gives a summary of airshed modelling findings and discusses possible improvements to the modelling. Section 7.4 provides suggestions for future applications of the model. Section 8.0 introduces the CALMET and AUSPLUME meteorological data sets, which are described fully in Appendices D[2] and E. Concluding remarks are made in Section 9.0 and references listed in Section 0.

This report is provided subject to the limitations listed in Appendix F.

[2] A description of the CALMET and AUSPLUME data sets and guidance on their use is contained Appendix D, which may be read as a stand-alone document.

2.0 REVIEW OF EMISSIONS INVENTORIES AND SOURCE APPORTIONMENT STUDIES IN THE HAWKE'S BAY REGION

2.1 Introduction

Source apportionment studies have been carried out and emissions inventories have been compiled for the Hawke's Bay region to quantify sources of $PM_{2.5}$ and PM_{10} (Wilton 2005; Wilton & Baynes, 2010; Wilton et al. 2007; Wilton et al. 2010). These studies examine PM source composition from different perspectives, namely, through surveys of emissions (based on human behaviour) over the region and through analysis of the elemental composition of the total PM at a number of monitoring sites. Quantitative differences in the proportional make-up of the total PM are due to dispersion effects, site location and the specific sources surveyed. One of the aims of this work is to provide the link between emissions and ambient levels through airshed modelling, which uses emissions inventory data as inputs. The model performance is evaluated by comparison with monitored ambient PM.

Before airshed modelling is carried out, *qualitative* differences between emissions and source-apportionment data should be examined. This can be as elementary as ensuring that the same source-types are present in each data set. It is to be expected that there will be differences. For instance, source-apportionment will see natural or secondary components of PM not quantified in an inventory. Or, specific industrial emissions included in an inventory may not arise statistically in source-apportionment analysis, or even be evident in the raw PM samples. After carrying out such a basic examination, expectations of the airshed modelling should not be unrealistic.

This section compares source apportionment and inventory data in a qualitative sense to determine whether the same source-types feature in each. Their respective proportions may differ quantitatively (due to dispersion effects), and the airshed modelling will be used in later sections to provide a link between them. In this section, the aim is to examine source types which feature in the source apportionment, but which may be missing from the emissions inventory, and devise a way of incorporating them into the airshed modelling results. These may be natural sources of PM (such as sea spray or crustal matter) or other long-range components, or they may be secondary particulates such as nitrates, sulphates or organic aerosols. The necessary focus in this section turns out to be natural sources.

The emissions inventory and source apportionment studies relating to the region are discussed in Sections 2.2 and 2.3, respectively. Section 2.4 compares the sources identified in these studies. Section 2.5 quantifies PM_{10} and $PM_{2.5}$ from natural sources to be incorporated into airshed modelling results.

2.2 Hawke's Bay Emissions Inventory

The 2010 air emissions inventory for the Hawke's Bay region includes emissions from domestic heating, motor vehicles, industry and other commercial activity, aviation and shipping (Wilton & Baynes 2010). The emissions inventory focused on PM_{10}, carbon monoxide (CO), sulphur oxides (SO_x), nitrogen oxides (NO_x), volatile organic compounds (VOC) and carbon dioxide (CO_2), but not $PM_{2.5}$. The inventory does not include outdoor burning, as it is now subject to controls that should prevent it occurring during meteorological conditions that would lead to high levels of PM_{10}. The inventory does not include natural sources, either.

Domestic heating emissions were determined by a survey of home heating methods and appliance use. Domestic heating is the main source of PM_{10} in the Hawke's Bay region during the winter, and accounts for between 92-97% of all PM_{10} emissions in Hastings, Napier and Havelock North. Port emissions were determined from Port of Napier records for the number and type of ships entering and leaving the port. The Napier airport emissions were based on airport records of the number of take-off and landing cycles of different aircraft. Motor vehicle emissions were based on a road network model developed for the region, along with the NZ Vehicle Fleet Emissions Model. Industrial emissions included the main industrial and commercial activities in the area, and included school boilers.

Dispersion modelling described in subsequent sections of this report has been based on two variations of the 2010 air emissions inventory, along with the inventory for 2005 and projections to 2020 (see Appendix B).

2.3 Source Apportionment Studies

2.3.1 Introduction

Source apportionment techniques are based on samples of PM, with filters exposed for 24 hours and analysed using the particle-induced X-ray emission (PIXE) to determine their elemental composition. The elemental profiles are then processed using positive matrix factorisation (PMF) to identify the predominant elemental signatures in the samples. The signatures are matched with specific source types, based on their chemical composition. For example, a signature with high levels of chlorine and sodium and few other elements is likely to be sea spray. Other signatures may have high levels of black carbon from combustion sources, such as domestic heating or motor vehicles, depending on the other elements in their signature. PMF does not always provide a robust distinction between sources, particularly combustion sources, and may not identify individual minor sources (such as specific industries) which have a low statistical significance

2.3.2 Napier source apportionment

PM samples were collected at Marewa Park, Napier, between February 2008 and November 2009. Samples were not distributed evenly throughout the year, with more being collected during the winter months and none during December or January. Of the 79 samples collected over the two year period, 61 were collected in autumn and winter, between March and August. Samples were analysed for coarse and fine PM ($PM_{2.5-10}$ and $PM_{2.5}$, respectively; PM_{10} is therefore the sum of these components).

Three components of $PM_{2.5-10}$ were identified, namely, sea spray, soil and domestic/sea spray. The domestic heating signature would usually be expected to be comprised mainly of black carbon (BC). However, the elemental fingerprint appearing in the Napier samples also contained significant components of sodium (Na) and chlorine (Cl), meaning that sea spray and domestic sources did not show up separately in the statistical analysis. Based on the proportions of Na, Cl and BC in the source apportionment results, (Wilton et al. 2010), estimated that 36 % of the combined domestic/sea spray PM could be attributed directly to domestic heating, and the remaining 64 % to sea spray. These percentages have been assumed in order to separate the domestic heating and sea spray components, for the purposes of development of a simple model for sea spray, and for airshed model validation. The contribution from the domestic/sea spray component was generally less than 5 $\mu g/m^3$. The contributions from sea spray to $PM_{2.5-10}$ tended to be higher in the late summer and autumn months. However, with no summer sampling, it cannot be determined if the higher sea spray contributions also occurred through the summer.

Four components of $PM_{2.5}$ were identified in the source apportionment analysis. These were domestic heating, sea spray, motor vehicles and secondary sea spray. The secondary sea spray portion was dominated by sulphur and sodium with some chlorine. This suggested to Wilton et al. (2010) the formation of secondary particulate from the neutralisation of sulphuric acid by sea salt. $PM_{2.5}$ was dominated by domestic heating, with small contributions from the other components. The sea spray concentration was generally less than 2 $\mu g/m^3$. The domestic heating component of $PM_{2.5}$ was seasonally varying, with significantly higher concentrations in mid-winter months than in the warmer months.

In Sections 2.4 and 2.5, PM_{10} for Napier is presented as the sum of $PM_{2.5}$ and $PM_{2.5-10}$.

2.3.3 Hastings source apportionment

PM samples were collected at St John’s College, Hastings, between April 2006 and April 2007. Samples were typically collected on one day in three, with two periods (March and August) where samples were collected on one day in two. Of the 111 PM_{10} samples, 71 were collected in autumn and winter, between March and August. Of the 120 $PM_{2.5}$ samples, 70 were collected between March and August.

Five components of PM_{10} were identified, namely domestic heating, sulphate, sea spray, motor vhicles and soil. The sulphate component was believed to be a combination of sea spray and industrial emissions. PM_{10}

was dominated by domestic heating, plus a significant proportion of sea spray. The sea spray component of PM_{10} was generally less than 5 µg/m³ and tended to have higher contributions during the summer months. The soil and sulphate proportions of the measured PM_{10} were small, with soil generally being less than 4 µg/m³ and sulphates being less than 2 µg/m³. There was only a slight seasonal variation in the soil contribution and no discernable seasonal variation in the sulphate contribution.

Four components of $PM_{2.5}$ were identified, namely sea spray, sulphate, domestic heating and motor vehicles. $PM_{2.5}$ was also dominated by domestic heating. Domestic PM_{10} and $PM_{2.5}$ were seasonally varying, with higher concentrations during the winter months and low concentrations during the warmer months.

2.4 Comparison between Source Types Identified by the Emissions Inventory and Source Apportionment Studies

A summary of the sources identified in the emissions inventory and source apportionment studies is shown in Table 2 for the Napier and Hastings airsheds. The proportions of each source between April and September according to each study are shown in Figure 2. The proportions of emissions shown in Figure 2 are as given in the emissions inventory for 2010. The proportions from source apportionment studies are derived from the total of all samples taken between April and September, and are essentially the fractions of the total mass sampled over the whole season.

The Napier source apportionment analysis did not identify contributions from the port, airport or industry. According to the inventory, these are not large in magnitude, and are located in a narrow range of directions from the monitoring site, and it is likely that their contribution to the measured PM is too small to be statistically significant. This is in contrast to domestic heating, vehicles and natural sources which have a larger magnitude and would be sampled under all wind directions.

As can be seen in Figure 2, 20-40 % of the total PM_{10} and approximately10 % of the total $PM_{2.5}$ measured by source apportionment in Napier and Hastings between April and September was attributed to natural sources. This is a significant portion of the total particulate, which is generally not part of an emissions inventory. However, basing airshed modelling only on the anthropogenic sources contained in the emissions inventory may not lead to a good match to observed air quality, unless some account is taken of the natural sources, particularly sea spray.

Table 2: Summary of sources identified in emissions inventories and source-apportionment studies.

Component	Emission inventory PM_{10}	Source apportionment			
		Napier $PM_{2.5-10}$	Hastings PM_{10}	Napier $PM_{2.5}$	Hastings $PM_{2.5}$
Domestic heating	✓	✓	✓	✓	✓
Industry	✓		✓*		✓*
Motor vehicles	✓		✓	✓	✓
Port activities	✓				
Napier airport	✓				
Sea spray		✓	✓	✓	✓
Soil		✓	✓		

* The sulphate portion measured in Hastings was attributed to industry and sea spray.

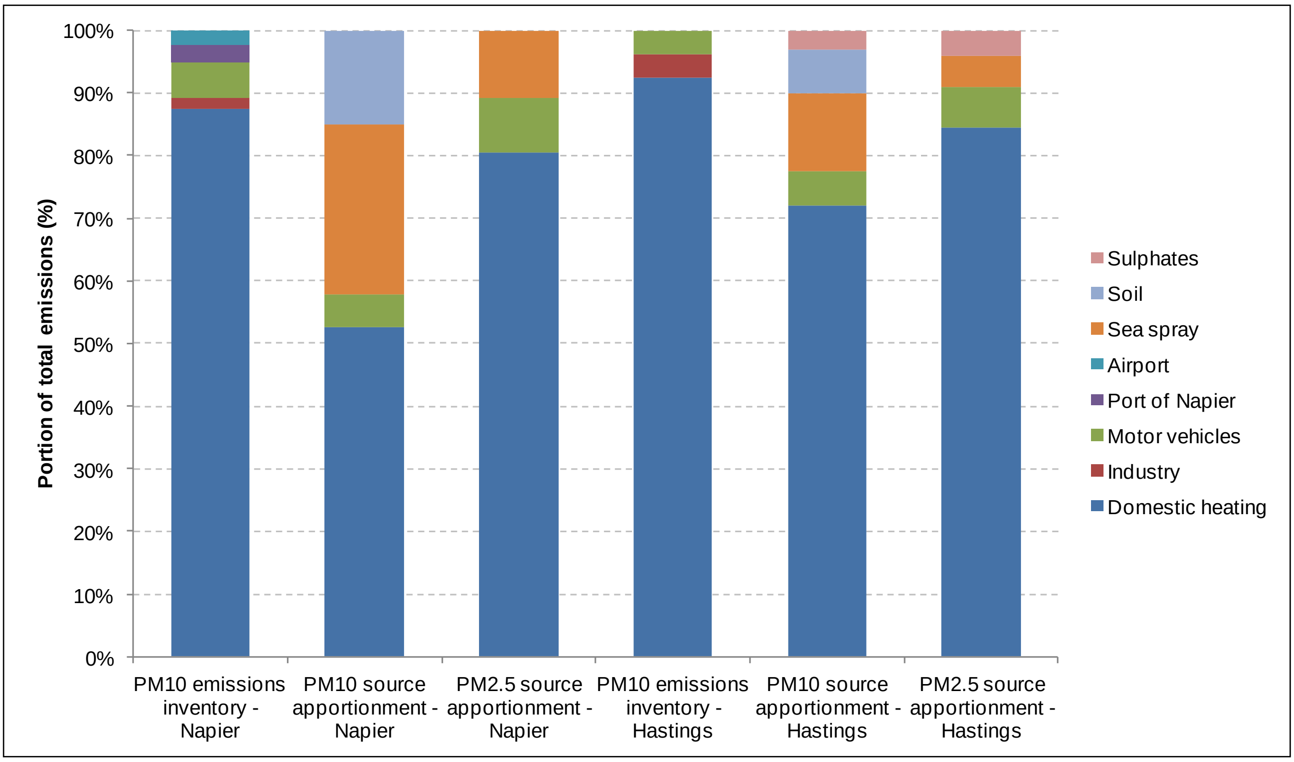


Figure 2: Proportion of total emissions or concentrations between April and September attributed to each source in the emissions inventory and source apportionment studies.

2.5 Combining Natural Sources with Airshed Modelling Results

The source-apportionment results have been examined, focusing on natural PM_{10} and $PM_{2.5}$ concentrations. The aim of this was to determine whether naturally-occurring PM in the Hawke's Bay region could be represented by a simple dependence on meteorological parameters, such as wind speed, wind direction, or on distance from the coast. However, there appears to be no simple relationship which accounts for the natural variability. Therefore, natural levels of PM will be added to the airshed modelling results as a post-processing step, as a range of concentrations (defined by the mean and standard deviation).

Statistics for natural PM_{10} and $PM_{2.5}$, derived from source apportionment results are shown in Table 3 and Table 4. The statistics are calculated from the natural components in the individual source apportionment samples. The data have been broken down into the months April to September and the months October to March. This has been done to account for seasonal differences, and to isolate the time period most relevant to the airshed modelling (April to September). The sea-spray component of PM_{10} for Napier is represented by the sum of the sea spray components of $PM_{2.5\text{-}10}$ and $PM_{2.5}$, plus 64 % of the combined domestic/sea spray category[3]. The sulphate contributions measured in Hastings have not been included in the calculated natural source components.

[3] Based on the proportions of sodium,, chlorine and black carbon in the source apportionment results, Wilton et al. (2010) estimated that 36 % of the combined domestic/sea spray PM could be attributed directly to domestic heating, and the remaining 64 % to sea spray.

The natural PM_{10} and $PM_{2.5}$ concentrations can therefore be added to the airshed modelling results as follows to produce the following ranges:

Total PM_{10} = modelled anthropogenic PM_{10} + natural PM_{10} (mean – 1 x standard deviation)

Total $PM_{2.5}$ = modelled anthropogenic $PM_{2.5}$ + natural $PM_{2.5}$ (mean – 1 x standard deviation).

The total PM_{10} and $PM_{2.5}$ concentrations are represented by a range of values, which incorporates the uncertainty in the natural source contribution. However, results presented in the following sections have assumed that during worst-case pollution event in calm conditions, the sea spray component is at the lower end of the range and given by the mean minus one standard deviation. In those conditions, a higher proportion of the total PM is anthropogenic. Concentration statistics are summarized in Table 3 and Table 4. In each table, the concentrations of PM_{10} and $PM_{2.5}$ which are to be added to the airshed model results for each town (for April to September) are emphasized in bold type.

Table 3: Concentration statistics for natural sources in Napier.

	PM_{10} (µg/m³)			**$PM_{2.5}$ (µg/m³)**
	Sea Spray	**Soil**	**Sea Spray and Soil Combined**	**Sea Spray**
April - September				
min	1.2	0.0	1.2	0.052
mean	4.1	2.3	6.3	0.97
max	8.1	8.0	13	3.3
standard deviation	1.7	1.9	2.5	0.66
value used in modelling			**3.8**	**0.3**
October - March				
min	1.9	0.0	4.8	0.17
mean	6.7	2.3	9.0	1.4
max	16	12	16	3.7
standard deviation	3.7	2.8	3.7	0.86

PM_{10} concentrations are the sum of the $PM_{2.5}$ and $PM_{2.5\text{-}10}$ concentrations.

Table 4: Concentration statistics for natural sources in Hastings.

	PM_{10} (µg/m³)			$PM_{2.5}$ (µg/m³)
	Sea Spray	**Soil**	**Sea Spray and Soil Combined**	**Sea Spray**
April - September				
min	0.0	0.0	0.44	0.00
mean	3.3	1.9	5.2	0.90
max	22	7.9	22	5.4
standard deviation	3.6	1.9	3.7	0.91
value used in modelling			**1.5**	**0.0**
October - March				
min	0.45	0.0	0.75	0.018
mean	5.2	1.8	7.0	1.9
max	17	5.4	18	6.7
standard deviation	3.9	1.5	4.2	1.5

2.6 Summary

A qualitative comparison of inventory and source apportionment results has been carried out in this section, which has identified a need to account for natural sources in the airshed modelling. Simple statistics of sea spray and soil $PM_{2.5}$ and PM_{10} concentrations have been calculated for Napier and Hastings, and will be added to the airshed modelling results, as the mean for the April to September period *minus* one standard deviation.

3.0 TAPM CONFIGURATION AND EVALUATION

3.1 Background – Use of TAPM in the Hawke's Bay region

As mentioned in the introduction, TAPM was originally developed by CSIRO in the late 1990s as a tool to carry out environmental impact assessments (Hurley 1999; Hurley et al. 2005b). It includes a prognostic meteorological model and several modules to simulate dispersion of air contaminants. It was developed to model dispersion from industrial point sources, and also as an urban airshed model (Hurley et al. 2003; Luhar & Hurley 2003). It has been evaluated by comparison to several standard test data sets, and compared with other commonly used dispersion models (Hurley & Luhar 2005; Hurley et al. 2005a; Hurley 2006). The work presented here uses Version 4.0 (Hurley 2008; Hurley et al. 2008).

TAPM has been used for air quality studies in several cities in NZ. These include Auckland (Gimson 2005a; Golder 2011), Christchurch (Zawar-Reza et al. 2005), Masterton (Xie et al. 2006) and Alexandra (Tate et al. 2011). Moreover, the model has been previously run to simulation winter dispersion of PM_{10} in the Hawke's Bay region, either for the HBRC or as part of government-funded research (Golder 2009; Gimson 2006; Wilton et al. 2009).

Gimson (2006) used TAPM to identify regions capable of exceeding the NES for PM_{10}, set straight-line path concentrations for Napier and Hastings, and determine emissions reductions targets for the main towns. Also, the model was used to provide estimates of PM_{10} levels in the small towns of Wairoa, Waipukurau and Waipawa based on the 2005 emissions inventory. Results from this work may be seen on the HBRC web pages on air quality. The airshed modelling was re-examined by Golder (2009) to determine transport of PM_{10} between urban and rural areas. It was found that some PM_{10} in Napier and Hastings could originate in the suburban areas (now designated Airzone 2), but not the rural areas. Moreover, it was found that occasions of highest PM_{10} in Hastings occurred by re-circulation of pollutants as the wind direction changed from on-shore to off-shore during the winter evening. On these occasions, the emitted PM_{10} passed over the urban area twice in one evening. Airshed modelling results were found to be consistent with source-apportionment analysis and receptor modelling in determining the fraction of total PM_{10} which arises from domestic heating (Wilton et al. 2009).

The current work builds on previous studies through the following:

1) Using the recent inventory of emissions to air, which incorporates information collected in 2010;

2) Specifically addressing new air quality management questions, which relate to the updated NES (MFE 2011);

3) Providing more robust conclusions through multi-year model integrations;

4) Providing meteorological data sets for several relevant industrial areas.

This report includes Appendices relating to various aspects of the use of TAPM. These include the preparation of meteorological and emissions data inputs, and the evaluation of meteorological and air pollution outputs. The following sub-sections contain brief summaries of these aspects, referring the reader to the relevant Appendix (as indicated in Table 5) for a fuller description.

Table 5: TAPM configuration and evaluation sections.

Subject	Subsection	Appendix
Meteorological model configuration	3.2	Appendix A
Meteorological model evaluation	3.2	Appendix A
Dispersion model configuration	3.3	Appendix B
Dispersion model evaluation	3.4	Appendix C

3.2 Meteorological Modelling with TAPM

TAPM is a nested grid-point model, which 'telescopes' through several grids from a large-scale, coarse-resolution grid, to a high-resolution grid over the area of interest. TAPM's simulations of meteorology and pollution dispersion have been carried out separately in this work. The configuration of the meteorological component of the model, including domain choices and parameter settings, is described in Appendix A.

Four TAPM grids have been used, the first (coarsest) covering NZ at a horizontal resolution of 25 km. The fourth (finest) TAPM grid is composed of cells with horizontal dimensions 1 km x 1 km, covering a region 35 km by 56 km. Local meteorological data from HBRC-owned sites and the National Climate Database (CliDb) have been assimilated into the model, to 'nudge' the modelled wind towards the observed wind. The six sites are listed in Table 2 of Appendix A, and shown on the map of model terrain at 1 km resolution in Figure 3 (terrain and land use classes for the third and fourth TAPM grids are shown in Appendix A). The meteorological model was run for the complete years 2006 and 2010, and for the months of April to September (inclusive) in 2007, 2008 and 2009. The years 2006 and 2010 were chosen in consultation with HBRC for the provision of full-year CALMET meteorological data sets based on TAPM's meteorological outputs. Airshed modelling was carried out for the mid-year periods only of 2006 to 2010 (inclusive).

An analysis of the meteorological model performance is also provided in Appendix A, in which model results at the monitoring site locations have been compared with the monitoring-site data for most of the modelled years. The analysis calculates the index of agreement and several 'skill' scores. These show a good model performance at those sites, which is to be expected as their data are also incorporated into the model. One of the years (2006) was also run without wind data assimilation, for comparison, showing that the performance measures are improved when wind data are assimilated into the model runs. A visual inspection of some of the output wind fields over the fine grid has been carried out, to ensure that the wind patterns over the region as a whole appear reasonable.

Figure 3: TAPM grid 4 elevation. Dimensions are 35 km by 56 km, resolution 1 km. Terrain contour interval is 50 m, starting at 50 m above sea level. Meteorological sites are marked on the map.

3.3 Inventory Emissions Data and TAPM Airshed Modelling

In addition to the meteorology, the other key inputs to the airshed model are the emissions data. PM_{10} emissions inventory data have been supplied by Environet Ltd (Wilton 2005; Wilton & Baynes 2010). Due to uncertainties in the 2010 inventory identified by Environet and HBRC regarding the number of domestic heating appliances currently in use, projections for 2010 based on 2005 appliance numbers were also carried out by Environet. Hence modelling has been carried out based on (i) the 2005 inventory, (ii) the 2010 inventory, (iii) the 2010 inventory with domestic heating projected from 2005 and (iv) projections out to 2020. Emissions data were provided at the CAU level. CAUs were then mapped onto a regular grid with 250 m by 250 m cells, fine enough to resolve the small CAUs and conserve source areas and emission rates[4]. Sources included domestic heating, motor vehicles, industry, outdoor burning, and port and airport emissions.

A fuller description of the emissions inventory data and its re-formatting for use in the airshed model are contained in Appendix B, and summarized in this section. Also, Appendix B includes a method for approximating $PM_{2.5}$ emissions, based on source-specific factors derived in consultation with Environet.

The airshed model was run over a domain covering the finest grid of the meteorological model (1 km), but at twice the horizontal resolution. That is, the airshed model disperses PM_{10} on 500 m grid cells. However, the emissions were mapped onto a 250 m grid to conserve CAU emission rates (in both kg/day and kg/km^2/day). The computational resources required to run the airshed model at 250 m resolution would have been prohibitive, as a large number of model runs have been carried out. However, shorter test cases have shown very little difference in resulting contaminant ground-level concentrations (glcs) between the 500 m and 250 m dispersion grids, and a 500 m dispersion grid is considered adequate[5]. The spatial patterns of daily emissions from the domestic heating and motor vehicle sources in the Heretaunga Plains area, according to the 2010 inventory, are shown in Figure 4. Enlarged versions of these and equivalent figures for the other inventory sources are shown in Appendix B.

The inventory provides daily emissions totals which vary from month to month for many sources, particularly domestic heating which peaks during the winter. Motor vehicle emissions are assumed not to vary by month, and no weekday/weekend variation of any source is considered in the inventory. Emissions of each source have been given hourly patterns, to represent (for example) peak traffic times and evening and night-time domestic wood burning. The temporal patterns are shown in Appendix B.

A set of airshed model runs has been carried out, dispersing PM_{10} as an inert tracer, modelling the four emissions inventory versions (2005, 2010, 2010 projected from 2005, and 2020), and calculating the contribution from each anthropogenic source type separately. The runs have been carried out based on the modelled meteorology of April to September for the years 2006 to 2010 inclusive. The years 2008-2010 were used for model evaluation purposes, comparing TAPM outputs with ambient air quality data at the HBRC sites Marewa Park and Meeanee Road (Napier) and St John's College (Hastings). Results of the model evaluation procedure are detailed in Appendix C and summarized in Section 3.4. For the presentation of worst-case modelled PM_{10} levels and determination of potential air pollution hot spots, the full five-year period was considered, to capture a larger selection of potential worst-case meteorological conditions.

Further sets of airshed model runs have been carried out to examine dispersion between Airzones 1 and 2, and between CAUs within each airshed. Also estimates of $PM_{2.5}$ concentrations in the region have been made using the approximated $PM_{2.5}$ emissions mentioned above. These further runs are described in Appendix B.

For comparison of model results with ambient air quality observations, and prediction of worst-case PM_{10} dispersion, the natural components of PM_{10} due to sea spray and soil dust, and of PM_{10} due to sea spray only, determined in Section 2.5, have been combined with TAPM results as a post-processing step.

[4] The mapping between model cells and CAUs was provided by HBRC.

[5] TAPM is able to account for gridded emissions not aligning with its meteorological and dispersion grids.

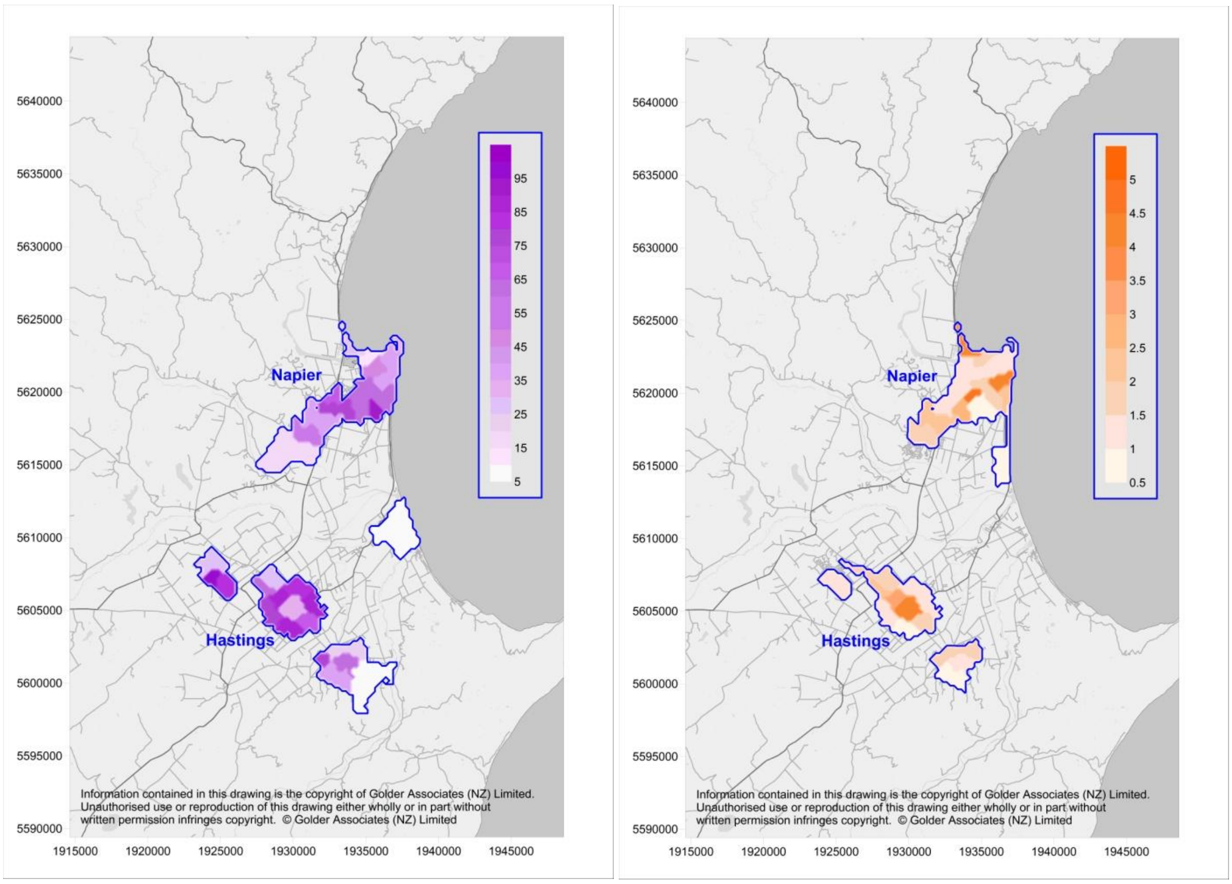


Figure 4: PM_{10} emissions from domestic heating (left) and motor vehicles (right), in kg/km^2/day, for July. Axes show eastings and northings in New Zealand Transverse Mercator coordinates (NZTM).

3.4 Airshed Model Optimization for PM_{10} Dispersion

An integral part of any work using computational models is the comparison of their results with measurements, evaluation of model performance, and re-visiting the original model settings to produce improved results. These processes have been followed in the current work, and they are described in more detail in Appendix C. This section is a summary of part of Appendix C.

Appendix C examined the model results at the Marewa Park and Meeanee Road, Napier, and at St John's College, Hastings, using the emissions data sets outlined in Section 3.3, and compared them with observations at the respective air quality monitoring sites. The performance of the model is discussed in Appendix C for the different emissions data sets, which has led to the following conclusions regarding optimization of model configuration:

a) Emissions inputs to the airshed model should use the 2010 domestic heating data as projected from 2005 appliance numbers.

b) The inventory data defines 'worst-case' and 'average' domestic heating emissions. The worst-case emissions may be represented by multiplication of the average domestic heating emissions by a factor of 1.4 (at all locations); peak PM_{10} concentrations have been assumed to occur under worst-case emissions. The factor of 1.4 is discussed in Appendix C. Items a) and b) in this list constitute Model Scenario 4 (defined in Section 3.1 of Appendix B).

c) Peak 24-hour PM_{10} levels over Napier should be represented by the modelled 2nd-highest PM_{10} concentration. This has the effect of disregarding unreasonable outliers in the modelling. This is not necessary for PM_{10} over Hastings, so that peak levels will be presented by the modelled maximum 24-hour PM_{10} concentration.

d) Emissions inputs to TAPM should be spread over the lowest two model layers (rather than the lowest single layer). This has been found necessary to prevent modelled occurrence of extremes which do not occur in reality. It appears that under calm conditions, TAPM under-estimates vertical mixing; the parameter choice of initial mixing through two layers serves to counteract this. Extreme outliers are removed, but other concentrations remain unchanged.

e) TAPM should not be expected to give predictions of localized peaks of PM_{10} near to the roadside, as modelled concentrations are averaged over 500 m by 500 m grid cells. Also, the emissions themselves are also averaged over grids cells, rather than being given as line sources. Model results from the Meeanee site location should therefore not be compared with measured PM_{10} there.

Carrying out the airshed modelling using TAPM under the above assumptions leads to a reasonable match of model predictions with observations of worst-case PM_{10} during winter, as driven largely by domestic heating. All discussion of model results in this report is based on model runs set up as described in Appendices A, B and C. Results from the airshed modelling and its application to air quality questions posed by HBRC are presented in Sections 4.0, 5.0 and 6.0.

4.0 AIRSHED MODEL RESULTS FOR PRESENT-DAY PM_{10}

4.1 Introduction

Having evaluated the airshed model through the use of current emissions information and ambient air quality monitoring, this section discusses applications of the airshed modelling to aspects of present-day PM_{10} levels in the Hawke's Bay region. Specifically, the following sub-sections discuss expected PM_{10} levels at the air quality monitoring sites in Napier and Hastings for a range of meteorological conditions (Section 4.2), expected PM_{10} levels over the whole region – considering potential hot spots and NES exceedences (Section 4.3), and the dispersion of PM_{10} between CAUs and Airzones (Section 4.5). Dispersion between CAUs and Airzones is discussed below, as emissions reduction measures applied to one location may have a bearing on others.

4.2 Peak PM_{10} at Air Quality Monitoring Sites

Modelled 24-hour PM_{10} concentrations at the locations of the Marewa and St John's College monitoring sites reached 74 $\mu g/m^3$ and 91 $\mu g/m^3$, respectively, over the modelled years 2008 to 2010. These compared well with the observed concentrations of 71 $\mu g/m^3$ and 105 $\mu g/m^3$, respectively, though underestimating a little at the St John's College site. The days of highest modelled PM_{10} at Marewa are all characterized by low wind speeds during the day (less than 2 m/s), followed by even lower wind speeds during the evening (down to 0.5 m/s) when PM_{10} concentrations increased. Easterly and northerly winds during the afternoon give way to southwesterlies during the evening, indicating a transition to down-slope drainage flows overnight. At St John's, the days of highest modelled PM_{10} show a similar change in wind direction, with wind speeds down to 0.2 m/s during the evenings.

TAPM has also been run for five years from 2006 to 2010, to determine the potential worst-case PM_{10} which, arising from present-day emissions, may be associated with a wide range of meteorological conditions. This provides a more robust prediction of likely worst-case PM_{10} levels, as the longer meteorological data set should cover a larger range of weather conditions.

The worst-case PM_{10} days modelled arise in quite calm conditions, although the wind direction changes from on- to off-shore during the evening. The wind direction change is similar to that noted by Golder (2009), which led to re-circulation of emitted pollutants over Hastings, such that they would pass over the city twice in one evening and lead to a higher 24-hour average PM_{10}.

4.3 Peak Modelled PM_{10} Concentrations over the Heretaunga Plains

This section discusses the modelled dispersion of PM_{10} over the whole region, based on the meteorology of the five years 2006-2010 and scaled worst-case emissions for 2010 (projected from 2005 domestic heating appliance numbers).

The modelled peak concentrations around the Napier urban area are shown in Figure 5[6]. This shows concentrations of 30 µg/m^3 or greater broadly corresponding with the Airzone 1 boundary, containing the 50 µg/m^3 NES criterion concentration (thick black line) over the more central urban areas. The total (anthropogenic plus natural) PM_{10} can be obtained by adding 3.8 µg/m^3 to the plotted concentrations, as described in Section 2.5. The cross on Figure 5 denotes the location of the Marewa Park monitoring site, at which the anthropogenic component of the peak PM_{10} is 70 µg/m^3. This is not the highest PM_{10} peak concentration in Napier. There are two localized maximum concentrations, hot spots of 85 µg/m^3 in the Pirimai CAU, and 63 µg/m^3 in the Taradale North CAU (the natural component not added to these concentrations).

The modelled peak concentrations around Hastings and its neighbouring urban areas are shown in Figure 6[7]. This shows concentrations of 30 µg/m^3 or greater broadly corresponding with the Airzone 1 boundaries for Flaxmere and Havelock North, although there are no modelled concentrations greater than the NES criterion of 50 µg/m^3 over these areas. However, concentrations of PM_{10} greater than the NES criterion are modelled to occur over an area larger than the Hastings Airzone 1. The total (anthropogenic plus natural) PM_{10} can be obtained by adding 1.5 µg/m^3 to the plotted concentrations, as described in Section 2.5. At the St John's monitoring site (in the Mayfair CAU), the anthropogenic component of the peak PM_{10} is 90 µg/m^3, and there is a small region over the Mayfair and Mahora CAUs with concentration greater than 90 µg/m^3. Peak modelled concentrations over 80 µg/m^3 occur in an annular region around Hastings Central, but the peak PM_{10} in Hastings Central itself is less than this.

Modelled peak anthropogenic PM_{10} concentrations in Flaxmere and Havelock North are greater than 40 µg/m^3 in portions of Airzone 1, reaching 44 µg/m^3 in Flaxmere and 49 µg/m^3 in Havelock North. These exclude the natural component of PM_{10}. Hence there is an indication from the modelling that the NES criterion PM_{10} concentration of 50 µg/m^3 is approached in these areas, more closely in Havelock North.

[6] To be consistent with Appendix C, the contours for Napier are the modelled 2nd highest 24-hour concentration.

[7] To be consistent with Appendix C, the contours for Hastings are the modelled highest 24-hour concentration.

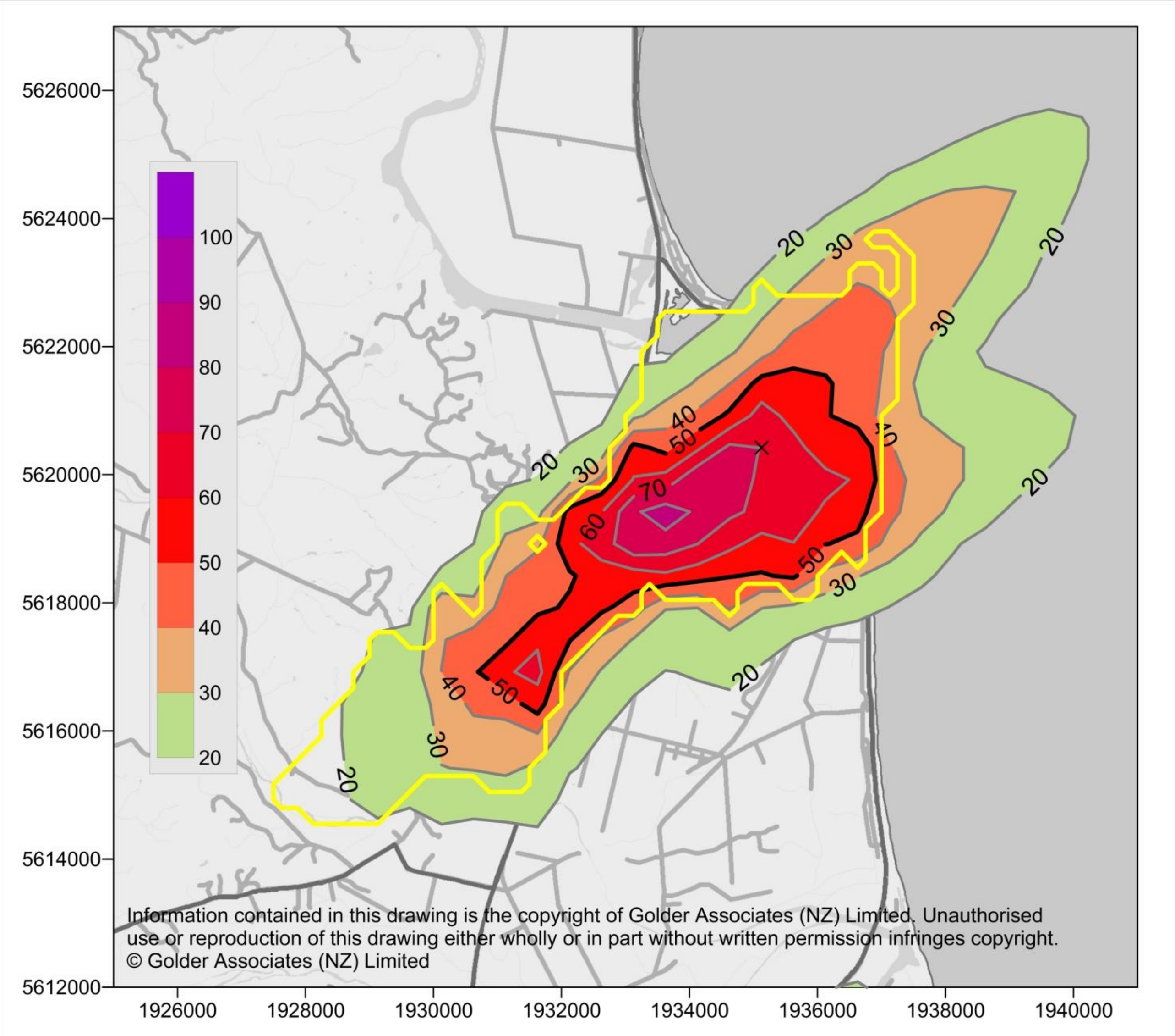


Figure 5: Peak modelled 24-hour PM_{10} concentrations (in $\mu g/m^3$) around Napier (natural component not added). Axes are in metres (NZTM). Airzone 1 is outlined in yellow. Marewa Park ambient air quality monitoring site is marked with a cross.

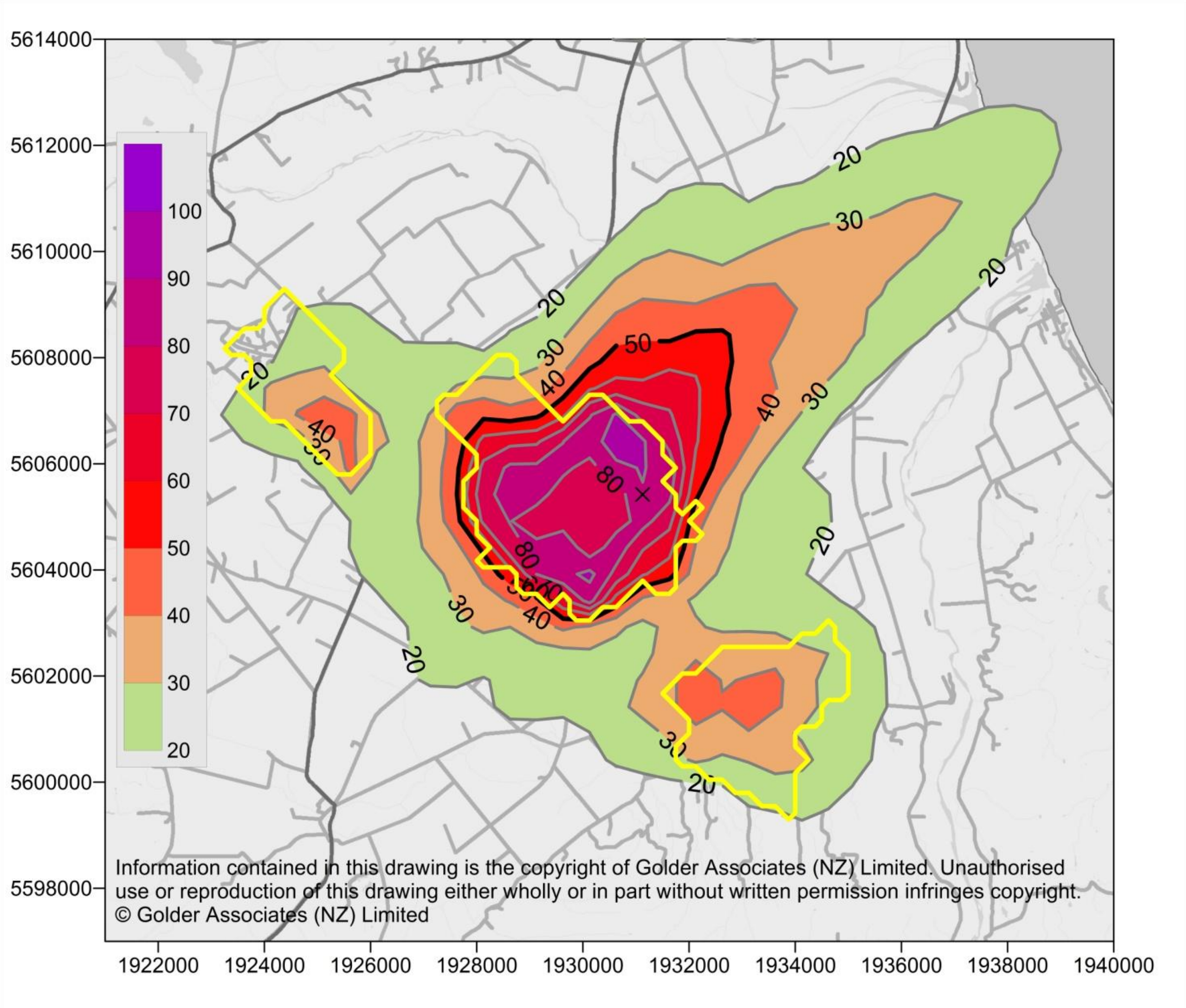


Figure 6: Peak modelled 24-hour PM_{10} concentrations (in µg/m^3) around Hastings, Flaxmere and Havelock North (natural component not added). Axes are in metres (NZTM). Airzone 1 areas are outlined in yellow. St John's College ambient air quality monitoring site is marked with a cross.

4.4 Hour-by-hour Dispersion of PM_{10}

Figure 5 and Figure 6 are composites, derived from worst-case conditions at each grid-point location. Those conditions need not arise on the same occasion, as the apparent plumes extending in different directions from the main source regions occur on days of different general wind direction. Moreover, the dispersion is time-dependent, reflecting changes in the wind speed and direction from hour to hour. Variations in plume position lead to contributions to the 24-hour average concentration arising from different locations at different times.

An example of the time-varying PM_{10} dispersion from the sources (largely in Airzone 1) on the evening of an example modelled day is shown in Figure 7. The four panels of Figure 7 show hourly-average PM_{10} concentrations at two-hour intervals, starting from initial evening emissions producing low ambient PM_{10} concentrations over Airzone 1 (Figure 7(a)). In the relatively calm conditions, PM_{10} concentrations increase *in situ*, drifting slightly inland to the southwest (Figure 7(b)). The night-time drainage flow to the northeast develops during the evening, so that the PM_{10} plumes change direction and re-circulate over the urban areas (Figure 7(c)), and later on the plumes extend off-shore in the more developed southwesterly flow (Figure

7(d)). Note that slope flows converge into a valley flow in the southern half of the figure, such that PM_{10} plumes originating in Flaxmere and Havelock North converge with the plume originating in Hastings to produce a single plume extending over Hawke Bay. Visual inspection of model results indicates that this is a typical sequence of events during an air pollution episode over the region.

4.5 Cross-Boundary Dispersion of PM_{10}

4.5.1 Introduction

Of interest to HBRC is the dispersion of air pollutants between urban areas within Airzone 1, and CAUs within the same urban area. Information on the contribution to PM_{10} in a specific area from neighbouring areas is useful in determining the contribution to NES exceedences in one area from its neighbours and the effect of air quality management decisions applied to one area on air quality in another. The following sections (4.5.2 and 4.5.3) discuss dispersion of PM_{10} between Airzone 1 areas and dispersion between CAUs within an Airzone 1 area, in preparation for an examination of the effects of emissions reductions within and between urban areas in Section 5.0.

4.5.2 Dispersion of PM_{10} between Airzone 1 areas

To determine the extent of dispersion between the urban areas of Airzone 1 (namely, Napier, Hastings, Flaxmere and Havelock North), TAPM was run for the months April to August inclusive, and years 2006 to 2010. This amounts to 615 winter days. Emissions were taken from the 2010 inventory, using projections from 2005, and applying the chosen scale factor of 1.4 for worst-case emissions (all domestic heating appliances in use, Scenario 4 in Appendix B). The modelled tracers were the emitted PM_{10} from all sources, split into the four Airzone 1 urban areas, so that modelled PM_{10} could be apportioned into contributions from different source locations. PM_{10} emitted from areas other than the four urban areas was calculated as the residual of the total PM_{10} from all locations, minus the PM_{10} from the urban areas. The contributions to PM_{10} at Marewa Park, St John's College and receptors in the centres of Flaxmere and Havelock North have been examined in the following.

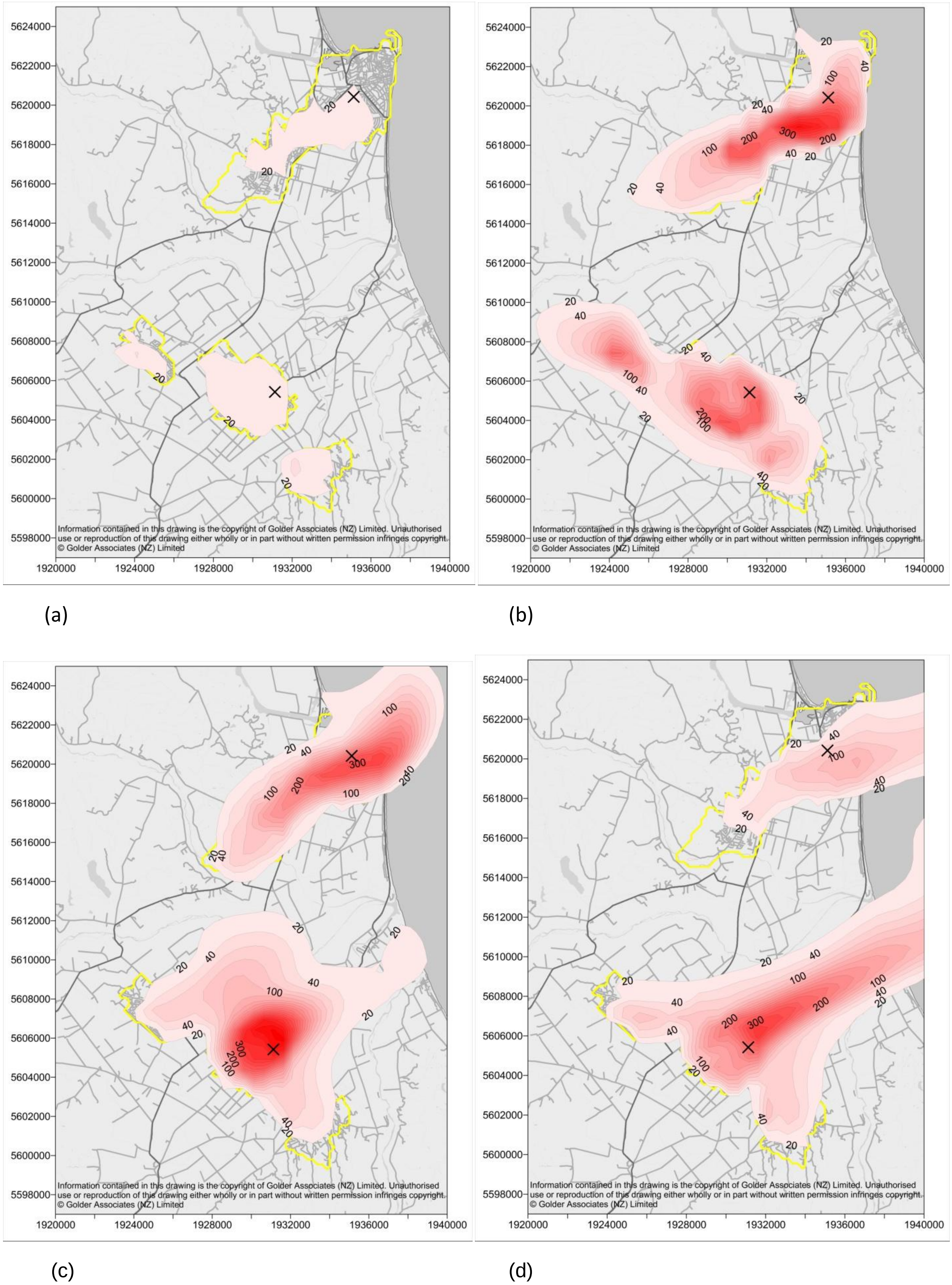


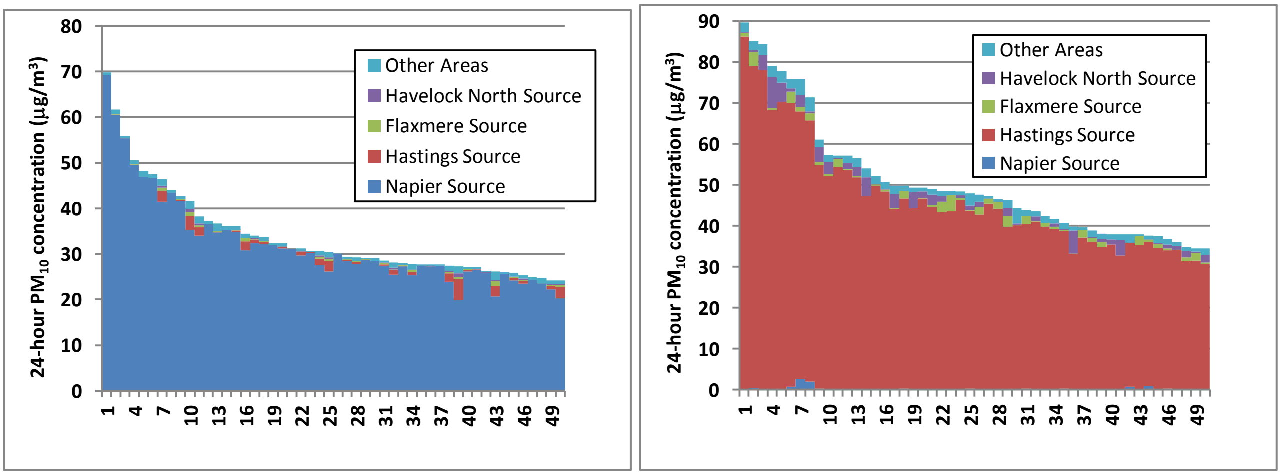
Figure 7: Hourly PM_{10} on model day 10 July 2009, with contours marked from 20 µg/m^3 at intervals of 20 µg/m^3. Times are (a) 5 pm, (b) 7 pm, (c) 9 pm and (d) 11 pm.

Figure 8(a) shows the highest 50 24-hour anthropogenic PM_{10} concentrations under worst-case winter conditions at Marewa Park, Napier, apportioned according to Airzone 1 area of origin. It can be seen that the worst-case levels of PM_{10} modelled at this receptor were emitted almost entirely from Napier itself. This is expected in calm meteorological conditions under which dispersion is limited and concentrations are high. Some of the higher PM_{10} concentrations comprise between 5 % and 8 % from Hastings, amounting to no more than 5 µg/m^3, drifting in from the Heretaunga Plains. No more than 2 µg/m^3 of the modelled PM_{10} originates from Flaxmere, Havelock North or areas outside Airzone 1[8].

Figure 8(b) shows the top 50 modelled PM_{10} concentrations at St John's College, Hastings. As for Napier, the worst-case levels of PM_{10} modelled at this receptor were emitted almost entirely from Hastings itself. Some of the higher PM_{10} concentrations comprise up to 10 % from Havelock North, which is up to 8 µg/m^3. Less than 4 µg/m^3 of the modelled PM_{10} originates from each of Napier, Flaxmere and Airzone 2 areas.

Figure 9(a) shows the top 50 modelled PM_{10} concentrations at a receptor in the centre of Flaxmere. The worst-case levels of PM_{10} modelled at this receptor were emitted mostly from Flaxmere itself. Some of the higher PM_{10} concentrations comprise up to 5 µg/m^3 from Hastings, 3 µg/m^3 from Napier, 1 µg/m^3 from Havelock North and 2 µg/m^3 from Airzone 2 areas.

Figure 9(b) shows the top 50 modelled PM_{10} concentrations at a receptor in the centre of Havelock North. The worst-case levels of PM_{10} modelled at this receptor were emitted mostly from Havelock North itself. Some of the higher PM_{10} concentrations comprise up to 10 µg/m^3 from Hastings, 3 µg/m^3 from Napier, 2 µg/m^3 from Flaxmere and 3 µg/m^3 from Airzone 2 areas.



(a) (b)

Figure 8: Ranked modelled 24-hour PM_{10}, apportioned according to Airzone 1 area of origin. (a) PM_{10} at Marewa Park, Napier; (b) PM_{10} at St John's College, Hastings.

[8] Sources of PM_{10} in rural areas are negligible, hence PM_{10} originating outside Airzone 1 areas actually originate from Airzone 2 in the airshed under consideration.

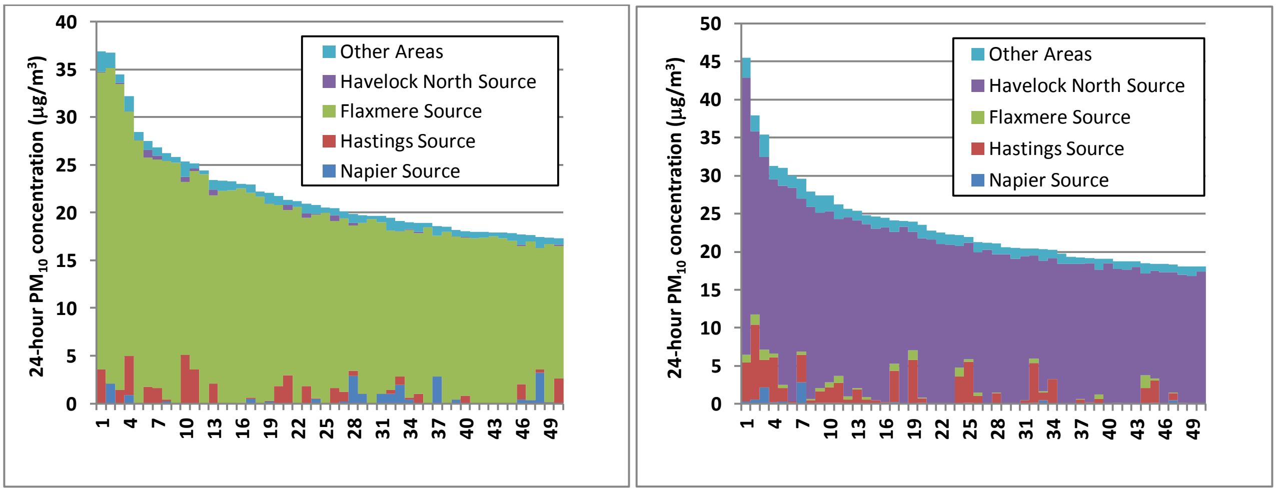


Figure 9: Ranked modelled 24-hour PM_{10}, apportioned according to Airzone 1 area of origin. (a) PM_{10} at a location in central Flaxmere; (b) PM_{10} at a location in central Havelock North.

HBRC has posed some specific questions regarding the dispersion of PM_{10} between Airzone 1 areas (email from Kathleen Kozyniak to Neil Gimson, 19 January, 2012). They are reproduced here *verbatim*, with responses from Golder inserted, based on the modelling investigation described in this section.

Question 1: *On days we have exceedences in Napier, if we turned emissions off from Hastings, Havelock North and Flaxmere, would we still get an exceedence in Napier (and in the process quantify how much those other areas combined contribute to Napier's measurements on exceedance days)?*

Response 1: As contributions of PM_{10} from Hastings, Havelock North and Flaxmere to levels in Napier appear to be small relative to the amount by which Napier can exceed the NES criterion concentration, the modelling indicates that there would still be an exceedence in Napier, due to the dominance of emissions in Napier itself. However, a few 'borderline' exceedences, where the observed PM_{10} concentration in Napier is between 50 µg/m³ and 55 µg/m³ might not occur if there were no emissions from the other urban areas.

Question 2: *As above for Hastings exceedences, this time turning Napier off*.

Response 2: There would still be exceedences in Hastings, for the same reasons as outlined in Response 1, in cases where Hastings currently exceeds the NES criterion by at least 4 µg/m³.

Question 3: *For exceedence days in Hastings, how much PM_{10} from Flaxmere and Havelock North ends up at the monitor, i.e. would we still get the exceedences at the monitor's location if one or the other had no emissions?*

Response 3: The modelling indicates that there may be a larger contribution to PM_{10} in Hastings from Havelock North, such that some exceedences by less than 8 µg/m³ in Hastings may no longer be exceedences if there were no emissions from Havelock North. Similarly, exceedences by less than 4 µg/m³ of PM_{10} from Flaxmere may occur at the Hastings monitor.

Note that the small concentrations of PM_{10} which arise through transport between urban areas are *maximum* modelled concentrations. For instance, the 4 µg/m³ of PM_{10} in Hastings modelled to have originated in Flaxmere does not occur every day. The modelling therefore indicates that very few of the exceedences in Napier and Hastings would not occur if emissions in their neighbouring Airzone 1 areas were switched off. In general, the answer to the question 'would exceedences still occur' is 'yes, there would be almost as many'.

Question 4: *Which CAU in Napier contributes most to concentrations measured at the monitor's location on exceedence days and similarly in Hastings?*

Response 4: This question cannot be answered from the model results described above. It requires the modelling of PM_{10} dispersion from emissions in individual CAUs. This is carried out in the following section.

4.5.3 Dispersion of PM_{10} between CAUs

To provide a response to HBRC's question on inter-CAU dispersion, modelling has been carried out to assess transport between CAUs and examine the origins of PM_{10} arriving at the monitoring sites during worse-case pollution days.

The modelling carried out in Section 4.5.2 treated the emissions from each of four Airzone 1 areas as separate tracers in the TAPM runs (of five years length). TAPM models the dispersion of up to four tracers in a single run. As there are 61 CAUs in the Heretaunga Plains area, modelling dispersion from each would require sixteen runs. Moreover, a horizontal resolution of 500 m for the dispersion model component does not resolve CAUs with small areas well. Modelling for this section of the report has been carried out with a dispersion grid of resolution 250 m, matching the emissions grid. It is impractical to run TAPM for five years, with 61 sources, at 250 m resolution, hence this section uses short case-study periods, based on modelled days of worst-case PM_{10} as determined by the full-domain runs.

The model case-study days are those of the top five modelled PM_{10} concentrations at each of Marewa Park and St John's College. This amounts to seven days (as three of the days occur in the top five at both sites). The emissions scenario is that used in Section 4.5.2, based on 2010 domestic emissions projected from 2005, scaled by 1.4 to reflect worst-case conditions (Scenario 4 in Appendix B). The PM_{10} concentrations arriving at the monitoring sites have been apportioned according to CAU from which the PM_{10} was emitted. Marewa Park monitoring site is in the Marewa CAU, and St John's College monitoring site is in the Mayfair CAU.

According to the modelling, under worst-case conditions, air pollution occurring in a given area of Airzone 1 is most likely to have been emitted from sources within that same area. However, the modelling indicates significant transport between CAUs within the same Airzone 1 area on such occasions. Figure 10 shows the contribution to modelled PM_{10} at Marewa Park from CAUs in Napier. Approximately 30 % to 40 % of the modelled PM_{10} at Marewa Park originated in the Marewa CAU. The largest contributions from other CAUs are 10-15 % from Onekawa Central and up to 20 % from Onekawa South, which are Marewa's adjoining neighbours to the south and west[9]. This is consistent with the southwesterly wind direction of drainage flows on winter evenings. The next highest contributions are from CAUs somewhat more distant, but in the same direction, namely, Tamatea North and South, Pirimai, Taradale North and Greenmeadows. There is no contribution from Onekawa West, which is an industrial rather than a residential CAU (and whose PM_{10} emissions are, according to the inventory, relatively small).

[9] A map of CAUs is shown in Appendix B, Figure 6.

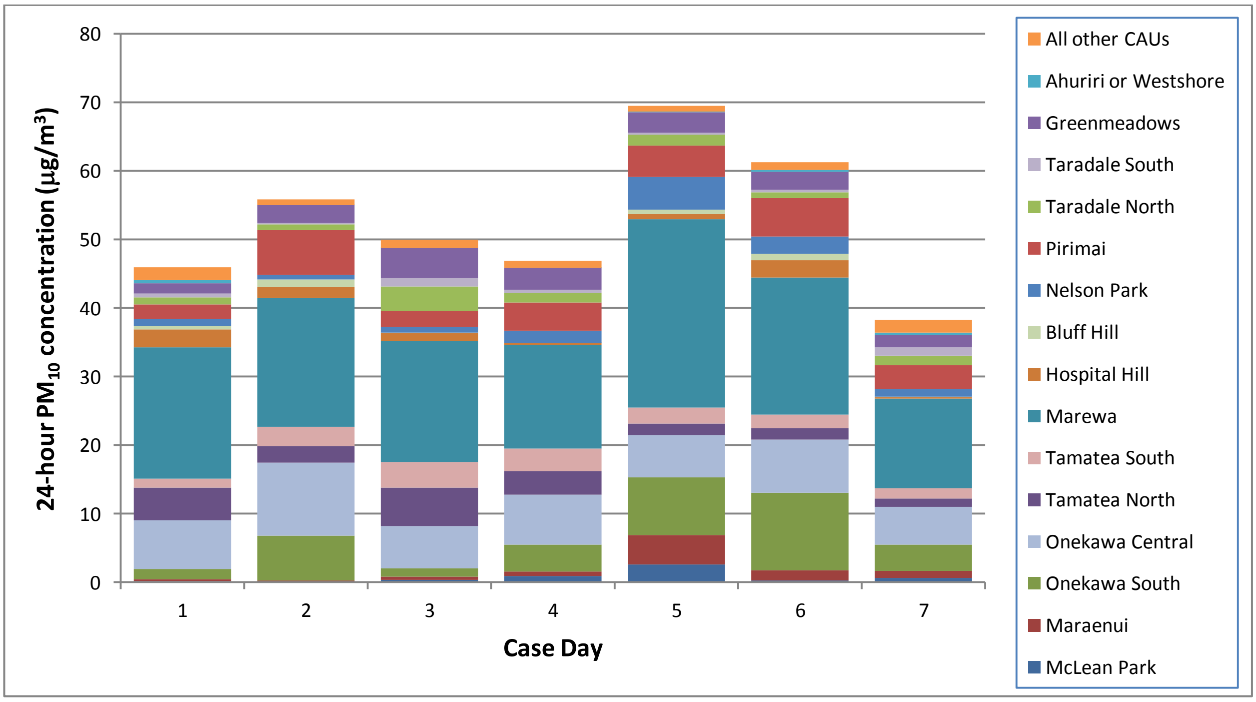


Figure 10: Contribution to modelled PM_{10} at Marewa Park from other CAUs in Napier, on selected case-study days.

Figure 11 shows the contribution to modelled PM_{10} at St John's College from CAUs in Hastings. Approximately 30 % to 60 % of the modelled PM_{10} originated in the Mayfair CAU (which contains St John's). The largest contributions from other CAUs are up to 20 % from Parkvale (the southern neighbour of Mayfair). The next highest contributions are from Akina, Mahora, Raureka, St Leonards and Hastings Central (each up to 10 %), which includes the ring of CAUs of high domestic heating emissions around Hastings Central.

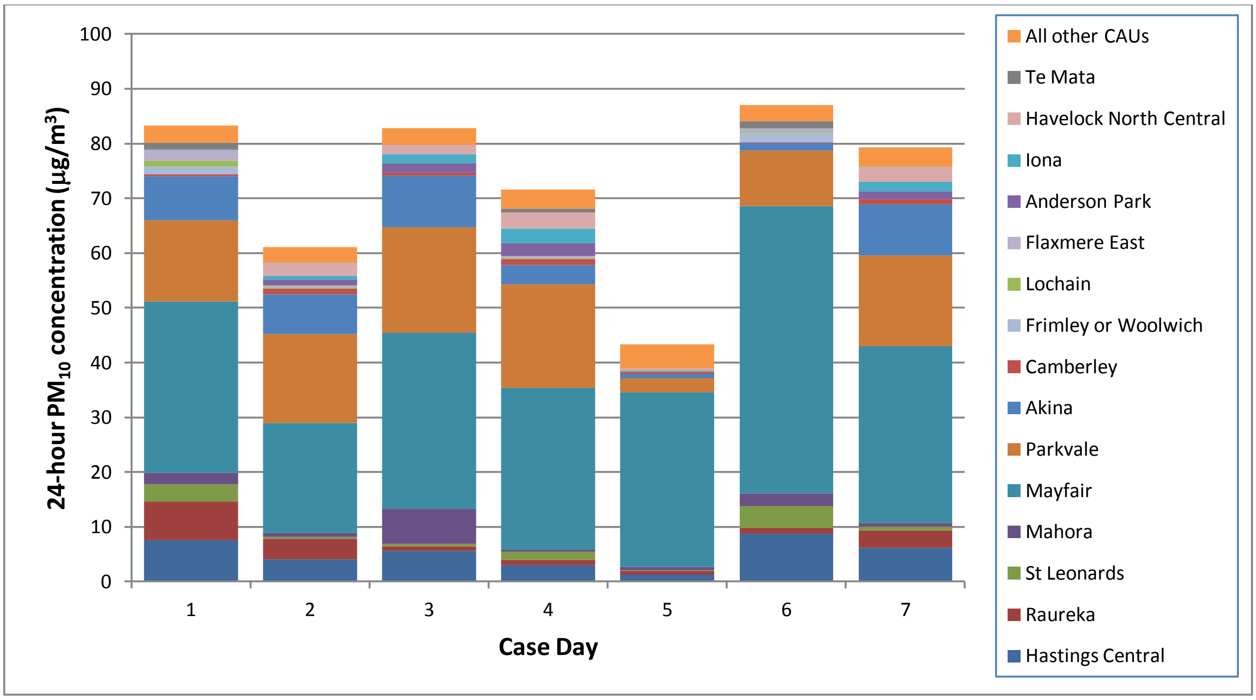


Figure 11: Contribution to modelled PM_{10} at St John's College from other CAUs in Hastings, on selected case-study days (the days are in the same order as those displayed in Figure 10).

Equivalent results have not been presented here for Flaxmere and Havelock North, as there are no specific monitoring locations in these urban areas, and the worst-case days may differ from those of Napier and Hastings. However, for the chosen receptor in central Flaxmere, which is located in the Lochain CAU, the origins of PM_{10} arriving at that location are Lochain itself, then Flaxmere East and Kingsley/Chatham CAUs, as would be expected – these are the CAUs comprising Flaxmere Airzone 1. Similarly, modelled PM_{10} at the chosen receptor in central Havelock North, which is located in the Havelock North Central CAU, originates in either Havelock North Central or Iona on the chosen case-study days.

This section has given an indication of inter-CAU transport of PM_{10}, as modelled by TAPM. The detail extracted from the modelling is likely near the limits of capability of the model, and at the limits of the input emissions data. For a fuller appraisal of inter-CAU transport, a higher level of inventory detail, higher resolution in the dispersion model, or a possible change to a particle- or puff-dispersion model, should be considered. At the least, the worst-case days for Flaxmere and Havelock North should be modelled to provide a more robust assessment of inter-CAU transport in those areas.

To respond to Question 4 of Section 4.5.2 from HBRC, *Which CAU in Napier contributes most to concentrations measured at the monitor's location on exceedence days and similarly in Hastings?* The short response is that the model indications that the CAU contributing most to concentrations at the monitor's location is the CAU in which the monitor is located. However, the contribution is far less than 100%, and a substantial portion – tens of % – of the total PM_{10} at the monitoring site may be dispersed from neighbouring CAUs.

4.5.4 Implications of cross-boundary dispersion for emission reduction measures

The results presented in the above sections indicate that there is little dispersion between urban areas during worst-case pollution event. This is related to their occurrence under calm conditions and the geographical separation between the urban areas of Napier, Hastings, Flaxmere and Havelock North (that is, the areas defined as Airzone 1). This means that emission reduction measures imposed in one area would have little effect on air quality in the others, under worst-case conditions, and the effects of those measures can be considered for each area independently.

However, there is significant dispersion between CAUs within urban areas. Emission reduction measures applied to some CAUs, but not others, would have their main effect in the CAUs whose emissions had decreased, and some effect on the rest of the urban area. The modelling gives an indication of the complexity of this situation.

5.0 AIRSHED MODEL RESULTS FOR FUTURE PM_{10}

5.1 Introduction

HBRC requires guidance on emissions reductions required to meet the NES for PM_{10} in Napier, Hastings and Havelock North. Some indication of this may be inferred from observations at the air quality monitoring sites. Complementary to this, airshed modelling may be used to guide the required emissions reductions, accounting for the following aspects:

i) Emissions reduction measures would be applied to specific source types. Reducing emissions from one type of source by a given proportion would reduce the ambient concentrations by a smaller proportion, as the contribution to the total PM_{10} from other sources – and the natural components – would not be changed. The airshed model can estimate the impact of source-specific changes in emissions.

ii) Monitoring sites may not be at peak locations. Emissions reductions leading to compliance with the NES at monitoring sites may not ensure compliance elsewhere. The airshed model may indicate other locations where peaks in air pollution levels occur.

iii) Emissions reduction measures may differ between neighbouring urban areas. The airshed modelling can account for cross-border dispersion and the effects of reduction measures in one area on its neighbours.

HBRC requires guidance with respect to Napier, Hastings and Havelock North. Section 5.2 discusses reductions required, relative to present-day PM_{10} emissions, to comply with the new NES. This is based on the airshed modelling scenarios presented in Sections 4.2 and 4.3, with the aim of reducing the PM_{10} peaks which appear in Figure 5 and Figure 6 (including natural PM_{10}) to 50 µg/m^3 or less. Section 5.3 discusses PM_{10} levels inferred from emissions data projected to 2020.

5.2 Reductions Relative to Present-Day Emissions

Airshed modelling has been carried out for a period of five years, to account for inter-annual variations in meteorology and capture the worst-case meteorological conditions for pollution dispersion and predict the highest-likely PM_{10} concentrations. These have been shown in Section 4.3. Domestic heating emission reductions calculated in this section are relative to the Scenario 4 emissions, assumed to represented present-day worst-case conditions.

At Marewa Park, Napier, the peak modelled PM_{10} is 74 µg/m^3, comprising 69 µg/m^3 from domestic heating, 4 µg/m^3 from natural sources and 1 µg/m^3 in total from vehicles, industry, port and airport activities. Reducing domestic heating emissions by 35 % relative to their current levels would decrease the domestic heating component to 45 µg/m^3 and the total PM_{10} to 50 µg/m^3, in compliance with the NES.

As shown in Section 4.3, the peak modelled PM_{10} in Napier occurs approximately 2 km to the southwest of Marewa Park, in Pirimai CAU. In Pirimai, the peak modelled PM_{10} is 89 µg/m^3, comprising 83 µg/m^3 from domestic heating, 4 µg/m^3 from natural sources and 2 µg/m^3 in total from vehicles, industry, port and airport activities. Reducing domestic heating emissions by 47 % relative to their current levels would decrease the domestic heating component to 44 µg/m^3 and the total PM_{10} to 50 µg/m^3, in compliance with the NES.

Therefore, for all of Napier to comply with the NES, the modelling indicates that domestic heating emissions would need to be reduced by 47 % of their present-day levels.

At St John's College, Hastings, the peak modelled PM_{10} is 91 µg/m^3, comprising 88 µg/m^3 from domestic heating, 2 µg/m^3 from natural sources and 1 µg/m^3 in total from vehicles and industry (rounded concentrations). Reducing domestic heating emissions by 47 % relative to their current levels would decrease the domestic heating component to 47 µg/m^3 and the total to 50 µg/m^3, in compliance with the NES.

As shown in Section 4.3, the peak modelled PM_{10} in Hastings occurs approximately 1 km to the northwest of St John's College, in Mahora CAU. In Mahora, the peak modelled PM_{10} is 96 µg/m^3, comprising 92 µg/m^3 from domestic heating, 2 µg/m^3 from natural sources and 2 µg/m^3 in total from vehicles and industry. Reducing domestic heating emissions by 50 % relative to their current levels would decrease the domestic heating component to 46 µg/m^3 and the total to 50 µg/m^3, in compliance with the NES.

Hence, for all of Hastings to comply with the NES, the modelling indicates that domestic heating emissions would need to be reduced by 50 % of their present-day levels.

As Havelock North appears to be on the borderline between compliance and non-compliance with the NES, it is difficult to estimate the required emissions reductions which would lead to compliance under all conditions. Emissions may not need to be reduced.

Estimates of necessary reductions to emission from domestic heating have been given this section for each of Napier and Hastings separately, as Section 4.5.2 indicates that reduction measures can be applied to those areas independently of each other, without cross-boundary effects. CAU-specific reductions have not been considered in this report, and section 4.5.3 indicates that outcomes of such measures would be complex.

5.3 Modelled PM_{10} with Emissions Projected to 2020

Modelled peak levels of PM_{10} based on emissions predictions to 2020 (data supplied by Environet Ltd) are shown for Napier in Figure 12 and Hastings in Figure 13[10]. These are equivalent to Figure 5 and Figure 6, respectively, which are based on present-day emissions. At both locations, the peak PM_{10} concentrations – 36 µg/m^3 in Napier, 28 µg/m^3 in Hastings – are less than the NES criterion (and would also be below the NES criterion with natural PM_{10} included). In other words, the projected emissions are sufficiently reduced from present-day emissions, implying compliance with the NES by 2020 in both airsheds.

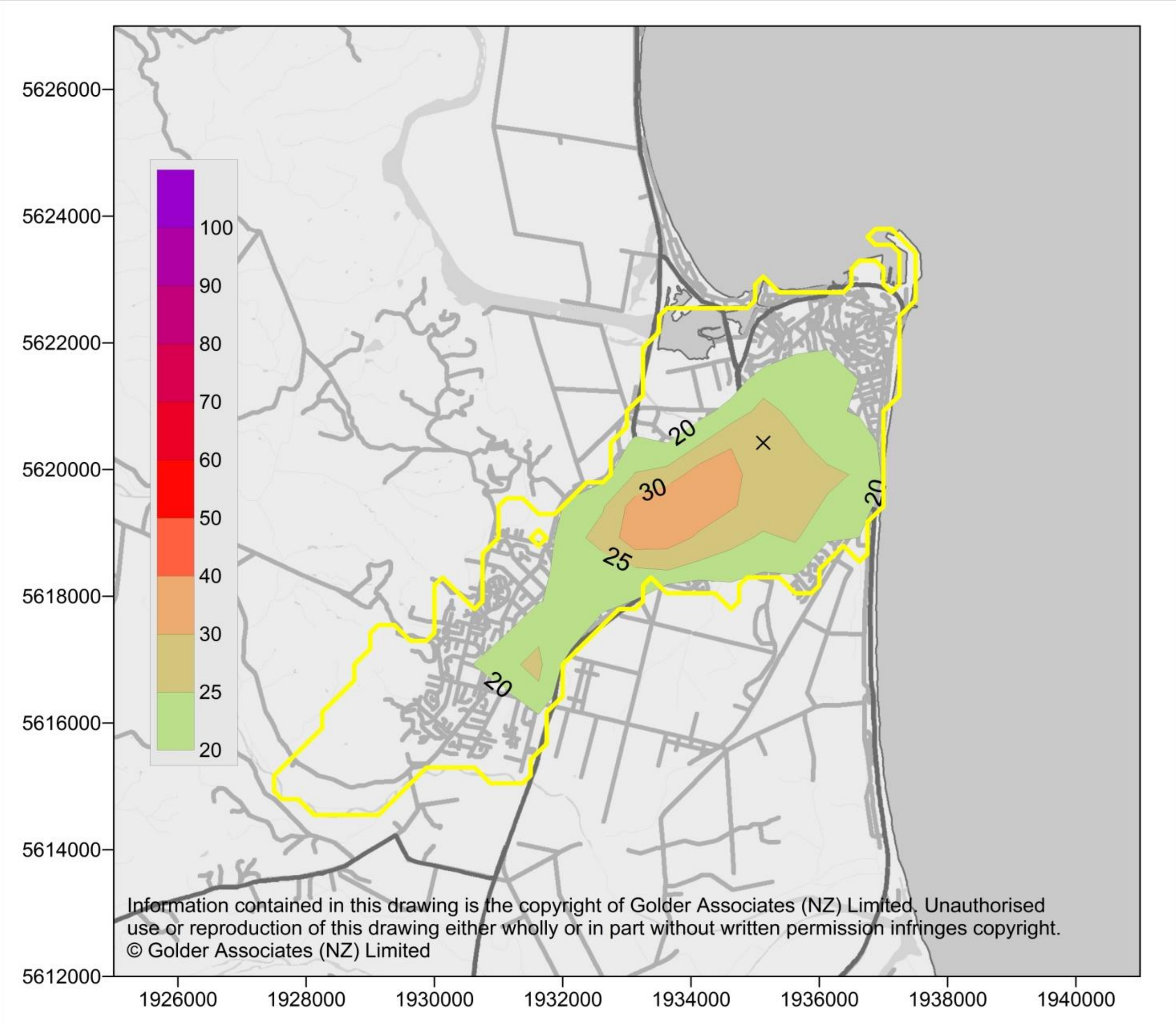


Figure 12: Peak modelled 24-hour PM_{10} concentrations (in µg/m^3) around Napier, based on emissions projections to 2020 (natural component not added). The Marewa Park ambient air quality monitoring site is marked with a cross.

[10] As in the present-day case, a scale factor of 1.4 has been applied to the domestic heating emissions for 2020 to approximate worst-case emissions.

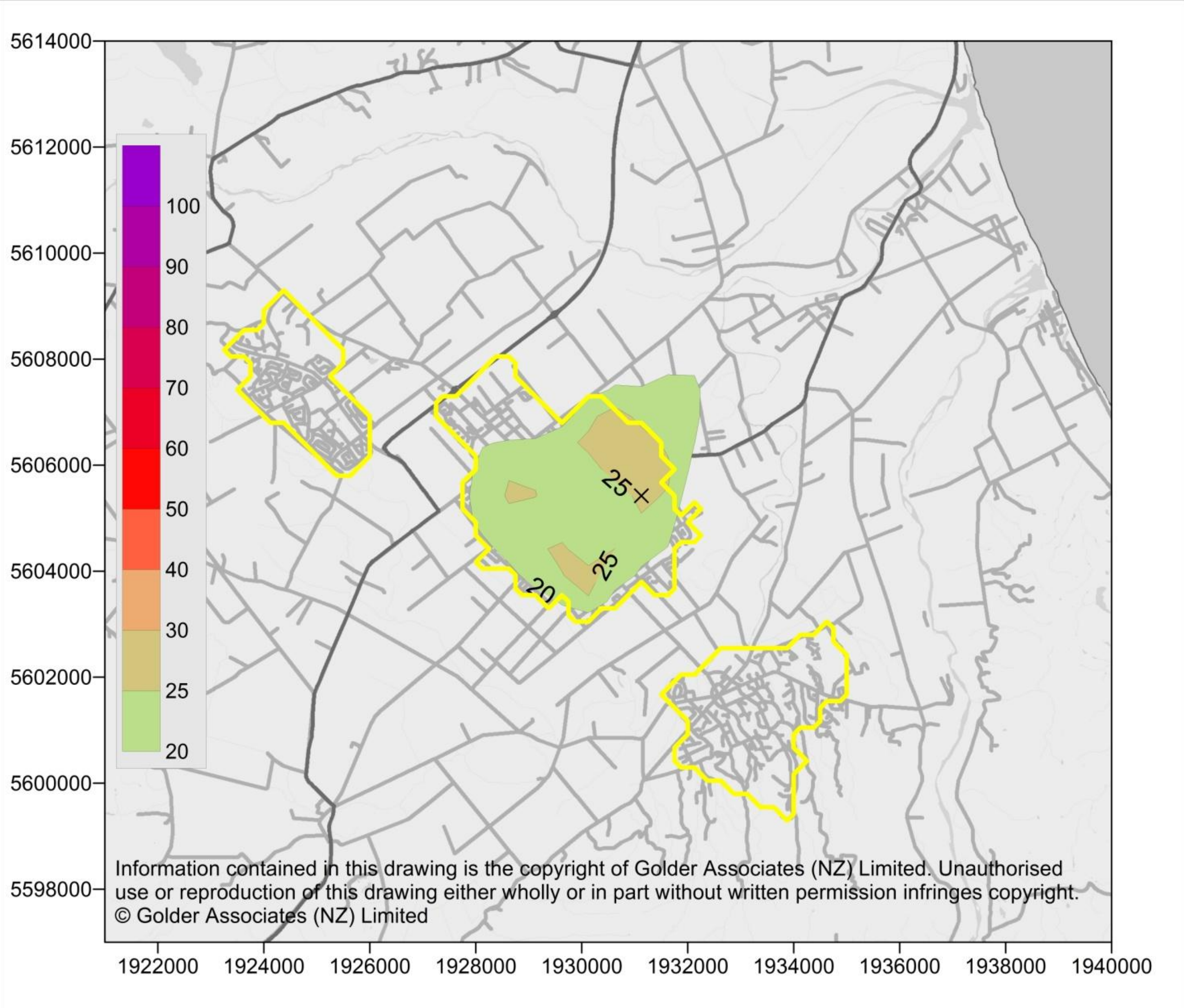


Figure 13: Peak modelled 24-hour PM_{10} concentrations (in µg/m^3) around Hastings, Flaxmere and Havelock North, based on emissions projections to 2020 (natural component not added). The St John's College ambient air quality monitoring site is marked with a cross.

6.0 COMPLIANCE WITH $PM_{2.5}$ GUIDELINES

The World Health Organization (WHO) has updated its recommended air quality guidelines (Krzyzanowski & Cohen 2008; WHO 2006), which now include a guideline concentration for 24-hour-average $PM_{2.5}$ of 25 µg/m^3. These are referred to in the good-practice guide for assessing discharges from air to industry (MfE 2008), although they have not become National Environment Standards in New Zealand. HBRC requires and estimates of peak levels of 24-hour $PM_{2.5}$ over the Heretaunga Plains, which are provided in this section, based on airshed modelling.

The emissions inventory for 2010 does not contain information on $PM_{2.5}$, although the 2005 inventory does include factors for $PM_{2.5}$. To predict $PM_{2.5}$ levels, information on the ratios of $PM_{2.5}$ and PM_{10} emissions from the 2005 inventory and from source apportionment has been used to re-scale the model results for PM_{10}. This is done by source, and is summarized in Table 6.

Table 6: $PM_{2.5}/PM_{10}$ emission fractions, used for scaling PM_{10} airshed model results. Anthropogenic emissions only.

Emission source	$PM_{2.5}/PM_{10}$ fraction	Information source
Domestic Heating	85 %	Indications from Napier and Hastings source apportionment.
Motor Vehicles	58 %	Ratio used for tailpipe emissions in the 2005 inventory
Industry	50 %	Approximate region-wide average in the 2005 inventory
Other Emissions	100 %	Used as a conservative default

As worst-case levels of PM_{10} are known to be dominated by domestic heating emissions, and the $PM_{2.5}/PM_{10}$ ratio is high, it is expected that modelled $PM_{2.5}$ levels would also be dominated by domestic heating, and be insensitive to the $PM_{2.5}/PM_{10}$ fractions ascribed to other sources.

Natural components of $PM_{2.5}$ are derived in Section 2.5 and shown in Table 3 and Table 4 for Napier and Hastings, respectively. The concentrations – calculated as mean minus one standard deviation – are 0.3 µg/m^3 for Napier and zero for Hastings. They have been disregarded in the following section.

At Marewa Park, the modelled peak 24-hour PM_{10} was 74 µg/m^3, with 70 µg/m^3 anthropogenic and 4 µg/m^3 natural components. Using the factors in Table 6, the modelled peak 24-hour $PM_{2.5}$ at this site would be 59 µg/m^3 (assuming the natural component of $PM_{2.5}$ is zero). The modelled peak $PM_{2.5}$ occurs on the same occasion as the modelled peak PM_{10}.

At St John's College, the modelled peak 24-hour PM_{10} was 91 µg/m^3, with 89 µg/m^3 anthropogenic and approximately 2 µg/m^3 natural components. Using the factors in Table 6, the modelled peak 24-hour $PM_{2.5}$ at this site would be 76 µg/m^3 (assuming the natural component of $PM_{2.5}$ is zero). The modelled peak $PM_{2.5}$ occurs on the same occasion as the modelled peak PM_{10}.

The peak modelled $PM_{2.5}$ concentration around Napier are shown in Figure 14. As PM_{10} from domestic heating contains a large proportion of $PM_{2.5}$, but the guideline for $PM_{2.5}$ is one-half of the NES for PM_{10}, there is a larger area of non-compliance of the $PM_{2.5}$ guideline (glc > 25 µg/m^3) than of the PM_{10} NES (glc > 50 µg/m^3, compare with Figure 5). The highest peak $PM_{2.5}$ in Figure 14 is 72 µg/m^3 in Pirimai. Including the natural component raises this to 76 µg/m^3. The modelling shown in Section 5.2 indicated that reducing domestic heating emissions by 47 % relative to their current levels would make Napier compliant with the NES for PM_{10}. However, further reductions – by 72% of the estimated present-day $PM_{2.5}$ emission levels – would be needed to make Napier compliant with the WHO guideline for 24-hour $PM_{2.5}$.

Figure 15 shows the peak modelled $PM_{2.5}$ concentration around Hastings. As for Napier, there is a larger area of non-compliance of the $PM_{2.5}$ guideline (glc > 25 µg/m^3) than of the PM_{10} NES (glc > 50 µg/m^3, compare with Figure 6). The highest peak $PM_{2.5}$ in Figure 15 is 79 µg/m^3 in Mahora. Including the natural component raises this to 81 µg/m^3. The modelling shown in Section 5.2 indicated that reducing domestic heating emissions by 50% relative to their current levels would make Hastings compliant with the NES for PM_{10}. However, further reductions – by 72% of the estimated present-day $PM_{2.5}$ emission levels – would be needed to make Hastings compliant with the WHO guideline for 24-hour $PM_{2.5}$.

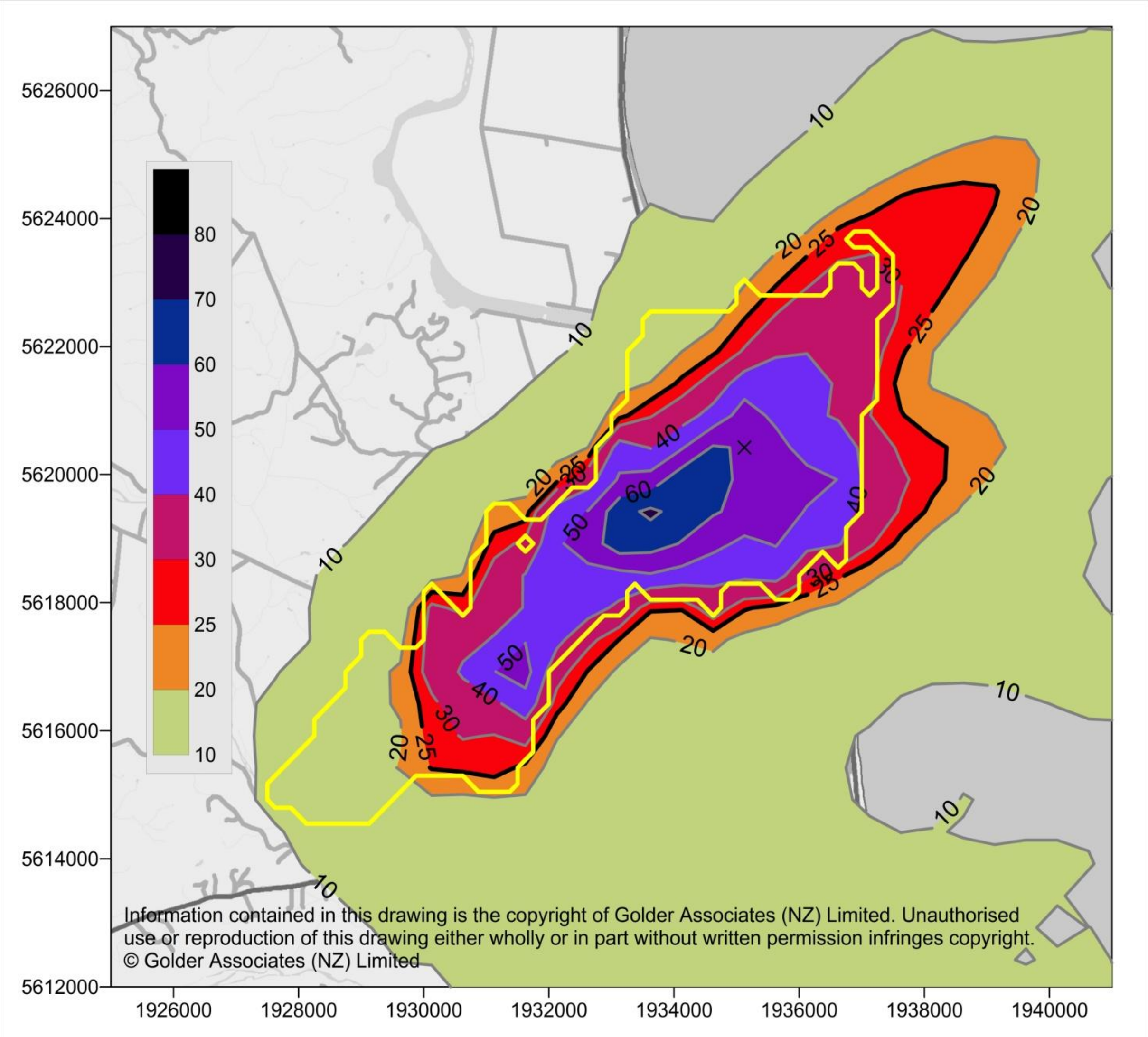


Figure 14: Peak modelled 24-hour $PM_{2.5}$ concentrations (in µg/m^3) around Napier. Airzone 1 is outlined in yellow. Marewa Park ambient air quality monitoring site is marked with a cross. WHO guideline concentration is 25 µg/m^3.

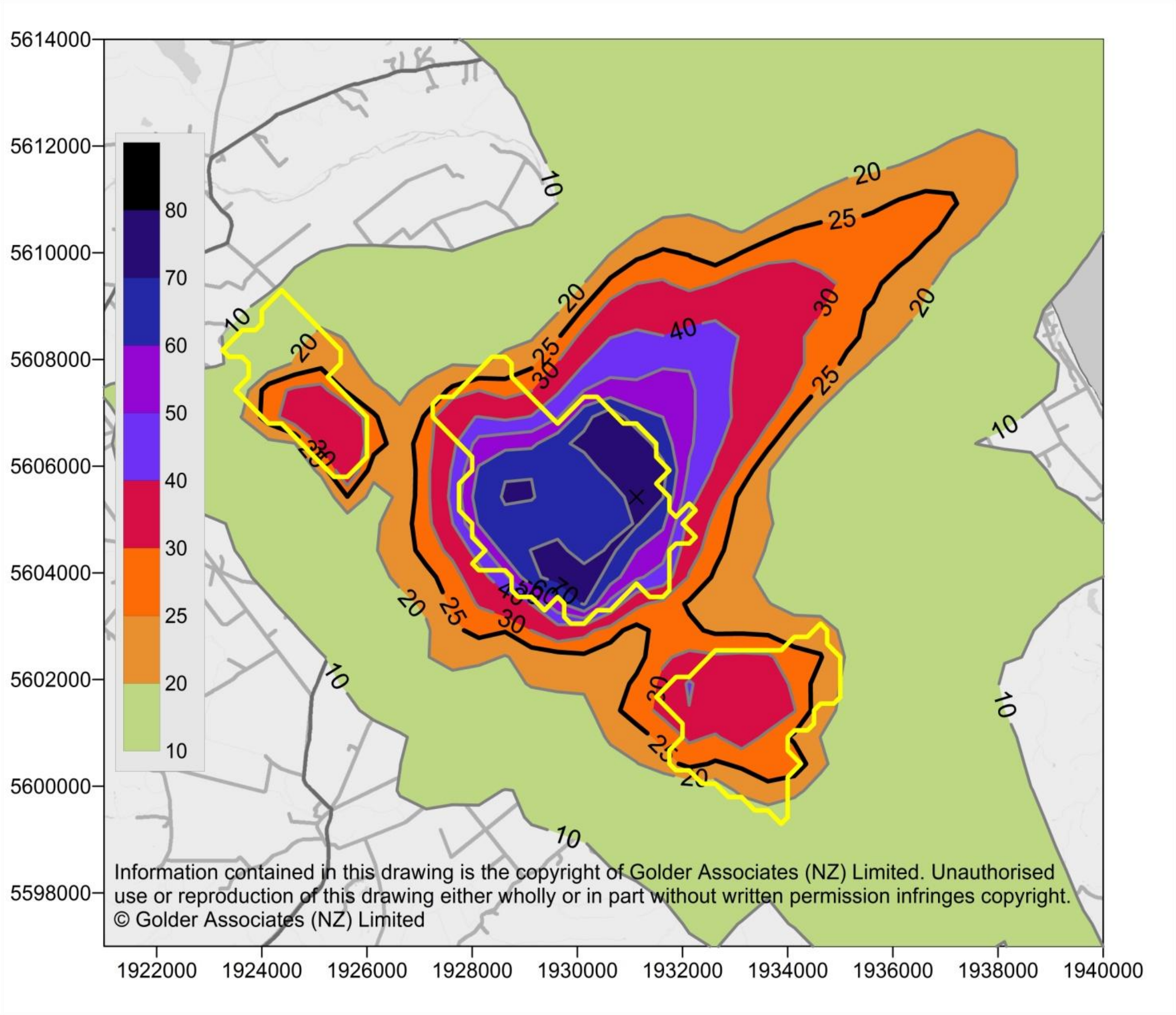


Figure 15: Peak modelled 24-hour $PM_{2.5}$ concentrations (in µg/m^3) around Hastings. Airzone 1 is outlined in yellow. St John's College ambient air quality monitoring site is marked with a cross. WHO guideline concentration is 25 µg/m^3.

7.0 DISCUSSION OF AIRSHED MODELLING

7.1 Introduction

Airshed modelling using TAPM has been used in this work to address some specific air quality management issues of importance to HBRC. These were outlined in Table 1, and are a focus on current and future PM_{10} and $PM_{2.5}$ in the region, identification of peaks in PM, effects of emissions reduction scenarios, cross-boundary dispersion, and compliance with the NES and WHO guidelines. Five years of model runs have been carried out, in an attempt to provide robust conclusions based on a range of meteorological conditions which includes inter-annual variability. Based on emissions information supplied by Environet at the CAU level, the calibrated model produces a good match to peak PM_{10} concentrations currently experienced at air-quality monitoring sites in Napier and Hastings. This gives confidence in its ability to model PM_{10} at other locations in the area, and its use in providing guidance on PM_{10} levels under various emissions scenarios (including emissions of $PM_{2.5}$). The following sections summarize and discuss the main findings from the modelling, and provide some recommendations for its future application.

7.2 Summary of Findings

This section summarizes the model findings from Sections 2.0 to 6.0, presented in the order given in Table 1. However, note that the first two items in the following – review of emissions and air quality observations, and model evaluation – do not appear in Table 1, but were necessary prerequisites for applications of the model.

Qualitative comparison of emissions inventory with source apportionment

This was carried out to examine which sources of PM_{10} could be modelled, based on the emissions inventory, and to what extent the airshed model results should match observed PM_{10}. It was found that the observations – being carried out at a limited number of sites – did not discern port and airport activities, industry and emissions of $PM_{2.5-10}$ from motor vehicles in Napier, though these components are included in the emissions inventory. Natural sources of PM_{10} from sea spray and soil dust were visible in the source apportionment analysis and were included in the airshed modelling results as a post-processing step. The mean 24-hour-average concentrations in Napier were 6.3 µg/m^3 of PM_{10} and 1.0 µg/m^3 of $PM_{2.5}$. In Hastings, these were 5.2 µg/m^3 of PM_{10} and 0.9 µg/m^3 of $PM_{2.5}$.

Airshed model performance evaluation

Calibrated model results provided a good match to the peak observed 24-hour PM_{10} concentrations of 71 µg/m^3 and 93 µg/m^3 over the last five years. Although the model was run with current emissions based on five years of meteorology, the worst-case modelled PM_{10} events occurred in the later three years (2008-2010). These occurred during winter on occasions where the wind speed dropped from around 2 m/s in the daytime to less than 0.5 m/s in the evening. A change in wind direction from onshore to offshore indicated the possibility of the same emissions passing over the urban areas twice and contributing twice to the 24-hour average, as had already been found by Golder (2009).

Identification of PM_{10} 'hot spots' in Napier and Hastings

Although the peak modelled PM_{10} (24-hour average 74 µg/m^3) was relatively high in Marewa, the concentration is potentially higher in Pirimai, about 2.5 km to the southeast (up to 85 µg/m^3). The area contained by the 50 µg/m^3 contour – as a peak – is smaller than Napier's Airzone 1.

The spatial distribution of modelled peak PM_{10} in Hastings indicates that the St John's College site (in Mayfair CAU) is part of a ring of peak PM_{10} levels around the Hastings Central CAU. The area contained by the 50 µg/m^3 contour is slightly larger than the Hastings Airzone 1.

The model indicates that peak PM_{10} levels in Hastings and Napier are likely to be similar, but the areal extent of potential concentrations about 50 µg/m^3 is larger for Hastings.

The model indicates that PM_{10} levels in Flaxmere and Havelock North can exceed 40 µg/m^3. Concentrations in Havelock North could conceivably exceed 50 µg/m^3.

Note that the identified hot spots in the modelling are due to domestic heating emissions during winter evenings. Peaks due to industry or transport have not been examined in this work.

In previous work for HBRC, start-point 24-hour-average PM_{10} concentrations for 'straight-line paths' to NES were calculated, based on peak PM_{10} arising from 2005 emissions (Gimson 2006). These were 95 µg/m^3 for Napier and 170 µg/m^3 for Hastings. They incorporated some conservative assumptions and were somewhat higher than concentrations observed before 2006 at Marewa Park and St John's College. A repeat of the calculations now would yield lower start-points. However, given recent changes to the NES, the straight-line path concept is now obsolete.

Dispersion of PM_{10} between Airzones and CAUs

The model indicates that the ambient PM_{10} under worst-case conditions in the Airzone 1 areas of each of Napier and Hastings is discharged from that area. That is, very little of the PM_{10} in Napier's Airzone 1 would have been discharged in Hastings, and *vice versa*. Airzone 2 areas are not residential, therefore emissions of PM_{10} are low. The modelling indicates that nearly all exceedences of the NES criterion for PM_{10} in Napier would still occur if there were no emissions in Hastings, and *vice versa.*

However, inter-CAU dispersion is significant. Under worst-case conditions, the modelling indicates that a few tens of % of the PM_{10} arriving at the Marewa Park or St John's College monitoring sites would have been discharged in neighbouring CAUs. These would be those in Napier to the southwest of Marewa, and all of the ring of high-emission CAUs around Hastings can contribute to PM_{10} reaching St John's.

Reduction of PM_{10} emissions required for compliance with the NES

For the entire region to comply with the NES for PM_{10} (maximum 24-hour concentration of 50 µg/m^3), the modelling indicates that reductions in domestic heating relative to present-day emissions of 47% in Napier and 50% in Hastings would be required. The reductions are higher than indicated by ambient concentrations at the monitoring sites, as only one component – domestic heating – was under consideration for emissions reductions and the monitoring sites need not be the locations of peak PM_{10} levels (though they are close).

Modelled ambient PM_{10} concentrations based on projected PM_{10} emissions to 2020

Airshed modelling carried out using projected emissions to the year 2020 indicates compliance with the NES for PM_{10} over the entire region by a substantial margin (around 20 µg/m^3). However, the results should be treated with caution. The 2020 emissions information was based on projections from 2010 data, and it has been noted that there are some doubts about the number of heating appliances currently in use.

Estimates of peak $PM_{2.5}$ concentrations and compliance with the WHO guideline

The airshed model has provided indications of ambient $PM_{2.5}$ levels, using an approximate ratio of emissions ($PM_{2.5}$/PM_{10}) for each source component. The peak modelled $PM_{2.5}$ is 76 µg/m^3 in Napier, and 81 µg/m^3 in Hastings. These are close in magnitude to the peak modelled PM_{10}, as PM_{10} from domestic heating has been assumed to be nearly all $PM_{2.5}$. Emissions reductions to comply with the WHO guideline for 24-hour $PM_{2.5}$ would be more stringent, as the criterion concentration for $PM_{2.5}$ is one-half that of the criterion for PM_{10}. The model indicates that a reduction of 72 % in domestic-heating emissions would be needed in both main cities to comply with the WHO guideline.

7.3 Improving Airshed Model Performance

This section discusses some aspects of the airshed model performance relevant to the current work, and gives suggestions as to how performance may be improved in future work.

TAPM meteorological modelling

The modelled wind field has benefited from the assimilation of wind observations into the model runs, as seen in the model performance statistics (IOA and skill scores), and the improvement at low wind speeds. Temperature data cannot be assimilated, and the model calculates this internally. The model predictions of night-time temperatures are sometimes warmer than those which occurred, which may affect boundary-layer stability. Assimilation of temperature data may lead to imbalances in the model's dynamics at the surface, and so is not recommended. Improvement of model performance should come about through improvement of the surface energy balance routines by the model developers.

Emissions inventory information

TAPM has been found to perform best using emissions information for 2010 projected from 2005, and including a scale factor to represent worst-case emission conditions. More certainty regarding model inputs would be gained if the uncertainties in heating appliance numbers were able to be reduced, and independent methods for incorporating day-to-day variability in emissions due to human behaviour were developed. These may account for increased fuel use under colder temperatures, for instance, and would better distinguish between average and worst-case emissions and give guidance as to when worst-case conditions would occur. Improvements to the 2010 inventory should also lead to improvements in the 2020 projections.

Case-study periods

This work has been carried out with the aim of providing a broad-brush model which represents average, long-term conditions reasonably and has some ability to predict worst-case situations. It is based on statistics derived from five-year runs of TAPM. To examine apparent shortcomings in the model it would be instructive to carry out short-term case studies (of a few days), investigating the modelled and observed hour-by-hour trends in meteorological conditions and air pollution concentrations, determining the physical processes at play through examination of data without reference to the model, and then determining whether those physical processes have been correctly incorporated into the model. This has been done to some extent in Section 2.0. A close examination of specific case studies may identify missing sources, or identify some deficiency in the model's representation of atmospheric turbulence and consequent pollution dispersion. It could then improve the representation of worst-case and near-worst-case conditions, improve performance statistics and quantile-quantile plots, and lead to a better representation of the number of target exceedences. At least, an assessment of uncertainties in the modelling may indicate where improvements may be made.

7.4 Airshed Management in the Hawke's Bay Region

This section outlines some potential future applications of modelling techniques to address airshed management issues in the region. Some have been mentioned in work for the Auckland, Nelson City and Tasman District Councils (Golder 2011, 2012), and are equally applicable to the Hawke's Bay Region.

Improvement in $PM_{2.5}$ estimates

Improvements in estimates of $PM_{2.5}$ glcs could be accomplished through compilation of an up-to-date $PM_{2.5}$ emissions inventory, and would provide guidance to HBRC in the event that WHO guidelines for $PM_{2.5}$ become regulatory standards in New Zealand. Complementary to any modelling, $PM_{2.5}$ could be carried out at the same location as PM_{10} monitoring as ground-truth for $PM_{2.5}$ levels and for model-validation purposes.

Contribution to PM_{10} and $PM_{2.5}$ from motor vehicles

Whilst airshed models do not resolve peaks in concentration next to the roadside, there are a number of models which are able do this. For instance, CALINE4 and AUSROADS are based on single-point meteorological data files, similar to those produced in this work for AUSPLUME. Files for CALINE4 or AUSROADS could also be produced from the CALMET modelling carried out here. CALPUFF could be run with line sources representing road links, based on the CALMET model outputs directly. In either case, emissions would need to be specified differently, but there are tools available in New Zealand to accomplish this. Validation could be provided by data from the Meeanee Road air quality monitoring site, and provide an improved estimate of the contribution from motor vehicles at the residential monitoring sites.

Guidance on monitoring site location

If monitoring in new urban areas were being considered, airshed model results could be used to identify peak PM_{10} locations, at which monitoring could be carried out in compliance with NES requirements. The current work can be used in the case of Wairoa, Havelock North or Flaxmere. Previous airshed modelling of the region may be used for the cases of Waipukurau and Waipawa (Gimson 2006).

The airshed modelling indicates that the current monitoring site at Marewa Park is not at the most impacted location in Napier. However, as the monitoring site has been established for several years, the model results should not be used on their own to dictate the site's removal or re-location. At the least, patterns of emissions would also need to be closely examined.

Baseline air quality maps

As air quality assessments have regard to existing air quality so that cumulative effects may be determined, the airshed modelling could be used to provide baseline PM_{10} maps (and associated numerical data) to be used in assessment of new industry and roading projects. These could be used in tandem with the meteorological data sets developed as part of this work.

Other air pollutants

Note that airshed models were originally developed to simulate atmospheric chemistry, in particular the photochemical production of ozone through reactions between oxides of nitrogen and volatile organic compounds (VOCs). Work that has been carried out here for PM_{10} could also be applied to other pollutants of interest, such as nitrogen dioxide, sulphur dioxide and secondary particles. Suitable emissions information would need to be provided, but, unlike most airshed models, TAPM does not need a detailed VOC inventory. The 2010 emissions inventory includes these chemical species, and TAPM could be run to examine the contribution to PM_{10} from secondary nitrates, sulphates or organic aerosols.

8.0 METEOROLOGICAL DATA SETS

Golder has produced meteorological data sets for supply to consultants for use in industrial applications. The data sets are in the form of high-resolution CALMET outputs (100 m or 200 m in the horizontal, as appropriate), covering several industrial areas in the Hawke's Bay region. These model domains cover Napier (centred on Onekawa), the whole of Hastings and Awatoto in combination, Whirinaki and Wairoa. Note that Awatoto and Whirinaki have been designated as airsheds by HBRC due to their industries (as opposed to the Napier and Hastings airsheds whose air quality is determined largely by residential heating and motor vehicles). Two years have been modelled, namely 2006 and 2010, chosen in consultation with HBRC. The data sets are intended to aid dispersion modelling with CALPUFF for industrial resource consent applications, by removing the need to run CALMET and allowing the user to focus on other aspects of the application. Single-point AUSPLUME meteorological files have been produced for selected locations in each CALMET area. Appendix D is a guide to the use of the data sets, which may be read in isolation from the main body of this report. Golder has produced CALMET and AUSPLUME meteorological data sets for the Auckland Council (Gimson et al. 2010), and Nelson City and Tasman District Councils (Golder 2012), following similar methods. Appendix E describes the processing of CALMET outputs to produce AUSPLUME meteorological files.

The CALMET meteorological fields are based on TAPM meteorological outputs, in that three-dimensional TAPM fields are used as an initial approximation to the three-dimensional CALMET fields[11]. Within CALMET, this initial approximation (known as the 'initial guess') is adjusted by terrain effects and the presence of measurements from climate sites. Terrain effects include slope and valley flows, and blocking of the wind by such features as Bluff Hill in Napier. The climate site data – from stations run by HBRC and from CliDb stations – are also used in TAPM, as described in Appendix A. This means that the meteorological fields produced by CALMET for higher-resolution industrial assessments are consistent with those produced by TAPM for regional-scale airshed modelling. Further, the meteorological files for AUSPLUME are based on time series at selected points in the CALMET, and are therefore also consistent. Also, CALMET and AUSPLUME outputs at climate-site locations match observations, and provide derived boundary-layer parameters such as mixing height, Pasquill-Gifford stability class and other turbulence parameters.

The CALMET and AUSPLUME data sets may be obtained on portable hard disk from HBRC.

9.0 CONCLUSIONS

This work has used the urban airshed model TAPM to address air quality issues in the Hawke's Bay region. The TAPM modelling has also been used as a basis for the production of CALMET and AUSPLUME meteorological data sets for use by dispersion modellers in carrying out air quality assessments in the region. The main conclusions are listed as follows:

1) Reductions in emissions from domestic heating by 47% in Napier and 50% in Hastings (relative to current emission levels) were indicated by the model for compliance with the NES for PM_{10}.

[11] This is not true for Wairoa, as the CALMET data sets for this area are created following a different methodology (see Appendix D for more details).

2) It is unclear whether emission reductions measures need to be taken in Havelock North, as the model indicates that this urban area is currently compliant with the NES by a small margin.

3) The model indicated that all airsheds would be compliant with the NES for PM_{10} by 2020, based on projected emissions. However, there are some uncertainties in the emissions projections supplied to Golder, and these results should be treated with care.

4) The modelling indicated a required reduction in domestic heating emissions of 72% (relative to current emission levels), in both Napier and Hastings, for compliance with the WHO guideline for $PM_{2.5}$.

This report also makes several suggestions for improvements in the modelling and associated data sets, and for further applications of the models to the management of air quality in the Hawke's Bay region.

The focus of this project has been the production of good-quality, physically-realistic results, creating a management tool which is robust enough to be used for future air quality planning and management.

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APPENDIX A

Configuration and Evaluation of the TAPM Meteorological Model

1.0 INTRODUCTION

This Appendix describes the configuration of the meteorological component of TAPM for the Heretaunga Plains (Section 2.0), and evaluates the model's performance using common statistical measures of performance (Section 3.0). A glossary of terms and reference list may be found in Sections 4.0 and 5.0 (respectively) of this Appendix.

2.0 CONFIGURATION OF THE METEOROLOGICAL MODEL

The TAPM runs were set up according to the parameters listed in Table 1. The model domain was centred on chosen latitude/longitude coordinates (39°32' S, 176° 51.5' E) relative to the WGS-84 geodetic datum, with New Zealand Transverse Mercator Grid (NZTM) coordinates assigned to the central point. TAPM works with latitude/longitude grids, converting from angular measures to distances 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 effects of curvature of the earth – for instance, the stretching of longitudinal distances at different latitudes – are accounted for by TAPM. However, there is a slight discrepancy between the regular NZTM grid and the latitude/longitude system, in that the NZTM axes are not exactly aligned with the cardinal directions. However, this discrepancy is small (relative to the model grid spacing) over the fine model grid used in this instance.

TAPM employs a one-way 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. Four grids were used in this work, with the third and fourth grids shown in Figure 1 and Figure 2 respectively. Grid 4 has the finest horizontal resolution (1 km grid cell size).

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 2006 to 2010 are used to drive the model runs described in this report. Local mesoscale meteorological features, such as sea breezes and slope flows, are produced by the model's internal dynamics.

TAPM can assimilate wind data, and uses a scheme which nudges the modelled wind components towards their observed values around climate site locations. Ideally, the performance of TAPM should be good enough so that this is not necessary. However, the model tends to overestimate wind speeds during calm conditions, which can be important for pollution events. It can also underestimate the daytime maximum wind speeds. As a way of counteracting this, and as the focus of this project is the dispersion of PM_{10}, rather than the meteorological solutions from TAPM *per se*, wind data assimilation has been used in the meteorological-model runs. This has been done at the six 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).

By default, TAPM computes the evolution of the meteorological and pollution-dispersion fields together, at the model's time step. Although this means the pollution dispersion responds to meteorological changes minute by minute, the calculation of the meteorology must be repeated for each dispersion modelling scenario. However, there is also an 'off-line' mode, where meteorological outputs are saved, to be used in subsequent airshed model runs. These can then be carried out without re-calculating the meteorology. As a large number of airshed model scenarios are being run in this work, the off-line option has been used to save computing time. In this case, the hourly meteorological fields on the finest grid only have been saved for this purpose (as this covers a sufficiently large area).

TAPM configuration parameters not mentioned in this Appendix 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 2006 to 31 December 2010
Grid centre (Lat/Long, WGS84)	39°32' S 176° 51.5' E
Grid centre (NZTM)	(1931625, 5616923) (m)
No. of grids; no. of grid cells in horizontal	4; 35 x 56
Horizontal grid-cell spacing (one value per grid)	25 km, 9 km, 3 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

The five-year modelling period was broken down into short TAPM runs, each three months long. Provision of meteorological data sets for the years 2006 and 2010 required the TAPM meteorological model to be run for these two years in full. Airshed modelling using TAPM requires the modelled meteorology for the months April to September, so that meteorological modelling was not necessary for the first and last quarters of the other years.

Table 2: List of meteorological stations whose wind data are assimilated into the TAPM runs.

Site name	Easting (NZTM, m)	Northing (NZTM, m)	Grid 4 i-coord.	Grid 4 j-coord.
Marewa	1935111	5620462	21	32
St John's	1931162	5605203	18	17
Meeanee	1931896	5616272	18	28
Napier Aero AWS	1932054	5625146	18	37
Whakatu EWS	1935895	5608405	22	20
Bridge Pa	1922903	5604721	9	16

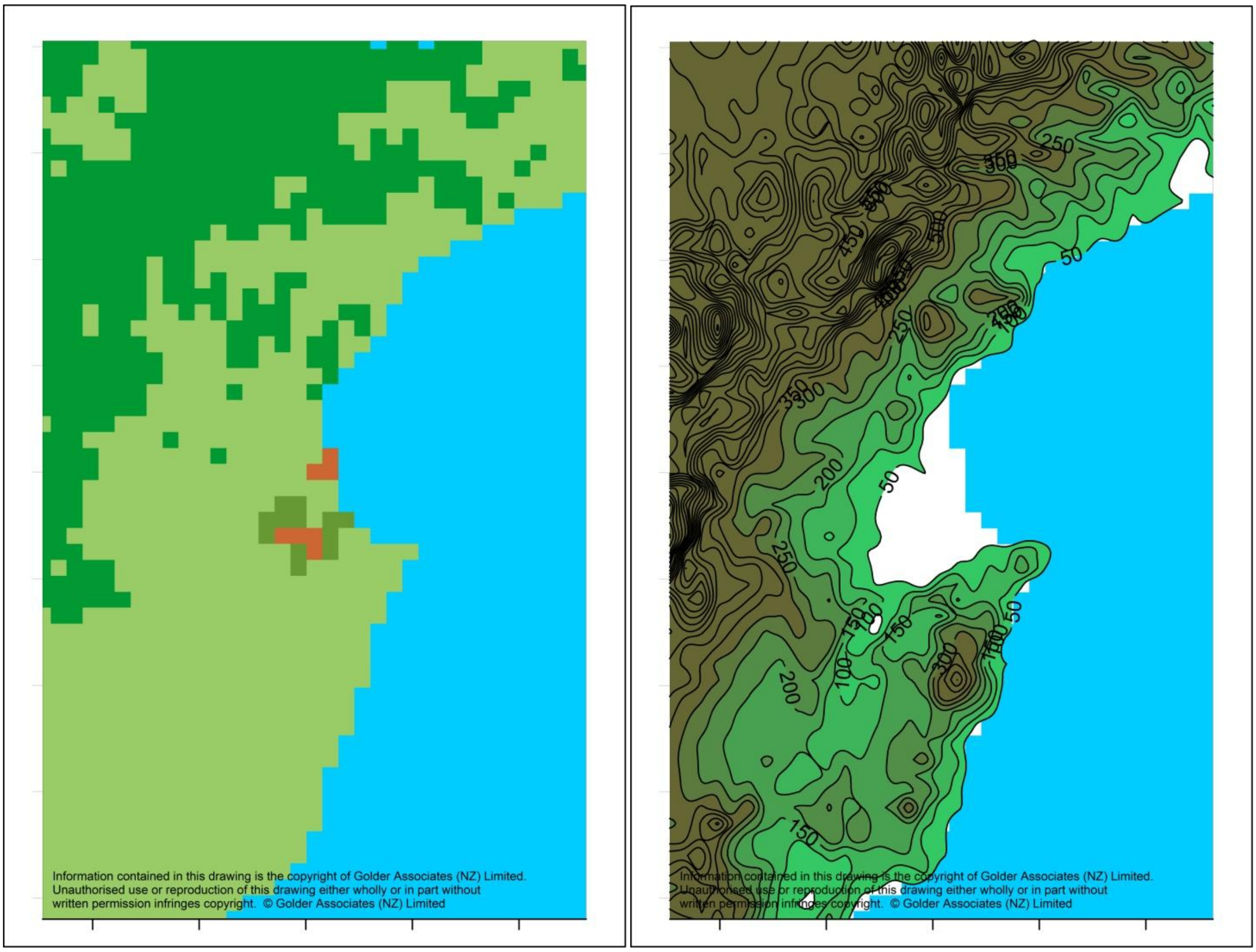

Figure 1: TAPM grid 3 land use (left panel) and elevation (right panel). Land use is coloured blue (sea), green (light for shrubland; dark for forest), orange (urban). Terrain contour interval is 50 m, starting at 50 m above sea level. Axis tick mark interval is 20 km.

3.0 EVALUATION OF MODEL PERFORMANCE

Time series of TAPM meteorological outputs have been compared with observations at monitoring sites for the years 2006, 2008, 2009 and 2010, using common statistical measures[1]. Model performance measures are described by Willmott (1981; 1982) and in the Glossary to this Appendix. Their formulas are given by Golder (2007), for example. The TAPM outputs have been compared with the HBRC meteorological data from ambient air quality monitoring sites, and with climate sites on the National Climate Database (CliDb). In Napier and Hastings there are six sites in all, whose wind data have been assimilated into the TAPM simulations, as described above.

The index of agreement (IOA) varies between 0 for no agreement and 1 for complete agreement between modelled and observed quantities. Table 3 shows this parameter for the wind speed (labelled WS), the westerly and southerly wind-velocity components (labelled U and V, respectively), and temperature and relative humidity (T and RH). Each line of the table represents a site/year combination, and the table includes results from 2006 without wind data assimilation.

[1] For the years 2008, 2009 and 2010, measures of model performance have been calculated for the months April to September inclusive (although 2010 was run for the full year). Performance measures for 2006 have been calculated from the full-year integration.

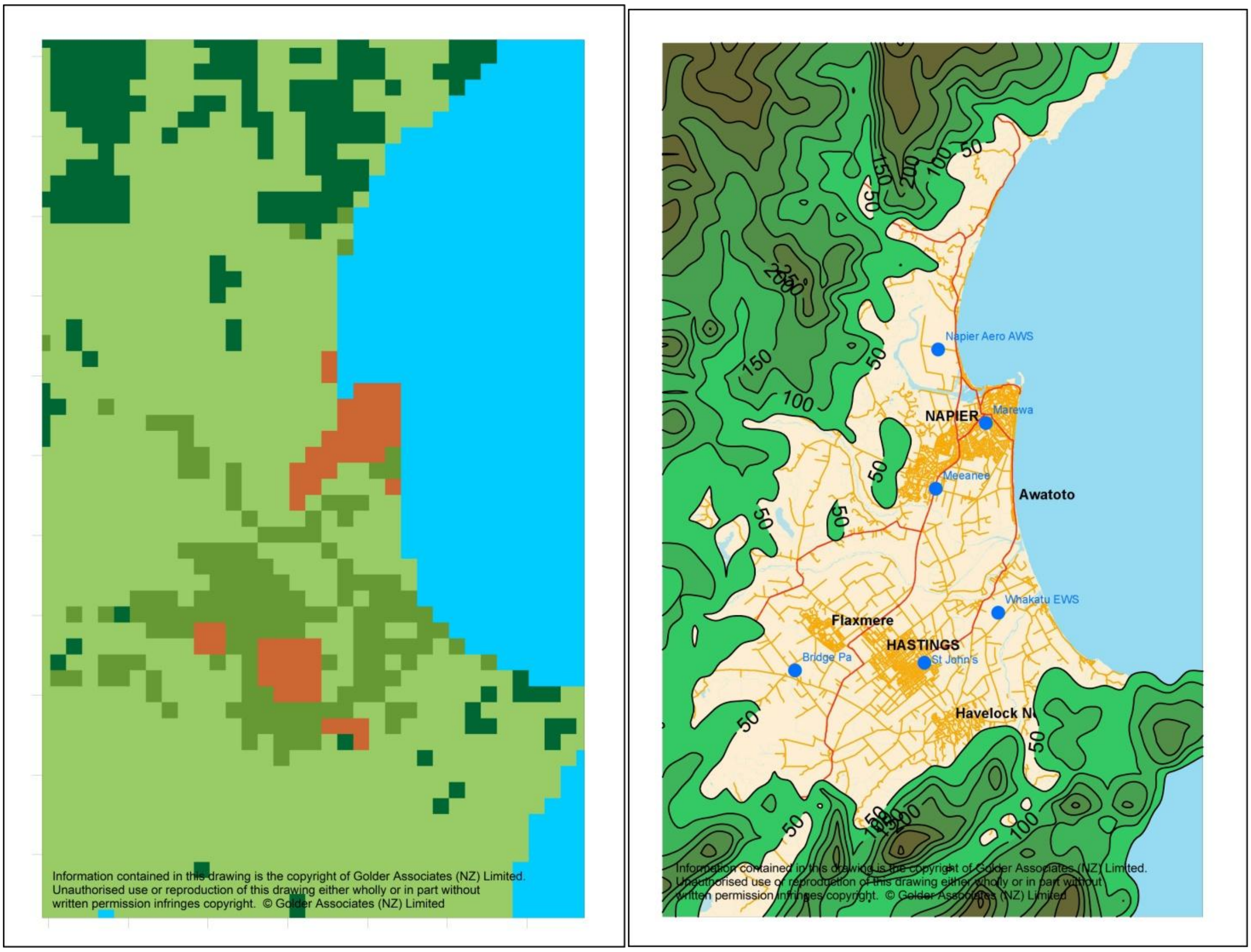

Figure 2: TAPM grid 4 land use (left panel) and elevation (right panel). Dimensions are 35 km by 56 km. Land use is coloured blue (sea), green (light for shrub land; dark for forest), orange (urban). Terrain contour interval is 50 m, starting at 50 m above sea level. Meteorological sites are marked on the map (right panel).

For the runs into which wind data were assimilated, values of IOA for the wind components and wind speed are generally high, being above 0.90 for all sites except St John's, which is above 0.85. Without wind data assimilation, the IOA is around 0.70 to 0.75. It is considered that values of 0.7-0.8 would indicate good model performance, which is the case here. Model performance is reasonable even without data assimilation. This would ideally be the case, and the data assimilation should amount to a weak forcing of the model results towards observations.

The IOA for temperature is at least 0.8 at these sites, which is considered good performance (noting that temperature data from the monitoring sites have not been assimilated into the model run). The IOA for relative humidity is somewhat less, between 0.6 and 0.87.

Other measures include the so-called "skill" scores. "Skill_R" is the root-mean-square model error divided by the standard deviation of the observed parameter, and is a measure of the model error relative to the observed variability. It should be as small as possible (and definitely less than 1). Values of Skill_R are presented in Table 4. For the wind components Skill_R is mostly below 0.4, with some values up to 0.8. Without wind data assimilation, they are well above 0.8. Skill_R for temperature ranges between 0.39 and 0.71.

"Skill_V" is the ratio of the standard deviations of the modelled and observed parameters. It should be as close as possible to 1, meaning that the model variability in the parameter is similar in size to the observed variability. Values of Skill_V for each meteorological variable and each site/year combination are presented in Table 5. Most of the values for wind components are in the range 0.8-1.0. For temperature, Skill_V ranges between 0.66 and 0.89. On the whole, modelled variability is less than observed.

Table 3: IOA between TAPM outputs and meteorological observations. 2006(NA) refers to the 2006 run without wind data assimilation. Parameters are wind speed (WS), wind components U and V (eastwards and northwards), temperature T and relative humidity RH.

Site	Year	WS	U	V	T	RH
Marewa	2010	0.93	0.96	0.96	0.88	0.80
Marewa	2009	0.93	0.95	0.97	0.88	0.76
Marewa	2008	0.93	0.95	0.97	0.89	0.79
Marewa	2006	0.91	0.94	0.95	0.93	0.80
Marewa	2006(NA)	0.78	0.70	0.72	0.95	0.82
Meeanee	2010	0.96	0.95	0.98	0.88	0.81
Meeanee	2009	0.95	0.95	0.98	0.88	0.78
Meeanee	2008	0.96	0.93	0.98	0.89	0.60
Meeanee	2006	0.96	0.95	0.98	0.94	0.82
Meeanee	2006(NA)	0.74	0.71	0.83	0.95	0.83
St John's	2010	0.96	0.93	0.98	0.89	0.85
St John's	2009	0.96	0.88	0.98	0.89	0.84
St John's	2008	0.95	0.90	0.98	0.91	0.85
St John's	2006	0.92	0.85	0.97	0.91	0.63
St John's	2006(NA)	0.74	0.49	0.79	0.93	0.64
Napier Aero	2010	0.96	0.97	0.98	0.88	0.75
Napier Aero	2009	0.98	0.99	0.99	0.87	0.71
Napier Aero	2008	0.98	0.98	0.99	0.88	0.75
Napier Aero	2006	0.97	0.98	0.99	0.94	0.82
Napier Aero	2006(NA)	0.73	0.78	0.82	0.95	0.84
Whataku	2010	0.98	0.99	0.99	0.81	0.77
Whataku	2009	0.98	0.98	0.99	0.82	0.74
Whataku	2008	0.98	0.98	0.99	0.83	0.76
Whataku	2006	0.97	0.98	0.99	0.91	0.80
Whataku	2006(NA)	0.83	0.82	0.87	0.94	0.86
Bridge Pa	2010	0.98	0.98	0.99	0.89	0.84
Bridge Pa	2009	0.96	0.98	0.99	0.82	0.74
Bridge Pa	2008	0.97	0.98	0.99	0.88	0.83
Bridge Pa	2006	0.94	0.98	0.99	0.93	0.87
Bridge Pa	2006(NA)	0.68	0.68	0.74	0.91	0.86

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

Site	Year	WS	U	V	T	RH
Marewa	2010	0.45	0.36	0.35	0.60	0.81
Marewa	2009	0.46	0.38	0.32	0.62	0.85
Marewa	2008	0.45	0.39	0.33	0.59	0.84
Marewa	2006	0.52	0.41	0.40	0.47	0.90
Marewa	2006(NA)	0.77	0.94	0.89	0.43	0.89
Meeanee	2010	0.36	0.50	0.28	0.60	0.78
Meeanee	2009	0.40	0.48	0.26	0.62	0.80
Meeanee	2008	0.40	0.57	0.26	0.62	1.56
Meeanee	2006	0.36	0.46	0.29	0.45	0.85
Meeanee	2006(NA)	0.94	1.24	0.77	0.39	0.84
St John's	2010	0.39	0.55	0.27	0.58	0.73
St John's	2009	0.41	0.71	0.29	0.59	0.73
St John's	2008	0.44	0.68	0.26	0.54	0.71
St John's	2006	0.55	0.80	0.31	0.52	1.38
St John's	2006(NA)	1.12	1.87	0.87	0.46	1.37
Napier Aero	2010	0.38	0.33	0.23	0.59	0.94
Napier Aero	2009	0.29	0.23	0.19	0.64	0.94
Napier Aero	2008	0.28	0.23	0.19	0.62	0.94
Napier Aero	2006	0.33	0.25	0.22	0.44	0.77
Napier Aero	2006(NA)	0.89	0.79	0.69	0.42	0.72
Whataku	2010	0.27	0.23	0.17	0.71	0.91
Whataku	2009	0.28	0.25	0.16	0.71	0.95
Whataku	2008	0.28	0.25	0.16	0.69	0.92
Whataku	2006	0.32	0.30	0.20	0.52	0.83
Whataku	2006(NA)	0.76	0.82	0.65	0.43	0.69
Bridge Pa	2010	0.31	0.25	0.18	0.57	0.75
Bridge Pa	2009	0.41	0.26	0.18	0.71	0.95
Bridge Pa	2008	0.37	0.26	0.17	0.59	0.76
Bridge Pa	2006	0.47	0.30	0.21	0.45	0.65
Bridge Pa	2006(NA)	1.30	0.99	0.84	0.52	0.67

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

Site	Year	WS	U	V	T	RH
Marewa	2010	0.74	0.77	0.77	0.78	0.88
Marewa	2009	0.75	0.78	0.80	0.81	0.83
Marewa	2008	0.75	0.79	0.80	0.87	0.90
Marewa	2006	0.73	0.75	0.75	0.87	1.12
Marewa	2006(NA)	0.68	0.83	0.76	0.89	1.18
Meeanee	2010	0.91	1.17	0.86	0.78	0.88
Meeanee	2009	0.88	1.10	0.89	0.81	0.80
Meeanee	2008	0.92	1.14	0.89	0.86	1.57
Meeanee	2006	0.88	1.02	0.87	0.86	1.09
Meeanee	2006(NA)	0.90	1.47	0.95	0.88	1.17
St John's	2010	1.02	1.21	0.92	0.78	0.92
St John's	2009	0.99	1.10	0.94	0.79	0.86
St John's	2008	1.00	1.21	0.92	0.83	0.92
St John's	2006	1.05	1.14	0.93	0.77	1.35
St John's	2006(NA)	1.28	1.78	1.00	0.80	1.42
Napier Aero	2010	0.89	0.93	0.91	0.78	0.84
Napier Aero	2009	0.85	0.88	0.86	0.79	0.76
Napier Aero	2008	0.86	0.88	0.87	0.84	0.88
Napier Aero	2006	0.85	0.86	0.85	0.85	0.88
Napier Aero	2006(NA)	0.74	0.76	0.71	0.85	0.89
Whataku	2010	0.95	0.93	0.91	0.66	0.86
Whataku	2009	0.94	0.94	0.92	0.70	0.80
Whataku	2008	0.93	0.93	0.91	0.71	0.89
Whataku	2006	0.92	0.91	0.89	0.77	0.86
Whataku	2006(NA)	0.96	1.02	0.88	0.80	0.89
Bridge Pa	2010	0.96	0.92	0.90	0.72	0.89
Bridge Pa	2009	0.98	0.90	0.89	0.70	0.80
Bridge Pa	2008	0.98	0.91	0.90	0.75	0.90
Bridge Pa	2006	1.02	0.90	0.88	0.76	0.86
Bridge Pa	2006(NA)	1.30	0.88	0.75	0.76	0.87

It is considered that the model performance measures discussed above show good overall performance of TAPM in simulating the meteorology of the Hawke's Bay area. This is particularly true of the modelled wind, upon which dispersion of pollution mostly depends.

The statistical performance measures relate to time series of meteorological parameters over the whole year's run. They do not, for instance, give information about how well the model simulates extremes in those parameters, such as low winds and cold temperatures.

The model has a tendency to miss extremes of wind speed. This is particularly important for dispersion in near-calm conditions, as pollution concentrations are sensitive to low wind speeds. The assimilation of wind data into the TAPM runs is beneficial; it brings about a small change in wind speed from, say, 1.0 m/s to 0.5 m/s, which enables a better simulation of pollution dispersion in calm conditions and associated high concentrations. It should be noted that difficulties with the simulation of calm conditions are common to many prognostic meteorological models.

Related to the occurrence of calm winds is the occurrence of cold surface temperatures at night. Calm, cold, stable conditions give rise to high pollution levels from domestic heating emissions during winter evenings. It is often the case that if a meteorological model does not simulate cold temperatures on a particular occasion, it also does not simulate low wind speeds at that time. TAPM has a tendency to over-estimate night-time temperatures by several degrees. There are several configuration parameters which can be altered, such as soil moisture, soil temperature, sea-surface temperature. These have been tested, in consultation with CSIRO, but have made little difference to the surface temperature. This may have a bearing on surface-layer stability, which affects nocturnal inversion strength, pollution mixing and ultimately the modelled pollution concentration. However, it is still the case that the meteorological component of TAPM performs well overall. It enables a reasonable simulation of the dispersion of air pollutants around the urban areas Napier, Hastings, Flaxmere and Havelock North and the surrounding Heretaunga Plains, as is seen by the comparison with air quality monitoring (see Appendix C).

4.0 GLOSSARY OF MODEL PERFORMANCE MEASURES

Standard model performance measures were defined by Willmott (1981; 1982). They are regularly used in papers describing the performance of TAPM. Their formulas are given by Golder (2007), for example.

Index of Agreement (IOA):

This 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 dispersion model performance. Higher values should be expected for meteorological models, particularly if observations have been assimilated.

Root-mean-square error (RMSE):

This is a measure of the average difference between modelled and observed values of the time series variable at each instant in the time series. This may be partitioned into systematic and unsystematic (or random) components (labelled RMSEs and RMSEu) by carrying out a linear regression of modelled on observed data. A desirable feature of model performance is that the systematic part should be lower than the random part. Values of RMSE, RMSEs and RMSEu are not presented in the above, but are mentioned here as the skill scores depend on them.

Model skill scores (Skill_E, Skill_R and Skill_V):

The model skill scores relate the variability in PM_{10} simulated by the model to the observed variability, for the whole time series of paired observed/modelled concentrations. Defining the time series standard deviations as Std_O for observations and Std_P for modelled variables, gives the following:

Skill_E = RMSEs/Std_O	the systematic error as a fraction of the observed variability,
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_E and Skill_R should be less than 1 (and Skill_E should be much less than Skill_R), meaning the errors in the model are less than the variability in the observations. Skill_V should be close to 1, meaning the model reproduces the observed variability.

5.0 REFERENCES

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APPENDIX B

Emissions Preparation and TAPM Airshed Model Configuration

1.0 INTRODUCTION

Full accounts of the development of emissions inventories for urban areas in the Hawke's Bay region are given by Wilton (2005) and Wilton and Baynes (2010). Emissions data from both inventories, broken down by Census Area Unit (CAU), hour of day, and month of the year were supplied to Golder by Environet Ltd in July 2011. This Appendix summarizes the PM_{10} emissions totals used as input to the airshed modelling of the Heretaunga Plains (Section 2.0), and discusses other aspects of the TAPM configuration (Section 0).

2.0 EMISSIONS INVENTORIES

2.1 Overview

The 2010 inventory survey indicated a significant decrease in the number of home heating appliances in use compared to 2005, due to removal of heaters in the interim. Coupled with ongoing replacement of old heaters by NES-compliant burners, the total calculated PM_{10} emissions from domestic heating was significantly lower in 2010 than 2005. However, some doubt remains with the inventory developer as to the true decrease in appliance numbers as inferred from responses to the surveys on heating methods, carried out as part of the emissions inventory development. An alternative inventory for 2010 has been developed by Environet. Golder understands that this is based on appliance numbers from the 2005 survey, projected to 2010. This alternative inventory indicates that the total domestic heating emissions are between the 2005 and the original 2010 estimates. There are thus three emissions inventory variations which could be used in the airshed modelling to represent present-day conditions and simulate present-day levels of ambient PM_{10}. In addition, projected emissions to the year 2020 have been supplied by Environet to Golder, for use as input to the airshed model in its estimation of future levels of PM_{10}.

The most appropriate inventory data set for modelling present-day ambient PM_{10} levels has been determined in Appendix C through comparison of model outputs with ambient PM_{10} concentrations. However, this should not be seen as endorsement of one variant of the emissions information in preference to another, nor as a validation of emissions data or the airshed model itself. A dispersion model should not be used to evaluate its own input data, due to uncertainties in the model itself.

The remaining sub-sections summarize the emissions inventory information used in the airshed modelling.

2.2 2005 Emissions Inventory

Daily emissions totals of PM_{10} from the 2005 inventory are shown in Table 1 for each mid-year month. These are taken from tables in the report by Wilton (2005) and represent 'average' conditions. Emissions were presented in the inventories for 'average' and 'worst-case' conditions, which depend on the number of days per week that households use their heating appliances. 'Average' refers to an average over the number of days appliances are actually in used (according to the surveys). This is less than 7 days per week. A 'worst-case' daily emissions total assumes all appliances are in use on that day. The ratio of worst-case to average emissions totals differs between urban areas, and ranges between 1.3 and 1.9. The emissions do not account for increased fuel usage on colder days.

Table 2 gives the total daily PM_{10} emissions from other sources in the region.

In the tables presented in this Appendix, the emissions totals for regions outside the main urban areas – denoted "Rest of Region" are less than those presented in inventory reports, as the airshed model domain (TAPM grid 4) covers the Heretaunga Plains only, and not the whole Hawke's Bay region. Also, updated motor vehicle emissions for 2006 were supplied separately by Environet – these are not in the 2005 inventory report.

Table 1: Domestic PM_{10} emissions from the 2005 inventory (in kg/day).

Location	April	May	June	July	August	September
Napier	326	1178	1985	2098	1564	780
Hastings/Flaxmere	456	1274	1577	1637	1463	940
Havelock North	270	409	509	541	446	364
Rest of Region	343	1374	1705	1738	1733	591

Table 2: PM_{10} Emissions from other sources in the 2005 inventory (in kg/day).

Location	Motor Vehicles (2006 update)	Industry	Outdoor Burning	Other
Napier	108	57	110	49
Hastings/Flaxmere	69	39	95	0
Havelock North	42	5	82	0
Rest of Region	110	187	275	30

'Other' refers to orchard heaters and the burning of vineyard and orchard pruning.

2.3 2010 Emissions Inventory

Table 3 contains domestic heating emissions for 'average' conditions, according to surveys of appliance use in 2010 (Wilton & Baynes 2010). Table 4 contains domestic heating emissions of PM_{10} for 2010 projected from 2005 data. Table 5 contains domestic heating emissions projected to 2020 and Table 6 contains emissions from other sources (for 2010).

Table 3: Domestic PM_{10} emissions from the 2010 inventory (in kg/day).

Location	April	May	June	July	August	September
Napier	113	584	1188	1288	1068	419
Hastings/Flaxmere	138	620	1182	1242	1078	394
Havelock North	16	147	298	311	288	107
Rest of Region	84	434	882	956	793	311

Table 4: Domestic PM_{10} emissions for 2010 projected from 2005 (in kg/day).

Location	April	May	June	July	August	September
Napier	158	812	1652	1790	1485	583
Hastings/Flaxmere	150	671	1280	1345	1167	426
Havelock North	17	159	323	337	311	116
Rest of Region	84	434	882	956	793	311

Table 5: Domestic PM_{10} emissions for 2020 projected from 2010 (in kg/day).

Location	April	May	June	July	August	September
Napier	63	323	657	713	591	232
Hastings/Flaxmere	39	175	334	351	305	111
Havelock North	4	42	84	88	81	30
Rest of Region	84	434	882	956	793	311

Table 6: PM_{10} Emissions from other sources in the 2010 inventory (in kg/day).

Location	Motor Vehicles	Industry	Outdoor Burning	Other
Napier	52	14	0	25[(a)]
Hastings/Flaxmere	33	17	0	0
Havelock North	9	0	0	0
Rest of Region	54	15	0	20[(b)]

'Other' refers to (a) port activities and (b) airport emissions. Limits have been placed by HBRC on outdoor burning, and its emissions are given as zero in the inventory. Industry emissions vary between months: July values are shown here.

As mentioned above, the 2010 inventory results indicate a decrease in domestic PM_{10} emissions between 2005 and 2010. For instance, average emissions in Napier in July changed from 2098 kg/day in 2005 (Table 1) to 1288 kg/day in 2010 (Table 3). Golder understands that there are uncertainties in the numbers of domestic heating appliances currently in use, and 2010 emissions were re-calculated by the inventory compilers, using projections of appliance numbers and emission factors from the 2005 data. In that case, the daily total for Napier in July is 1790 kg/day (Table 4), higher than calculated from the 2010 survey. Emissions were predicted to drop to 713 kg/day by 2020 (Table 5).

2.4 Spatial Patterns of PM_{10} Emissions

Daily emissions totals were supplied to Golder by Environet with a breakdown by CAU. Concentrations simulated by the airshed model are based on emissions from a regular grid. The meteorological model grid has a horizontal resolution of 1 km (described in Appendix A). However, to resolve the CAUs and conserve the total mass emissions (in kg/day) *and* the emission *density* (in $kg/km^2/day$), the emissions were modelled on a grid of 250 m resolution. A mapping between grid-cell centres and CAU name was provided by HBRC. Spatial patterns of daily emissions are shown here on the 250 m grid, with daily totals shown in Figure 1, Figure 2, Figure 3 and Figure 4 for each source type. These figures represent average conditions in July as given by the 2010 inventory.

Emissions of PM_{10} in the Hawke's Bay region are dominated by the domestic heating component, with values up to 96 $kg/km^2/day$ (Figure 1). They are highest in Hastings and Flaxmere, and certain CAUs in Napier. Motor vehicle emissions are lower, up to 4.6 $kg/km^2/day$ averaged over CAUs (Figure 2). However, it is likely that hot spots of PM_{10} arise close to the roadside, which are smoothed out in the CAU average. The airshed model should not be expected to resolve these road-side peaks; it is only able to model urban background PM_{10} levels due to road transport.

The industrial component of the inventory PM_{10} is dominated by contributions in the Onekawa West, Hastings Central and Kingsley/Chatham CAUs (Figure 3). These are also lower in magnitude than the domestic component. Finally, emissions from port activities and the airport are also small (Figure 4). Napier airport is in the Bayview CAU, which has a large area, leading to a very small emission density *per area*[1]. The airshed model should model the effects of domestic heating well, as residences are spread through the CAUs, but may not simulate the details of dispersion from the other sources, as these occur on smaller scales.

[1] Emissions used in the airshed modelling have been averaged over CAU. This could have been improved for airport activities by averaging over the area of the airport only, rather than the Bayview CAU. However, air pollution from airport activities is not a focus of this work, and emissions density would still be far smaller than domestic heating.

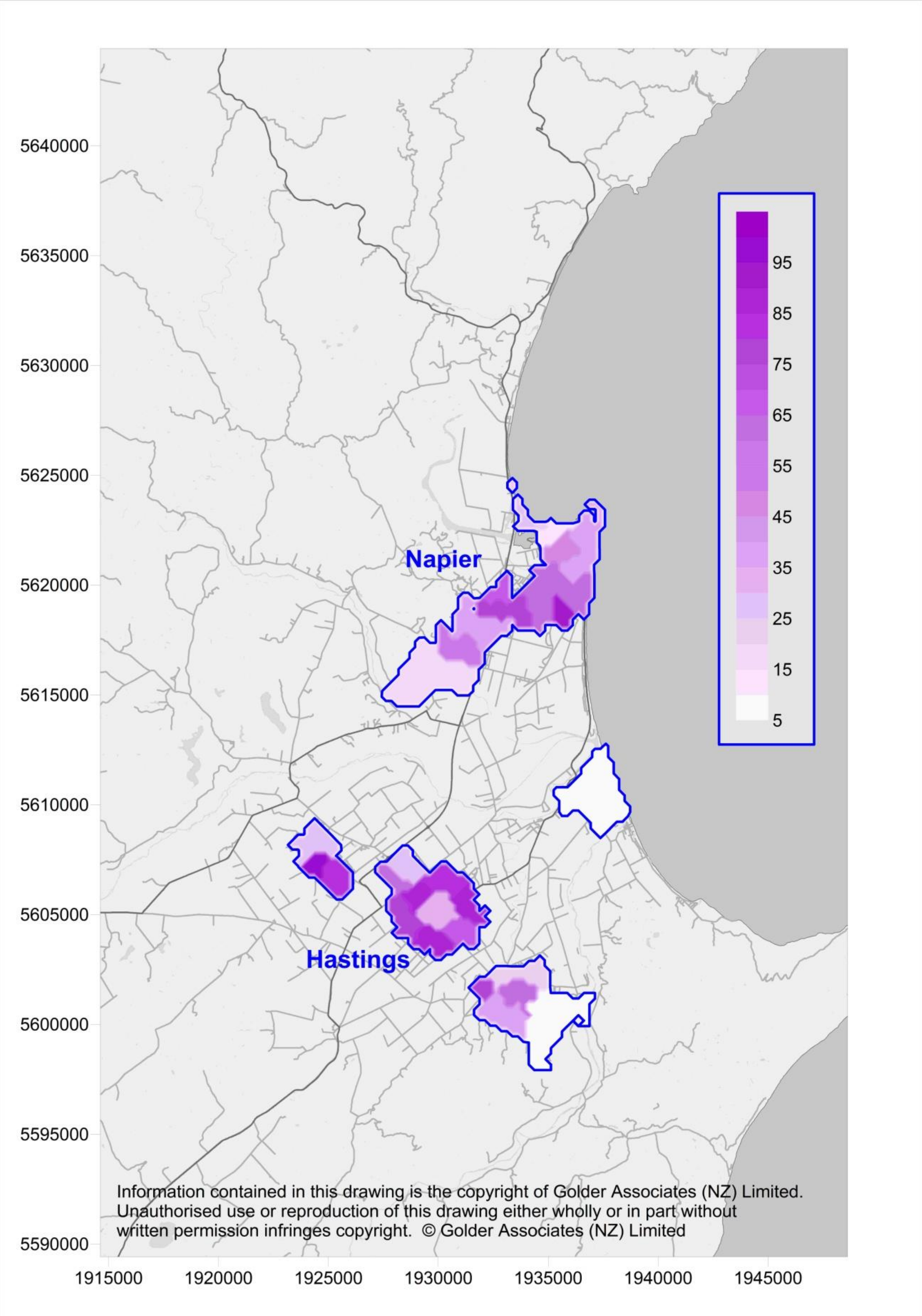


Figure 1: PM_{10} emissions from domestic heating, in kg/km^2/day, for the month of July. Emissions data for 2010 supplied by Environet on a CAU basis and plotted here using a 250 m grid. Axes show eastings and northings in NZTM.

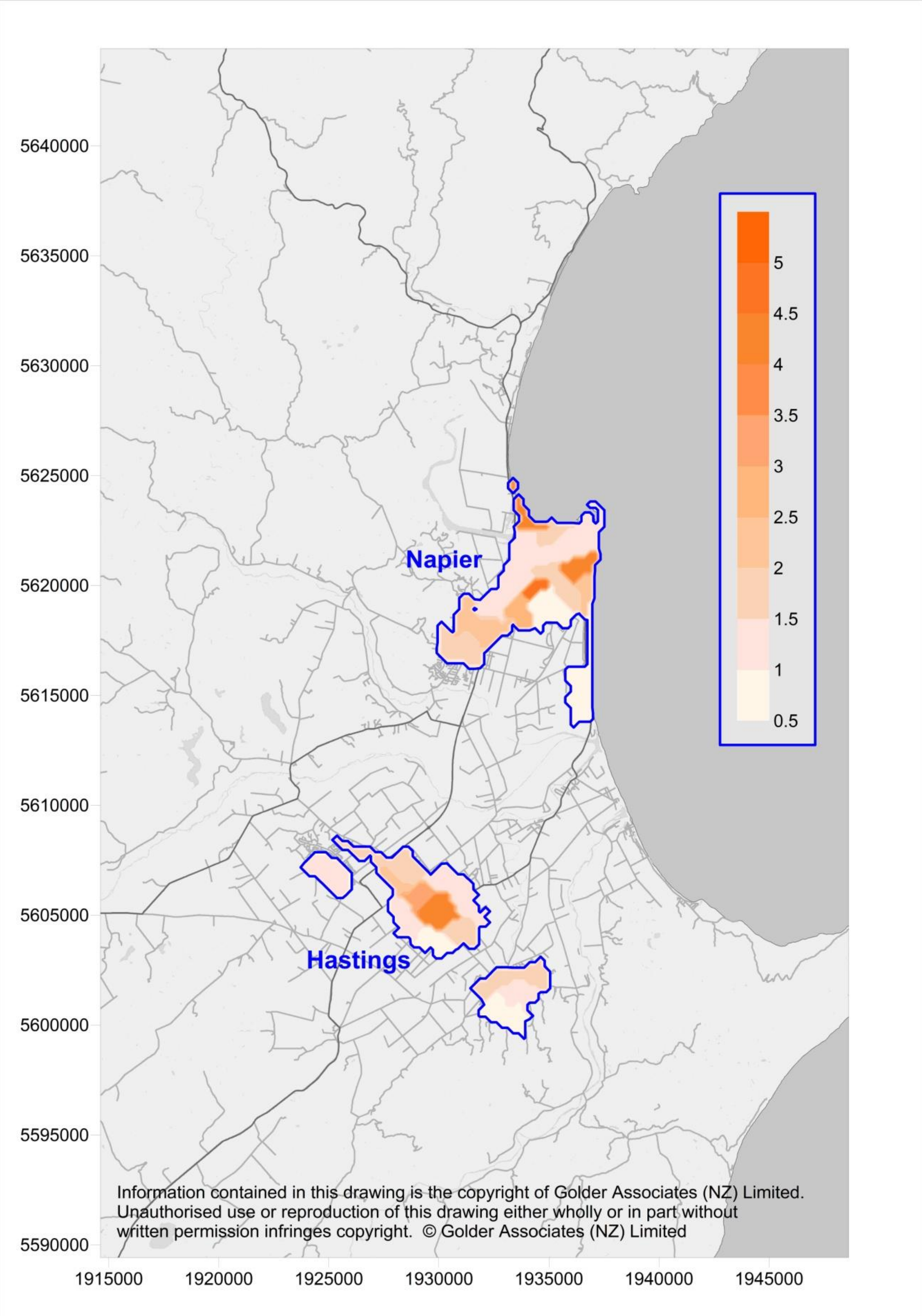


Figure 2: PM_{10} emissions from motor vehicles, in kg/km^2/day, for the month of July. Emissions data for 2010 supplied by Environet on a CAU basis and plotted here using a 250 m grid. Axes show eastings and northings in NZTM.

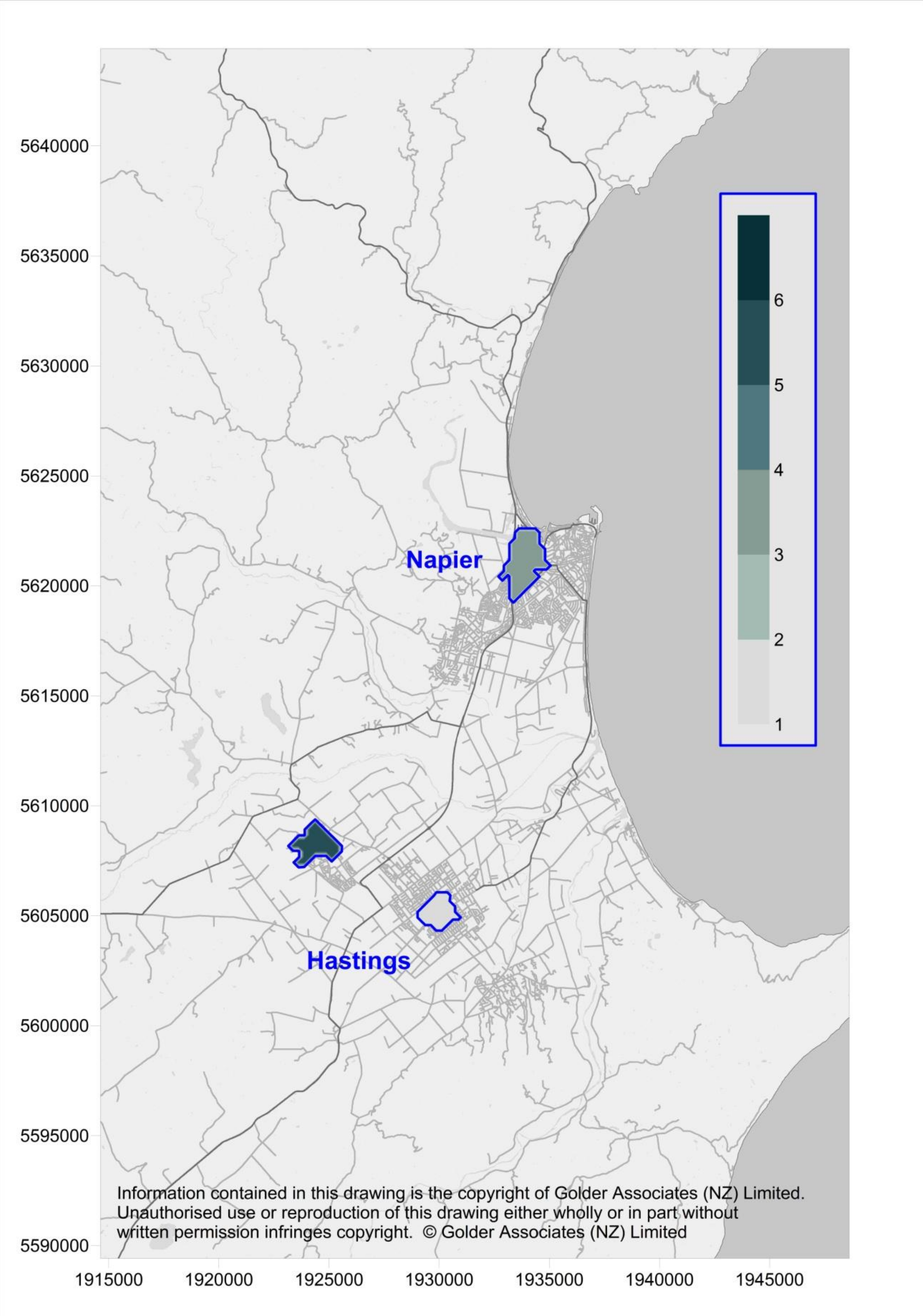


Figure 3: PM_{10} emissions from industry, in kg/km^2/day, for the month of July. Emissions data for 2010 supplied by Environet on a CAU basis and plotted here using a 250 m grid. Axes show eastings and northings in NZTM.

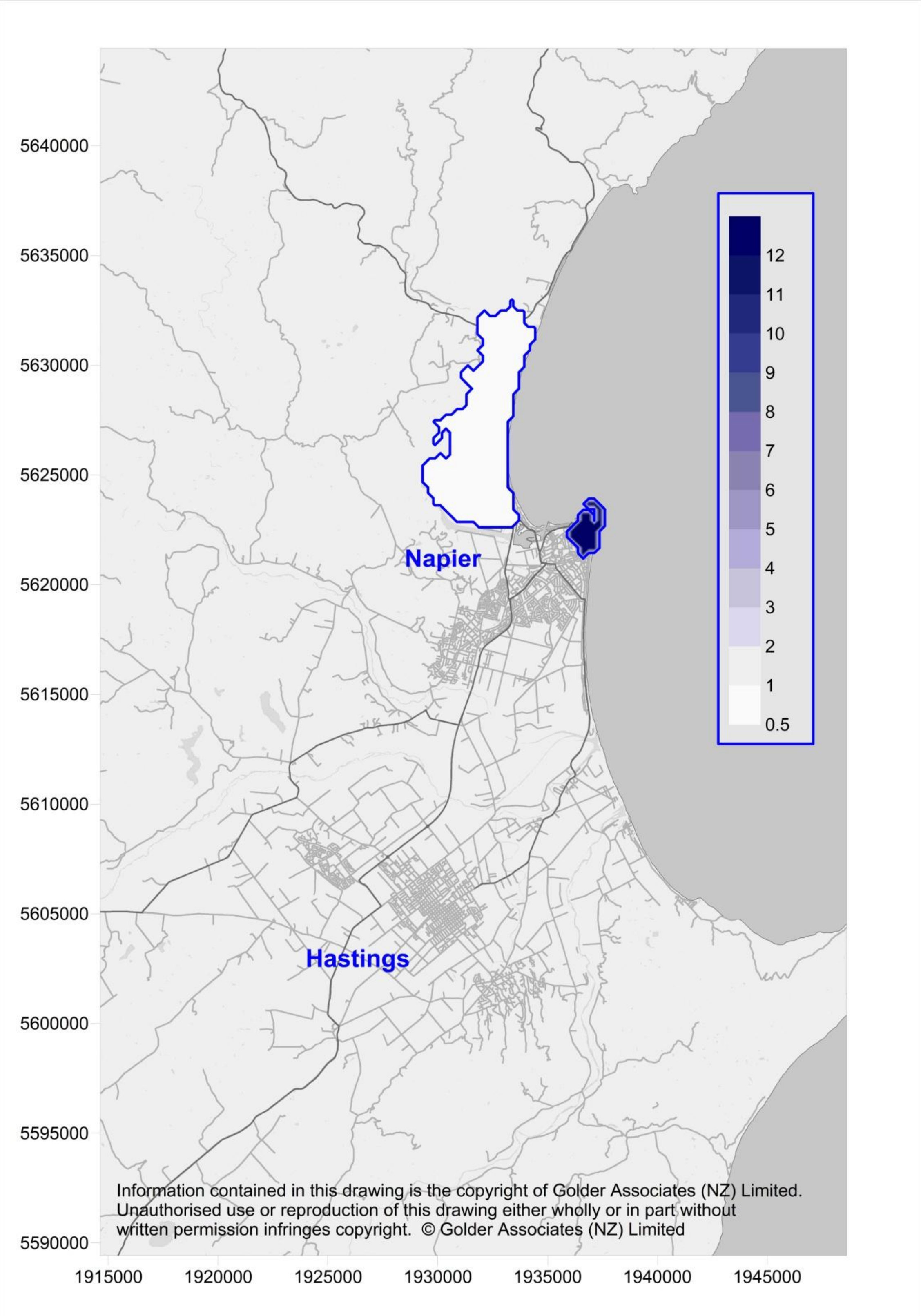


Figure 4: PM_{10} emissions from other sources, in kg/km^2/day, for the month of July. Emissions data for 2010 supplied by Environet on a CAU basis and plotted here using a 250 m grid. Axes show eastings and northings in NZTM.

2.5 Temporal Patterns of PM_{10} Emissions

The airshed model runs on a one-hour time step, so that an hourly breakdown of the daily emission total is required by the model. Hourly patterns of emissions were provided by Environet, and are shown in Figure 5. The patterns were provided with 2010 emissions data, and have also been used for runs based on 2005 emissions data.

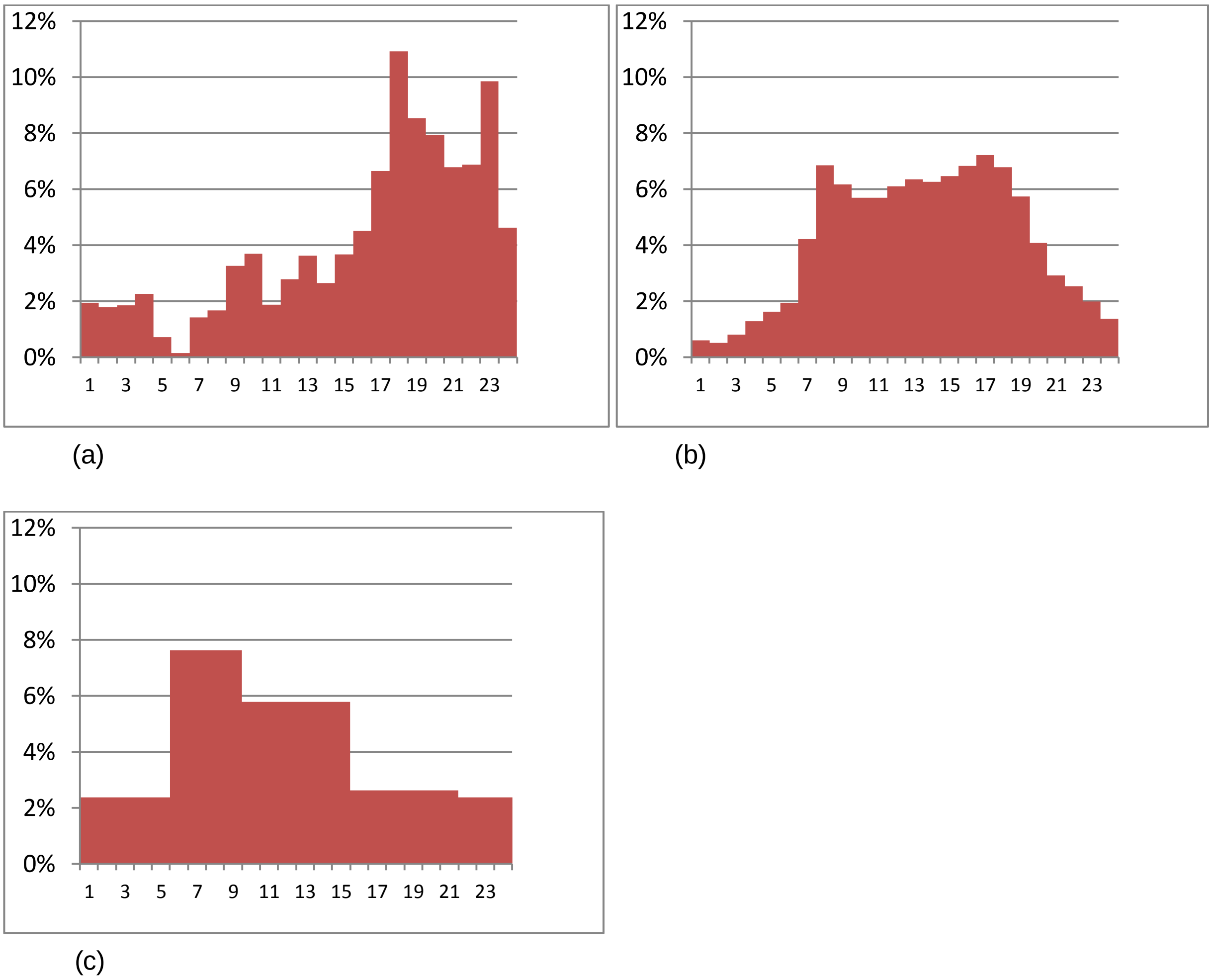


Figure 5: Hourly fraction of the daily PM_{10} emission total, by source-type. The fraction of the daily emission per hour is on the vertical axis, against hour of the day (1 to 24) on the horizontal axis. (a) Domestic (b) Motor Vehicles (c) Industry.

3.0 OTHER ASPECTS OF THE AIRSHED MODEL CONFIGURATION

3.1 Full-domain model runs

This section describes 'full-domain' model runs, which consider the PM_{10} due to emissions from all CAUs, broken down by source type. Subsequent sections describe 'sub-domain' model runs, which partition the modelled PM_{10} according to sub-area of origin (for example, by town, Airzone or CAU).

TAPM was configured to model the dispersion of PM_{10} around the Heretaunga Plains area of the Hawke's Bay region. The time-dependent, three-dimensional meteorology was calculated by TAPM's prognostic model, for the years 2006 to 2010. The meteorological model configuration is described in Appendix A, which also contains a discussion of meteorological model performance. Emissions of PM_{10} were input to TAPM as described above in this Appendix.

The airshed model runs carried out over the region have required a large amount of computing resources. Year-long runs over a region 35 km by 56 km at 500 m horizontal resolution take several days. Two key features of the model configuration have allowed a reduction in the resources required to carry out the runs. These do not change the conclusions of this work, and are as follows:

1) Dispersion modelling has been carried out separately from the meteorological modelling. This means that the meteorological model only needs to be run once, rather than repeated for each airshed model run. This approximately halves the total run time;
2) PM_{10} is treated as an inert tracer, and is not deposited to the surface. This enables four pollutant tracers to be simulated at once. TAPM has a 'dust' mode, which includes deposition. However, this solves for four fixed PM size fractions, three of which have greater than 10 µm particle size. Also, calculations of deposition slow the model run. Tests have shown that dry deposition does not remove significant amounts of PM_{10} over a few hours, so this process has been disregarded.

Appendix A contains most of the TAPM configuration parameters, listed for the meteorological modelling, and these are applicable to the airshed modelling component. The airshed model uses the terrain elevation, land cover data and output meteorology at the resolution defined in Appendix A. The grid-cell size of the finest meteorological grid is 1 km. The dispersion modelling is carried out 'off-line', on a 500 m grid which covers the area of the finest meteorological grid (with four times as many grid points). As mentioned above, the emissions are input to TAPM on a 250 m grid covering the same area, and TAPM then smoothes the emissions onto the 500 m grid. Some short case-study tests have been carried out with dispersion also on a 250 m grid. Only small differences in results were found, so the coarser resolution was chosen. To reiterate, the meteorology is modelled to 1 km resolution; dispersion is modelled on a 500 m grid; emissions are provided on a 250 m grid, which the dispersion model averages out to 500 m.

Several emissions scenarios have been run, listed in Table 7. TAPM allows the dispersion of up to four tracers in the same run. These are labelled Tracer #1 to Tracer #4 in Table 7 and have been assigned the specific source-types as shown in the table. Three scenarios were required to model all of the PM_{10} components given in the emissions inventories and projections. Each emissions scenario was carried out based on the same meteorological data sets. For convenience, all versions of the domestic emissions data were run together in Scenario 3, so that Tracer #1 and Tracer #3 in Scenario 3 are duplicates of other scenarios. Scenario 2 has no outdoor burning component, as restrictions on this activity are intended to make its contribution negligible. Running the source types as separate tracers allows some post-processing flexibility, whereby their individual contributions to the total PM_{10} may be examined. Also, the total PM_{10} may require some rescaling of individual components, to account for the different between 'typical' and 'worst-case' domestic emissions as defined in the inventories, for instance. This is easily done when the components have been modelled separately.

The total anthropogenic PM_{10} is the sum of tracers from Scenario 1 for 2005 emissions, and the sum of tracers from Scenario 2 for 2010 emissions. The variants of the domestic emissions – including projections of domestic heating emissions to 2020 – can be derived by replacing Scenario 2 Tracer #1 with the appropriate Tracer from Scenario 3. One particular variant, named Scenario 4, has been included in Table 7. It is convenient for future reference to identify this combination of sources as a worst-case emissions scenario. Its provenance is described in Appendix C and summarized in Section 3.4 of the main report.

Table 7: Airshed model emissions scenarios.

Scenario	Description	Tracer #1	Tracer #2	Tracer #3	Tracer #4
1	2005 Inventory[&]	Domestic	Vehicles	Industry	Outdoor+Other
2	2010 Inventory	Domestic	Vehicles	Industry	Other
3	All Domestic	Inventory Domestic 2005	Domestic 2010 projected from Inventory 2005	Inventory Domestic 2010	Domestic 2020 projected from Inventory 2010
4	Worst-case Emissions	Domestic 2010 projected from Inventory 2005 (scaled by 1.4)	Vehicles from 2010 Inventory	Industry from 2010 Inventory	Other from 2010 Inventory

[&]This includes motor vehicle emissions updated in 2006.

As mentioned above, airshed model runs were carried out based on the meteorology of the mid-year months of the years 2006 to 2010 inclusive. This provides a range of meteorological conditions which should include those under which worst-case dispersion occurs. Model predictions of likely worst-case PM_{10} concentrations from multi-year runs are more likely to represent the worst of any year, if a larger number of years is modelled. As trends in emissions are likely to be occurring over the years, it is not appropriate to use a long time series of PM_{10} observations for evaluating model performance based on a single emissions scenario. Hence the results from the various scenarios have been compared with ambient PM_{10} at the HBRC monitoring sites for the most recent years only (2008 to 2010) in Appendix C.

3.2 Sub-domain model runs

HBRC has requested estimates of PM_{10} dispersion between Airzone 1 areas and between CAUs. These have been accommodated within the airshed modelling framework through the simulation of dispersion from selected subsets of CAUs. They are described in the next two sub-sections.

3.2.1 Airzone 1 runs

HBRC has defined Airzone 1 and Airzone 2 within the gazetted airsheds of Napier and Hastings. Airzone 1 includes the more densely populated areas, and the two zones are subject to differing emissions reduction policy (with Airzone 1 restrictions on home heating being more stringent). Figure 6 shows the CAUs in the region, with Airzone 1 areas delineated. Modelling has been carried out to estimate dispersion of PM_{10} between these zones, with the TAPM tracers defined in Table 8. Each tracer contains the total 2010 emissions, with worst-case domestic emissions as projected from 2005, for subsets of Airzone 1 CAUs. That is, each TAPM tracer is now the sum of all tracers in Scenario 4, but including emissions over a part of the computational domain. PM_{10} arising from sources in Airzone 2 has been derived as the residual after subtracting all of the Airzone 1 contributions (the tracers in Table 8) from full-domain Scenario 4. TAPM was run for the mid-year periods in 2006 to 2010.

Table 8: Tracers for Airzone 1 runs.

Emissions Zone	Ambient PM_{10} Calculation Method
Napier Airzone 1	Modelled – Tracer #1 of TAPM
Hastings Airzone 1	Modelled – Tracer #2 of TAPM
Flaxmere Airzone 1	Modelled – Tracer #3 of TAPM
Havelock North Airzone 1	Modelled – Tracer #4 of TAPM
Airzone 2[(&)]	Residual – Scenario 4 total over the whole domain minus Airzone 1 tracers

[(&)]In addition to emissions from Airzone 2, the residual includes PM_{10} due to emissions from the inter-zone rural areas. However, emissions are negligible from the rural areas, and the residual effectively represents PM_{10} from emissions in Napier Airzone 2 and Hastings Airzone 2 combined.

3.2.2 Inter-CAU runs

The contribution of PM_{10} from individual CAUs at the Napier and Hastings monitoring sites has been modelled under worst-case conditions. In this case, the total PM_{10} (sources defined by Scenario 4) has been modelled separately from single CAUs for seven modelled worst-case days in the period 2006-2010[2]. As the sources cover small areas, the dispersion-model resolution was changed from 500 m to 250 m for these case study periods.

3.2.3 $PM_{2.5}$ runs

The 2010 emissions inventory for Hawke's Bay does not include data on $PM_{2.5}$. However, emissions factors for $PM_{2.5}$ are available, and have been used for other inventories. Also, source apportionment results give indications of the relative ambient levels of $PM_{2.5}$ and PM_{10} (and therefore their relative emission magnitudes) by source (Wilton et al. 2010; Wilton et al. 2007). Hence it is possible to infer model estimates of $PM_{2.5}$ levels, by post-processing the PM_{10} model results using the scaling factors shown in Table 9.

Table 9: Scaling factors used to infer PM2.5 glcs from modelled PM10.

Source	$PM_{2.5}/PM_{10}$ emissions	Source of information
Domestic Heating	0.85	Source apportionment studies
Motor Vehicles	0.58	Tailpipe fraction from Hawke's Bay 2005 inventory
Industry	0.50	Region-wide totals in Hawke's Bay 2005 inventory
Other Sources	1.0	No information, so assume all PM_{10} is $PM_{2.5}$
Sea Spray and Soil	n/a	Ambient levels from source apportionment (summarized in Section 2.5 of the main report)

[2] The seven case days arise from the five worst-case days at each site. Three of these days were common to both sites.

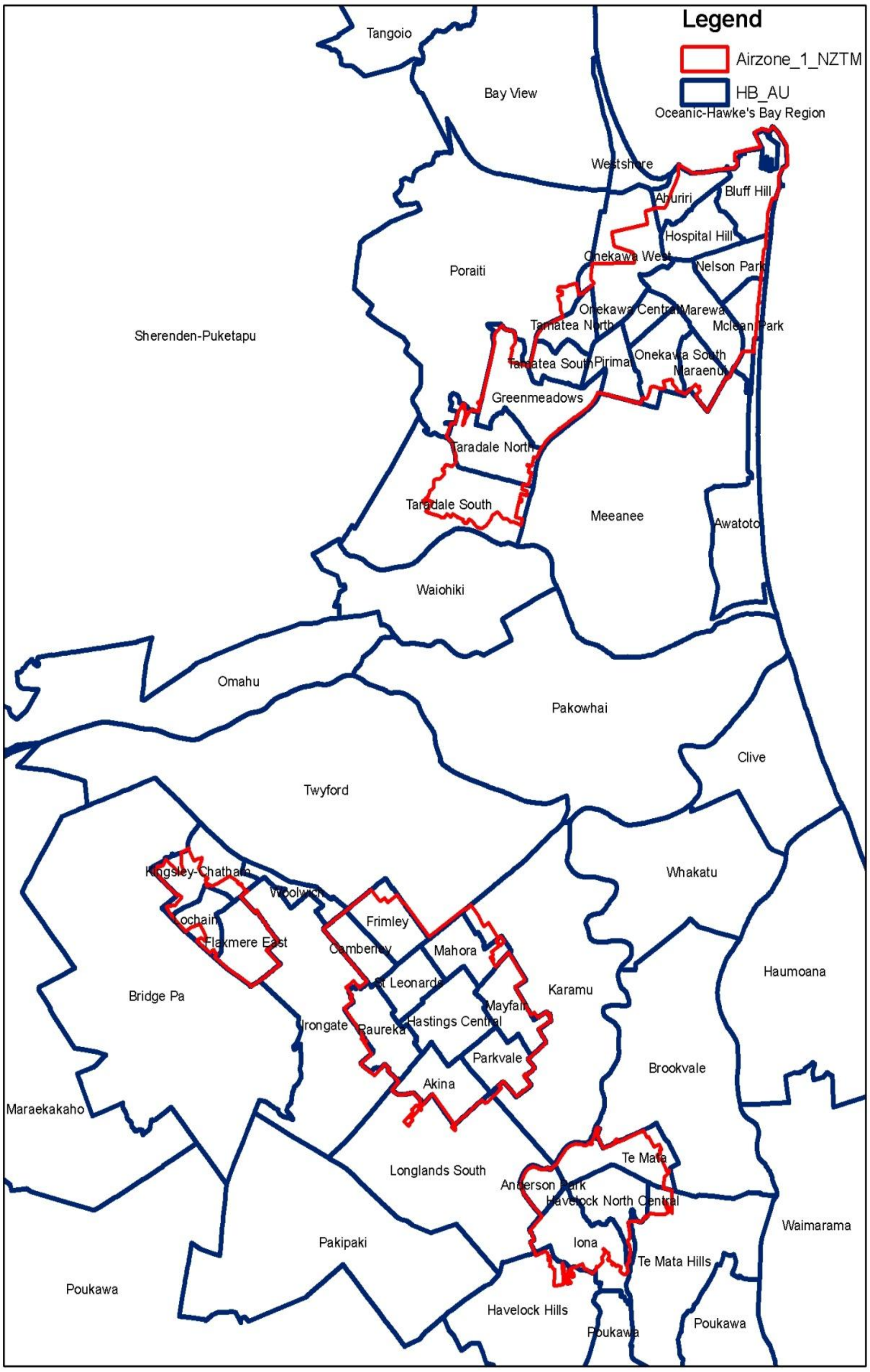


Figure 6: Census area units in the Hawke's Bay Region. Airzone 1 areas are outlined in red (figure supplied by Hawke's Bay Regional Council).

4.0 REFERENCES

Wilton, E., 2005. *Air Emission Inventory - Hawke's Bay Region - 2005*, Report prepared by Environet Ltd for the Hawke's Bay Regional Council.

Wilton, E. & Baynes, M., 2010. *Air Emission Inventory - Napier, Hastings and Havelock North 2010*, Environet Limited, Prepared for Hawke's Bay Regional Council, July 2010.

Wilton, E., Baynes, M. & Zawar-Reza, P., 2010. *Source Apportionment of Particulate in Napier*, Report prepared for Hawke's Bay Regional Council, April 2010.

Wilton, E., Davy, P. & Smith, J., 2007. *Source identification and apportionment of PM_{10} and $PM_{2.5}$ in Hastings and Auckland*, NIWA Client Report: CHC2007-137. Christchurch, New Zealand.

APPENDIX C

Airshed Model Calibration and Performance Evaluation

1.0 INTRODUCTION

This Appendix describes the calibration and performance evaluation of the airshed-model component of TAPM. It compares TAPM's simulation of the dispersion of PM_{10} around the Hawke's Bay region with ambient PM_{10} data from the HBRC air quality monitoring sites in Napier and Hastings. TAPM results and observations have been used to optimize the model with respect to

i) commonly-used measures of model performance,

ii) the model's ability to predict worst-case glcs and numbers of exceedences of the NES for PM_{10} (a 24-hour average concentration of 50 µg/m^3), and

iii) the model's prediction of the distribution of PM_{10} concentrations as a whole at the monitoring sites.

The following examination of model results based on the modelled meteorology of April to September of the years 2008 to 2010 (and compared with the observed ambient air quality during those periods) leads to decisions on the following aspects of the configuration:

a) The choice of emissions inventory (the 2005 inventory, the 2010 inventory or the 2005-to-2010 projections).

b) Other emissions decisions, such as the use of 'average' or 'worst-case' emissions data.

c) User-defined parameters in TAPM relating to dispersion.

Given the flexibility in the airshed model configuration with respect to emissions inputs, this Appendix does not attempt to validate either TAPM or the emissions inventories. Each contains uncertainties which have not been evaluated independently to give a definitive and correct emissions inventory for 2010, or a perfect dispersion model. The sections below serve to optimize the performance of the dispersion model and emissions inventory combination with respect to observed air pollution levels, and provide a tool which is able to produce realistic estimates of air quality at places other than the monitoring locations and under a variety of emission scenarios. The optimized model has been used in this report to examine several air quality issues, as required by HBRC.

The following sections examine TAPM results at each HBRC monitoring site in turn, to arrive at decisions on the above aspects of model performance and optimization (Section 2.0). A summary of the choices leading to the optimized model configuration is provided in Section 3.0.

2.0 MODEL RESULTS FOR PM_{10} AT AIR QUALITY SITE LOCATIONS

2.1 Marewa Park, Napier

TAPM results for 24-hour average PM_{10} for April to September in the years 2008 to 2010 have been extracted from the location of the Marewa Park air quality monitoring site in Napier and compared with observations from that site. Model performance is evaluated using common statistical measures, and these are shown for each inventory in Table 1 (for average emission conditions), along with the maximum and 2nd-highest modelled and observed PM_{10} concentrations over the three years. Model concentrations include the natural component of PM_{10} from sea spray and soil as determined in Section 2.5 of the main report. Note that the performance statistics are calculated from model results and observations paired in time. However, the maximum modelled PM_{10} need not occur on the same date as the maximum observed. The performance statistics used here are defined in the Glossary at the end of Appendix A.

Table 1: Summary of model results for PM_{10} at Marewa Park (average emission conditions).

	2005 Inventory	2010 Inventory	2005 to 2010 Projections
Index of Agreement (IOA)	0.62	0.51	0.57
Skill_E (ideally close to 0)	0.64	0.40	0.55
Skill_R (ideally close to 0)	1.13	1.39	1.27
Skill_V (ideally close to 1)	0.75	0.47	0.64
Maximum 24-hour PM_{10}[$]	67	41	56
...+ lower natural[&] PM_{10}	71	45	60
...+ higher natural PM_{10}	76	50	65
2nd-highest 24-hour PM_{10}[$]	53	37	50
...+ lower natural PM_{10}	57	40	54
...+ higher natural PM_{10}	62	45	59
Observed Max. PM_{10}	71	71	71
2nd-highest Obs. PM_{10}	68	68	68

[$]TAPM results for anthropogenic sources; no natural component added.

[&]The lower (resp. higher) natural PM_{10} refers to the winter mean PM_{10} from sea spray and soil minus (resp. plus) one standard deviation.

For the model runs based on the 2010 inventory or 2005 to 2010 projections, the resulting upper range of PM_{10} concentrations is below the upper range of the observed PM_{10}, even when adding the higher concentration of natural PM_{10}. Modelling using the 2005 inventory leads to higher concentrations than using the 2005 to 2010 projections. Concentrations arising from the 2005 to 2010 emissions projections are higher than those using the 2010 inventory.

The model performance statistics using the 2010 inventory are worse than for the other model runs. In this case, there is a lower IOA, higher Skill_R and lower Skill_V. However, Skill_R, the ratio of model root-mean-square error to the observed variability, is higher than ideal in all runs. Runs using the 2005 inventory or 2005-2010 projections produce reasonable results, with IOAs around 0.6.

The results shown in Table 1 indicate that the 2005 inventory as a basis for the TAPM urban airshed model runs may be the 'best' option, as it provides the closest match to the observed highest PM_{10} and the model performance measures for this case appear to be slightly better than the others. However, on closer inspection this is not the best option, for the following reasons:

i) In principle, emissions information appropriate to present-day conditions should be based on and benefit from present-day data, so that emissions appropriate for 2010 benefit from data gathered in 2010, and do not rely on 2005 data only.

ii) The inventory information used in the model runs described above applies to 'average' winter conditions. It is considered that the worst-case ambient PM_{10} would have occurred under 'worst-case' emissions conditions, so that a model simulation of these PM_{10} events should be based on worst-case emissions. The difference between average and worst-case daily emissions arises from the worst-case assuming all home-heating appliances are in use on those occasions. The difference may be further enhanced by above-average fuel use if the worst cases coincide with the coldest external temperatures. This effect, being difficult to quantify, is not generally included in emissions inventories. Depending on inventory year and urban area, the ratio of worst-case to average mass-emission totals ranges between 1.2 and 1.9.

iii) Modelling uncertainties have not been quantified here. It is difficult to assess sensitivities and uncertainties associated with the model itself, and apparently good agreement may to some extent be fortuitous. The 'total' uncertainty may be encapsulated in some measure of model performance, which quantifies the difference between modelled and observed concentrations. However, its breakdown into components due to uncertainties in say, emissions, meteorology, numerical formulation or ambient data, has not been carried out in this work.

iv) The maximum modelled PM_{10} is an outlier from the rest of the modelled PM_{10} distribution at that location. Table 1 shows the highest and 2nd-highest modelled concentrations using 2005 emissions differing by 15 µg/m³, whereas as subsequent ranked concentrations differ by no more than 5 µg/m³ from their neighbour. It would be considered good practice to disregard it (see MfE (2004)).

Following these considerations, the model configurations were updated, according to the following assumptions:

1) Golder received data from Environet representing average winter emissions. Domestic heating emissions have been re-scaled by a factor of 1.4 to represent worst-case conditions. This choice is based on the factors used in the emissions inventory for each urban area, on the desirability of using a single factor for the whole region, on a visual inspection of the full range of PM_{10} concentrations using quantile-quantile plots, and on improvement of model-performance statistics. The factor of 1.4 thus optimizes the combination of inventory emissions and airshed model performance relative to ambient monitoring. It does not serve to validate any of these components, but enables development of a usable tool for application to air quality management scenarios.

2) The highest-modelled 24-hour PM_{10} concentration is disregarded at the Marewa site, so that the 2nd-highest is considered to be an estimator of the observed maximum (and a predictor of the maximum elsewhere in the Napier urban area).

3) The natural component of PM_{10} is low during PM_{10} events, due to their occurrence under calm conditions and associated reduced levels of wind-blown sea spray and soil PM_{10}. Hence the natural component of PM_{10} is assumed to be a constant concentration equal to the mean minus one standard deviation of observed 24-hour PM_{10} (the 'lower natural PM_{10}' referred to in Table 1).

In addition to the above, emissions inputs to TAPM have been spread over the lowest two model layers (rather than the lowest single layer). This has been found necessary to prevent modelled occurrence of extremes which do not occur in reality. It appears that under calm conditions, TAPM under-estimates vertical mixing; the parameter choice of initial mixing through two layers serves to counteract this. Extreme outliers are removed, but other concentrations are unchanged.

The model performance statistics under the above assumptions are summarized in Table 2 for worst-case emissions. This table indicates that the model is optimized using the 2005-2010 projected emissions, which provide a good balance between prediction of peak PM_{10} levels based on up-to-date emissions information, and reasonable model performance.

Table 2: Summary of 24-hour average PM_{10} at Marewa Park (worst-case emission conditions).

	2005 Inventory	2010 Inventory	2005 to 2010 Projections
Index of Agreement (IOA)	0.69	0.57	0.64
Skill_E (ideally close to 0)	0.88	0.56	0.76
Skill_R (ideally close to 0)	1.08	1.26	1.15
Skill_V (ideally close to 1)	1.03	0.65	0.89
Modelled peak PM_{10}[&]	77	55	74
Observed max. PM_{10}	71	71	71

[&]The modelled peak PM_{10} is the 2nd-highest concentration from TAPM, with the low natural PM_{10} added.

Under the assumptions listed above, and basing the airshed modelling on 2010 emissions projected from 2005 home heating appliance numbers with up-to-date emissions factors, a quantile-quantile plot of model results against observations is shown in Figure 1. This type of plot gives a comparison between model results and observations *unpaired in time*. The model should not be expected to match observations from day to day, as both are subject to different types of uncertainty. If the modelled *distribution* of 24-hour PM_{10} concentrations matches that observed, then the points should lie along the 1:1 line, and this would be considered good dispersion model performance. The quantile-quantile plot of the distribution of concentrations is useful in showing how well the model simulates peak concentrations and exceedences of air quality criteria.

The quantile-quantile plot for Marewa Park (Figure 1) shows a reasonable agreement with observations at the upper end of the PM_{10} range. There remains some under-prediction by the model at medium PM_{10} concentrations; this may be due to a higher natural component of PM_{10}, or contributions from motor vehicle emissions which are not represented well by the airshed model. (The *minimum* modelled PM_{10} – which is all natural – matches the minimum observed PM_{10}, which is presumably also due to natural sources only).

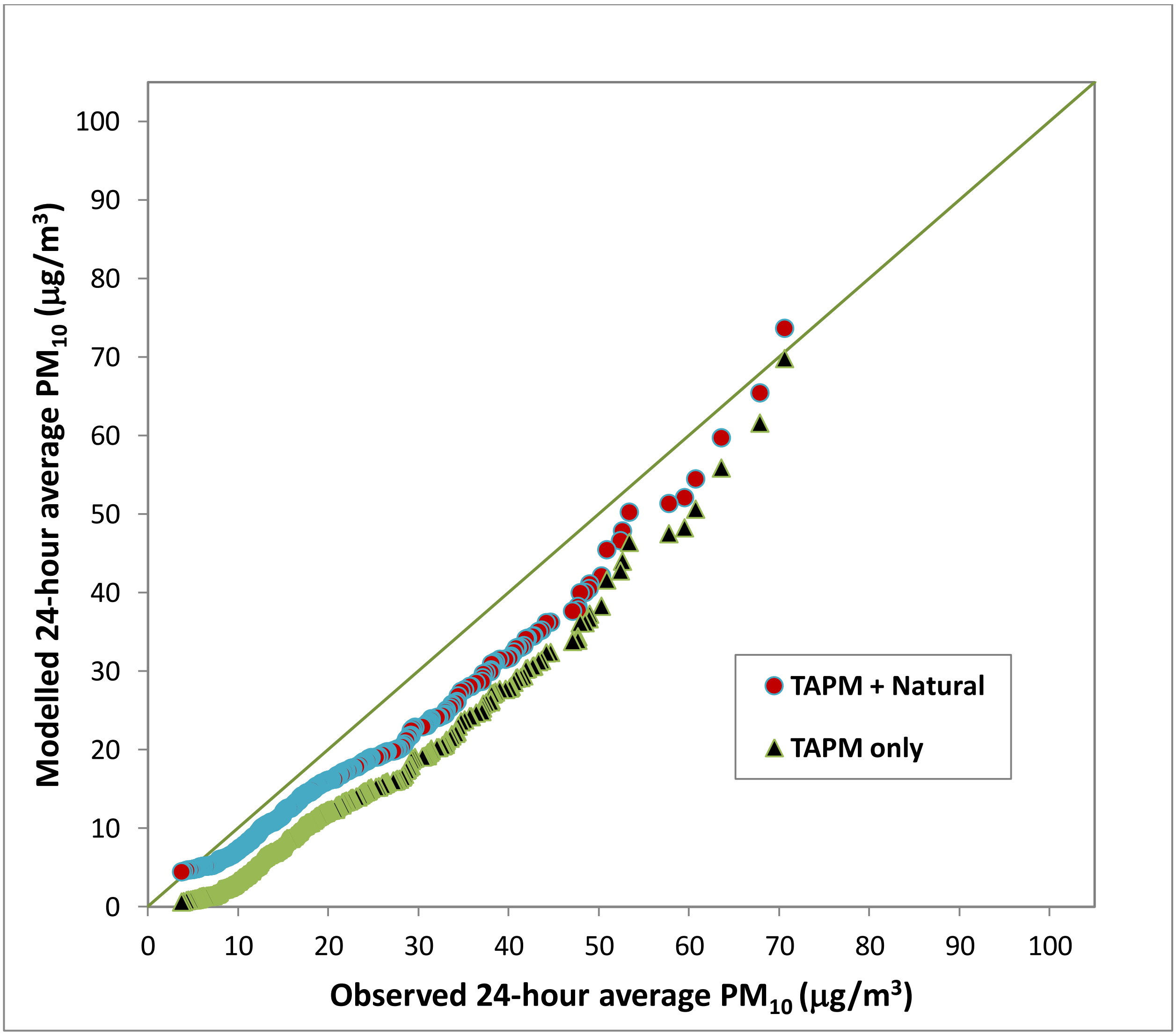


Figure 1: Quantile-quantile plot of 24-hour average PM_{10} at Marewa Park, Napier.

2.2 St John's College, Hastings

As for Marewa Park, TAPM results for 24-hour average PM_{10} have been extracted from the location of the St John's College air quality monitoring site in Hastings and compared with observations from that site. Model performance for average emission conditions is shown in Table 3, along with the peak modelled and observed PM_{10} concentrations over the years 2008-2010.

Table 3: Summary of model results for PM_{10} at St John's College (average emission conditions).

	2005 Inventory	2010 Inventory	2005 to 2010 Projections
Index of Agreement (IOA)	0.75	0.62	0.64
Skill_E (ideally close to 0)	0.62	0.40	0.44
Skill_R (ideally close to 0)	0.87	1.08	1.05
Skill_V (ideally close to 1)	0.79	0.53	0.57
Maximum 24-hour PM_{10}	84	60	64
...+ lower natural PM_{10}	85	61	66
...+ higher natural PM_{10}	93	68	73
2nd-highest 24-hour PM_{10}	82	57	61
...+ lower natural PM_{10}	83	58	63
...+ higher natural PM_{10}	91	66	70
Observed Max. PM_{10}	105	105	105
2nd-highest Obs. PM_{10}	93	93	93

Results for average emission conditions are similar to those for Marewa Park and need not be discussed in detail. The lines of reasoning leading to an optimization of the model configuration, including the final choice of emissions inventory, are also the same as those for Marewa Park, therefore assumptions made in the previous section regarding worst-case emissions also apply to St John's College (and presumably the rest of Hastings). The exceptions to this are that the maximum modelled PM_{10} is *not* an outlier from the rest of the PM_{10} distribution, and the peak modelled PM_{10} concentration at St John's may be taken to be the maximum modelled, rather than the second-highest. Table 4 results from the application of the above assumptions for worst-case emissions, retaining the maximum modelled PM_{10}.

Table 4: Summary of model results for PM_{10} at St John's College (worst-case emission conditions).

	2005 Inventory	2010 Inventory	2005 to 2010 Projections
Index of Agreement (IOA)	0.78	0.72	0.74
Skill_E (ideally close to 0)	0.86	0.56	0.61
Skill_R (ideally close to 0)	0.92	0.94	0.92
Skill_V (ideally close to 1)	1.09	0.74	0.80
Modelled peak PM_{10}[&]	117	84	91
Observed Max. PM_{10}	105	105	105

[&]The modelled peak PM_{10} is the maximum concentration from TAPM, with the low natural PM_{10} added.

As for Marewa Park, Table 4 shows that the model is optimized at St John's using the 2005-to-2010 projected emissions. Again, this results in a good prediction of peak PM_{10} levels based on up-to-date emissions information, and reasonable model performance.

The quantile-quantile plot at St John's College (Figure 2, based on 2005 to 2010 emissions projections) shows a reasonable agreement with observations, with similar caveats to those around Figure 1. The highest observed concentration of 105 µg/m³ appears to be an outlier from the rest of the observed concentration distribution (with the second-highest being 93 µg/m³), and if it occurred under unusual emission conditions then it should be disregarded. However, there is no evidence to suggest that emissions might have been unusual, and therefore no reason to disregard this observation. Hence, it should be borne in mind that the assumptions arrived at in this Appendix from inspection of model results and subsequent calibration of the airshed model would lead to an under-prediction of PM_{10} concentrations in Hastings.

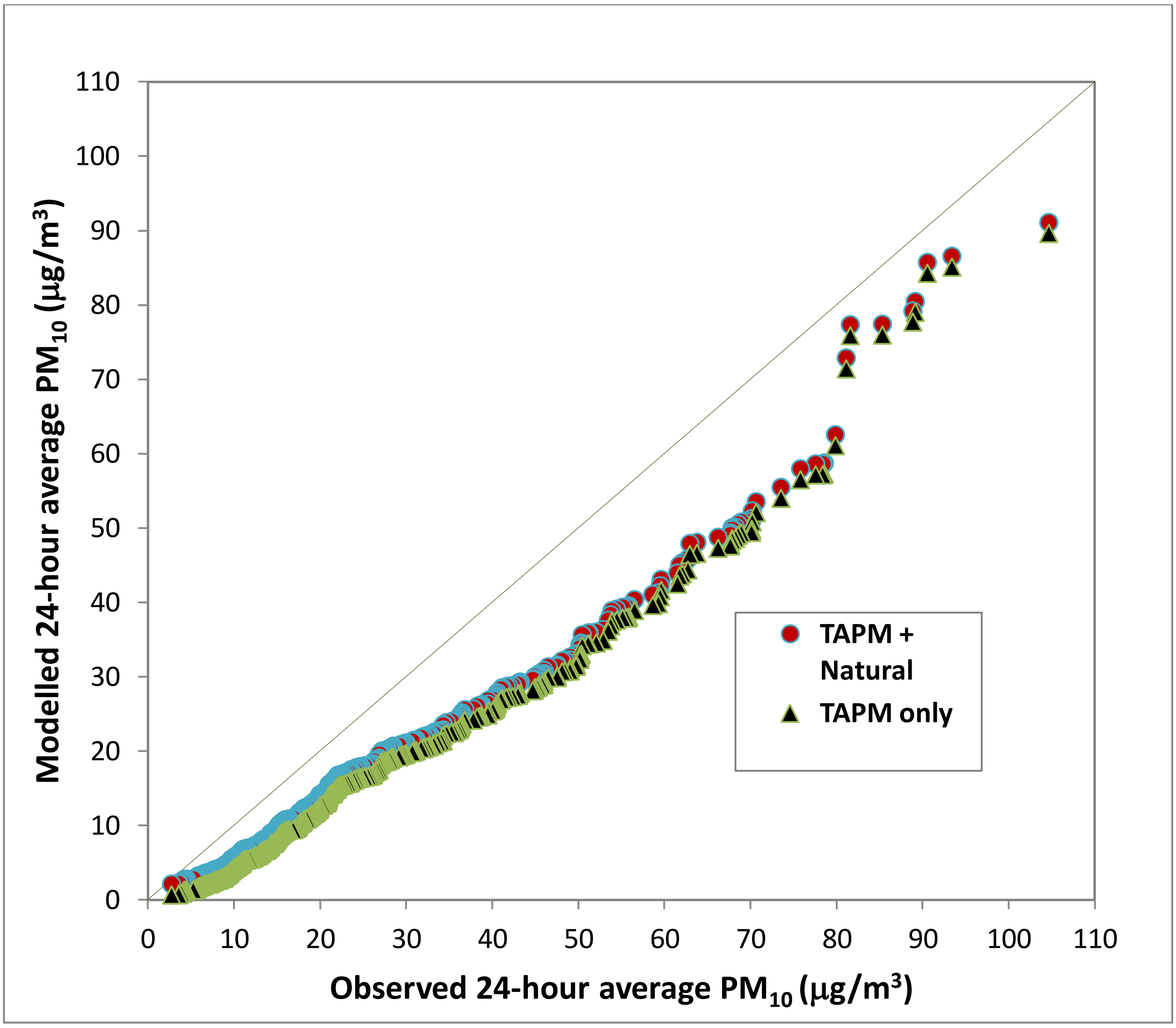


Figure 2: Quantile-quantile plot of 24-hour average PM_{10} at St John's College, Hastings. Mid-year periods in 2008, 2009 and 2010.

2.3 Meeanee Road, Napier

Airshed model results at HBRC's Meeanee monitoring site do not match observations well. The Meeanee site, situated at the intersection of Meeanee Road with the Napier Hastings Expressway (SH50) was commissioned to measure the air quality impacts of motor vehicles. Airshed models are not intended to simulate localized peaks of primary air pollutants next to the roadside, as they provide averages over grid cell areas (in this case 500 m by 500 m). Hence a match of model results with measured PM_{10} at the roadside is not expected, and the predicted motor vehicle component of PM_{10} is a factor of roughly sixty below observed concentrations, due to the area-averaging effect of the model. The performance of the airshed model at this location is not discussed further in the report.

3.0 SUMMARY

This Appendix has examined the model results at the Marewa Park, Napier, and at St John's College, Hastings using several emissions data sets, and compared them with observations at the respective air quality monitoring sites. The following model-configuration decisions have been arrived at which optimize the model results:

a) Emissions inputs to the airshed model should use the 2010 domestic heating data as projected from 2005 appliance numbers, with PM_{10} emitted into the lowest two layers of the model.

b) Worst-case conditions may be represented by multiplication of the average domestic heating emissions by a factor of 1.4 (at all locations). This factor is discussed in the above discussion.

c) Peak 24-hour PM_{10} levels over Napier will be represented by the modelled 2nd-highest PM_{10} concentration. This has the effect of disregarding unreasonable outliers in the modelling. This is not necessary for PM_{10} over Hastings, so that peak levels will be presented by the modelled maximum 24-hour PM_{10} concentration.

d) TAPM should not be expected to give predictions of localized peaks of PM_{10} near to the roadside, as modelled concentrations are averaged over 500 m by 500 m grid cells. Also, the emissions themselves are also averaged over grids cells, rather than being given as line sources. Model results from the Meeanee site location should therefore not be compared with measured PM_{10} there[1].

Items a) and b) in this list constitute Model Scenario 4 (defined in Section 3.1 of Appendix B).

Carrying out the airshed modelling under the above assumptions leads to a reasonable match of model predictions with observations of worst-case PM_{10} during winter, as driven largely by domestic heating. All discussion of model results in this report is based on model runs set up as described in Appendices A, B and here. As mentioned at the start of this Appendix, the analysis presented here should not be thought of as a model validation. Rather, it presents a calibration of the model and associated input and output data to enable a reasonable and consistent representation of the observed air quality, so that it may be used as a tool for assessing air quality in the entire region, under present-day and alternative emissions scenarios.

4.0 REFERENCE

MfE, 2004. *Good practice guide for atmospheric dispersion modelling*, Report ME522. Wellington, New Zealand: Ministry for the Environment.

[1] Alternative dispersion modelling approaches for the transport sector, based on meteorological data produced for this study, are discussed in the main report, Section 7.4.

APPENDIX D

CALMET and AUSPLUME Data Sets for Industrial Applications

1.0 INTRODUCTION

This Appendix is a guide to the use of CALMET and AUSPLUME meteorological data sets produced for the Hawke's Bay Regional Council (HBRC). They are supplied for direct input to commonly-used dispersion models, precluding the need for consultants to re-run complex meteorological models for industrial air quality assessments. This has the advantage that consistent and accepted meteorological data are used in assessments of air quality effects throughout the region.

The data sets cover the industrial areas in Napier, Hastings, Awatoto, Whirinaki and Wairoa. They have been prepared primarily for the CALPUFF dispersion model, with subsidiary meteorological files for use with the AUSPLUME dispersion model. The locations of the CALMET computational domains and single-point files for AUSPLUME are shown in Figure 1.

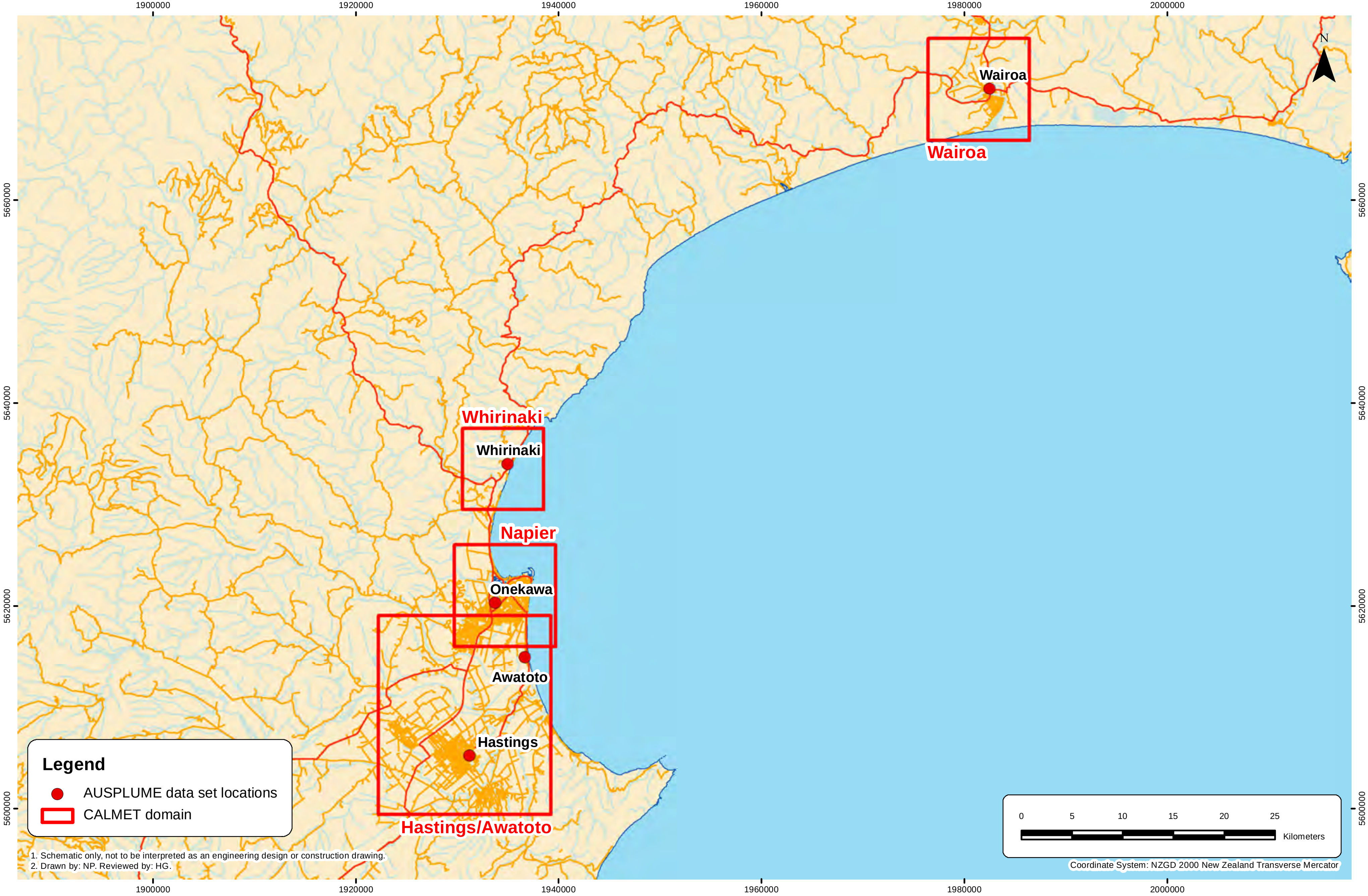
Although part of a larger report on airshed modelling in the Hawke‟s Bay region, this guide may be read as a stand-alone document.

Several Good-Practice Guides (GPGs) have been developed by air-quality scientists in New Zealand, and published by the Ministry for the Environment (MfE). These include GPGs for atmospheric dispersion modelling (MfE 2004), and for assessing discharges to air from industry (MfE 2008a) and land transport (MfE 2008b). The information contained in this guide is consistent with these GPGs and is intended to reflect current good practice.

This guide is intended to provide advice to a broad range of users, which includes:

- Technical experts such as environmental consultants using the meteorological data sets as input to dispersion models, as part of an air quality assessment or AEE.
- Investigating officers, planners and other environmental managers at HBRC, reviewing resource consent applications which have made use of the data sets.
- Scientific researchers carrying out projects relating to HBRC policy.
- Independent researchers and interested members of the general public.

In the remainder of this guide, Section 2.0 describes the data set development and provides necessary user information. Section 3.0 shows some model results, in the form of wind roses at selected locations. Section 4.0 provides further user guidance on model choice. Section 5.0 discusses in some detail the modelling process and provides comments on model performance. Concluding remarks are given in Section 6.0 and references are listed in Section 7.0.



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2.0 METEOROLOGICAL DATA SET DEVELOPMENT

2.1 Overview of CALMET and AUSPLUME Data Sets

CALMET meteorological data sets which cover the Napier, Hastings and Awatoto, Whirinaki and Wairoa urban areas on four domains have been developed for use with CALPUFF. Information has been extracted from the CALMET data sets to produce single-station meteorological files at locations of key industries for the steady-state model AUSPLUME. The CALMET data sets may also be used to develop meteorological inputs for other models, such as ADMS-Roads, AERMOD, AUSROADS and CALINE4.

Several stages were involved in the development of the CALMET and AUSPLUME data sets. The stages are outlined as follows:

a) Model years 2006 and 2010 were selected in consultation with HBRC. The process described here was carried out for each year.

b) The data for the two years at the council-run sites, plus data from local sites on the National Climate Database (CliDb), were provided by HBRC and formatted for input into CALMET.

c) CALMET requires upper-air information in its production of hourly three-dimensional meteorological fields. To provide this, the meteorological component of TAPM was run to generate hourly fields, which were converted using the CALTAPM utility and used as inputs to CALMET. This provided a 1 km gridded initialization of CALMET over the Heretaunga Plains, based on the finest-resolution nested TAPM grid. The TAPM runs used for this purpose are identical to those used for the airshed modelling. Wairoa is an exception to this, being outside the 1 km TAPM grid. Upper-air information for Wairoa was based on a profile extracted from TAPM"s 3 km grid.

d) CALMET was run over four areas covering Napier, Hastings and Awatoto combined, Whirinaki and Wairoa at 100 m or 200 m grid resolution (depending on the complexity of the terrain). The output data sets were intended for applications of CALPUFF around industrial areas. However, they happen to cover nearly all of the urbanized areas in the region, and may be used for other urban air quality applications.

e) Several single-point meteorological data sets were extracted from the CALMET results for use with AUSPLUME. This followed the procedure outlined in Appendix E. The locations of the single-point data sets were chosen in consultation with HBRC to be representative of the key industrial areas of the Hawke's Bay region, and are shown on Figure 1.

A similar methodology has been followed to produce CALMET and AUSPLUME data sets for other regions of New Zealand (Gimson et al. 2010; Golder 2012).

2.2 CALMET Data Set Description

Four high-resolution three-dimensional CALMET meteorological data sets have been developed for areas of significant industrial activity around the Hawke's Bay region, for each of 2006 and 2010. The locations and extents of the high resolution CALMET domains are shown in Figure 2 to Figure 9. These figures also show the model terrain elevation and land-use category, and the locations of climate monitoring stations (whose data have been used as inputs to the CALMET modelling).

Full details on the configuration of the CALMET runs may be found in the electronic files accompanying the meteorological data sets. The following section focuses only on the CALMET parameters which are user inputs to CALPUFF.

Grid control parameters

CALPUFF requires the map projection of the CALMET data set used. The CALMET configuration uses the Tangential Transverse Mercator projection, so that [PMAP] = TTM[1]. The latitude and longitude, along with a corresponding easting and northing (in NZTM coordinates) for the projection origin are listed in Table 1[2].

CALPUFF also requires the geographic extent and grid configuration of the CALMET data set. This includes the coordinates of the southwest corner of the domain, along with the number of grid cells and their horizontal spacing. The grid parameters for the CALMET domain are listed in Table 1. The size of each CALMET domain is [NX]x[DGRIDKM] east to west, and [NY]x[DGRIDKM] north to south.

CALPUFF also requires the vertical grid structure used in CALMET. Twelve vertical layers ([NZ] = 12) were used with the height of each layer face [ZFACE], in metres, as follows:

[ZFACE] = 0.,20.,45.,80.,130.,195.,275.,385.,540.,740.,1000.,1700.,3000.

For twelve layers, there are thirteen values of [ZFACE]. The grid control parameters have been saved for each domain as a .cmn file using the CALMET GUI. The parameters can then be read from this file in the CALPUFF GUI, and therefore need not be entered manually.

Date and time parameters

Twelve month-long CALMET runs were carried out for each modelled year. CALPUFF reads in all output files to perform a year-long run. The configuration parameters needed by CALPUFF define the start and finish of each year, and these are listed in Table 2. The start and finish times of the twelve CALMET output files do not need to be specified.

Input filenames

Finally, CALPUFF requires the filenames of the meteorological outputs from CALMET. As there are twelve binary output files from CALMET for each year and for each location, CALPUFF requires [NMETDAT] = 12. Then the filenames are specified using the parameter [METDAT]. For 2006, this means a list of names as follows, each line completed by “!END!”:

! METDAT= D:\CALMET\HawkesBa\v6.334\2006\Napier\Napier01.MET ! !END!

! METDAT= D:\CALMET\HawkesBa\v6.334\2006\Napier\Napier02.MET ! !END!

! METDAT= D:\CALMET\HawkesBa\v6.334\2006\Napier\Napier03.MET ! !END!

etc., until

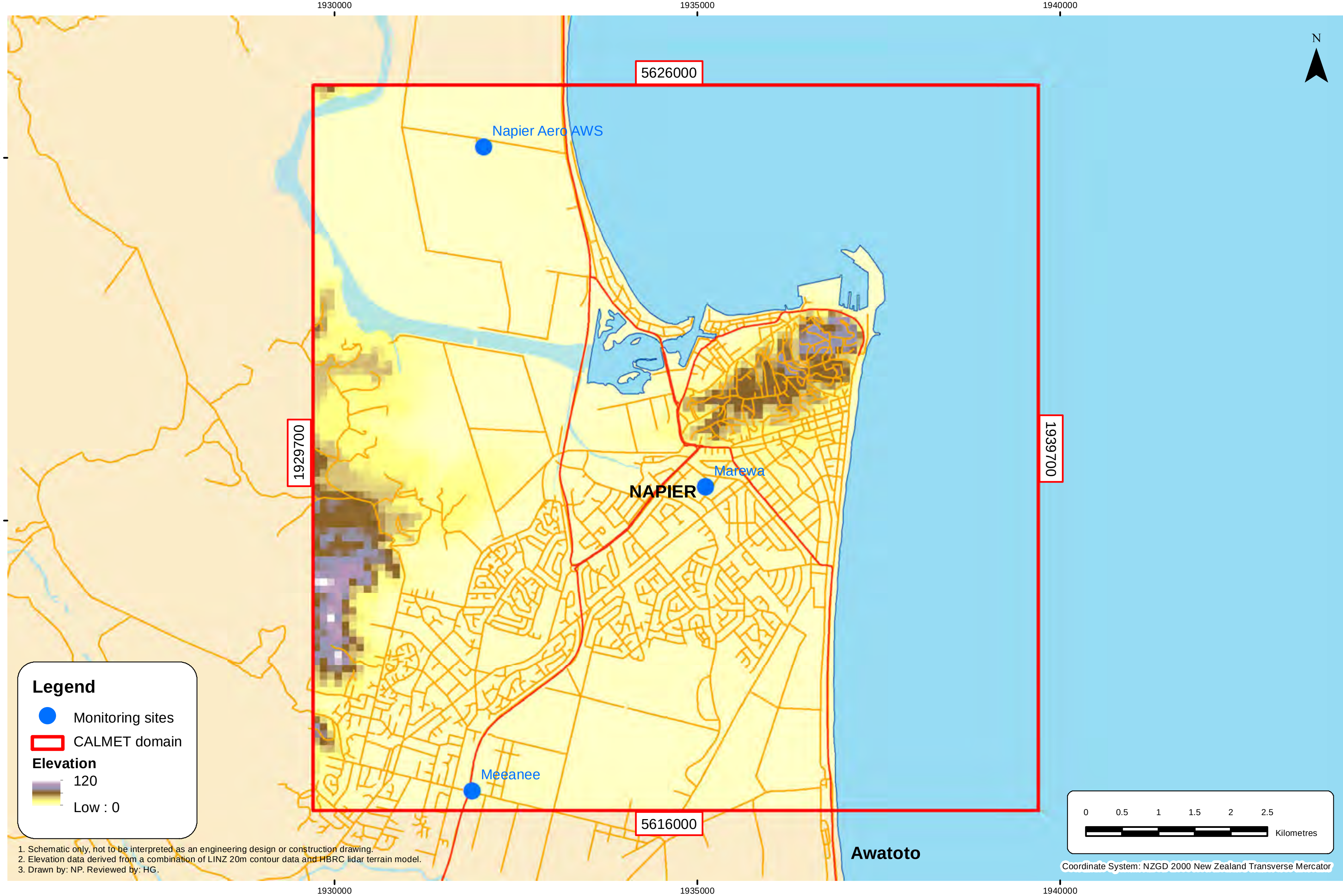
! METDAT= D:\CALMET\HawkesBa\v6.334\2006\Napier\Napier12.MET ! !END!

The pathname has been included here as an example of the required formatting. Analogous lists would be used for the 2010 CALPUFF runs.

---

1 CALPUFF parameter names are given in square brackets here.

[2] Choice of the TTM option allows a rectangular grid system to be specified, provided the grid coordinates are linked to the correct latitude and longitude.



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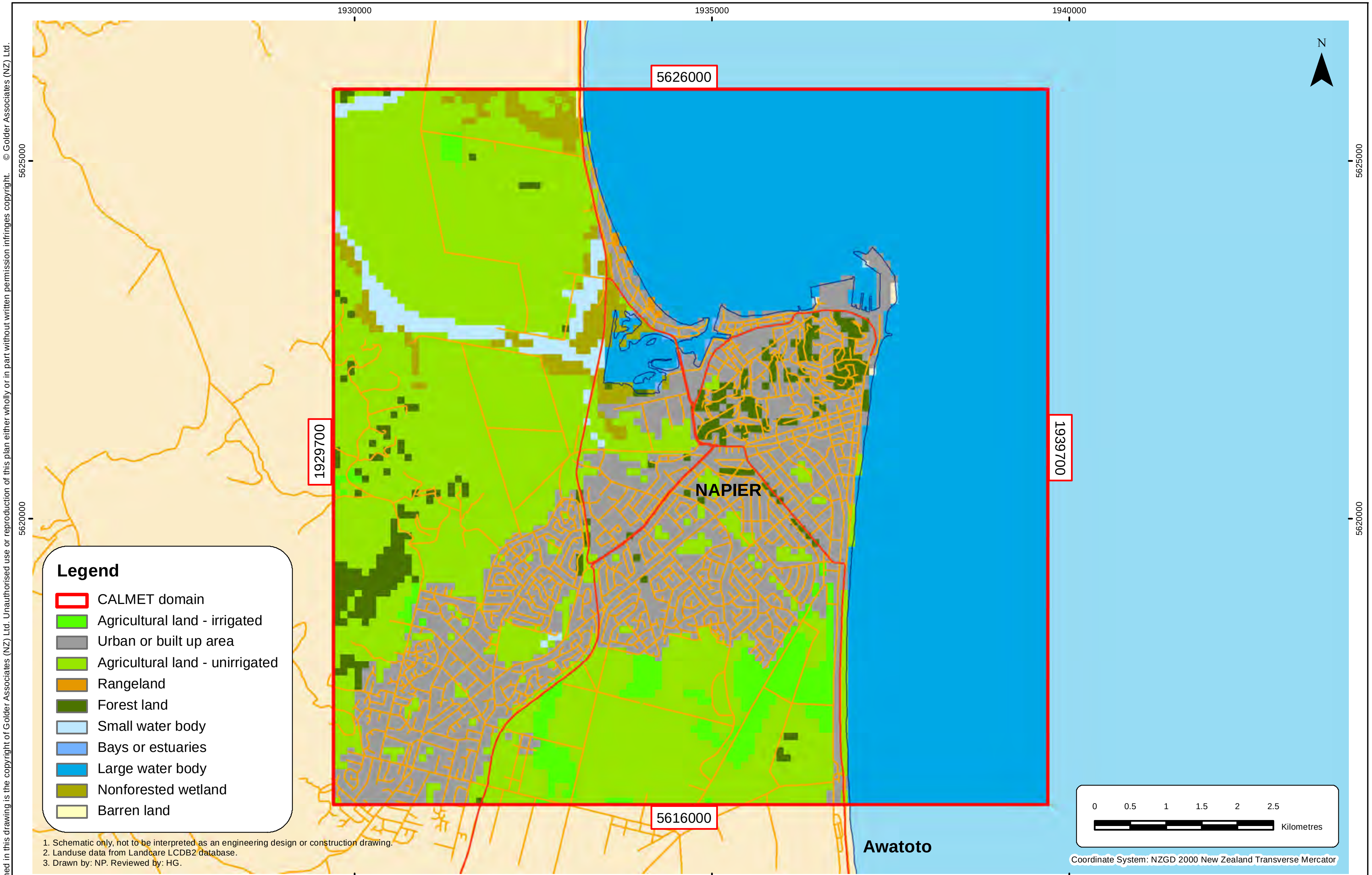

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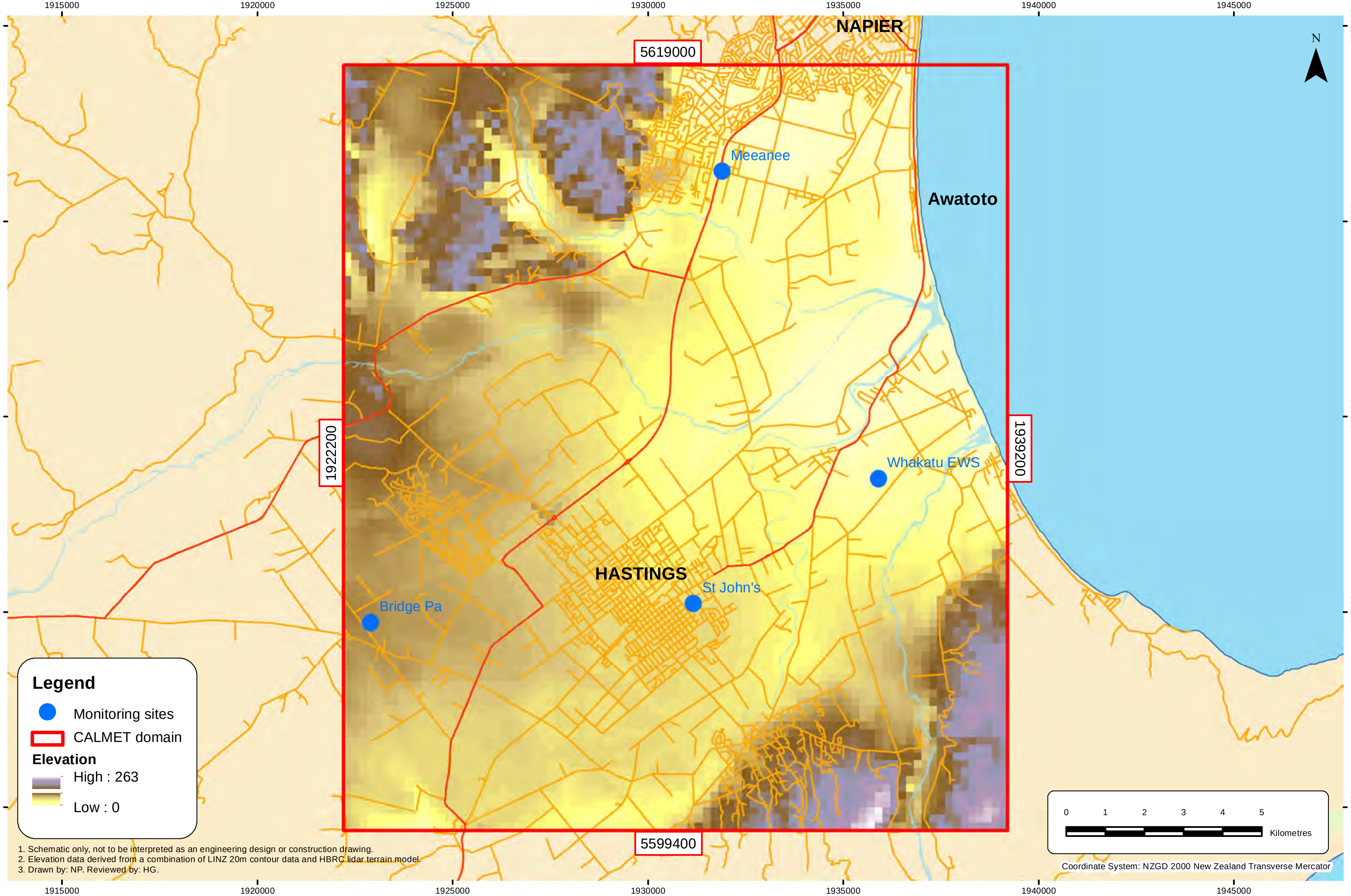

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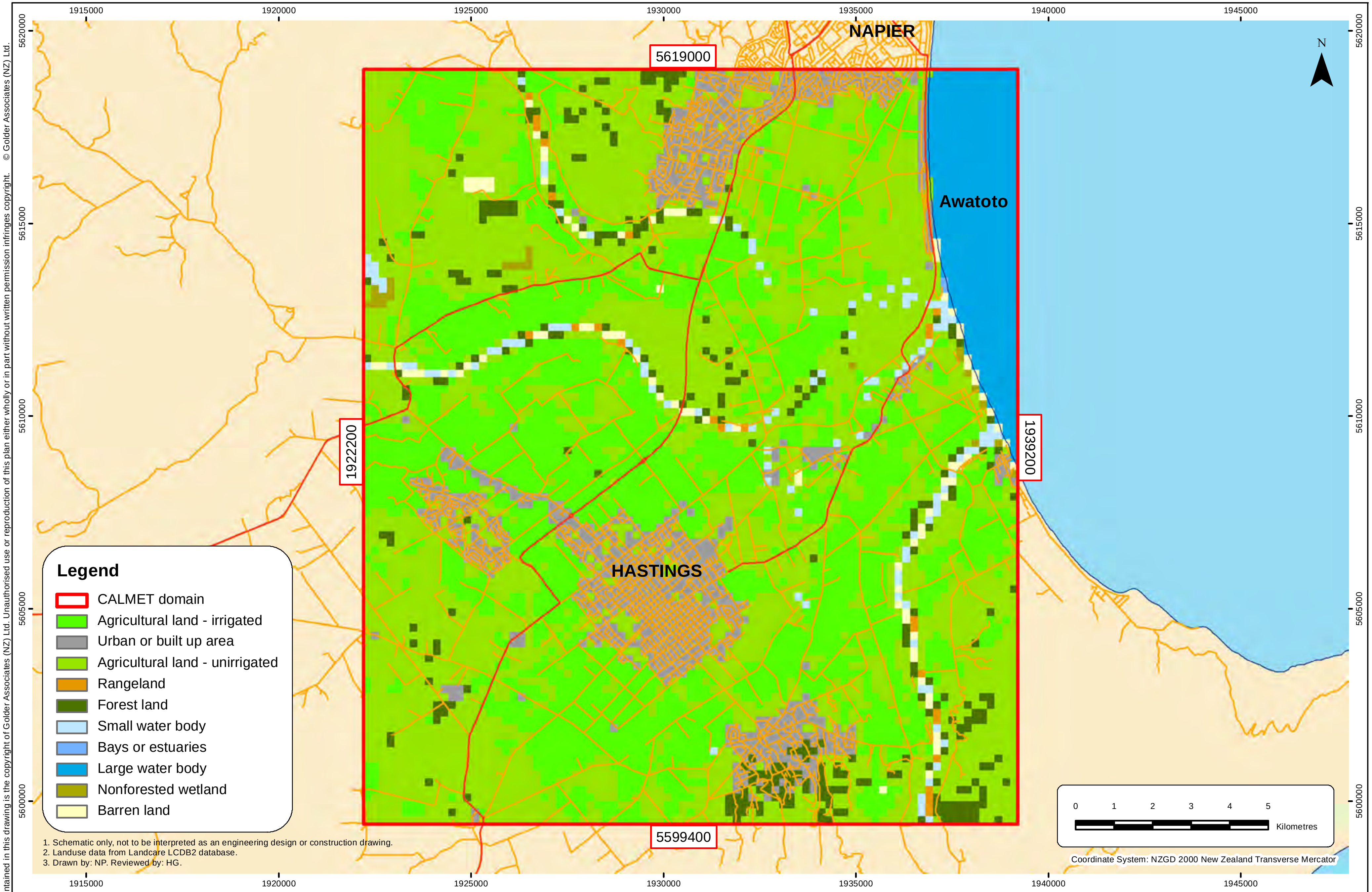

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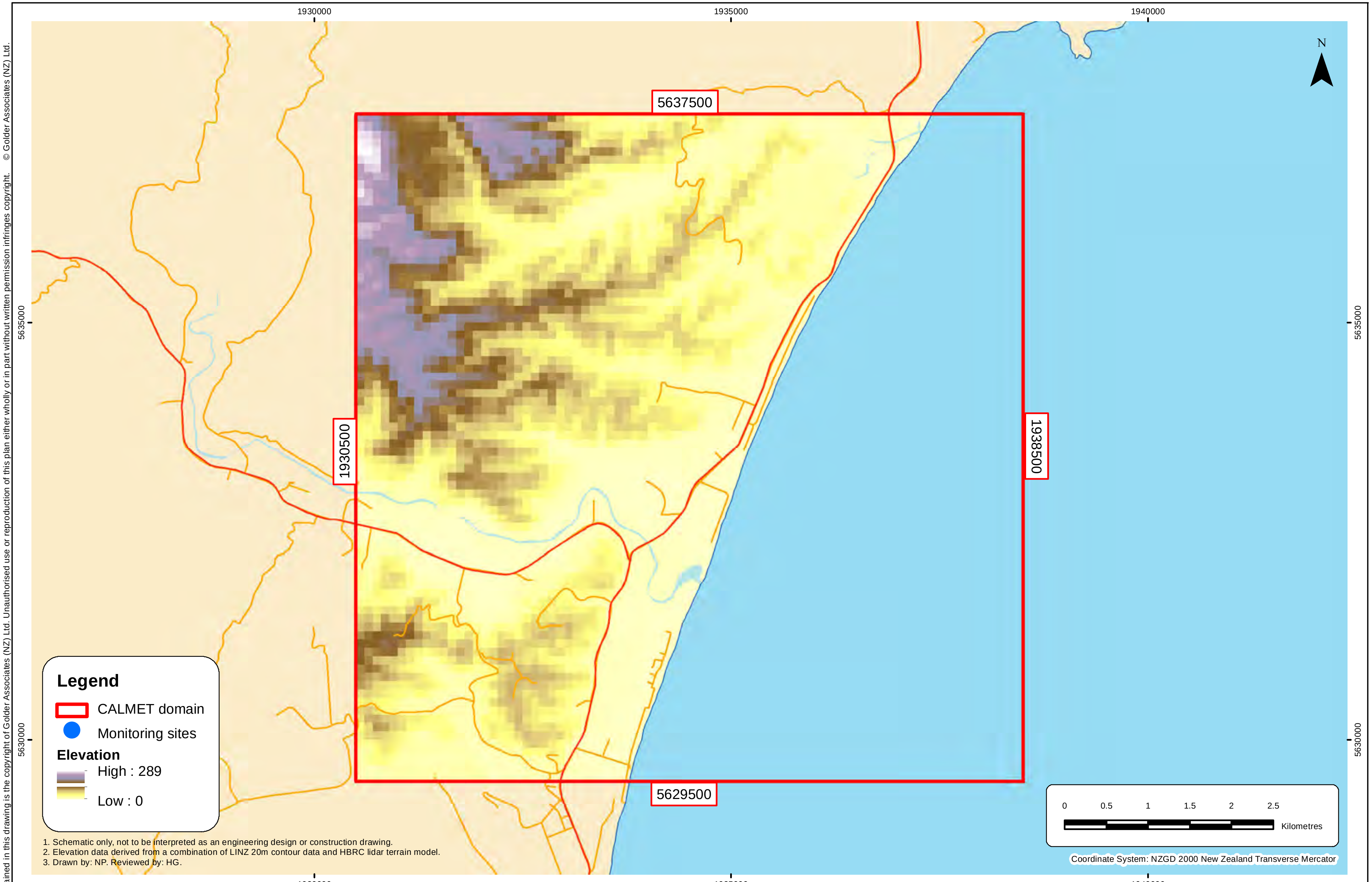

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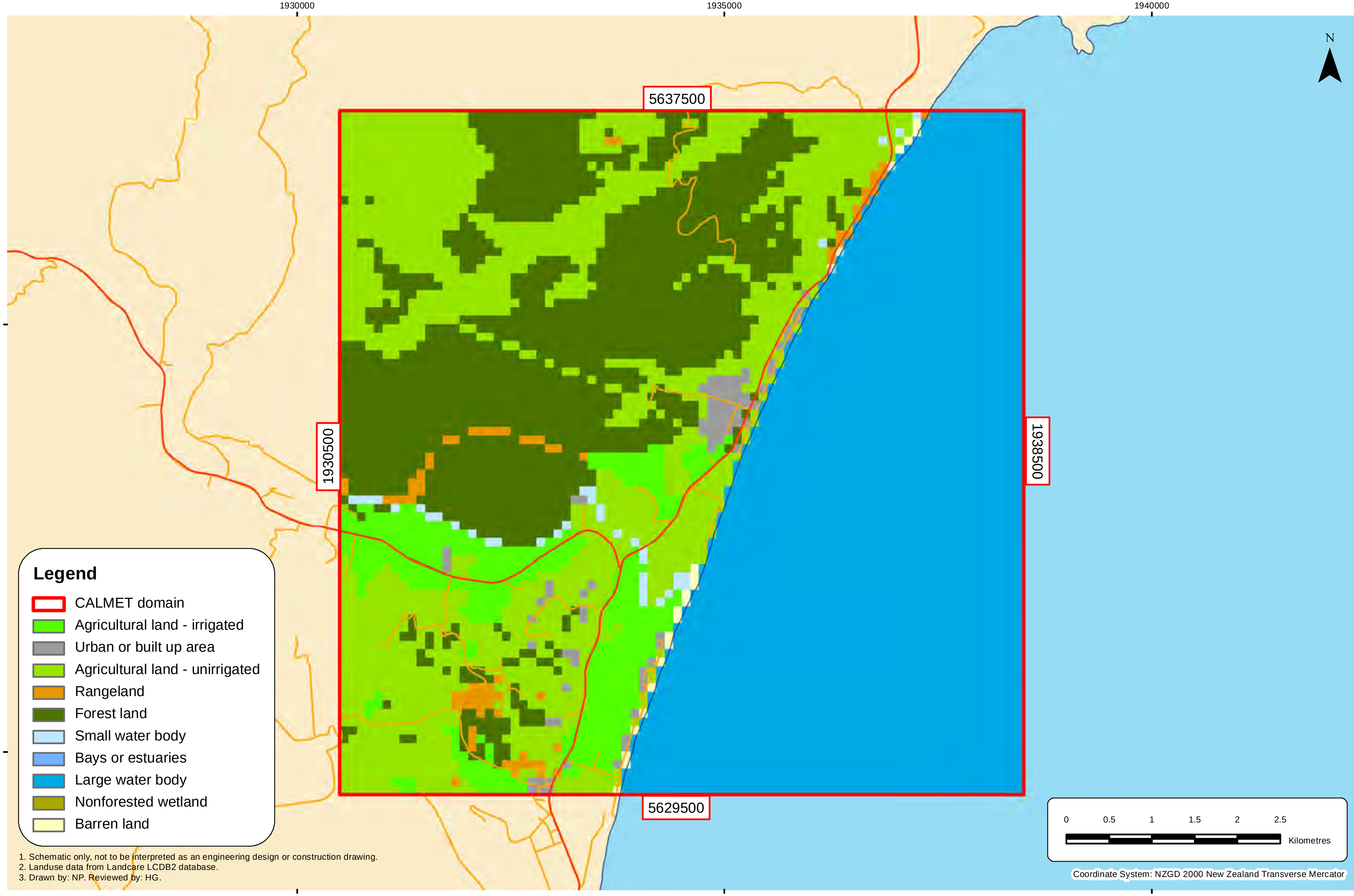

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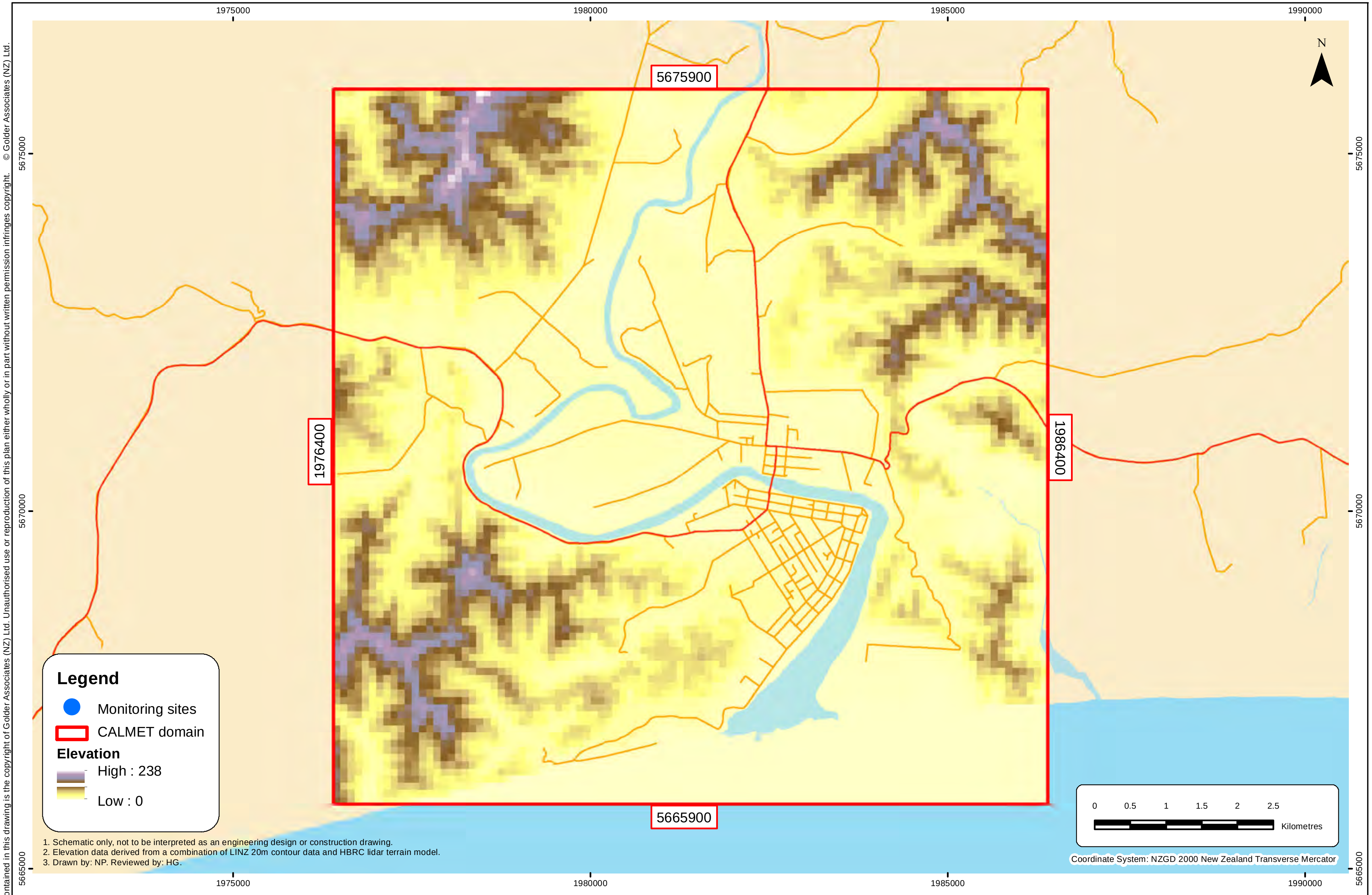

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Table 1: Grid control parameters for the CALMET domains.

Parameter	Value
All grids	
Latitude [RLAT0]	39.416 S (decimal degrees)
Longitude [RLON0]	176.833 E (decimal degrees)
False Easting [FEAST]	1930.000 (NZTM km)
False Northing [FNORTH]	5630.000 (NZTM km)
Napier	
South west corner x-coordinate [XORIGKM]	1929.700 (NZTM km)
South west corner y-coordinate [YORIGKM]	5616.000 (NZTM km)
Number of grid cells west to east [NX]	100
Number of grid cells south to north [NY]	100
Grid spacing [DGRIDKM]	0.1 km
Hastings and Awatoto	
South west corner x-coordinate [XORIGKM]	1922.200 (NZTM km)
South west corner y-coordinate [YORIGKM]	5599.400 (NZTM km)
Number of grid cells west to east [NX]	85
Number of grid cells south to north [NY]	98
Grid spacing [DGRIDKM]	0.2 km
Whirinaki	
South west corner x-coordinate [XORIGKM]	1930.500 (NZTM km)
South west corner y-coordinate [YORIGKM]	5629.500 (NZTM km)
Number of grid cells west to east [NX]	80
Number of grid cells south to north [NY]	80
Grid spacing [DGRIDKM]	0.1 km
Wairoa	
South west corner x-coordinate [XORIGKM]	1976.400 (NZTM km)
South west corner y-coordinate [YORIGKM]	5665.900 (NZTM km)
Number of grid cells west to east [NX]	100
Number of grid cells south to north [NY]	100
Grid spacing [DGRIDKM]	0.1 km

The Hastings and Awatoto domain, being over flatter terrain than the other areas, has 200 m horizontal resolution.

Compatible CALMET model versions

The data sets have been produced using CALMET version 6.334 (released 21 April 2011). They are compatible with CALPUFF version 6.42 (released 25 March 2011). As the format of the output fields from CALMET has not changed in a number of years, it is expected that previous (and probably future) versions of CALPUFF would also be compatible with the CALMET data sets produced using version 6.334.

Table 2: Date and time parameters for each CALMET domain.

Parameter	Year 2006	Year 2010
Start date - year [IBYR]	2006	2010
- month [IBMO]	1	1
- day [IBDY]	1	1
- hour [IBHR]	0	0
- second [IBSEC]	0	0
End date - year [IEYR]	2007	2011
- month [IEMO]	1	1
- day [IEDY]	1	1
- hour [IEHR]	0	0
- second [IESEC]	0	0
UTC time zone [ABTZ]	UTC+1200	UTC+1200

2.3 AUSPLUME Data Set Description

Five time series for each year have been extracted from the high-resolution CALMET data sets at single points for use with AUSPLUME. Steady-state models, such as AUSPLUME, do not usually require detailed information regarding the meteorological data inputs; the dispersion model only needs to know the file path and file names. For reference, the coordinates at which each AUSPLUME file was extracted are shown in Table 3, in addition to the filename of each data set. The map locations of the AUSPLUME data sets are shown in Figure 1.

Table 3: Locations of single-point data sets for Gaussian-plume models.

Filename	Location	X (km, NZTM)	Y (km, NZTM)
Aus_Onekawa06.met Aus_Onekawa10.met	Industrial zone in Onekawa West CAU.	1933.695	5620.252
Aus_Hastings06.met Aus_Hastings10.met	St John's College monitoring site (Mayfair CAU).	1931.162	5605.203
Aus_Awatoto06.met Aus_Awatoto10.met	Representative location in the Awatoto CAU.	1936.625	5614.923
Aus_Whirinaki06.met Aus_Whirinaki10.met	Representative location in the Whirinaki industrial area (Eskdale CAU).	1934.933	5633.946
Aus_Wairoa06.met Aus_Wairoa10.met	Industrial zone to the north of the residential area.	1982.450	5670.950

The sites listed in Table 3 have been chosen in consultation with HBRC, to be relevant to industrial areas or up-coming industrial resource consent applications, not necessarily at the location of a meteorological site. AUSPLUME files generated at the location of a meteorological site would contain the observed wind and temperature (at St John"s, for example). The list of sites may be extended as requested by HBRC.

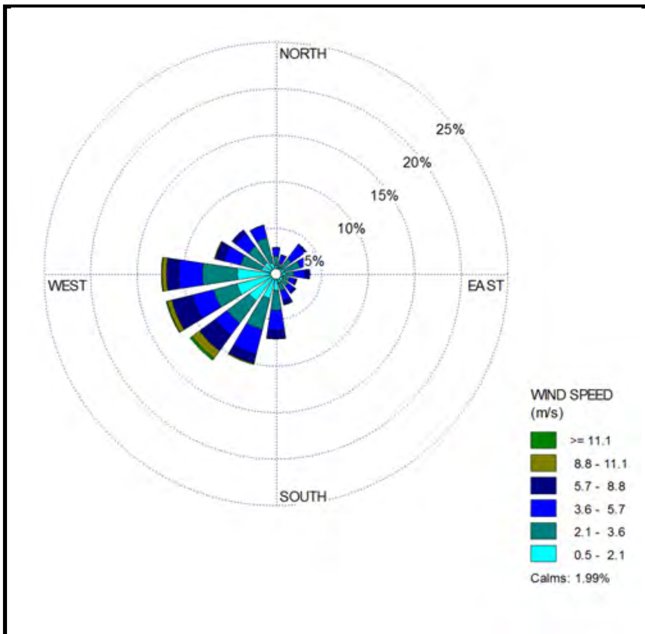
The AUSPLUME meteorological file contains a row of data for each hour. Each row contains the year, month, day, hour, temperature, wind speed, wind direction, stability classification and mixing height, which have been extracted from CALMET outputs, as detailed in Appendix E. Wind roses for the sites in Table 3 are presented in the next section.

The meteorological files are compatible with AUSPLUME versions 5.4 and 6.0.

3.0 METEOROLOGICAL MODEL RESULTS

Wind roses are shown for six locations in Figure 10 to Figure 15, for each of the years modelled (2006 and 2010). The locations are Marewa Park, followed the five locations of the AUSPLUME files listed in Table 3. These have been extracted from the CALMET model results[3]. Model results extracted from the monitoring site locations Marewa Park and St John"s College should match observations at those sites.

The figures show that the essential characteristics of the wind patterns at each site – for instance, the predominant wind directions and range of speeds – are similar in 2006 and 2010. There is some interannual variability, which is to be expected. The main wind directions vary somewhat between sites, as the prevailing large-scale wind flows are diverted by the local topography. For example, the SW-NE valley system diverts air in the direction of the main urban areas, giving predominantly southwesterly winds in Napier and Awatoto. Flows along the Esk Valley approach Whirinaki from the west, and the along-valley wind direction towards Wairoa is from the northwest. These diverted flows are clearly visible in the wind roses, and will include components at lower wind speeds due to night-time down-slope drainage.



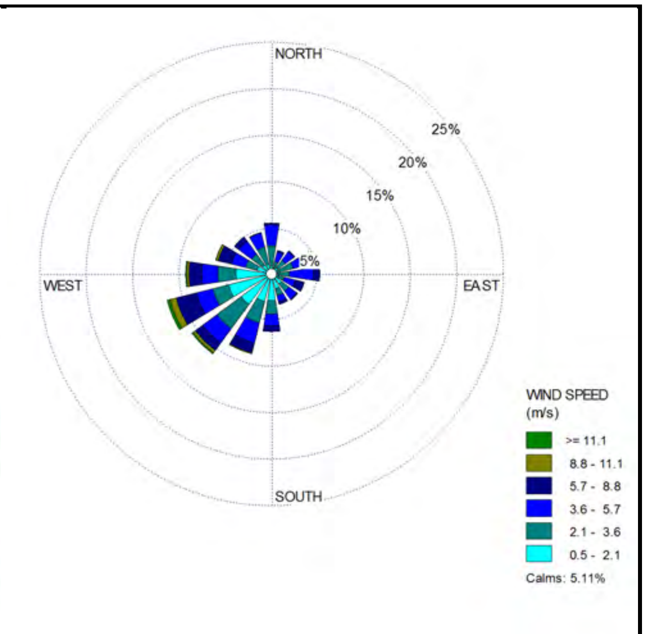


Figure 10: Wind roses for Marewa Park, years 2006 (left) and 2010 (right).

[3] The AUSPLUME wind roses look essentially the same the CALMET wind roses. The only change to the wind data made in the construction of AUSPLUME meteorological files is to set a minimum wind speed of 0.5 m/s.

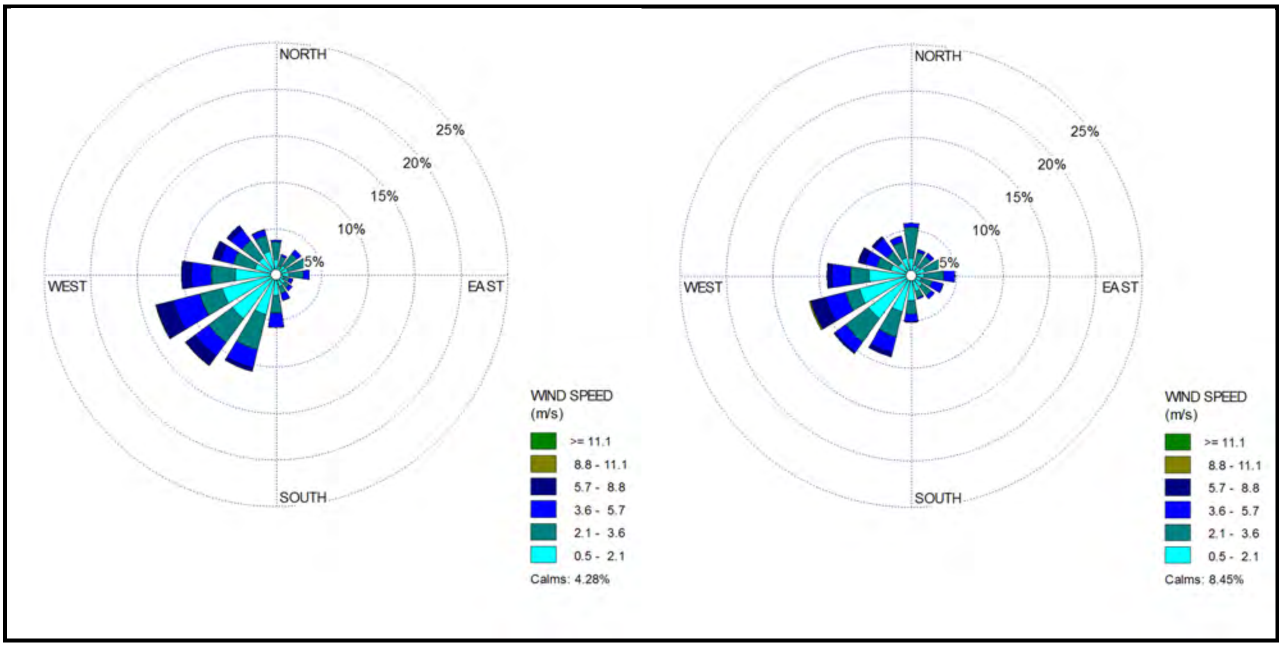


Figure 11: Wind roses for Onekawa, years 2006 (left) and 2010 (right).

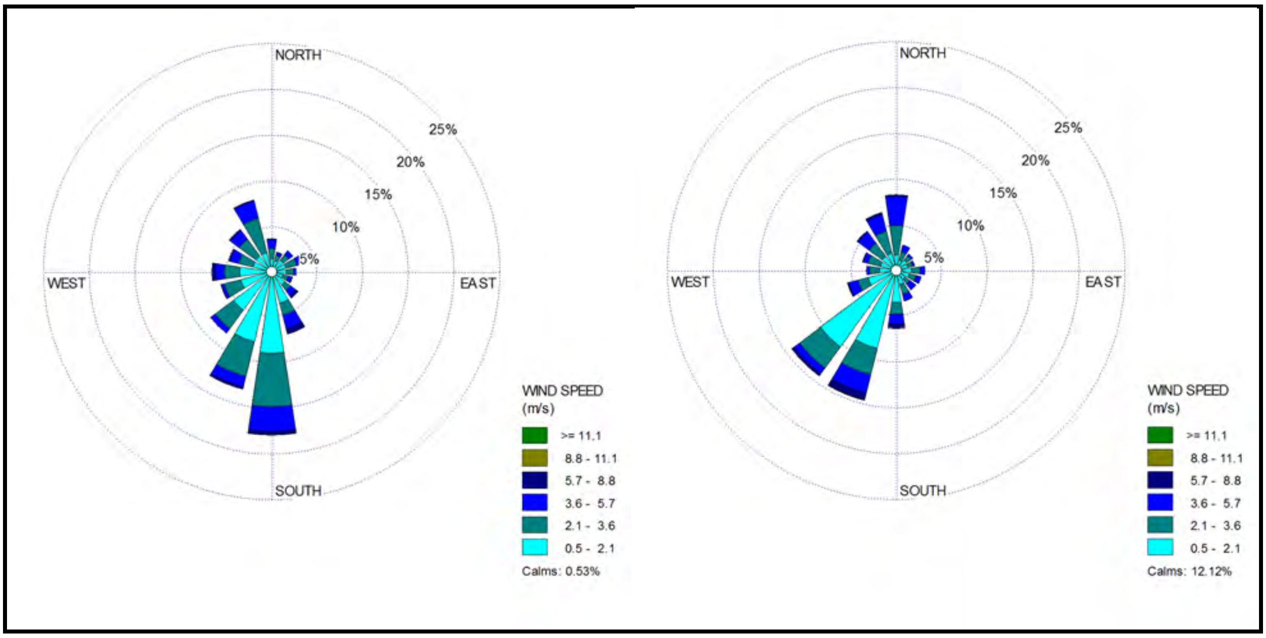


Figure 12: Wind roses for St John's College, Hastings, years 2006 (left) and 2010 (right)[4].

[4] There appears to be uniform rotation of the general shape of the St John‟s College wind rose between the two years. HBRC has confirmed that the data are correct (email from Kathleen Kozyniak of HBRC to Neil Gimson of Golder, 18 April 2012).

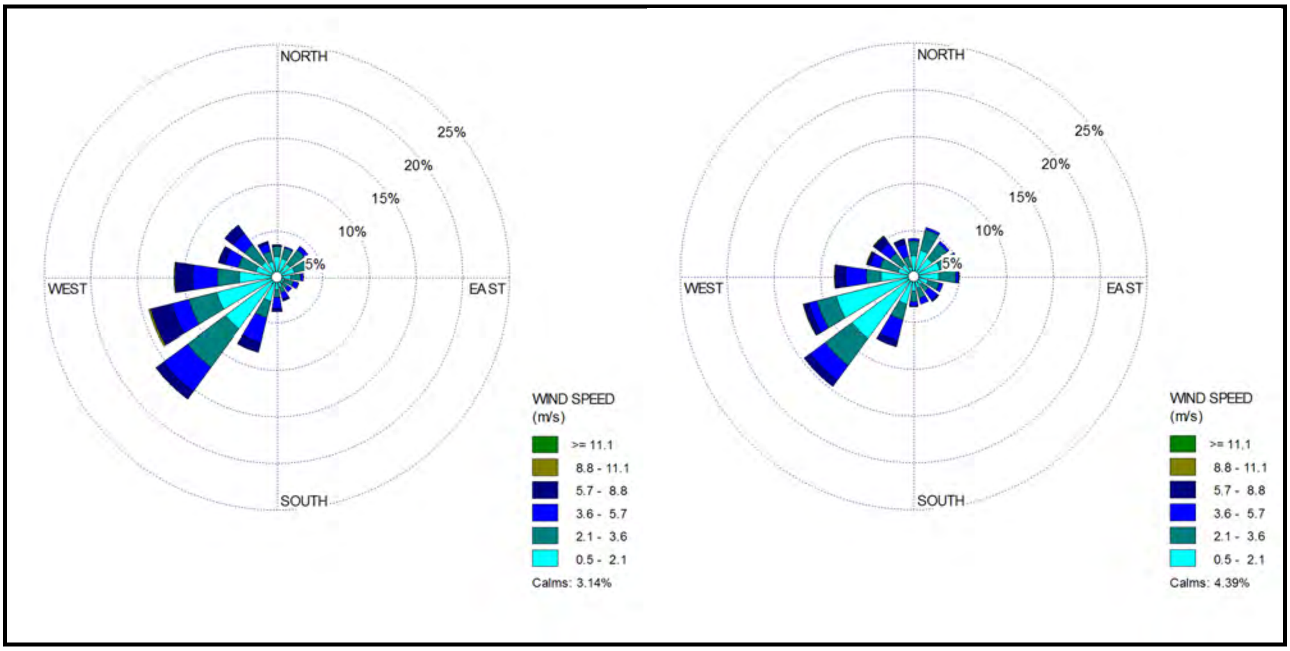


Figure 13: Wind roses for Awatoto, years 2006 (left) and 2010 (right).

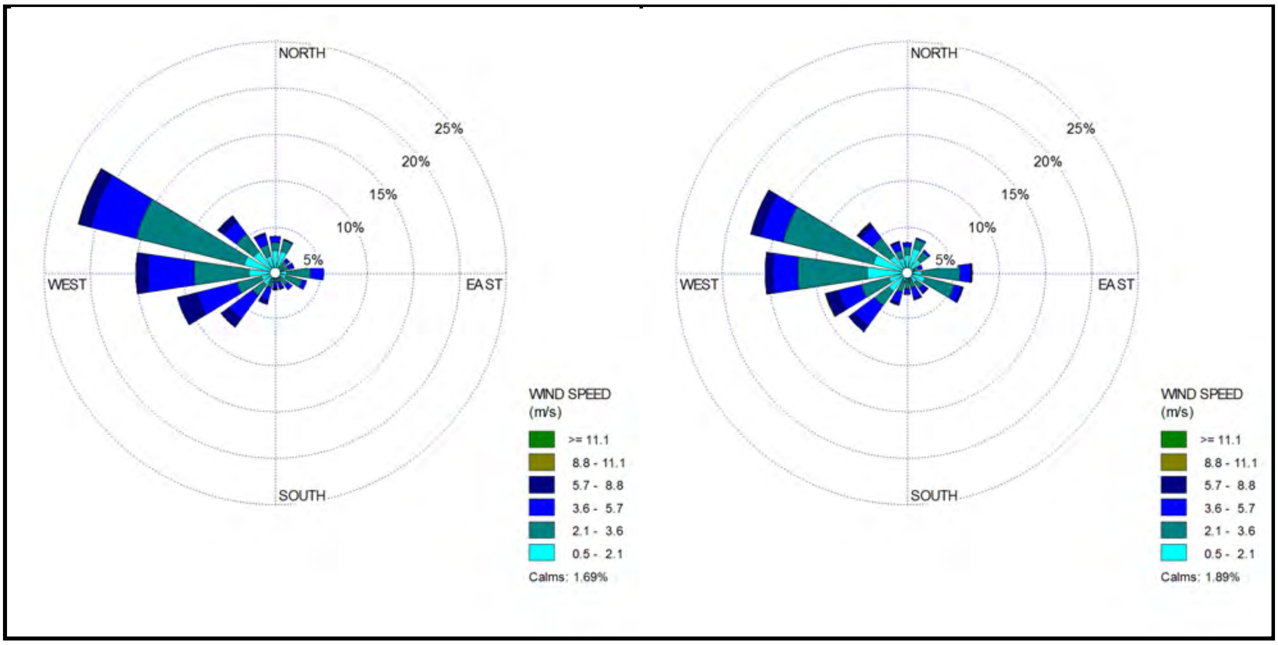


Figure 14: Wind roses for Whirinaki, years 2006 (left) and 2010 (right).

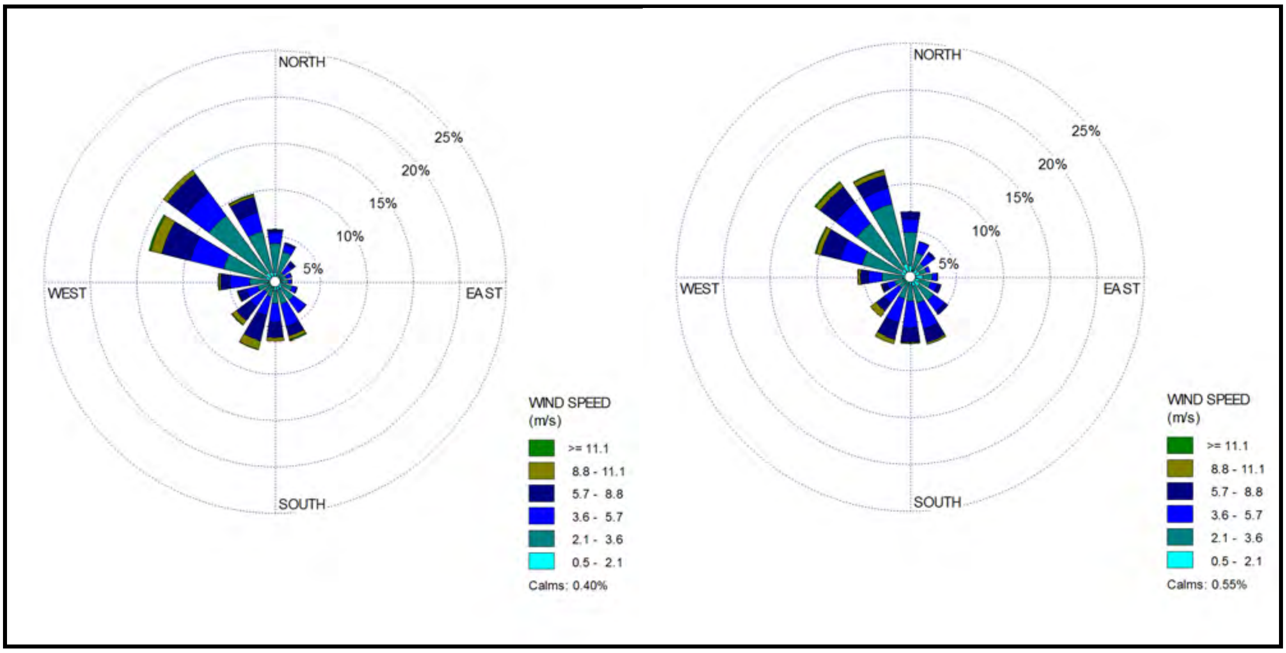


Figure 15: Wind roses for Wairoa, years 2006 (left) and 2010 (right).

4.0 GUIDANCE ON MODEL CHOICE

Guidance based on meteorological complexity

Contaminant concentrations predicted by a dispersion model are dependent on the meteorology of an area, and the source characteristics. The meteorology determines how a contaminant plume disperses and dilutes in the atmosphere as the plume moves away from its source. The most important meteorological elements are wind direction and speed (for pollution transport), and turbulence and mixing in the boundary layer (for dispersion).

Until recently, the dispersion models most commonly used for industrial applications have been steady-state Gaussian plume models, such as AUSPLUME and ISCST3. These models have relatively simple meteorological data requirements. However, steady-state Gaussian plume models have a number of limitations. In particular, they should only be considered appropriate for situations where terrain is not complex or steep, meteorology is spatially uniform and periods of calm or light winds are infrequent. More advanced dispersion models, such as CALPUFF or TAPM, are being used increasingly in New Zealand to overcome these limitations.

The Hawke's Bay region contains complex terrain, and experiences terrain-induced flows, land-sea breeze circulations and periods of calm or light wind. Therefore, the use of steady-state Gaussian plume models in this region may not be considered ideal. Advanced dispersion models, such as CALPUFF, use spatially-varying meteorological fields, and are considered to better represent dispersion through the atmosphere. However, they have significantly greater meteorological data requirements than the steady-state models, and details on the use of such data by CALMET are given in Section 5.1 of this Appendix. CALPUFF is likely to be the most appropriate dispersion model for most industrial applications in the Hawke's Bay region, for reasons discussed in this section. However, for „screening" assessments, or for near-field effects in flat terrain, the use of a steady-state plume model, such as AUSPLUME, with a single-point meteorological file may be justified. The dispersion modelling GPG produced by MfE (2004) notes the following key situations where a steady-state model may be appropriate:

- For near-field applications, on spatial scales over which the meteorology may be considered spatially uniform;
- Calm atmospheric conditions are not prevalent;
- Away from a coastal environment and in flat terrain;
- If dry and wet deposition and chemistry do not need to be modelled.

The above list summarizes Recommendations 3 and 5 of the GPG. The limitations of steady-state models are listed on pages 15-16 of the GPG. For applications beyond these limitations – which will be many applications in the Hawke's Bay area – the CALPUFF model should be used with three-dimensional meteorology provided by CALMET.

Note that as strict targets are defined by the NES and other guidelines, a detailed understanding of the interaction of discharged pollutants and background air quality is often required, as both components are spatially and temporally varying. CALPUFF is based on spatially and temporally varying meteorology and can provide the necessary analysis for this. This is also true of TAPM, which has been run over the Hawke"s Bay area for this project.

The provision of meteorological data sets as a basis for dispersion modelling means that the user only needs to configure the dispersion modelling component. The expertise and effort required for this is similar for any of the commonly-used dispersion models (once the meteorological modelling has been done). For example, there may be no significant difference in the configuration time or effort in using CALPUFF, compared to AUSPLUME.

Ministry for the Environment good-practice guidance for air assessments

The GPGs for industrial and land-transport assessments (MfE 2008(a,b)) describe several levels of assessment that may be required as a succession of Tiers, numbered 1 to 3. The basic Tier definitions are quoted below:

- Tier 1 – a preliminary assessment to identify whether there are likely to be significant air quality effects;
- Tier 2 – a largely qualitative assessment with screening-level modelling only;
- Tier 3 – a largely quantitative assessment with increased complexity in the modelling and reliance on site-specific data.

The GPGs state that "a Tier 2 screening dispersion modelling study provides conservative estimates of likely air quality impacts". This may traditionally have meant that the screening dispersion modelling assessment could use a Gaussian-plume model such as AUSPLUME because its results are expected to be conservative. Whilst this may be true if idealised meteorological files (such as "Metsamp") are used, the meteorological files developed here for use with AUSPLUME are derived from CALMET outputs. All else being equal – for example, if the dispersion modelling is of inert tracers in flat terrain, with no calms – AUSPLUME and CALPUFF concentrations should be consistent with each other. In other words, AUSPLUME itself is not necessarily conservative, but other simplifying assumptions in a Tier 2 assessment may make the results conservative. For example, given a realistic meteorological data set, conservative results may arise from an assumption of constant maximum emission rates or an assumption of no chemical losses or removal to the surface.

In short, a Tier 2 assessment of effects may include the use of AUSPLUME, with some conservative assumptions. However, if predicted air quality impacts are sufficiently large, a Tier 3 assessment should be carried out. The Tier 3 assessment would then use CALPUFF to provide a more realistic assessment.

5.0 DISCUSSION

5.1 The CALMET Modelling Process

Introduction

The modelled meteorology consists of three-dimensional hourly wind, temperature and humidity fields, and two dimensional surface-based parameters such as mixing height, Pasquill-Gifford stability class, friction velocity and Monin-Obukhov length. As mentioned earlier, the model runs cover industrial areas of Napier, Hastings and Awatoto, Whirinaki and Wairoa. Airshed modelling using TAPM, for the main body of this report, covers the Heretaunga Plains and a large amount of the surrounding area, in order to simulate longer-range transport and possible re-circulation of air pollutants. Three-dimensional fields of wind, temperature and humidity from TAPM have been used as input to CALMET.

The following sections describe the preparation of input data, which includes modelled meteorology from the numerical weather prediction model TAPM, geographical information such as terrain heights, and data from meteorological monitoring stations. The inputs are discussed in the order in which the information is used by CALMET to calculate hourly meteorological fields.

TAPM data used as CALMET's initial wind field

The CALMET meteorological processor allows for the assimilation of outputs from a variety of prognostic weather prediction models, and these are used to generate an initial estimate of each hour‟s meteorological fields in CALMET. This is known as the „initial guess‟.

In this work, modelled hourly, three-dimensional fields of wind, temperature, relative humidity from TAPM were used in the initial-guess stage of the CALMET run for each hour. TAPM solves the equations of atmospheric motion mathematically to give physically-realistic meteorological fields. Numerical outputs from TAPM were converted to CALMET inputs using the CALTAPM utility to provide data for the years 2006 and 2010 from the finest TAPM grid (resolution 1 km x 1 km), which covered the Heretaunga Plains. This was used as the initial guess for CALMET modelling over Napier, Hastings, Awatoto and Whirinaki.

The spatial resolution of CALMET is higher than that of TAPM, with the TAPM fields interpolated onto the CALMET grid at the initial-guess stage. As described below, the wind fields were then adjusted according to the higher-resolution terrain and land use to produce the CALMET Step 1 wind field, and the objective analysis stage led to the final CALMET fields. No meteorological observations were used until the objective analysis stage, at which data from surface stations were incorporated. CALMET progresses through these stages every hour of its run.

As the finest TAPM grid (Grid 4) did not cover Wairoa, CALMET was run with upper-air information supplied through hourly profiles of wind, temperature and relative humidity extracted from the TAPM Grid 3 at a location in Wairoa (see below).

Geographical Information for CALMET's 'Step 1' wind field

CALMET requires terrain and land-use data on a regular grid of points. These have been derived using Golder‟s in-house GIS and converted to the CALMET input format. The resulting model domains are shown in Figure 2 to Figure 9, with numerical parameters shown in Table 1. This geographical information enables the model to produce terrain-driven effects, such as blocking and slope and valley flows, and to produce the variations in boundary-layer structure associated with changes in land use (particularly the contrast between land and sea). This is known as the „Step 1‟ wind field.

Meteorological Station Data for Objective Analysis

CALMET uses meteorological data from local weather stations. Local data are used to ensure that the modelled fields are consistent with observations. Incorporation of local observations overrides the terrain-driven Step 1 field; hence the observations are only used in the vicinity of monitoring sites, where the data are representative of the meteorology nearby. There are several monitoring sites in the Hawke's Bay area operated by HBRC, along with additional sites operated by the MetService and NIWA. Data from these sites have been used in the CALMET modelling, as described in this section.

The meteorological monitoring stations run by HBRC measure surface wind, temperature and humidity. These are co-located with the air quality monitoring sites at Marewa, St John's, Meeanee and Bridge Pa (where rainfall is also measured). The meteorological site data from HBRC were supplemented by data from stations at Napier Airport and Whakatu, obtained from the National Climate Database (CLiDB).

A summary of the data availability from the meteorological stations is shown in Table 4. Wind speed and direction, temperature and relative humidity are available at all six sites, while rainfall and pressure are only available at one site. Hours of missing rainfall data have been assumed zero mm/hr – there are seven missing hours in 2006 and 177 in 2010. Rainfall data (in mm/hr) were input to CALMET from a precipitation file, separate from the rest of the surface-based data.

Cloud data were available at Napier Airport. However, as there were a large number of periods with no recorded cloud information, cloud properties for CALMET were diagnosed from TAPM‟s relative humidity (RH) profiles. Cloud height at each hour was defined as the height of maximum RH. Then cloud cover was defined as a range from 2 oktas at RH=73%, to 8 oktas at RH=99%[5] (at the height of maximum RH).

Wairoa Meteorological Data Sets

CALMET modelling of the Wairoa domain was carried out differently from the other domains. This is due to the domain being outside TAPM Grid 4, and there being no surface meteorological data available in Wairoa. In this case, the meteorological inputs to CALMET are *all* outputs of TAPM, and the CALMET model solution is based on hourly profiles and surface information from a single location on TAPM Grid 3. Although the inputs are results from another model, they are treated by CALMET as if they were measurements. Hence the „initial guess‟ in CALMET is based on the one-dimensional hourly profile and surface time series from TAPM, extrapolated horizontally to produce a three-dimensional initial-guess field[6]. The „Step 1‟ field is calculated as described above for the other domains, and the final fields each hour follow the objective analysis procedure operating on the surface inputs from TAPM. As for the other domains, cloud height and cloud cover are diagnosed from the RH profile extracted from TAPM.

Some model testing was carried out to obtain realistic effects of topography in the river valley through Wairoa township. Optimal terrain-influence parameters were obtained which enable CALMET to produce reasonable downslope flows and blocking of upslope flows. (This optimization was done for all model domains, with particular attention paid to the Napier domain containing Bluff Hill).

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[5] This scheme is based on cloud height and cloud cover measurements in Auckland, which have been related to modelled RH profiles. Further details on this work are available on request.

[6] By default, CALMET extrapolates surface information upwards to generate theoretical surface-layer profiles. This was not done here, as vertically-consistent hourly profiles were available from TAPM.

Table 4: Summary of surface meteorological station data used by CALMET.

Station name	Operator	Location (km, NZTM)	Parameters	Time series availability – start and end date	Percentage of calms (wind speed <0.5 m/s)	% of time series complete (between given dates)
Marewa	HBRC	1935.111, 5620.462	Wind speed, wind direction, air temperature, relative humidity	17/1/2006-1/1/2007; 1/1/2010-1/1/2011	2006: 4.6% 2010: 9.5%	2006: 93% 2010: 100%
St John's	HBRC	1931.162, 5605.203	Wind speed, wind direction, air temperature, relative humidity	9/2/2006-1/1/2007; 1/1/2010-1/1/2011	2006: 3.9% 2010: 22%	2006: 97% 2010: 100%
Meeanee	HBRC	1931.896, 5616.271	Wind speed, wind direction, air temperature, relative humidity	17/1/2006-1/1/2007; 1/1/2010-1/1/2011	2006: 9.2% 2010: 33%	2006: 100% 2010: 100%
Napier Aero Aws (Agent number 2980)	MetService	1932.054, 5625.146	Wind speed, wind direction, air temperature, relative humidity, pressure, rainfall[7]	1/1/2006-1/1/2007; 1/1/2010-1/1/2011	2006: 2.5% 2010: 11%	2006: 100% 2010: 100%
Whakatu Ews (Agent number 15876)	NIWA	1935.895, 5608.405	Wind speed, wind direction, air temperature, relative humidity	1/1/2006-1/1/2007; 1/1/2010-1/1/2011	2006: 0.64% 2010: 0.33%	2006: 100% 2010: 100%
Bridge Pa	HBRC	1922.903, 5604.721	Wind speed, wind direction, air temperature, relative humidity	1/1/2006-1/1/2007; 1/1/2010-1/1/2011	2006: 0.33% 2010: 4.6%	2006: 100% 2010: 100%

[7] Cloud data were also available from Napier Airport. However, cloud parameters in CALMET have been diagnosed from the relative humidity in TAPM.

5.2 CALMET Model Performance

Evaluation of results from the CALMET model is less straightforward than evaluation of other models. Ideally, meteorological model outputs would be compared with observations of wind, temperature, humidity and rainfall, for instance. Standard measures of model performance are available, and these have been applied to the TAPM results elsewhere in this report, in the comparison of modelled PM_{10} and modelled meteorology to measurements of ambient PM_{10} and meteorological observations. In the case of CALMET, the observations at monitoring stations have been used as model inputs, and the model reproduces those at those sites. A formal performance assessment of CALMET is thus not possible, and evaluation must consist mainly of an inspection of the output fields from CALMET and their evolution with time.

In this work, CALMET is driven by a combination of large-scale, modelled meteorology (generated by the prognostic model TAPM) with data from several climate monitoring sites in the Napier/Hastings area. The climate monitoring sites are presumed representative of conditions over a pre-specified range, given by the input radius of influence parameters in CALMET. Outside this range, the CALMET solution depends on the TAPM results (in the current work, local wind data have also been assimilated into TAPM). An evaluation of CALMET involves ensuring that the meteorological fields (especially wind) give realistic patterns in the coastal and orographic settings of Napier, Hastings, Whirinaki and Wairoa. Also, there should be a smooth transition at the edges of the influence of the local observations to the TAPM solution further afield.

A visual examination of some of the CALMET results over the winter months has been carried out. This has lead to some changes in the model configuration and model re-runs, leading finally to a reasonable meteorological solution upon which to base dispersion model runs with CALPUFF, AUSPLUME or other single-site Gaussian-plume dispersion models.

6.0 CONCLUSION

A suite of meteorological data sets has been developed for use in air quality assessments for industry in the Hawke‟s Bay region. The data sets have been created using a combination of climate-site data and meteorological models, and are formatted as CALMET and AUSPLUME files. They are intended for use with the CALPUFF and AUSPLUME dispersion models.

It is envisaged that the data sets will be promoted by HBRC, and accepted as the standard data sets to be used for air quality assessments for industrial projects around the Hawke's Bay region. It is also envisaged that CALPUFF will be the preferred dispersion model for the assessment of industrial discharges that require resource consents. However, single-site meteorological files have been produced for AUSPLUME, and final model choice should be determined by the user in consultation with HBRC.

The data sets and associated electronic files may be obtained on portable hard disk from HBRC, and their use is expected to be subject to a data sharing agreement between HBRC and the user.

7.0 REFERENCES

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APPENDIX E

Creation of AUSPLUME Meteorological Files

1.0 INTRODUCTION

This Appendix describes the methods used to create meteorological files for AUSPLUME, applicable to locations around the Hawke's Bay region. The files are created from time series of CALMET results at discrete points in the CALMET domain corresponding to key industrial areas, or to meteorological monitoring sites. The CALMET results are extracted and post-processed to ensure that the wind speed, Pasquill-Gifford (PG) stability class and mixing height are consistent with each other for each hour. The method followed here is the same as that followed to produce AUSPLUME files for industrial locations around Auckland (Gimson et al. 2010), and Nelson and Richmond (Golder 2012). It has undergone peer-review by members of the air quality community and the procedure is a reasonable one to follow, producing physically realistic results, appropriate for input to dispersion modelling with AUSPLUME.

As CALMET has already been run to produce single-location time series of meteorology for input to the AUSPLUME dispersion model, CALPUFF could easily be used for dispersion modelling rather than AUSPLUME. However, in some cases, it is sufficient to use AUSPLUME, and therefore meteorological files in the AUSPLUME format have been supplied. The following should be noted:

(i) The extracted meteorological data have been checked for consistency between wind speed, stability class and mixing height.
(ii) The methods used for extracting and checking the data have been discussed with and reviewed by members of the air quality community in New Zealand.
(iii) If the single site is located at a monitoring site, whose data have been input to CALMET, the AUSPLUME meteorological file will contain those measurements.

The following sections describe the methods used for extracting meteorological parameters from CALMET and updating them to be in line with common practice among air quality professionals.

2.0 METEOROLOGICAL PARAMETERS

2.1 Overview

Although the meteorological parameters needed for AUSPLUME are provided by CALMET, there are several methods for calculating mixing height and PG stability class. This section reviews those methods and compares them with the scheme used by CALMET. It shows that certain combinations of wind speed, mixing height and stability class calculated by CALMET are not realistic, nor consistent with each other. Accordingly, the method for producing AUSPLUME files accounts for this and adjusts the parameters in accordance with standard practice of air quality professionals in NZ.

2.2 Wind Speed

Gaussian-plume models (of which AUSPLUME is an example) can overestimate contaminant concentrations when wind speeds are lower than about 0.5 m/s. In AUSPLUME, the wind speed should not be below this value. Recent versions of AUSPLUME (version 4 onwards) automatically increase the wind speed to 0.5 m/s whenever the input value is lower. This change has been applied to the wind speed extracted from CALMET for consistency of use in other Gaussian-plume models.

2.3 Pasquill-Gifford Stability Class Assignments

CALMET assigns stability class using Turner's method (Turner 1964), where cloud cover and solar angle determine the net radiation index, or insolation category. In combination with the wind speed the radiation index determines the stability class. The net radiation index is negative (resp. positive) during the night (resp.

day) with the absolute value decreasing with increasing cloud cover (to more neutral conditions when overcast). A summary of stability assignments based on this method is shown in Table 1.

We have compared the method with that used by Environment Protection Authority (EPA) Victoria, the developers of AUSPLUME and AUSROADS. EPA uses a solar radiation method for daytime and a modified Pasquill-Gifford scheme for night-time to define stability class. A summary of the EPA stability assignments is shown in Table 2.

The two methods have similarities in their dependence on wind speed, solar radiation and cloud cover (as the radiation index is derived from sun angle and cloud cover). The matrix of stability classes looks similar in both tables with, for example, stability class A in the top-left for calm, sunny conditions.

The method used by EPA includes imposing class D before sunset and after sunrise, for all wind speeds. This is not explicitly done in the Turner scheme, but with a low sun angle (zenith angle less than 15°) at such times, the insolation category is 1 or 0. For category 1, the resulting stability class would be C under low-wind conditions, and D under stronger winds. Under insolation category 0, the stability class is D.

It is important to note that the dependence of stability class on wind speed is slightly different between the Turner and modified Pasquill-Gifford schemes. As Gaussian-plume dispersion models (including AUSPLUME) generally base their lateral and vertical plume dispersion schemes on the Pasquill-Gifford class, the scheme used by CALMET to assign stability classes has been modified as a post-processing step, according to the following rules:

i) If the wind speed is less than 2 m/s, and the stability class is C, change the stability class to B;

ii) If the wind speed is greater than 3 m/s and the stability class is F, change the stability class to E;

iii) If the wind speed is greater than 5 m/s and the stability class is E, change the stability class to D.

This leads to stability class assignments closer to the modified Pasquill-Gifford scheme, as used by EPA. The final stability classes used for the AUSPLUME data sets produced here are shown in Table 3. Changes around sunrise and sunset have not been applied, and at low wind speed and low sun angle (insolation category 1) the stability class is now B.

Table 1: Summary of stability-class assignments used by CALMET.

Wind Speed (m/s)	Net Radiation Index (Insolation Category)							
	4	3	2	1	0	-2	-1	0
0.5	A	A	B	C	D	F	F	D
1	A	B	B	C	D	F	F	D
1.5	A	B	B	C	D	F	F	D
2.1	A	B	C	D	D	F	E	D
2.6	A	B	C	D	D	F	E	D
3.1	B	B	C	D	D	F	E	D
3.6	B	B	C	D	D	E	D	D
4.1	B	C	C	D	D	E	D	D
4.6	B	C	C	D	D	E	D	D
5.1	C	C	C	D	D	E	D	D
5.7	C	C	C	D	D	D	D	D
6.2	C	D	C	D	D	D	D	D

Table 2: Summary of stability-class assignments used by EPA.

	Day time				1h before sunset and after sunrise	Night time		
Wind Speed (m/s)	**Solar Radiation (W/m²)**					**Cloud cover (okta)**		
	Strong >925	**Moderate 675-900**	**Slight 175-675**	**Overcast <175**		**0-3 cloud**	**4-7 cloud**	**8 cloud**
<2	A	A	B	D	D	F	F	D
<3	A	B	C	D	D	F	E	D
<5	B	B	C	D	D	E	D	D
5-6	C	C	D	D	D	D	D	D
>6	C	D	D	D	D	D	D	D

Table 3: Summary of final stability-class assignments used in the AUSPLUME data sets. Entries differing from Table 1 are in bold red type.

Wind Speed (m/s)	Net Radiation Index (Insolation Category)							
	4	**3**	**2**	**1**	**0**	**-2**	**-1**	**0**
0.5	A	A	B	**B**	D	F	F	D
1	A	B	B	**B**	D	F	F	D
1.5	A	B	B	**B**	D	F	F	D
2.1	A	B	C	D	D	F	E	D
2.6	A	B	C	D	D	F	E	D
3.1	B	B	C	D	D	**E**	E	D
3.6	B	B	C	D	D	E	D	D
4.1	B	C	C	D	D	E	D	D
4.6	B	C	C	D	D	E	D	D
5.1	C	C	C	D	D	**D**	D	D
5.7	C	C	C	D	D	D	D	D
6.2	C	D	C	D	D	D	D	D

2.4 Mixing height

The minimum mixing height in CALMET is set to 50 m. This is the default value and is recommended in the dispersion modelling GPG (MfE 2004). Mixing heights are calculated internally by CALMET using several schemes (according to time of day and dominance of convective or mechanical turbulence), ensuring that the result is not below 50 m.

However, as there is no check in CALMET of consistency between mixing heights and stability, there is a possibility that unreasonable combinations of these parameters will occur. The direct outputs from CALMET give many hundreds of neutral or unstable hours per year with a mixing height below 100 m. Under such stability conditions it is not physically reasonable to expect the dispersion of discharged pollutants to be confined within such a shallow layer. Therefore, a minimum mixing height has been set for each stability class as a post-processing step, as shown in Table 4.

The chosen minimum mixing heights under neutral and unstable conditions (classes A-D) would be considered by most air quality practitioners to be at the lower end of the range expected for those stability classes. Under neutral conditions, with higher wind speeds, shear-driven turbulence would occur in a layer much deeper than 100 m. Likewise, under unstable convective conditions, the mixing layer may reach 1 km to 2 km in depth in the middle of a summer day. Therefore, ‘average’ mixing heights would be larger than those presented in Table 4. However, as mixing heights could conceivably be as low as the values given in the table, those values have been chosen for the AUSPLUME data sets so that dispersion modelling would yield conservative results – that is, results which are worst-case, but still reasonable.

Table 4: Minimum mixing height, as a function of stability class.

Stability Class	Minimum Mixing Height
A	300 m
B	200 m
C	100 m
D	100 m
E	50 m
F	50 m

2.5 Summary

Boundary-layer parameters, such as surface wind, stability class and mixing height, have been extracted from the high-resolution CALMET data sets and converted into a format compatible with Gaussian plume models. Some adjustments to those parameters have been made as post-processing steps, as described in the previous section. These have been made to ensure consistency between the parameters and to provide AUSPLUME meteorological files which would lead to reasonable, but conservative, dispersion model results. It should be noted their use is envisaged for different levels of assessment. AUSPLUME may be used in a Tier 2 screening assessment, where conservative model results should be expected. If the model predictions indicate a breach of relevant air quality standards or guidelines, then a refined assessment (Tier 3) would be carried out using CALMET/CALPUFF.

The AUSPLUME meteorological file contains a row of data for each hour. Each row contains the year, month, day, hour, temperature, wind speed, wind direction, stability classification and mixing height, which have been extracted from CALMET outputs. There are several optional parameters, namely, wind-direction variability (σ_θ), wind profile exponent, potential temperature gradient, precipitation code and precipitation data, friction velocity and Monin-Obukhov length. These are required for simulation of chemistry and wet deposition. However, they have not been incorporated into the AUSPLUME data sets, and if these processes need to be modelled, it is recommended that CALPUFF be used.

3.0 REFERENCES

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APPENDIX F

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