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NELSON-RICHMOND AIR QUALITY MODELLING

Development of an Air Quality Model and Meteorological Data Sets for the Nelson-Richmond Urban Area

Submitted to:
Nelson City Council
Tasman District Council

REPORT

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Distribution:

Paul Sheldon
Trevor James

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EXECUTIVE SUMMARY

This report describes the development, calibration and testing of models for use in the management of air quality in the Nelson and Tasman regions. The computational tools comprise an airshed model of PM_{10} dispersion for the Nelson-Richmond urban area, and three-dimensional meteorological data sets for industrial applications. These tools have been developed to support Nelson City Council (NCC) and Tasman District Council (TDC) in their resource management obligations.

The airshed model was based on the dispersion model CALPUFF, and its meteorological pre-processor, CALMET. Meteorological information was provided by the numerical weather prediction model MM5, and local observations from monitoring by the Councils and MetService. Emissions information for airshed modelling was derived from inventories of domestic heating, industry and motor vehicles, compiled in 2005 and 2006 for the Councils. Natural sources from sea spray were incorporated through use of a simple wind-dependent model based on source-apportionment monitoring results. The airshed model of PM_{10} was developed for a base year 2008, with 500 m horizontal resolution, at hourly intervals.

The model generally performed well in winter, when PM_{10} levels are dominated by domestic heating. Typical diurnal patterns of PM_{10} were seen with dual peaks during low wind speeds and inversion conditions in the early morning and mid-evening. Variation between the urban airsheds of Nelson City, Nelson South, Stoke/Tahunanui and Richmond occurred due to varying meteorological conditions at those locations, and varying contributions from the different source types. The modelled proportions showed between 70 % and 90 % of PM_{10} from domestic heating, 5 % to 10 % from road transport, and around 5 % from sea spray. An industrial component of up to 20 % was seen in the Tahunanui area.

During wintertime PM_{10} events, the diurnally-changing wind direction often varied between approximately southerly during the night and approximately northerly during the day. The night-time flow could be from the SW (with the potential for inter-airshed transport of PM_{10} northwards) to SE drainage conditions (where emitted PM_{10} would blow out to sea). As worst-case conditions were quite calm, most modelled PM_{10} in each airshed originated from the same airshed. However, the remainder could originate in the neighbouring airsheds. For example, around 20 % to 30 % of modelled PM_{10} in the Nelson South airshed originated in the Nelson City airshed. However, given the varying wind directions during calm conditions, a small amount of PM_{10} in Tahunanui could originate from Nelson City or Nelson South if the daytime NE wind continued into the early evening. PM_{10} in Richmond originated in that airshed almost entirely, with the occasional small contribution from Stoke during NE conditions (note that these findings are from model results).

Compared with observations at monitoring sites, the model underestimates the number of NES exceedences (24-hour PM_{10} concentration greater than 50 $\mu g/m^3$). However, there is a strong spatial variability in this quantity, with the number of modelled exceedences increasing a few hundred metres from the site. There are several other reasons for a mismatch between observations and modelled exceedences; these are discussed in the report.

Spatial maps of model results over the Nelson/Richmond area have been presented. These show modelled PM_{10} concentration and modelled number of exceedences, which – notwithstanding pollution transport between urban areas – occur generally over areas of highest emission rates from domestic heating. These have been used to indicate possible airshed boundaries based on emissions and dispersion of domestic PM_{10}. They cover much smaller areas than the gazetted airsheds of Nelson and Richmond, as the gazetted airsheds include rural areas and transport corridors.

Airshed model performance during months outside of winter is not good, as sources other than domestic heating contribute to the total PM_{10} and their emissions could not be specified well in the model. For instance, area-based sources do not give a good representation of transport effects next to the roadside, and can only be used to give an account of the urban background PM_{10} due to transport (rather than roadside peaks).

Several applications of the modelling to airshed management have been discussed. These are State of the Environment reporting, cross-boundary transport, airshed boundary review, emissions reduction scenarios, and baseline PM_{10} for industrial assessments and compliance with the new NES (as defined in early 2011). Whilst a detailed examination of these was beyond the original scope of the project – as they would be significant tasks in their own right – a preliminary application of the current modelling to them has been outlined in the report, and recommendations for further refinements have been provided.

Meteorological data sets have been produced for industrial applications, supplied electronically for distribution to consultants and promulgation by NCC and TDC. These include CALMET outputs on a 250 m grid, and AUSPLUME files for several sites in the Nelson and Richmond airsheds. A user guide is included as an Appendix to this report, which can be read as a stand-alone document.

1.0 INTRODUCTION

This report describes the development, calibration and testing of models for use in the management of air quality in the Nelson and Tasman regions. The computational tools comprise an airshed model for the Nelson-Richmond urban area, and three-dimensional meteorological data sets for industrial applications. These tools have been developed to support Nelson City Council (NCC) and Tasman District Council (TDC) in their resource management obligations. Some aspects of this have been mentioned by NCC and TDC in their request for proposal[1] and, though not part of the scope of this project, are listed here as follows:

i) Review the location of current monitoring sites (for both compliance and 'State of the Environment' Monitoring').

ii) Review the appropriateness of current airshed boundaries.

iii) Review implemented and proposed strategies to achieve the NES (National Environmental Standards for air quality (MfE, 2004a, 2011)).

iv) Consider the need for controlling emissions sources specific to certain sub-airsheds.

v) "State of the Environment" reporting.

vi) Improved air quality management in the airshed that spans the Nelson City/Tasman District Council border.

vii) Provide standardized, high-quality meteorological data sets for assessments of environmental effects and air resource consent applications.

These items would be substantial projects in themselves, and have only been addressed here in broad terms; Golder's role has been to provide tools to NCC and TDC fit for the purpose of addressing the above airshed-management issues. Specifically, these are the following:

1) A regional air quality model (or "airshed model") of PM_{10} dispersion, produced using the CALPUFF model, based on meteorological data sets (see below) and recent PM_{10} emissions information for the airsheds of Nelson and Richmond, for a base year 2008.
2) Meteorological data sets:
    a. A regional-scale three-dimensional meteorological data set produced using the CALMET model, covering an area 75 km by 76 km, at 500 m horizontal resolution, centred on Nelson and Richmond, for the year 2008. This is a constituent of the airshed model for that year.
    b. Two higher-resolution CALMET data sets, 26 km by 26 km at 250 m horizontal resolution, containing Nelson and Richmond, for 2008 and 2009. These are for industrial applications, allowing a more detailed representation of short-range effects from industrial sources.
    c. Several single-point meteorological time series formatted for AUSPLUME. Items (b) and (c) are intended to enable consultants and other users to carry out dispersion modelling for industrial applications using CALPUFF or AUSPLUME, based on a standardized meteorological data set. Consultants would not need to carry out the meteorological modelling themselves. Items (b) and (c) fulfil requirement (vii) above, through the provision of suitable meteorological information for the dispersion modelling component of industrial resource consent applications.

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[1] Nelson City Council and Tasman District Council – request for proposals for development of regional three dimensional meteorology dataset and regional air quality model for the Nelson-Richmond urban area. 2 October 2009.

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 National Environmental Standards (NES) and ambient air quality guidelines (MfE, 2002), and to assess the effects of emissions management options.

The high spatial resolution of the airshed and meteorological models, coupled with their regional extent, covers the urban airsheds of Nelson and Richmond, with sufficient detail to resolve the effects of pollution transport over the surrounding topography. The models have been evaluated by comparison with observations of meteorology and ambient PM_{10} concentrations, and they provide physically realistic results.

The two purposes of this document are to:

i) describe the development of the models, including testing and calibration, and evaluation by comparison with observations; and

ii) provide guidance for the use of the meteorological data sets for industrial applications.

In the following, Section 2.0 provides a general introduction to dispersion modelling, and Section 3.0 details the data sources and the configuration of the meteorological and airshed models for the Nelson and Richmond region. Section 4.0 presents the airshed modelling results for winter and summer PM_{10} concentrations and number of NES exceedences. Section 5.0 discusses findings of the modelling, their implications for air quality in the region, and suggests further applications of the modelling to airshed management issues. Section 6.0 introduces the CALMET and AUSPLUME meteorological data sets, referring to Appendices which provide details on their development and guidance as to their use by consultants in the dispersion modelling component of assessments of effects. Section 7.0 discusses strategies for the maintenance and upkeep of the models and associated data sets. Section 8.0 provides some concluding remarks, and references are listed in Section 9.0.

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

2.0 DISPERSION AND METEOROLOGICAL MODELLING

This section provides background information on the dispersion and meteorological modelling techniques, and provides a rationale for the models used in this work.

2.1 Air Dispersion Models

Air dispersion models are tools which calculate air pollutant concentrations downwind of an emission source, or calculate concentration variations within an airshed due to discharges from a number of sources. They require information on the contaminant emission rate, other source characteristics, the local topography and meteorology of the area, and in some situations ambient or background pollutant concentrations. A schematic of the dispersion modelling process is shown in Figure 1, showing the flow of information.

Air dispersion models are frequently used as a tool for assessing potential environmental effects from air discharges. The key advantage of dispersion modelling is that detailed predictions of contaminant concentrations may be made over a wide area, as a supplement to (or instead of) ambient monitoring or other methods, which are usually only available at isolated locations.

This report is primarily concerned with urban airshed modelling. Urban airshed models simulate the dispersion of air pollutants from all sources around and beyond an urban area. Sources usually include road transport, industry and domestic heating.

In this work the CALPUFF dispersion model has been used as an airshed model to predict cumulative ground-level PM_{10} concentrations from domestic, industrial and road transport sources in the Nelson-

Richmond area. The CALPUFF model has been used in this way for case-study periods in Christchurch (Barna and Gimson, 2002).

Observational studies in many New Zealand cities, in which the PM_{10} can be apportioned by source, have identified components due to sea spray and dust (crustal matter and road dust). These components are present in PM_{10} around Nelson/Richmond. A simple model for sea spray has been developed as part of this work, and the sea spray component incorporated into the airshed modelling results as a post-processing step. In the current work, other natural components such as crustal matter and road dust have not been included. These have been assumed to be less important than sea spray.

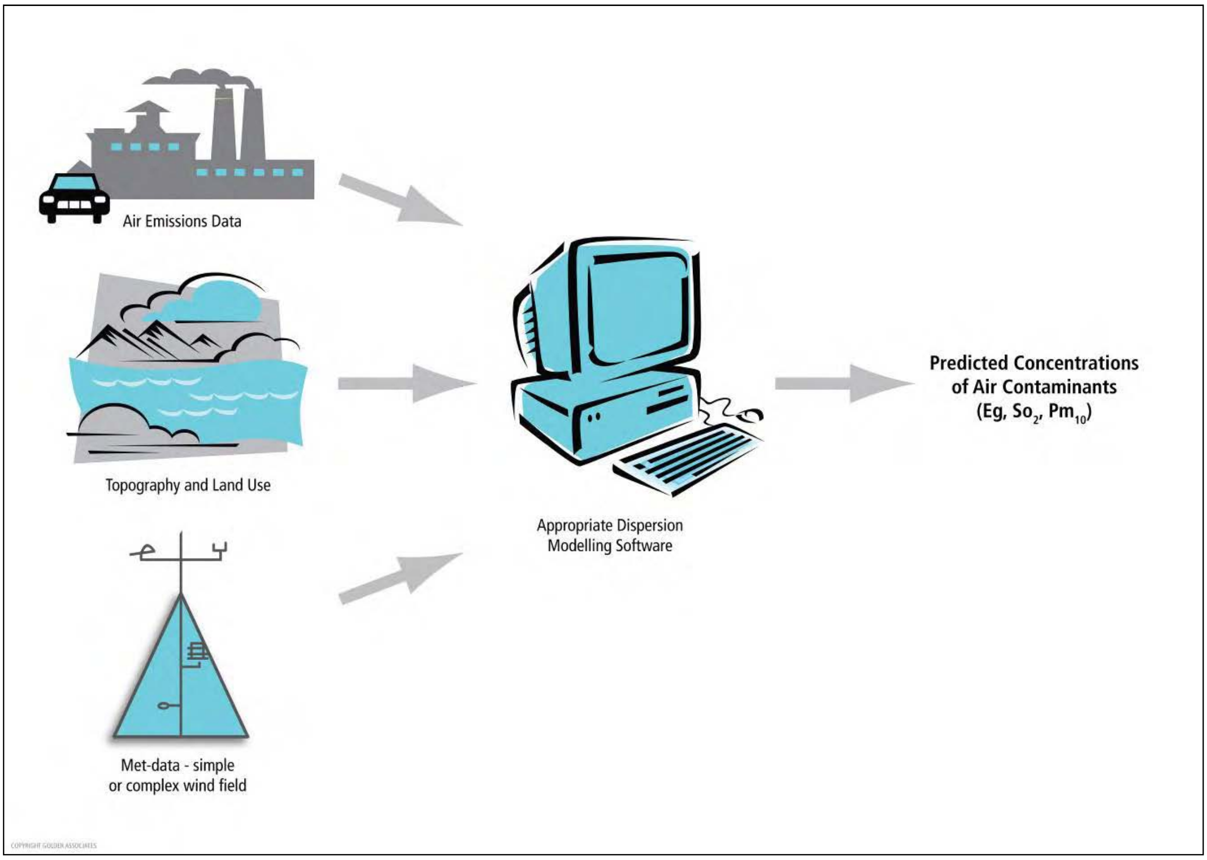

Figure 1: Conceptual illustration of air dispersion modelling, including the role of meteorological data.

2.2 Meteorological Models

The ability to predict contaminant concentrations depends on meteorological information and source emission rates and other 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, and turbulence and mixing in the atmospheric boundary layer.

For industrial applications, it has been common to use steady-state Gaussian plume models, such as AUSPLUME and ISCST3. These models have relatively simple meteorological data requirements, but have a number of limitations. In particular, they are only appropriate for situations where terrain is not complex or steep, meteorology is spatially uniform and periods of calm or light winds are infrequent. The Nelson-Richmond region contains complex terrain, and experiences complex land-sea breeze interactions and periods of calm or light wind, and the use of steady-state Gaussian plume models in these areas is not usually appropriate. More advanced dispersion models, such as CALPUFF, are being used increasingly in an effort to overcome these limitations.

Complex dispersion models such as CALPUFF have significantly greater meteorological data requirements than the steady-state models. CALPUFF's meteorological pre-processor, CALMET, is a diagnostic meteorological model which can use data from many monitoring stations, producing an hourly three-dimensional grid of meteorological information, which is directly input to CALPUFF.

The meteorological data sets produced for this project as key inputs to the CALPUFF model have been developed using CALMET. In addition to being used as an airshed model for this project, it is envisaged that CALPUFF will become the preferred dispersion model for the assessment of industrial discharges that require resource consents. However, as requested by NCC and TDC meteorological files for use with the AUSPLUME model have also been provided, which are derived from CALMET outputs.

3.0 AIRSHED MODELLING CONFIGURATION AND SOURCE DATA

3.1 Introduction

This section describes the configuration of CALMET and CALPUFF for modelling the dispersion of PM_{10} in the Nelson and Richmond airsheds. It contains a basic outline of the modelling procedures and input data used, which are discussed more fully in Appendices B to E. This section also describes data for input to the airshed and meteorological models.

3.2 CALMET Data Processing and Configuration for Airshed Modelling

This section summarises the meteorological modelling process using CALMET, which is a precursor to the airshed modelling with CALPUFF. It also briefly outlines the model configuration used in this work. Both aspects are expanded upon in Appendix B.

CALMET has been run to produce hourly, three-dimensional meteorological fields, through which CALPUFF disperses pollutants according to the modelled wind and turbulence fields. For each hour of the full-year runs, CALMET proceeds through a number of stages to calculate its meteorological fields. Key inputs to CALMET are geographical data (terrain and land use), surface-based meteorological data, and large-scale modelled meteorology from MM5, and these are required at different stages as follows:

i) **Initial wind field:** Known as the 'initial guess', this is the first approximation to the three-dimensional wind field. Large-scale meteorological fields, including the region surrounding the Nelson-Richmond area, were obtained from the weather forecasting model, MM5. MM5 was run over areas centred on Nelson Airport (150 km x 150 km for 2008 and 50 km x 50 km for 2009; 4 km horizontal resolution in both cases). MM5 outputs were purchased from Lakes Environmental, who ran the model according to Golder's specifications. The resolution of the MM5 data is coarser than required in CALMET, and the data are interpolated to produce a wind field at the CALMET resolution. The subsequent stages in the CALMET modelling are designed to refine the meteorological model solution by accounting for terrain and local meteorological observations.

ii) **Terrain adjustment:** Aircraft flights have been carried out over Nelson and Richmond recently with on-board LIDAR remote sensing equipment to determine terrain elevation. The resulting terrain height data, at 5-metre contour resolution, have been provided for this project by NCC and TDC. Gridded terrain information for the surrounding area has been derived using Golder's in-house GIS procedures. The terrain-adjustment stage introduces the terrain and land use data at the required resolution, and adjusts the winds to account for terrain-driven and landuse-driven effects. These effects include slope and valley flows and blocking of the flow by the terrain, and the effect on boundary-layer structure of land use changes (particularly the contrast between land and sea). The solution at this point is known as the ‘Step 1’ wind field.

iii) **Objective analysis:** This stage introduces the local meteorological data, to produce the final meteorological fields for the modelled hour (known as the ‘Step 2’ wind field). Several meteorological monitoring stations are operated by NCC and TDC, measuring surface wind, temperature, humidity, rainfall and gust data. These are Blackwood St, St Vincent St and Princess Drive in Nelson, the TDC office in Richmond, Richmond Park racecourse, and Brightwater. Wind speed data from Brightwater were found by Golder to be unreliable, and in consultation with TDC it was decided to not use the wind data from that site[2]. The meteorological monitoring data from NCC and TDC were supplemented by data from stations at Nelson Airport and Motueka (Riwaka), obtained from the NIWA Climate Database. Meteorological observations are blended with the Step 1 field so that the solution matches them near to the monitoring site.

The resulting CALMET meteorological data set provides a basis for the airshed modelling, with the model run over an area 75 km by 76 km, at 500 m horizontal resolution, for the year 2008. The terrain and land use of the model domain are shown in Figure 2 and Figure 3, with the locations of meteorological monitoring sites also marked. The colour coding for Figure 3 is given in Table 1. Other model parameters are listed in Appendix B.

Table 1: Land use categories used by CALMET.

Colour coding on Figure 3.	Land use category
Brown	Urban or built-up land
Yellow	Agriculture
Light green	Rangeland (e.g. shrubs)
Dark green	Forest
Blue	Water
Olive green	Wetland
White	Barren land (e.g. beaches, sand spits, dry river beds)

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[2] The instrument was old and of low quality, with the measured wind speed being generally lower than that at nearby monitors by a factor of three of four. It was not considered reasonable to simply re-scale the wind speeds, and MM5 winds for that location were expected to be more realistic. Although the wind *direction* data were reliable, resolution is quite coarse (with bearings to the nearest 22.5^0), and the CALMET model requires *both* speed and direction.

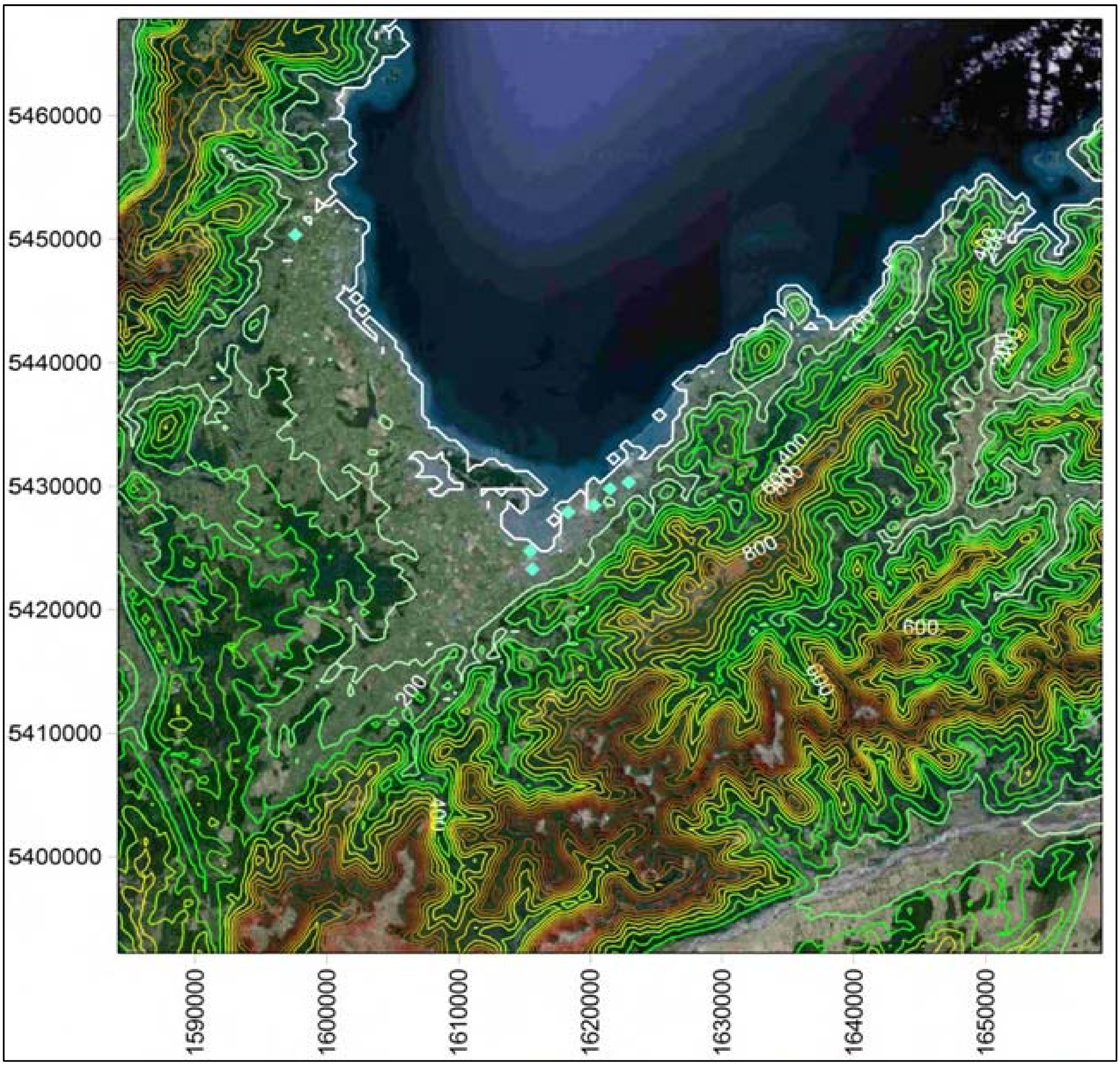

Figure 2: Contours of terrain height used by CALMET for airshed modelling (contour interval 100 m, starting at zero). New Zealand Transverse Mercator coordinates are given in metres. Meteorological stations are indicated by blue diamonds.

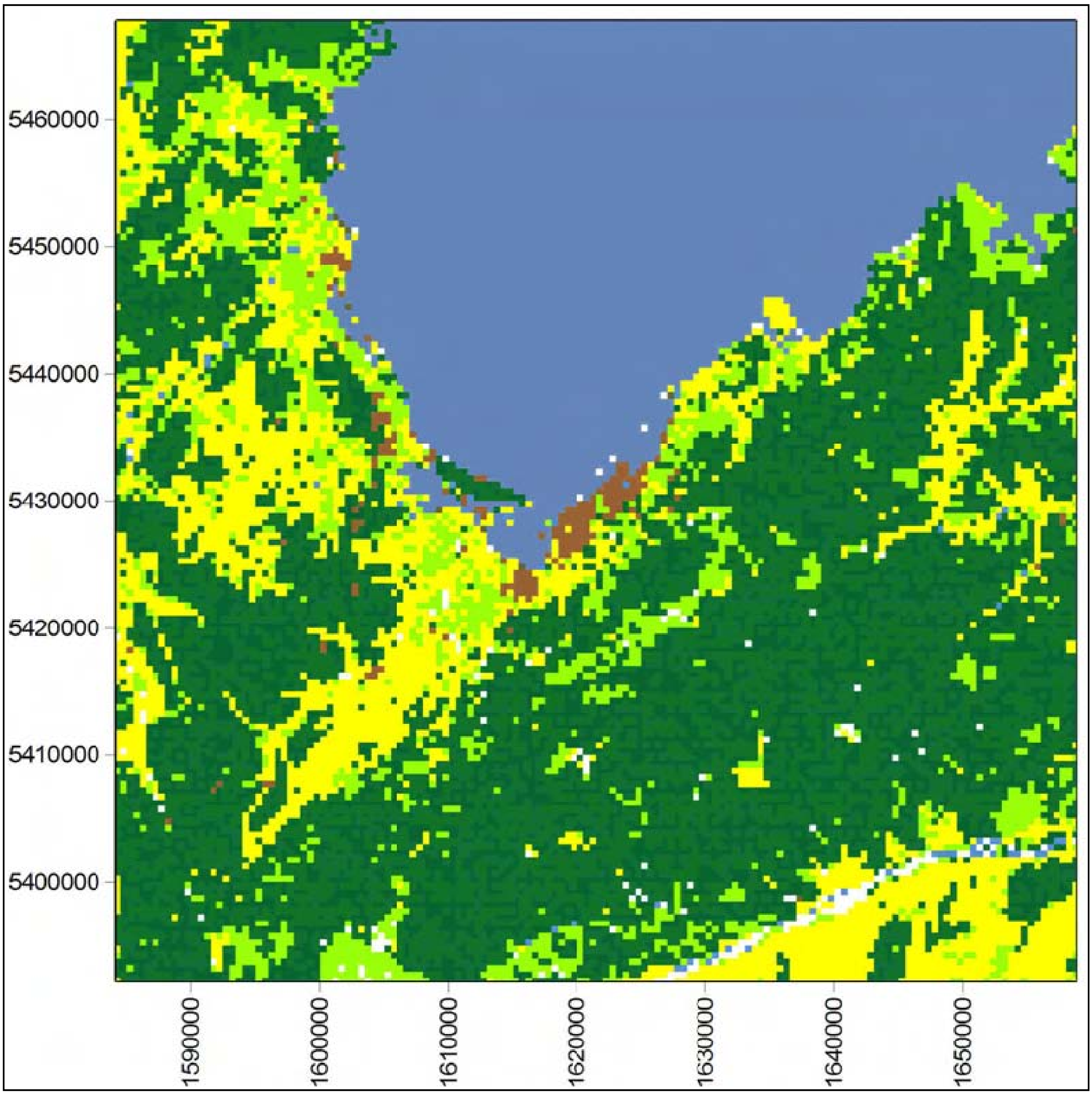

Figure 3: Land-use map for the CALMET airshed modelling domain. Colour coding as shown in Table 1.

Appendix B also contains a description of the CALMET configuration for the supply of meteorological data sets at 250 m for the years 2008 and 2009.

Over Nelson and Richmond, the CALMET solution is driven by meteorological monitoring data; in data-sparse areas, the solution is driven by the MM5 model information. The challenge is to produce a smooth transition over the domain between results from these two sources of information. Judicious choice of model configuration parameters has allowed this to occur, and some examples of wind fields have been provided in the model evaluation in Appendix B (Section 6.0).

3.3 CALPUFF – Airshed Model Configuration

Within Nelson City and Tasman District four airsheds were identified and gazetted with the Ministry for the Environment (MfE) in September 2005 (three in Nelson City and one in Richmond)[3]. These airsheds are identified as areas in which the NES for PM_{10} is, or could potentially be, exceeded due to home heating or motor vehicles (a few airsheds elsewhere are industrial areas, where the NES for SO_2 might be breached).

The area covered by the airshed model includes the urban areas of Nelson and Richmond, and the surrounding hills and settlements along Tasman Bay. The area has been chosen so that the model can capture the recirculation of pollutants emitted from the four gazetted airsheds which potentially return later if the wind changes direction.

CALPUFF has been run to produce hourly, ground-level PM_{10} concentrations as a two-dimensional field. The inputs required by CALPUFF are the meteorological outputs from CALMET (described above and in Appendix B), and PM_{10} emissions data. Emissions inventories have been developed for Nelson (Environet, 2006) and Richmond (Environet, 2005), for the years 2006 and 2004, respectively. These inventories provide daily contaminant mass emission totals (including PM_{10}), by airshed, from several source types, including domestic heating, industry, motor vehicles and outdoor burning. The inventories also provide data on monthly emissions variations.

The emissions data have been used to derive sources of PM_{10} for inclusion in the airshed model. For realistic dispersion of PM_{10} from domestic heating based on the inventory data, the modelling required hourly-varying emission rates and a more detailed spatial resolution of emissions. Environet have supplied PM_{10} emissions data broken down into hourly-varying and monthly-varying) totals by mesh block area. A detailed description of the how the emissions data have been used is given in Appendix C, and summarized as follows:

i) **Domestic heating sources:** Airshed PM_{10} emission totals were downscaled by Environet into mesh block totals according to population density. However, the number of mesh blocks is too large to simulate each as an individual source in the CALPUFF model. To overcome this, they have been merged to create a manageable number of sources in the model. This has been done so as to retain as much of the spatial variability as possible, resolving hot-spots of PM_{10} emissions, and to conserve the total mass of PM_{10} released to the air. The procedure used for this is described in detail in Appendix C. Data from Environet included monthly scaling factors for domestic heating emissions. Some adjustment of these has been carried out as part of a model-calibration procedure. This is described in detail in Appendix D, and results described in Section 4.0 are based on the adjusted monthly scaling factors.

ii) **Industrial sources:** For the Nelson area, specific information on individual industrial sources and their locations were not available. However, a total mass of PM_{10} emission from industry was available for each of three gazetted airsheds. This total mass was apportioned to the industrial land use zones of Nelson, rather than being assumed to cover the whole airshed. Each gazetted airshed contains a single industrial zone, and the total PM_{10} emissions were confined spatially to that area. Airshed A (Nelson South) contains the hospital, whose emissions were modelled separately from the other industrial sources.

Industrial emissions for Richmond were supplied by Environet, and included details on individual sources and their locations. Because of the greater level of source information, these industrial sources were modelled individually, instead of a whole industrial zone being modelled as a single source.

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[3] See the MfE website, in particular, http://www.mfe.govt.nz/environmental-reporting/air/air-quality/pm10/nes/tasman/ and http://www.mfe.govt.nz/environmental-reporting/air/air-quality/pm10/nes/nelson/. Airshed outlines are shown on maps of PM_{10} results in later sections of this report.

iii) **Motor vehicles:** Airshed PM_{10} emissions totals for transport have been modelled as area emissions sources covering only the urban portions of the airsheds (not rural land, or water). This is not expected to give a realistic representation of PM_{10} ground level concentrations due to motor vehicle emissions, whose main impacts would be confined close to the roadside. However, emissions data were not supplied in a format that would enable a realistic representation of motor vehicle emissions. Furthermore, CALPUFF is not designed to model dispersion from vehicles. Accordingly, predicted PM_{10} concentrations resulting from the modelling of motor vehicle emissions in this manner should be thought of as representing vehicle effects due to the urban baseline.

Emission sources have been represented as areas bounded by four-sided polygons, as required by CALPUFF. Figure 4 and Figure 5 show the locations of the modelled area sources. CALPUFF simulates the emissions as a stream of ellipsoidal puffs of material released from each source. The released puffs are transported by the wind field calculated by CALMET, growing through modelled diffusive processes. Ground-level concentrations are then calculated by the model at selected receptor locations, by summing the puff concentrations at those locations.

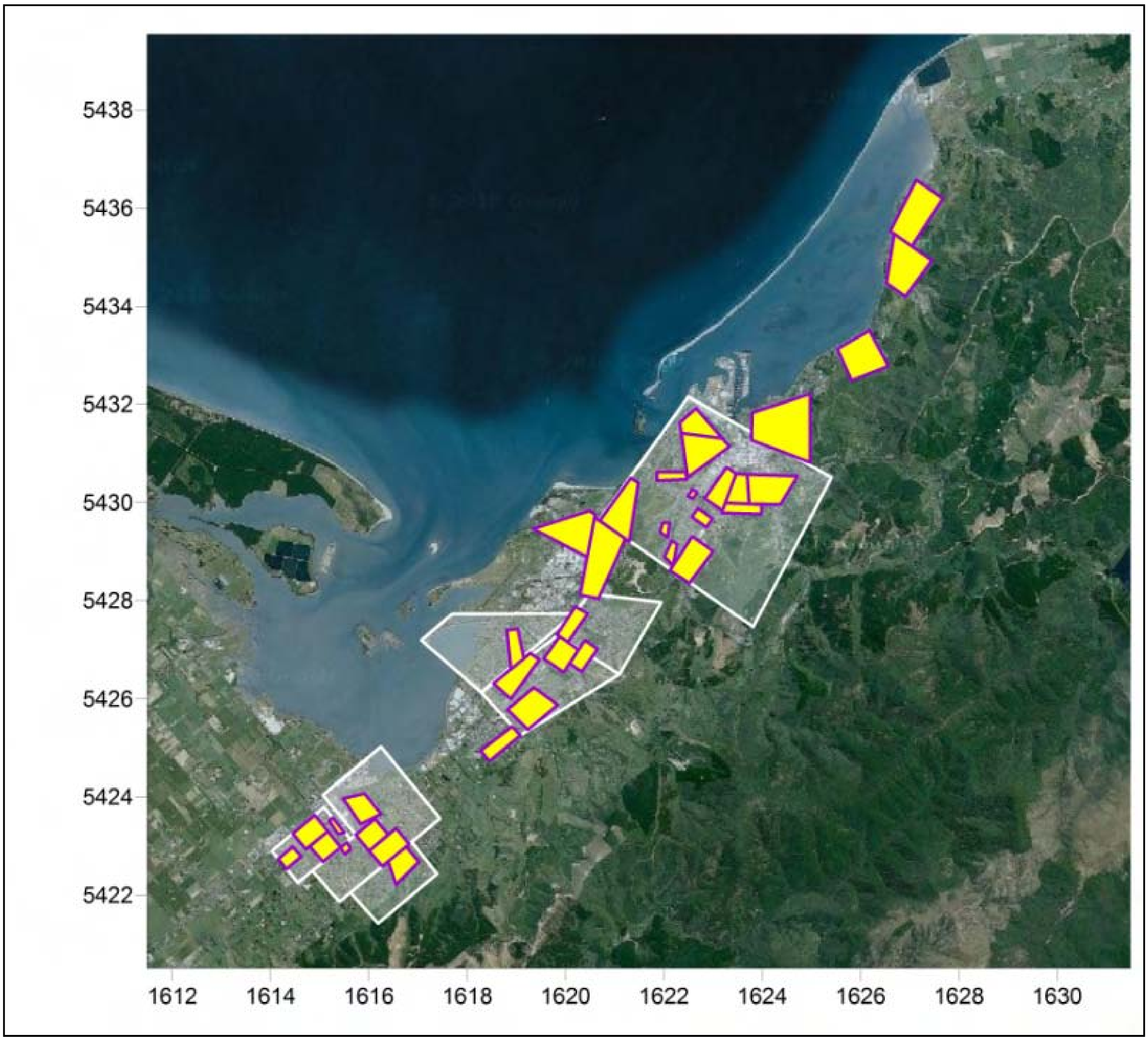

Figure 4: Locations of modelled domestic-heating sources. Hot spots containing the majority of PM_{10} emissions are shaded yellow (labelled "Level-1" in Appendix C); lower emissions over larger areas (labelled "Level-2" in Appendix C) are translucent white. Axes are labelled in km (NZ Transverse Mercator coordinates).

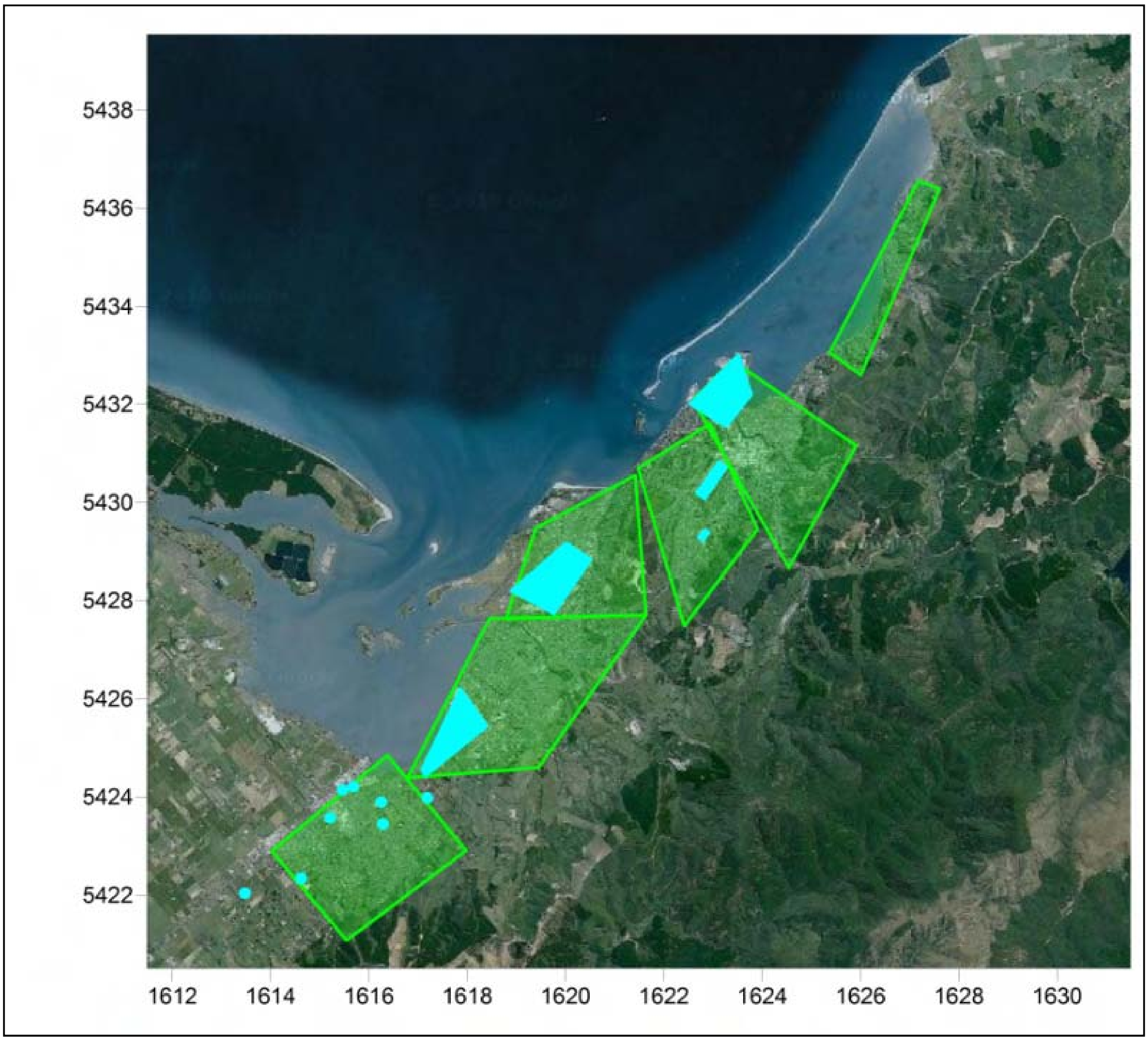

Figure 5: Locations of other modelled area sources. These are industry (blue) and transport (green).

In addition to the modelled dispersion of PM_{10} from anthropogenic sources, a simplified representation of sea spray has been derived. This is based on source-apportionment work carried out in Tahunanui (data supplied by Perry Davy, GNS, August 2010), and is described in Appendix E. The sea-spray component of PM_{10} has been added to the modelled PM_{10} as a post-processing step, and depends on wind speed, wind direction and (indirectly) season.

Other CALPUFF input parameters are listed in Appendix C. In short, CALPUFF was run over an area 75 km by 76 km, for the year 2008, using air emissions data for the three main source-types as described. The area covered by CALPUFF matches that covered by CALMET. An inner grid of receptor points at 500 m resolution, congruent to the meteorological grid points has been defined, centred on the urban areas. This covers an area 40.5 km by 39.5 km. The receptor points are merely the locations at which modelled concentrations are output – the PM_{10} is dispersed by CALPUFF over the full CALMET grid.

Ambient air quality monitoring sites operated by NCC and TDC are co-located with the meteorological monitoring sites. Hourly PM_{10} data from St Vincent Street and Blackwood Street, Nelson, and Oxford Street, Richmond have been supplied by NCC and TDC for the purposes of model performance evaluation. Airshed model results have been compared with only these sites – other sites provide daily PM_{10} averages, which are less amenable to close examination if there is disagreement between model results and observations. Discrete receptors have been specified in CALPUFF at the coordinates of the monitoring sites.

Figure 6 shows the domain used for airshed modelling. The airshed modelling is carried out on the whole of the CALMET meteorological model domain, which is large enough for pollution emitted in the urban areas to re-circulate and return to those areas if the wind changes direction. The modelled PM_{10} has been output on a regular grid of receptors (500 m resolution, shown as white dots), and a set of discrete receptors corresponding to monitoring sites (yellow triangles).

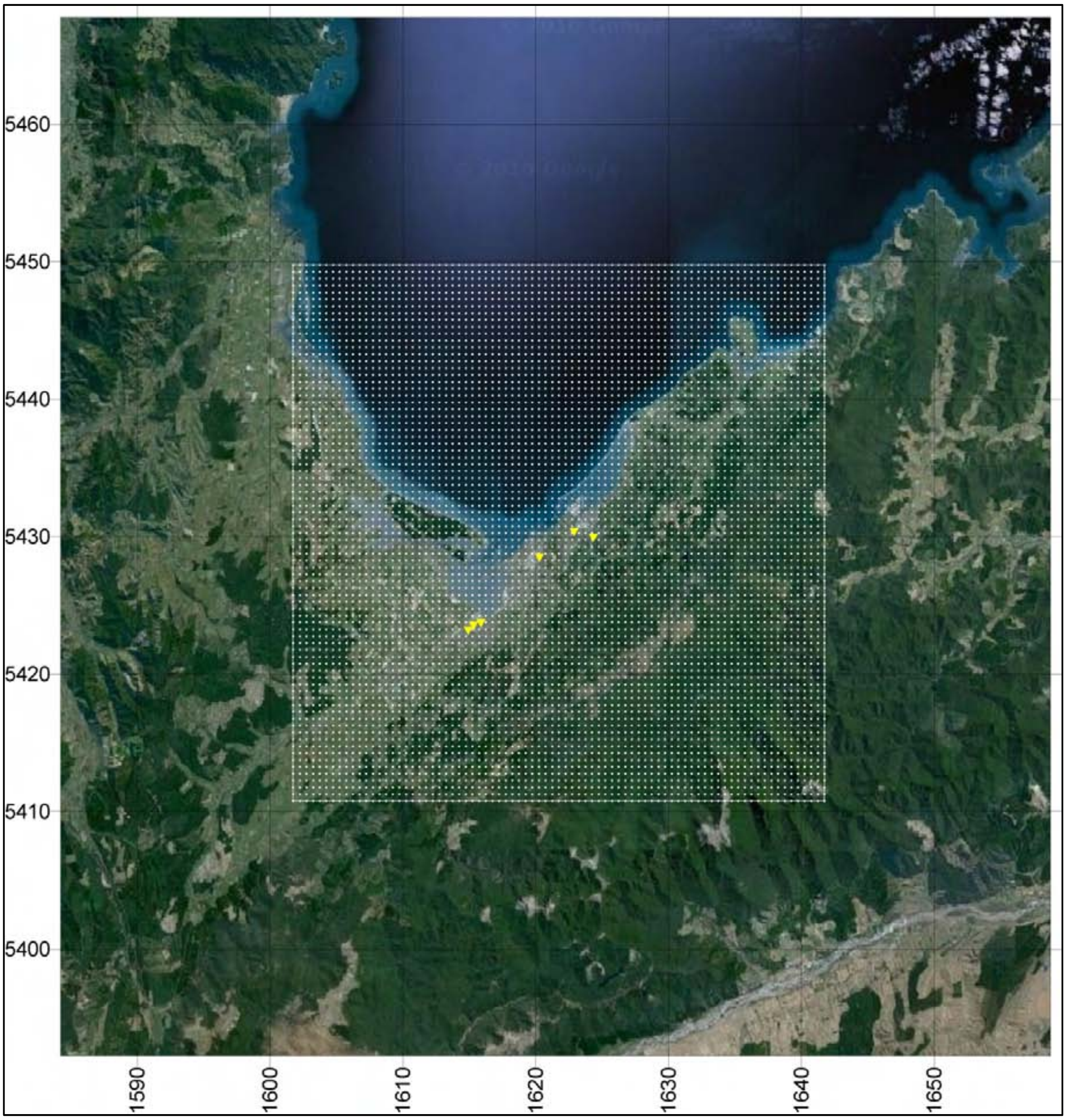

Figure 6: CALMET/CALPUFF model domain, with CALPUFF sampling points (gridded and discrete receptors marked).

3.4 Comments on the Modelling Approach

The approach of specifying urban airshed sources as area sources in CALPUFF (as described in Section 3.3) is not commonly followed by modellers. While some success has been achieved in the flat terrain of Christchurch city (Barna and Gimson, 2002), an extensive amount of parameter testing has been needed here to produce reasonable results, due to the more complex topography of Nelson City. CALPUFF requires specification of source height (above the surface), surface height (above sea level) and initial vertical diffusion, which are not straightforwardly chosen in sloping terrain.

As described in Appendix D, monthly re-scaling of domestic emission factors was carried out to produce a closer match between modelled and observed PM_{10} concentrations. Golder has carefully considered whether this is appropriate, or whether the resulting modelled PM_{10} concentrations should be presented without re-scaling. For this work, it was concluded that the model would be more useful as a policy tool with the re-scaling applied. This is discussed more fully in Section 4.0 of Appendix D.

Emissions from domestic heating were initially specified at the airshed scale, followed by a breakdown to the mesh block scale. While this is approach is appropriate for domestic heating, it is less appropriate for motor vehicle or industrial sources, which have a strong gradient in PM_{10} concentrations away from the source. In other words, airshed, sub-airshed or mesh block-scale emission totals from motor vehicles or industrial sources do not provide a realistic spatial representation of those sources. Accordingly, it is not reasonable to expect CALPUFF to model dispersion well from these sources configured in this manner. The scales of the modelled emission patterns are too large, compared to expected localized dispersion patterns at the roadside or near to industrial sites, and good results from CALPUFF running this way should not be expected. CALPUFF is *capable* of simulating dispersion from industrial point-sources and individual road links, but emissions data have not been supplied in this form. (The exceptions are industrial point sources in the Richmond area, but there is uncertainty in most of the stack parameters).

Finally, it is not common practice to incorporate natural emission components, such as sea spray, into airshed model results, possibly due to lack of source-apportioned data, or to the perceived unimportance of such components in the past. However, it has been done in this work, provides an approximate picture of the contribution of sea spray to total PM_{10} (in relation to the anthropogenic components).

4.0 AIRSHED MODELLING RESULTS

4.1 Introduction

The following sections present results from airshed modelling using 2008 meteorology. It is logical to present results for winter (May to August) and the rest of the year separately. This is because levels of PM_{10} and their contributions from various sources differ significantly between seasons. Accordingly, modelling results for winter PM_{10} at the air quality monitoring sites are presented in Section 4.2, with an examination of inter-airshed dispersion in Section 4.3. Model results for summer PM_{10} at the air quality monitoring sites are presented in Section 4.4, and model results for both seasons are compared with observations of PM_{10} in Section 4.5. Then source-apportioned time series of 24-hour average PM_{10} results are presented in Section 4.6. Section 4.7 examines spatial patterns of PM_{10} for winter and summer in the Nelson/Richmond area, presenting maps of peak PM_{10} concentrations, number of exceedences, and comparing model results with current airshed boundaries and mobile monitoring campaigns.

4.2 Modelled Wintertime PM_{10} Levels at Monitoring Sites

Several case-study days have been chosen from the airshed model results, by their high levels of 24-hour-averaged PM_{10} at one or more of the air quality monitoring sites. These cases are listed in Table 2. For Case W1 the highest-modelled daily PM_{10} occurred at all sites on the same date. The second-highest modelled PM_{10} at each site occurred on a different day, leading to chosen case-days W2, W3 and W4. Cases W5, W6 and W7 are examples of high-ranked concentrations at some sites and low-ranked concentrations at others. The ranks may range from 1 to 123, the number of days in the defined winter period.

Table 2: Worst-case modelled PM_{10} levels on winter days at monitoring sites. Values shown are the 24-hour averaged PM_{10} concentration, and its rank at that site in parentheses.

Case	Date	St Vincent Street	Blackwood Street	Oxford Street	Comment
W1	15 June	73 µg/m^3 (1)	76 µg/m^3 (1)	82 µg/m^3 (1)	Maximum concentration at all sites
W2	7 May	71 µg/m^3 (2)	47 µg/m^3 (12)	63 µg/m^3 (4)	2nd highest at St Vincent
W3	16 July	45 µg/m^3 (25)	66 µg/m^3 (2)	62 µg/m^3 (5)	2nd highest at Blackwood
W4	1 August	70 µg/m^3 (3)	59 µg/m^3 (3)	77 µg/m^3 (2)	2nd highest at Oxford; 3rd at other sites
W5	19 May	57 µg/m^3 (9)	23 µg/m^3 (87)	44 µg/m^3 (27)	Mixture of high and low concentrations
W6	16 June	29 µg/m^3 (73)	49 µg/m^3 (11)	36 µg/m^3 (42)	Mixture of high and low concentrations
W7	24 May	31 µg/m^3 (70)	24 µg/m^3 (79)	51 µg/m^3 (10)	Mixture of high and low concentrations

Given that the emissions are assumed the same from day to day, the variations in modelled PM_{10} arise through the hourly variations in the meteorology. Therefore, it is useful to examine the meteorological conditions under which the above peak levels of PM_{10} occur. The important meteorological variables are wind, temperature and mixing height.

Figure 7(a)-(c) shows the modelled hourly PM_{10} at the three sites on 15 June 2008, the date on which the maximum PM_{10} occurred (Case W1). The concentration columns are coloured according to the source contribution, with most PM_{10} arising from domestic sources. Some transport component is visible at each site, and the sea spray component is comparatively negligible. A component due to industry can be seen at the Blackwood Street site (Figure 7(b)). The hourly PM_{10} is elevated both before sunrise and after sunset, so that this single high 24-hour average is composed of elevated PM_{10} on two nights.

The local meteorology at St Vincent Street is shown in Figure 7(d)-(f), and is essentially the same at all sites. The modelled event is characterized by very low wind speed (much less than 1 m/s) and low mixing height (the model's minimum of 50 m) during the night-time hours. These calm, stable conditions are well known to be conducive to pollution events, as there is a limited amount of dispersion of pollutants. The PM_{10} concentration does not directly depend on temperature – and the temperature is not especially low on this occasion – but it is cool enough for high home heating emissions to occur.

The evening PM_{10} peaks around 7:00 pm, then diminishes, rather than persisting until midnight. This is due to the slight increase in wind speed in the final hours dispersing pollution. Hour-by-hour levels of PM_{10} are highly sensitive to the wind speed when it is around 1 m/s or less. The wind direction during the morning and evening peaks of domestic heating emissions is S or SE (Figure 7(e)), indicating a down-slope drift due to drainage from the hills inshore of the urban areas. The plumes of PM_{10} from the urban areas drift out to sea to the NW later in the evening as the wind picks up slightly. This would indicate that there is little transport between the airsheds on the occasion of highest PM_{10} in the model, and that the peak PM_{10} concentrations in Nelson City result from emissions in that airshed. However, as will be examined below, the model indicates some inter-airshed transport on occasions of peak PM_{10} (see Section 4.3).

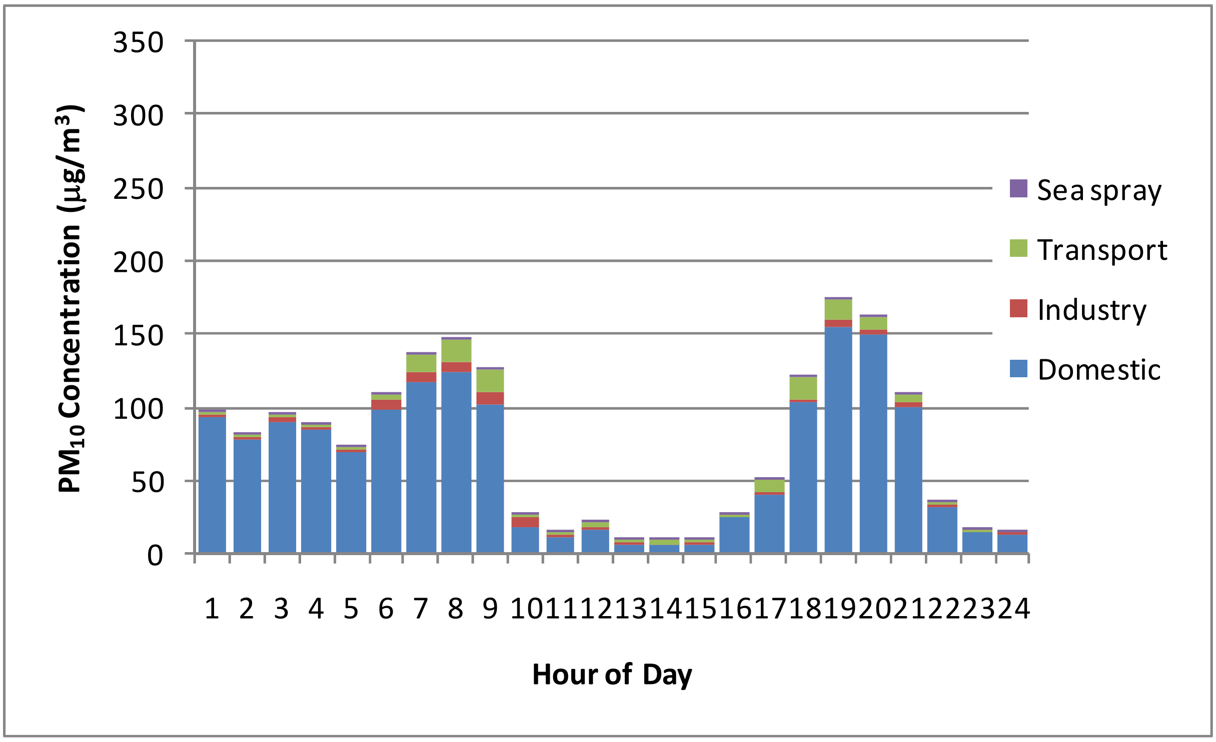

Figure 7(a) Case W1: PM_{10} at St Vincent Street.

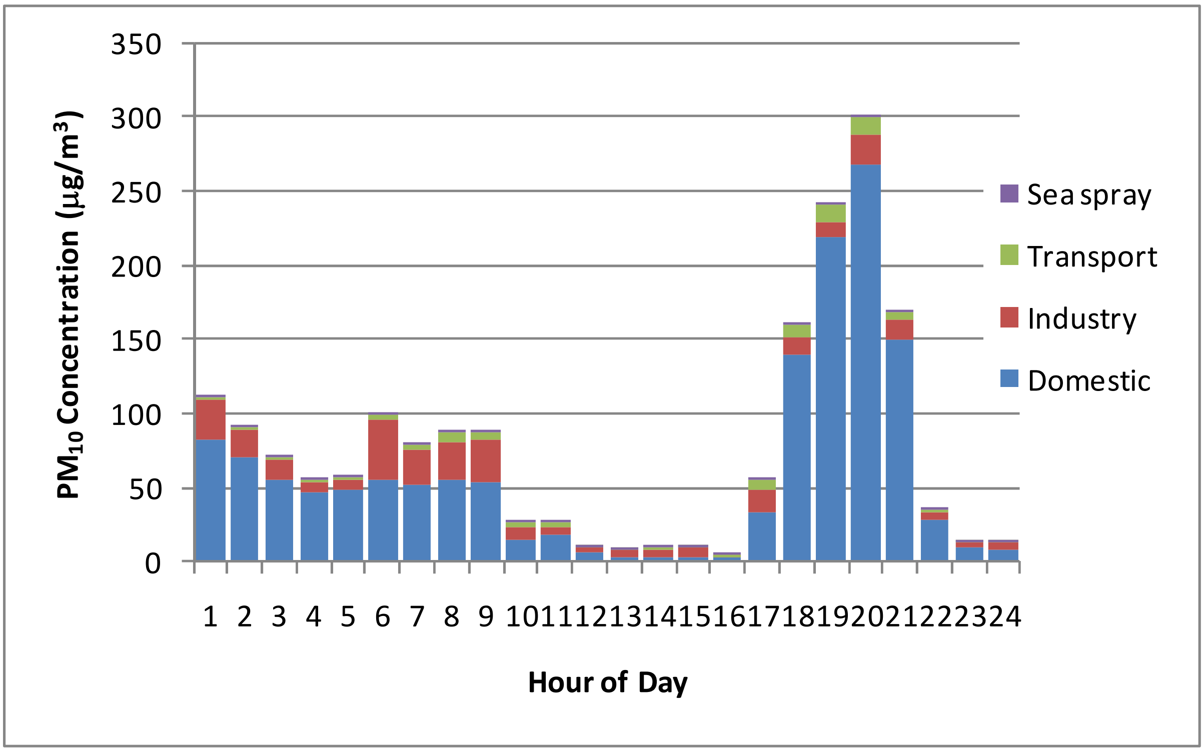

Figure 7(b) Case W1: PM_{10} at Blackwood Street.

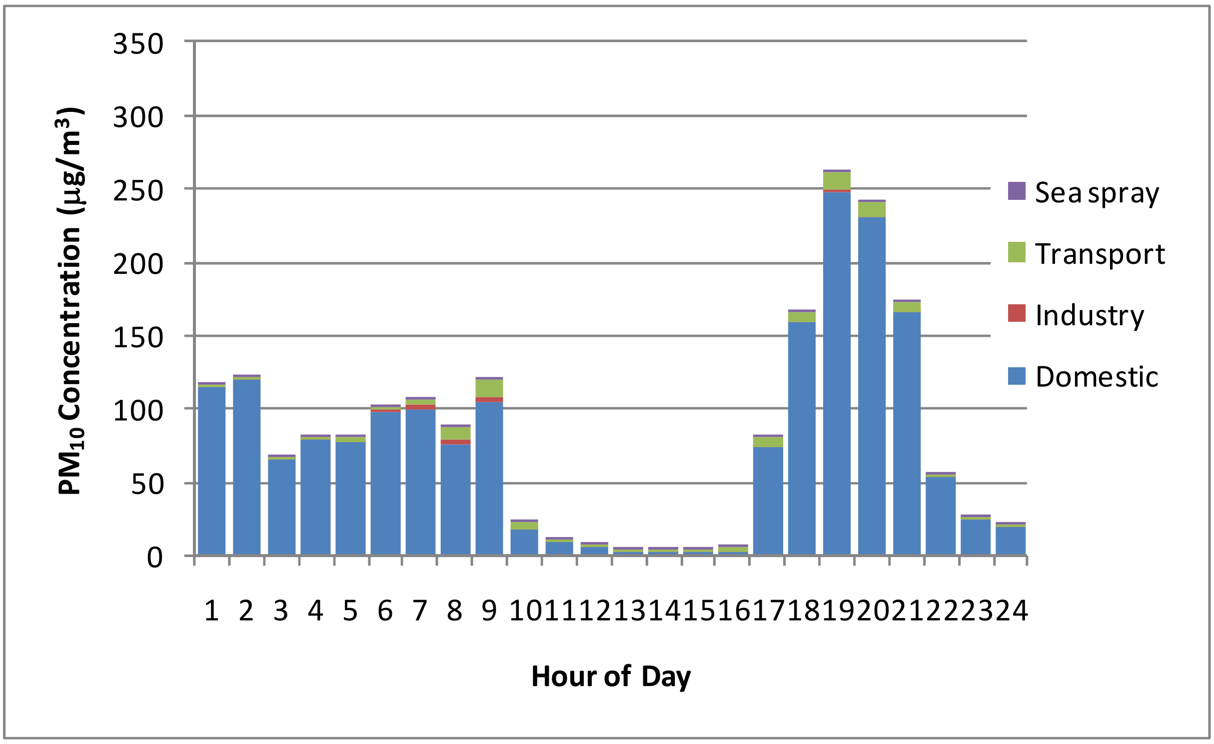

Figure 7(c) Case W1: PM_{10} at Oxford Street.

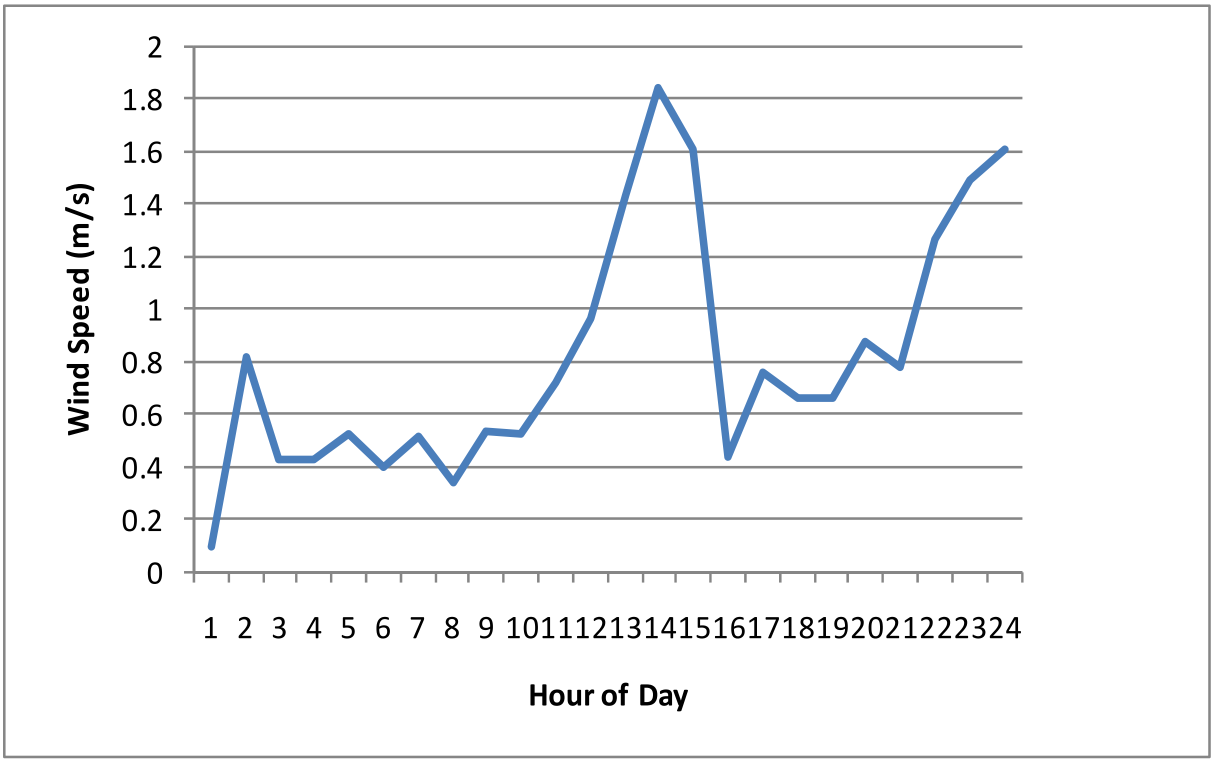

Figure 7(d) Case W1: Wind speed at St Vincent Street.

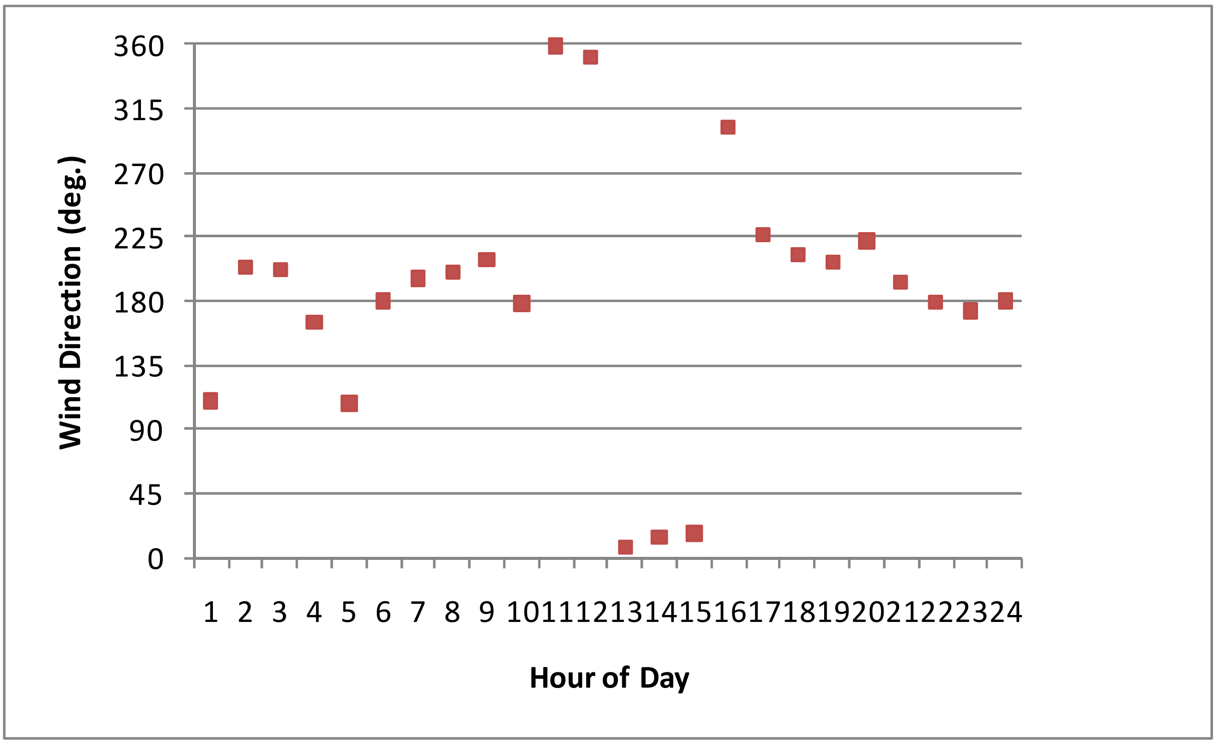

Figure 7(e) Case W1: Wind direction at St Vincent Street.

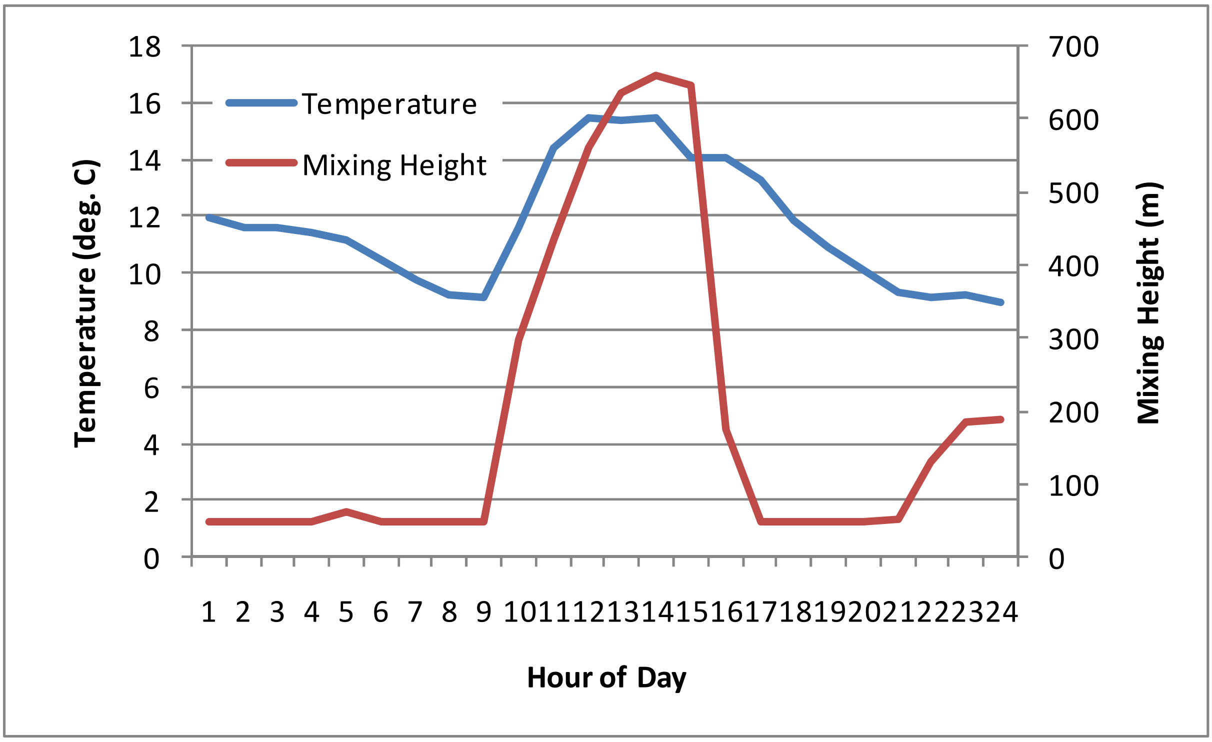

Figure 7(f) Case W1: Temperature and mixing height at St Vincent Street.

Figure 7: Case W1. Hourly PM_{10} at (a) St Vincent Street, (b) Blackwood Street, (c) Oxford Street. Hourly meteorology at St Vincent Street: (d) wind speed, (e) wind direction, (f) temperature and mixing height.

Figure 8(a)-(c) shows the modelled hourly PM_{10} at the three sites on 19 May 2008, a date with high PM_{10} at St Vincent and Oxford Streets, but low PM_{10} at Blackwood Street (Case W5). In this case also, the temperature and mixing height are similar between sites, but the variation in wind speed leads to variation in hourly PM_{10} Figure 8(d). The hourly peaks in PM_{10} occur when the wind speed dips below 1 m/s, the most notable being the dips below 0.5 m/s at St Vincent Street at hours 6 and 18 (blue line) leading to sudden rises in PM_{10} at the site (Figure 8(a)). PM_{10} at Blackwood Street (Figure 8(b)) is generally low, as the wind speed is around 2 m/s for the whole day. The wind direction on this occasion varies between the urban areas, ranging from S to E during early morning and evening, due to off-shore drainage during stable conditions).

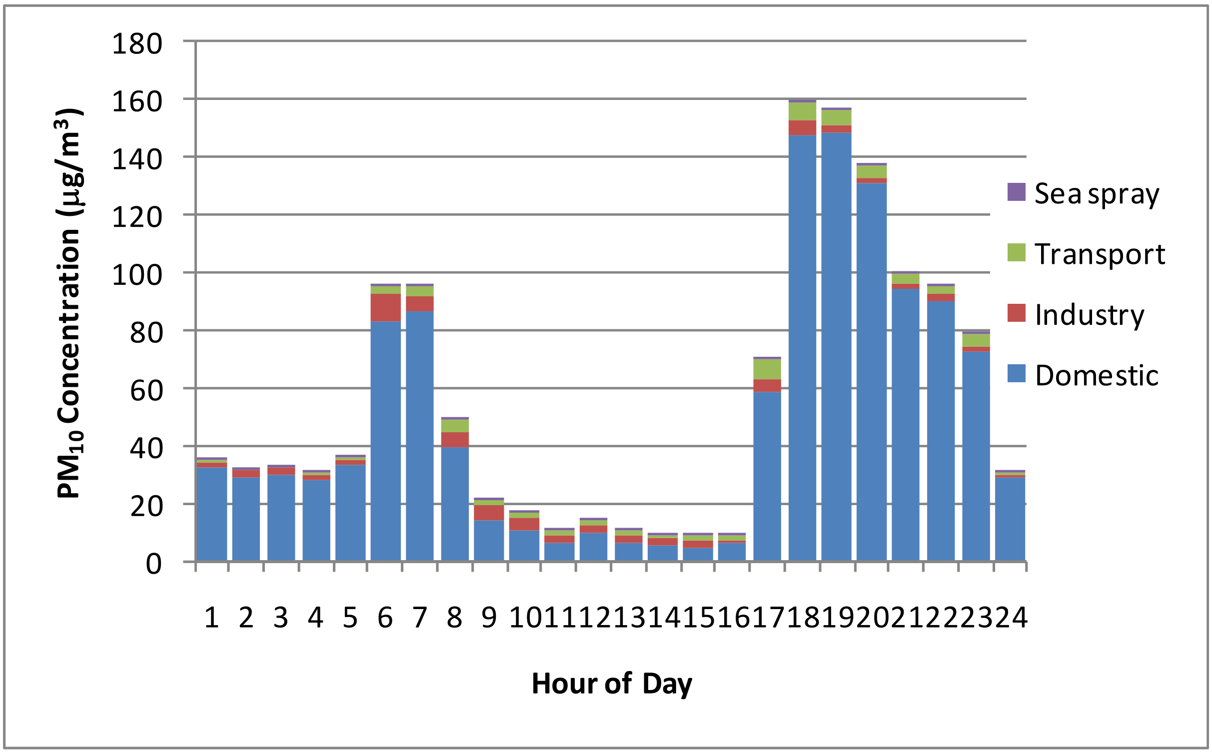

Figure 8(a) Case W5: PM_{10} at St Vincent Street.

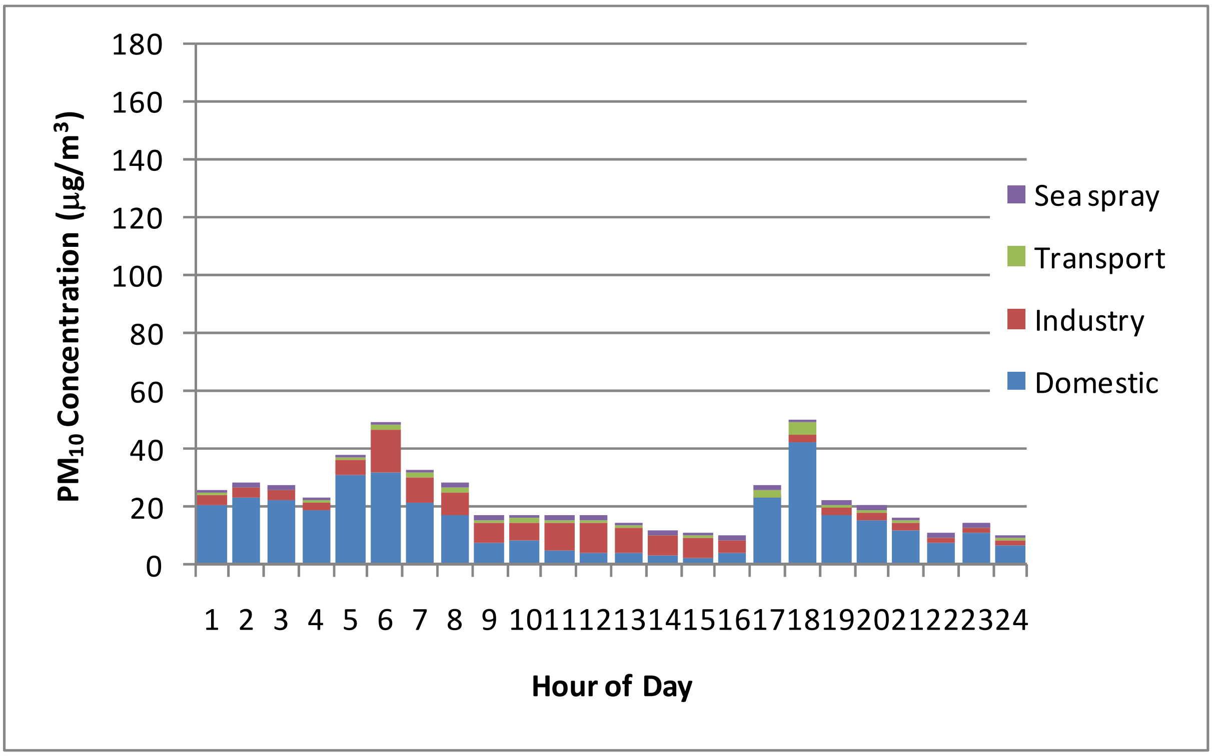

Figure 8(b) Case W5: PM$_{10}$ at Blackwood Street.

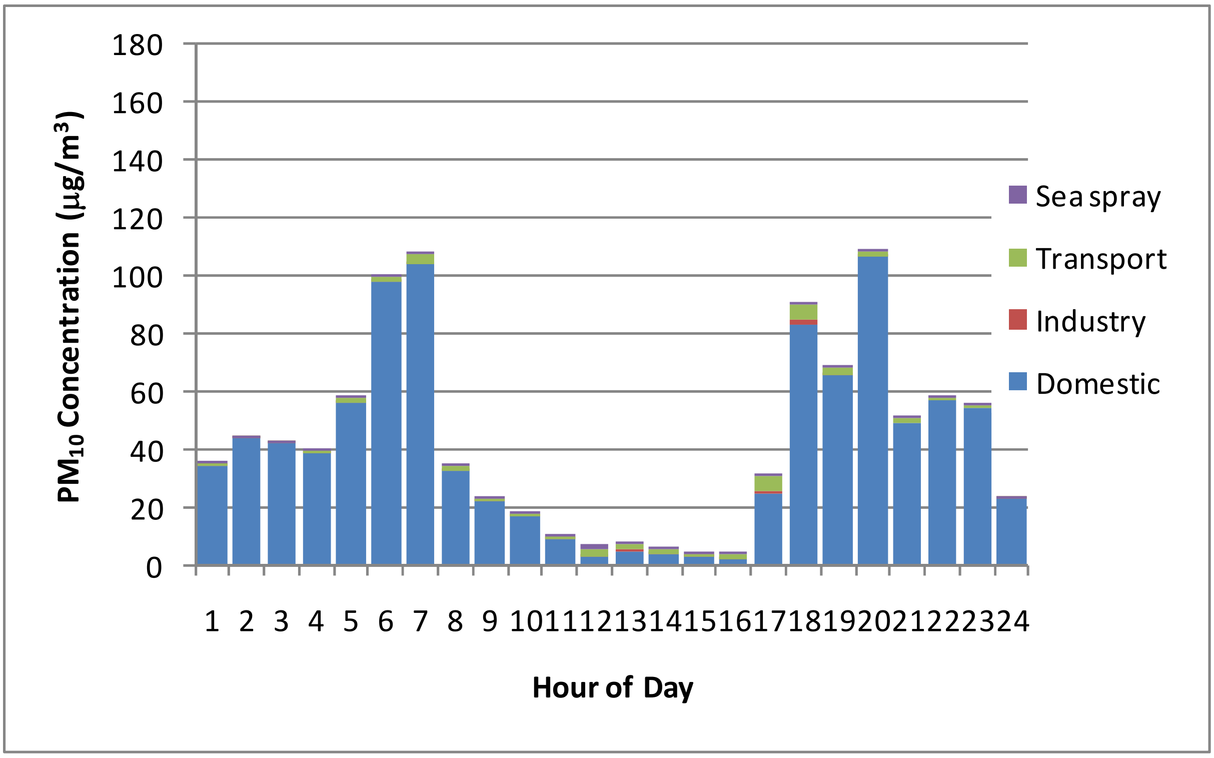

Figure 8(c) Case W5: PM$_{10}$ at Oxford Street.

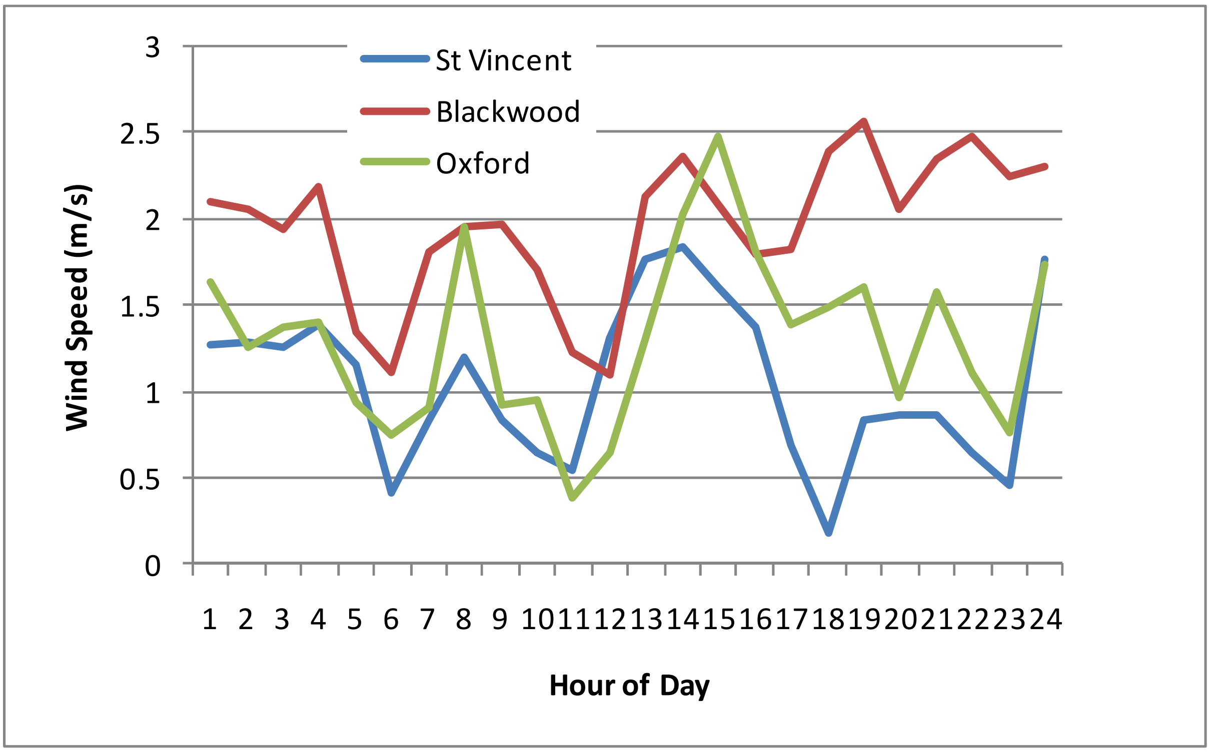

Figure 8(d) Case W5: Wind speed at all sites.

Figure 8: Case W5 – 19 May 2008. Hourly PM_{10} at (a) St Vincent Street, (b) Blackwood Street, (c) Oxford Street; hourly wind speed at all sites.

The wind direction during cases W1 to W7 follows a roughly similar diurnal pattern (though note that the wind direction is not well-defined when the wind speed is low). In the early morning hours, the wind direction is approximately southerly, but varying between SW and SE between days and locations. During daylight hours, the wind is approximately northerly, but varying between NW and NE between days and locations. During the evening, it returns to the approximately southerly direction. Although the wind speed on these occasions is relatively low, this feature gives rise to the possibility of transport of pollution between airsheds. Inter-airshed transport may be less likely on the near-calm worst-case days, but may be apparent on occasions of intermediate PM_{10} levels. In the following section, the PM_{10} during winter is examined, with modelled PM_{10} at the monitoring sites apportioned according to its airshed of origin.

4.3 Inter-airshed Transport of PM_{10} during Winter Months

This section examines the modelled contribution of PM_{10} due to domestic heating at the air quality monitoring sites from the airsheds in Nelson and Richmond separately. In addition to quantifying the effects of one airshed's emissions on another airshed, it can give an indication of the effects of the meteorology of the area in transporting pollutants between airsheds. Figure 9 shows the modelled domestic PM_{10} at St Vincent Street, Nelson, apportioned according to airshed of origin[4]. It can be seen that at least half of the PM_{10} at this site is modelled to have originated in Airshed A (Nelson South), which is where the site is located. There is a significant component from Airshed C (Nelson City), which is to the NE of St Vincent Street, and small components from Airshed B (split into B1 and B2), which is more distant. The contribution from Richmond appears to be insignificant. Cases W1, W2, W5, W6 and W7 are from May and June 2008, and in most of these cases, the fraction of total PM_{10} from Nelson South ranges between 63 % and 72 %, with 22 % to

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[4] Airsheds are labelled as follows: A is Nelson South, B1 is Tahunanui, B2 is Stoke and C is Nelson City. Richmond N and S are the north and south CAUs as defined in the Richmond emissions inventory.

31 % from Nelson City[5]. It is interesting to note that on these occasions, PM_{10} can be transported between airsheds from the SW during times of variable wind direction, before any SE drainage flows occur later in the evening.

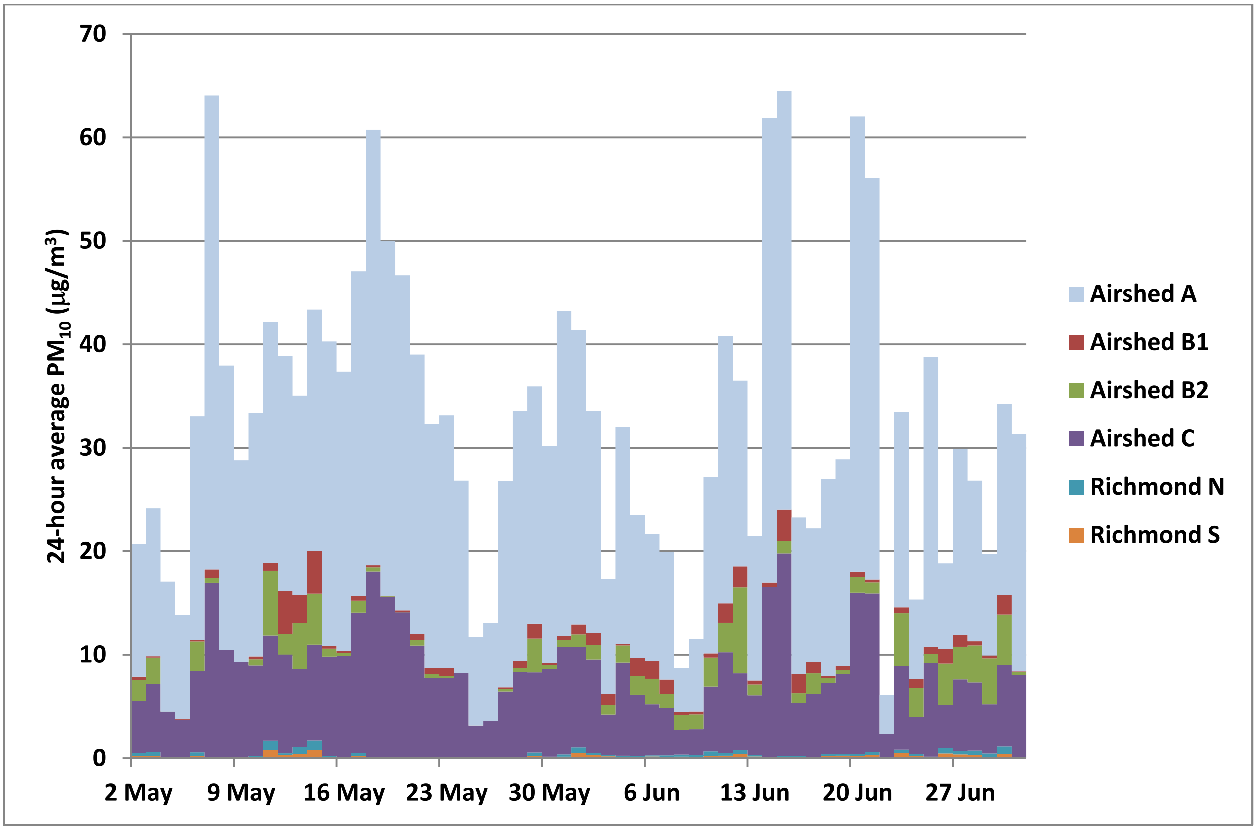

Figure 9: Modelled contribution to domestic-heating PM_{10} at St Vincent Street, Nelson, during May and June 2008.

Figure 10 shows the modelled domestic-heating PM_{10} at Blackwood Street, Tahunanui, apportioned according to airshed of origin. It can be seen that most of the PM_{10} at this site is modelled to have originated in Airshed B. The site is located in sub-airshed B1, but close to the boundary with sub-airshed B2 to its south. Hence there are significant contributions from both B1 and B2, as the wind direction changes during the calmer southerly conditions. Contributions from Richmond are small. However, there is an occasional contribution, up to 5 µg/m³, originating in Airsheds A and C to the NE of the site. This can occur if the day-time NE wind persists into the early evening when domestic emissions start to increase.

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[5] The exception is Case W6, with 65 % from Nelson City and 22 % from Nelson South; on this occasion, the total PM_{10} at St Vincent Street was not high.

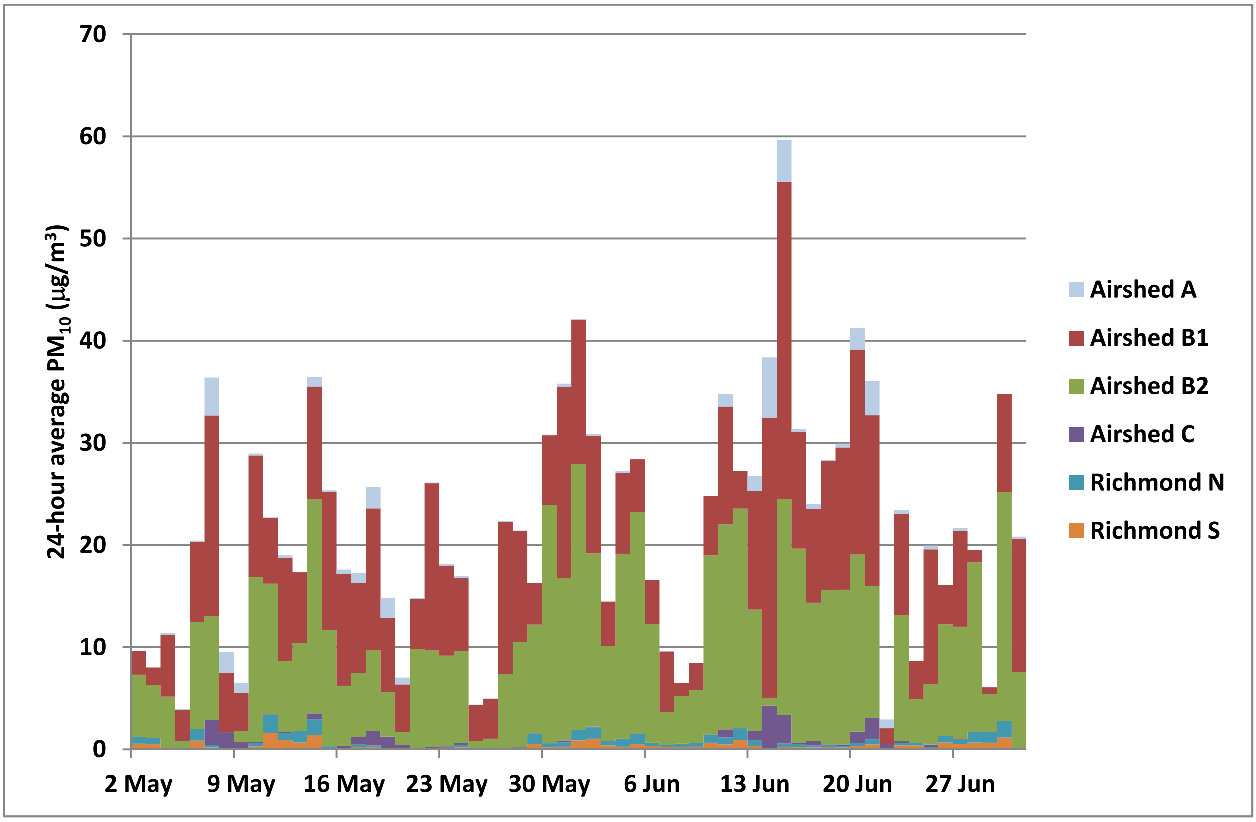

Figure 10: Modelled contribution to domestic-heating PM_{10} at Blackwood Street, Tahunanui, during May and June 2008.

Golder understands that there is evidence of the transport of particulate material from the industrial area northwest of Richmond to the Blackwood Street monitoring site (personal communication, Paul Sheldon, 14 Jul 2011). The model results shown in Figure 10 would indicate this to be a small effect. However, the industrial area is in a slightly different direction from the Tahunanui monitoring site, compared with Richmond itself. To be more conclusive, a closer examination of the conditions under which the transport is observed would be required, along with further modelling which includes these industrial sources. The industrial area outside Richmond is more directly southwest of Tahunanui than the Richmond urban area, and that the emissions information supplied for this work did not include those industrial sources (note their absence from Figure 5).

Figure 11 shows the modelled domestic PM_{10} at Oxford Street, Richmond, apportioned according to airshed of origin. It can be seen that almost all of the PM_{10} at this site is modelled to have originated in the Richmond airshed. The Oxford Street site is in the Richmond South CAU, and most of the PM_{10} is from this CAU, with some from the Richmond North CAU. A small amount of the modelled PM_{10} arriving at Oxford Street occasionally comes from Airshed B2 (Stoke).

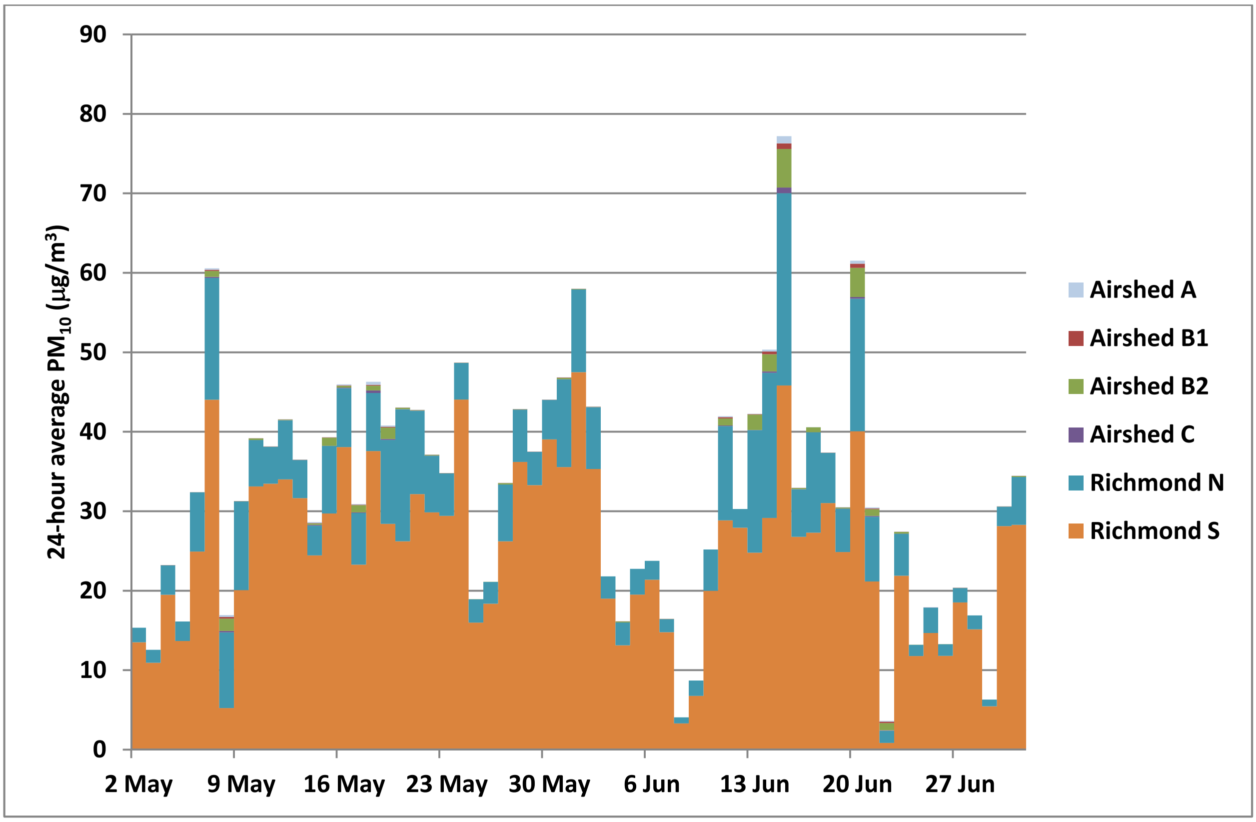

Figure 11: Modelled contribution to domestic-heating PM_{10} at Oxford Street, Richmond, during May and June 2008.

4.4 Modelled Summertime PM_{10} Levels at Monitoring Sites

Four case-study days have been identified in the airshed model results by their highest summer levels of 24-hour-averaged PM_{10} at one or more of the air quality monitoring sites. These are described in Table 3. The table also shows the contributions from anthropogenic sources of PM_{10} and sea spray PM_{10} to the total modelled PM_{10}, for each case. The maximum modelled PM_{10} is between 10 $\mu g/m^3$ and 12 $\mu g/m^3$ at the monitoring sites in Case S1. However, the PM_{10} at Blackwood Street can be double this amount under different meteorological conditions (Case S2).

Cases S1 and S4 are dominated by sea spray and cases S2 and S3 have a larger anthropogenic component. The modelled total PM_{10} concentrations are similar for each case. Cases S2 and S3 are composed of predominantly anthropogenic PM_{10} at St Vincent and Blackwood Streets; at Oxford Street the components are more equal. Cases S1 and S3 are examined hour by hour in the following.

An hourly time series of modelled PM_{10} concentrations by sector and meteorological parameters at St Vincent Street and Oxford Street on the day of maximum 24-hour PM_{10} at these two sites is shown in Figure 12 (22 January 2008, Case S1). On this date, the wind blew consistently from the northeast across the whole region, reaching up to 8 m/s around midday (Figure 12(c)). The temperature remains around 20°C throughout the day (Figure 12(d)). The mixing height ranges between around 200 m and 1600 m. These moderate and warm wind conditions combined with a well-mixed boundary layer are conducive to elevated levels of PM_{10} from windblown sea spray. (Note that the sea spray contribution has been calculated as a 24-hour average and therefore cannot be depicted on an hourly chart).

Table 3: Worst-case modelled PM_{10} levels on summer days at monitoring sites. Values shown are the 24-hour averaged PM_{10} concentration (in µg/m^3), and its rank (between 1 and 91) at that site in parentheses. Concentrations are partitioned into anthropogenic and sea spray components (italics).

Case	**Date**	**St Vincent Street**	**Blackwood Street**	**Oxford Street**	**Comment**
S1	22 January 2008	9.6 (1)	11.2 (8)	11.0 (1)	Max. concentration St Vincent and Oxford
	Anthopogenic	*1.5*	*1.2*	*0.5*	
	Sea spray	*8.1*	*10.0*	*10.5*	
S2	31 March 2008	9.3 (2)	20.3 (1)	4.8 (39)	Max. conc. at Blackw'd; 2nd at St Vincent
	Anthopogenic	*7.7*	*18.1*	*2.6*	
	Sea spray	*1.6*	*2.2*	*2.2*	
S3	30 March 2008	8.1 (8)	14.1 (2)	4.5 (43)	2nd highest at Blackwood Street
	Anthopogenic	*7.4*	*11.7*	*2.1*	
	Sea spray	*0.7*	*2.4*	*2.4*	
S4	29 March 2008	8.9 (3)	10.3 (11)	9.3 (2)	2nd highest at Oxford Street
	Anthopogenic	*1.8*	*3.1*	*0.6*	
	Sea spray	*7.1*	*7.2*	*8.7*	

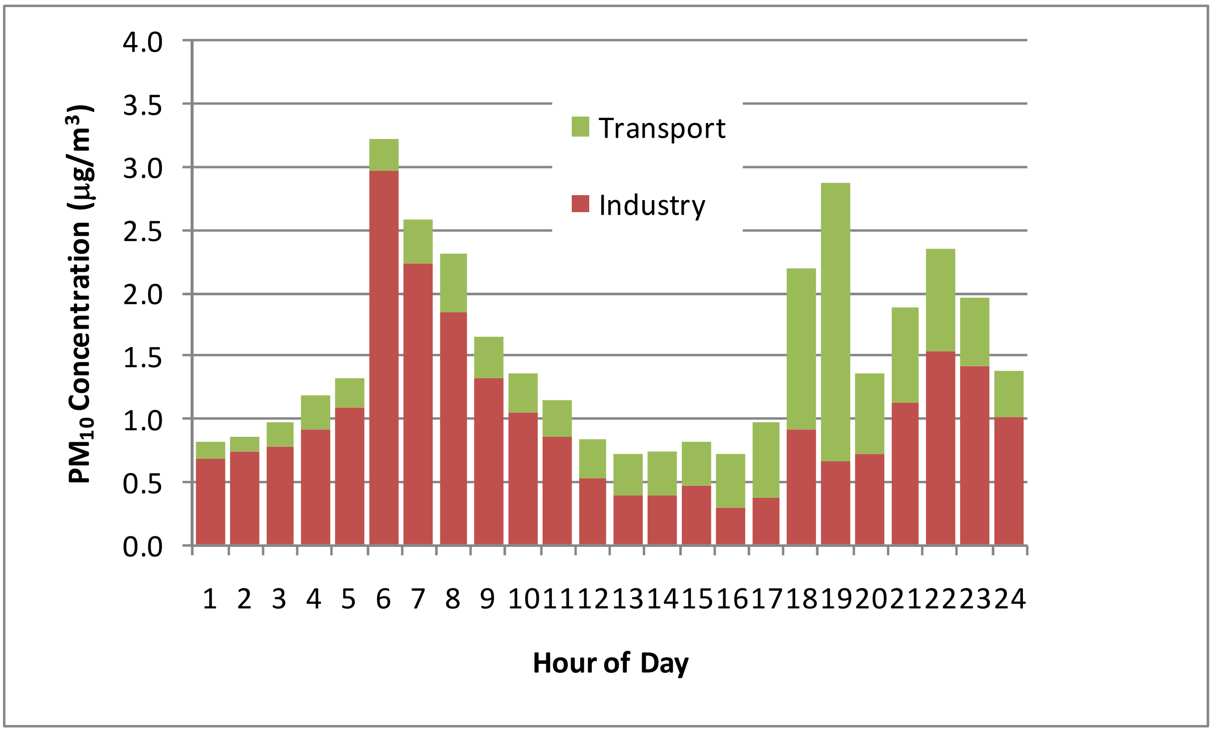

Figure 12(a) Case S1: St Vincent Street PM_{10}.

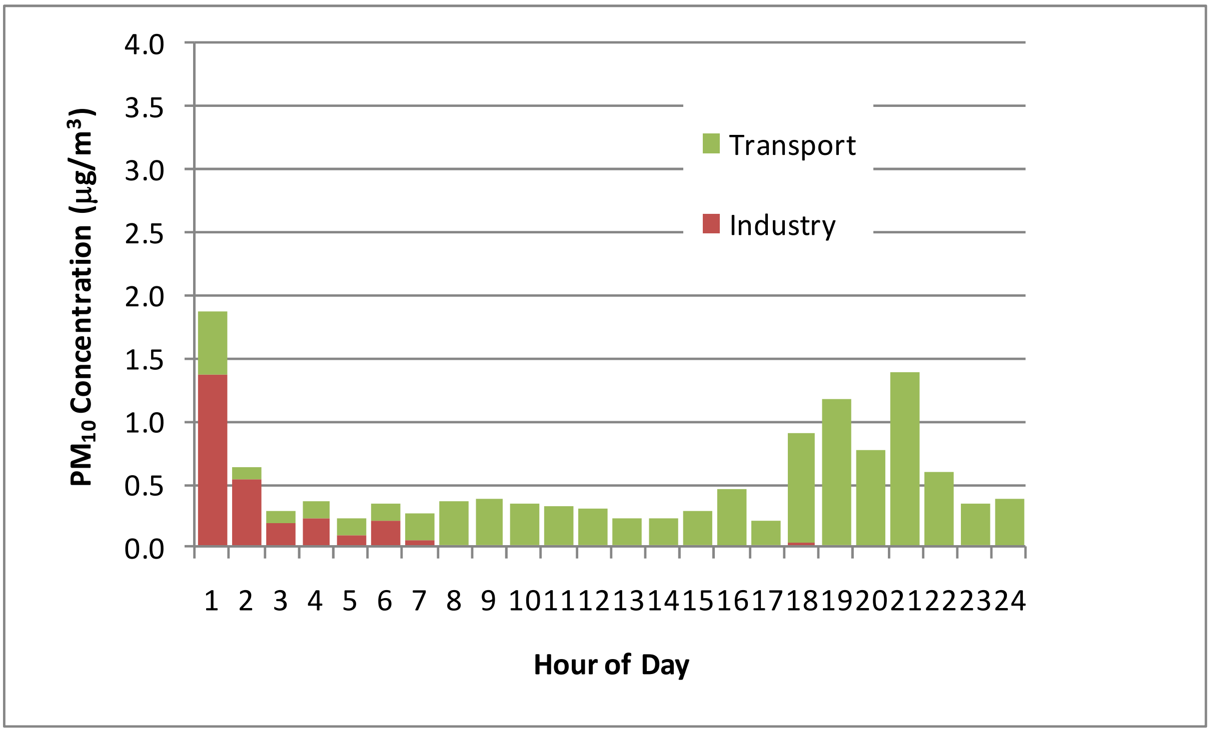

Figure 12(b) Case S1: Oxford Street PM_{10}.

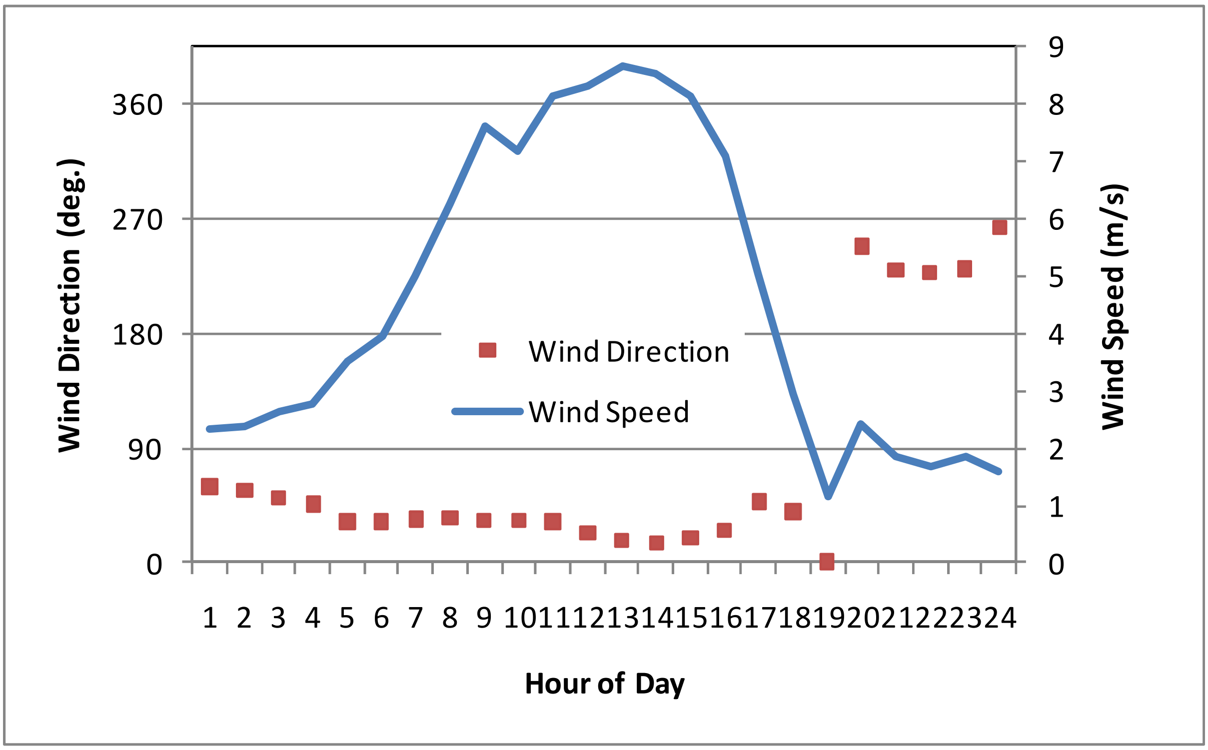

Figure 12(c) Case S1: St Vincent Street wind speed and direction.

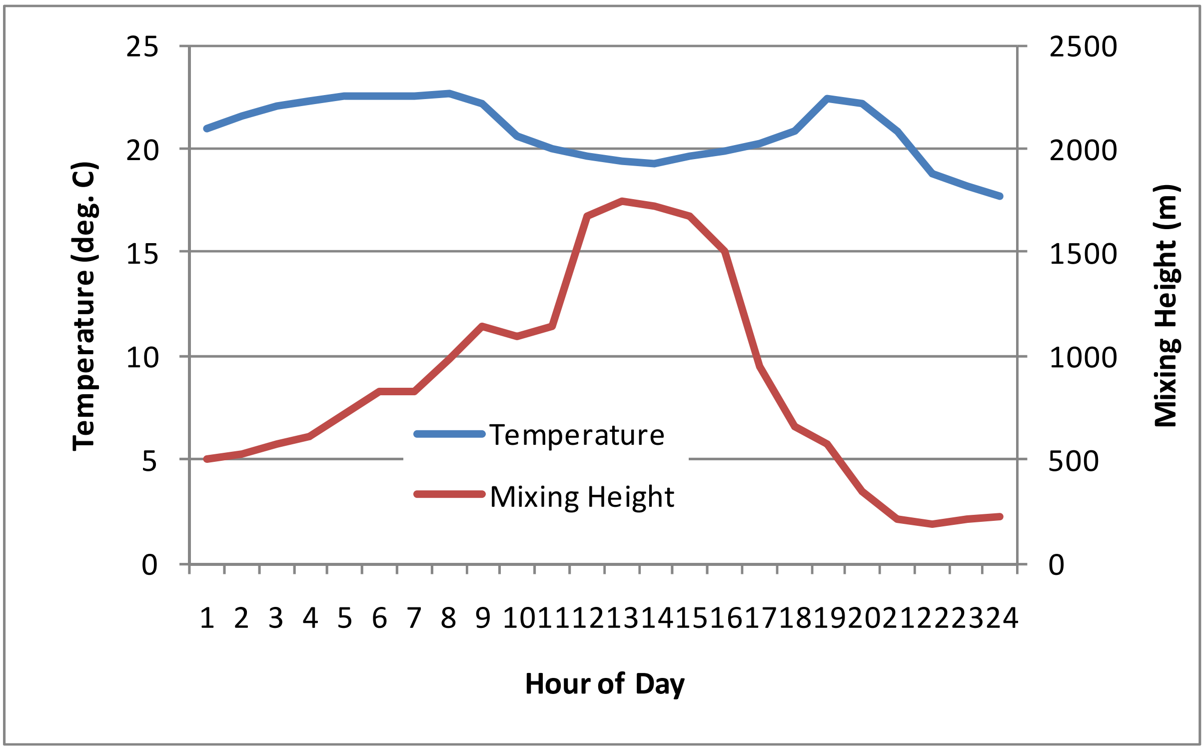

Figure 12(d) Case S1: St Vincent Street Temperature and mixing height.

Figure 12: Case S1 – 22 January 2008. Hourly anthropogenic PM$_{10}$ *at (a) St Vincent Street, (b) Oxford Street; meteorology at St Vincent Street: (c) wind speed and direction, (d) temperature and mixing height.*

A time series for summer Case S3, at the date on which the total PM$_{10}$ at Blackwood Street was second highest is given in Figure 13. On this occasion, Blackwood Street experienced a relatively large component of PM$_{10}$ due to industry (Figure 13(a)). The component due to transport is low here (Figure 13(b)), as it is at Oxford Street (Figure 13(c)). PM$_{10}$ from industry is negligible at Oxford Street, so is not shown here. The higher anthropogenic levels of PM$_{10}$ occurred in calmer conditions (with wind speed shown in Figure 13(d)), during which the sea spray component was low. Some short-term peaks can be seen in the hourly PM$_{10}$ time series.

It should be pointed out the modelled PM$_{10}$ components due to industry, transport and sea spray are of similar orders of magnitude in winter and summer. The absence of a dominating domestic component – which appears only in winter – allows a focus on the other components. However, care should be taken over the interpretation of airshed model results in summer months, as the component of PM$_{10}$ may be underestimated. High concentrations due to road transport at locations next to the roadside cannot be reproduced when emissions inputs are spread over CAU areas. Consequently, the modelled peak concentrations shown in Table 3 are around 10 µg/m^3 smaller than the observed peaks at the monitoring sites. This can be up to 50% of the total PM$_{10}$ concentration.

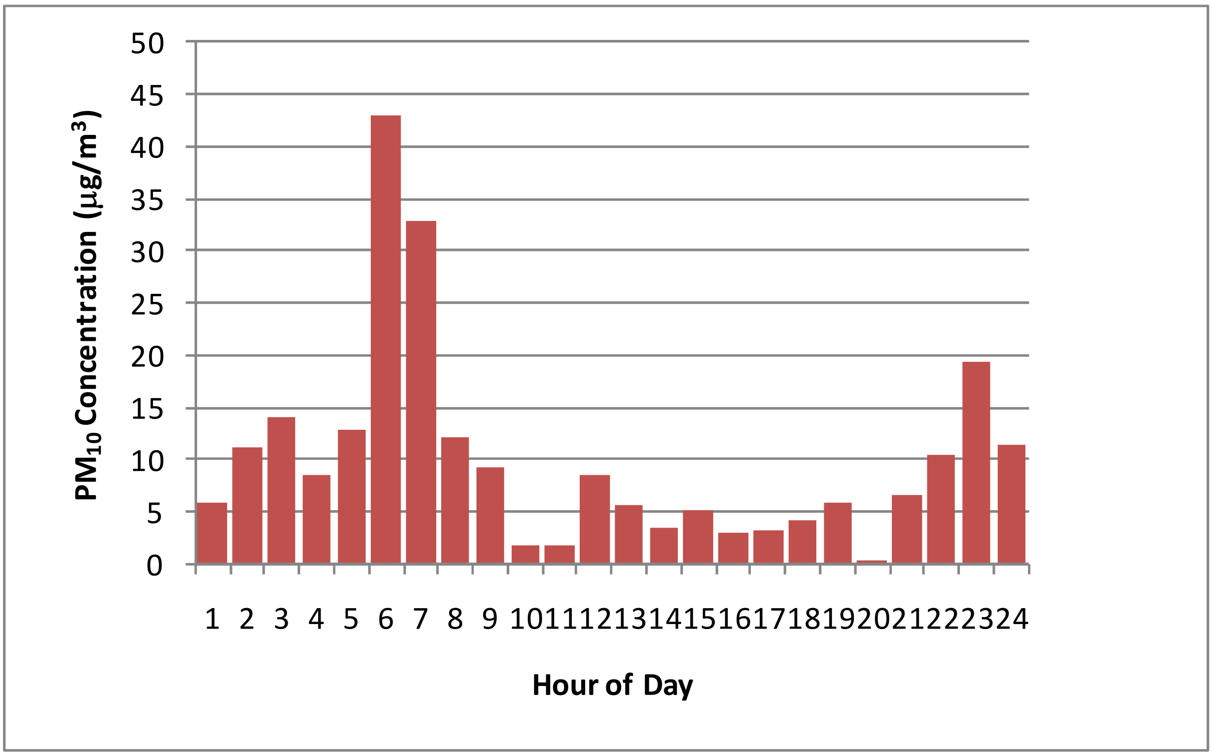

Figure 13(a) Case S3: Blackwood Street PM_{10} from industry.

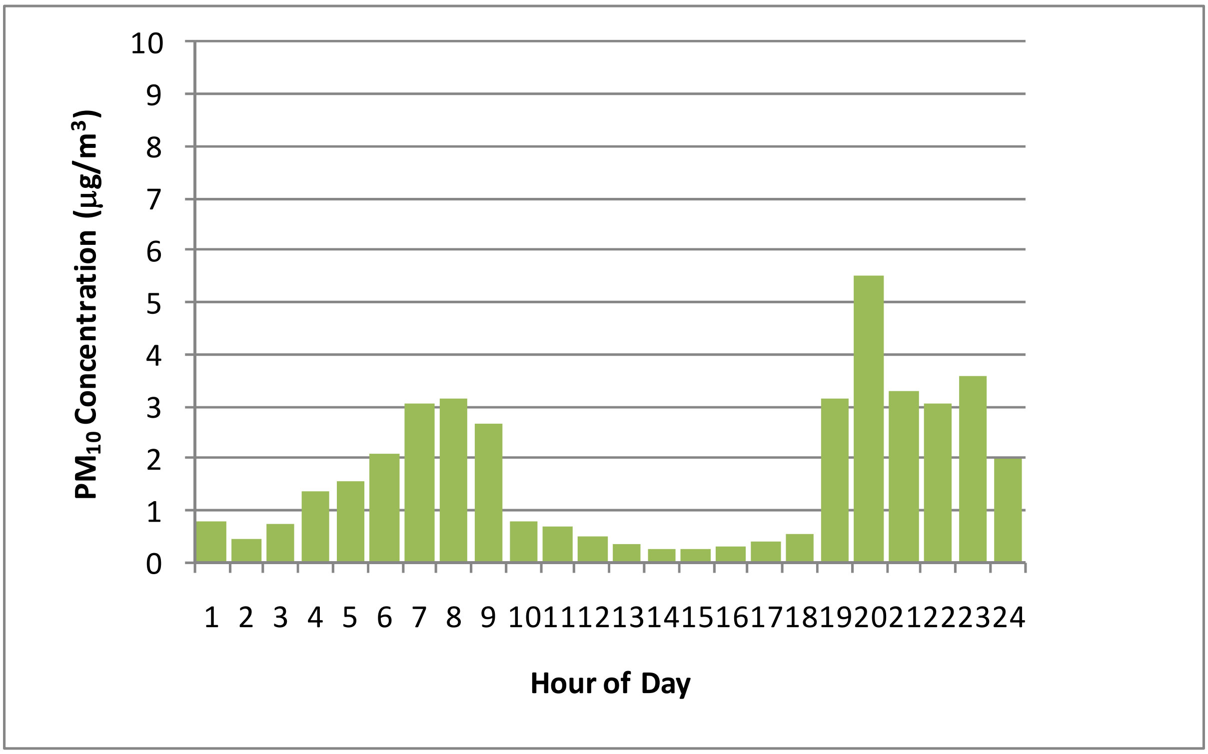

Figure 13(b) Case S3: Blackwood Street PM_{10} from transport.

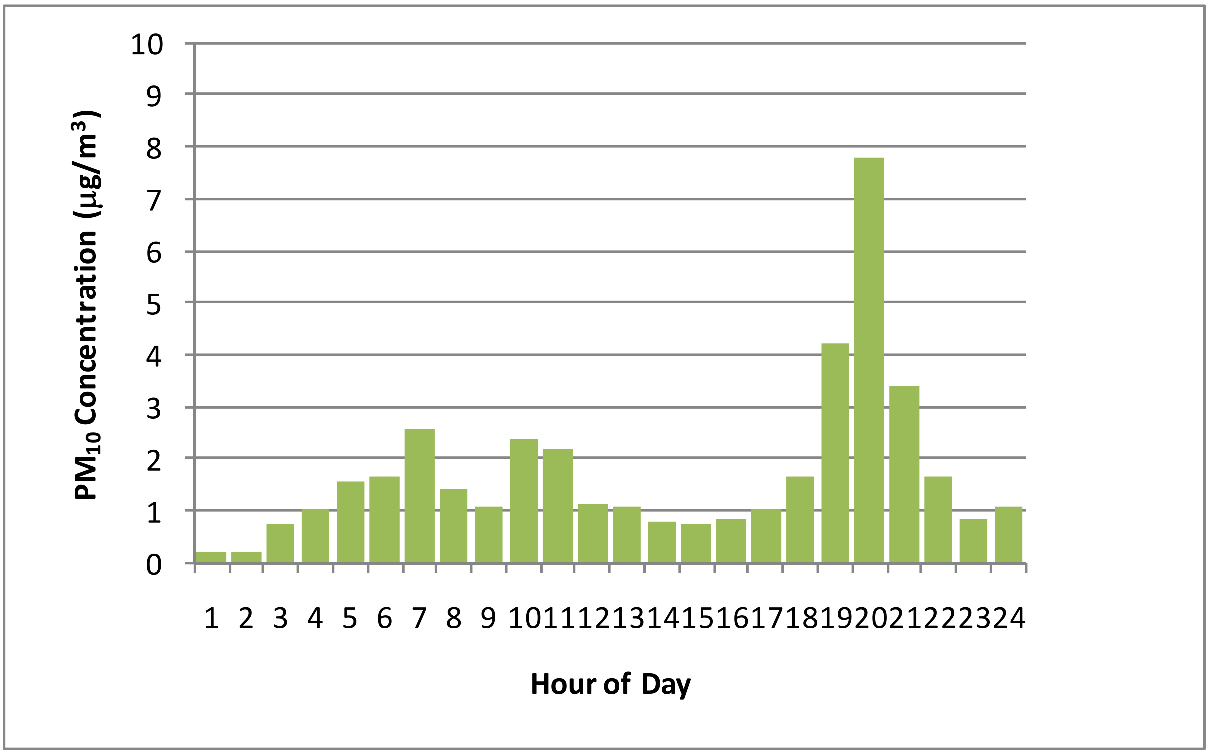

Figure 13(c) Case S3: Oxford Street PM_{10} from transport.

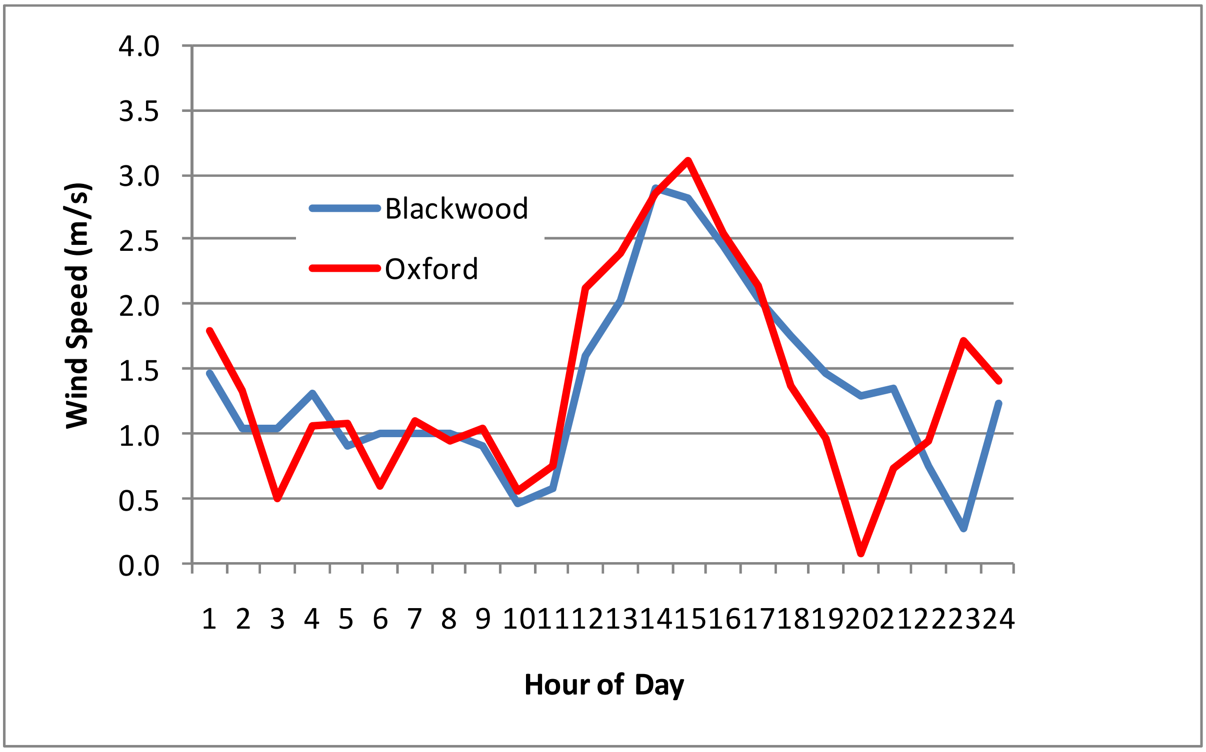

Figure 13(d) Case S3: Wind speed at Blackwood and Oxford Streets.

Figure 13: Case S3 – 30 March 2008. Hourly PM_{10} at (a) Blackwood Street due to industry, (b) Blackwood Street due to transport, (c) Oxford Street due to transport. (d) hourly wind speed at Blackwood Street and Oxford Street.

4.5 Comparison of Model Results with Observed PM_{10} Concentrations

4.5.1 Introduction

This section discusses airshed model performance, as defined by commonly-used statistical measures of model performance. These measures have been determined for the winter months and the rest of the year, and are described in Appendix F. Also in this section, quantile-quantile plots and examinations of the high-ranked concentrations and number of NES exceedences are presented for winter.

4.5.2 Model-performance statistics

Model-performance statistics are tabulated in Appendix F. It suffices here to make a few qualitative statements on the performance of CALPUFF as an airshed model (but note that they are backed-up quantitatively in Appendix F).

Winter conditions are simulated well by CALPUFF, with good levels of agreement between the observed and modelled time series of PM_{10}. The model errors are largely unbiased, that is, the model over- and under-predicts equally, and errors are generally smaller than the observed variability in PM_{10}. There is some tendency to miss extremes of PM_{10}. It is speculated that the model performance for winter may be improved by accounting for day to day variation in emissions, so that more of the variability in PM_{10} and its extreme concentrations may be captured by the model. There would still be some natural component of turbulent variability whose fluctuations are not resolved by the model. This is why it is sufficient to reduce model errors to until they are smaller than natural fluctuations – they cannot be eliminated entirely.

However, model performance is not good for the non-winter months. The model significantly underestimates the observed PM_{10}, and this shows up in the mean concentrations, in statistics which quantify the agreement between the time series, in the presence of bias, and in the magnitudes of the errors (compared with observed variability). The most likely causes of this are the smoothed-out area sources used to represent transport emissions, or the simplified model for sea spray which probably misses extremes in that component of PM_{10}.

4.5.3 High-ranked concentrations and NES exceedence numbers in winter

Quantile-quantile plots of observed and modelled PM_{10} concentrations for the three air quality monitoring sites are shown in Figure 14. These show modelled PM_{10} against observed PM_{10}, after ranking each time series separately. Ideally, the points should lie on the 1:1 line. The plots are divided into quadrants, delimited by the NES target concentration of 50 $\mu g/m^3$. A good model simulation of the number of exceedences of the target would result in points either in the top-right or bottom-left quadrants, but not the others.

The results shown in Figure 14 lie mostly along the 1:1 line, indicating good model performance. However, there are one or two outliers in the model results at Blackwood Street and Oxford Street. At Blackwood Street, the wind speed was between 0.5 m/s and 1.0 m/s for several hours during the evening of the highest modelled 24-hour PM_{10}. The low wind speed resulted in high hourly concentrations of PM_{10} which contributed to the high 24-hour PM_{10} on that occasion. On the occasions of second- and third-highest modelled 24-hour PM_{10}, the evening wind speed was between 1.0 m/s and 1.5 m/s. The model results are sensitive to low wind speeds. Modelling good-practice guidance given by MfE (2004b) indicates that the highest-percentile concentration results should be examined to filter out unrealistic outliers and allow those results remaining to be taken to represent the highest observed concentrations. Under such guidance, the highest modelled PM_{10} concentrations at Blackwood Street and the highest two modelled PM_{10} concentrations at Oxford Street would be disregarded, and the next-highest taken to be the best predictor of the likely maximum PM_{10} concentration at those sites.

Removing outliers would improve the model simulation of the highest PM_{10} concentrations at the monitoring sites, improve the quantile-quantile plot, and improve the match between modelled and observed numbers of exceedences. The potential improvement can clearly be seen here, through a comparison of results with observations of PM_{10} and inspection of the quantile-quantile plot.

At St Vincent Street and Oxford Street, there are a number of points in the bottom-right quadrant of Figure 14, indicating the model predicts fewer exceedences than occurred. At Blackwood Street, the modelled number of exceedences matches that observed. However, there is some spatial variation in the modelled number of exceedences in the areas around the monitoring, and this is discussed in Section 4.7.4. Table 4 provides a summary of the high-end concentrations at each site (modelled and observed, no outliers removed).

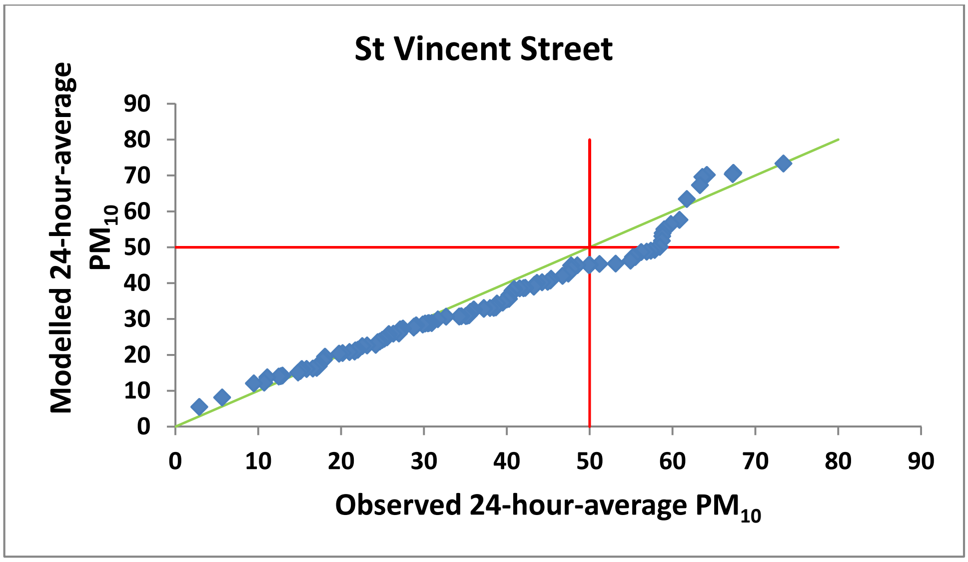

Figure 14(a) Quantile-Quantile plot for St Vincent Street.

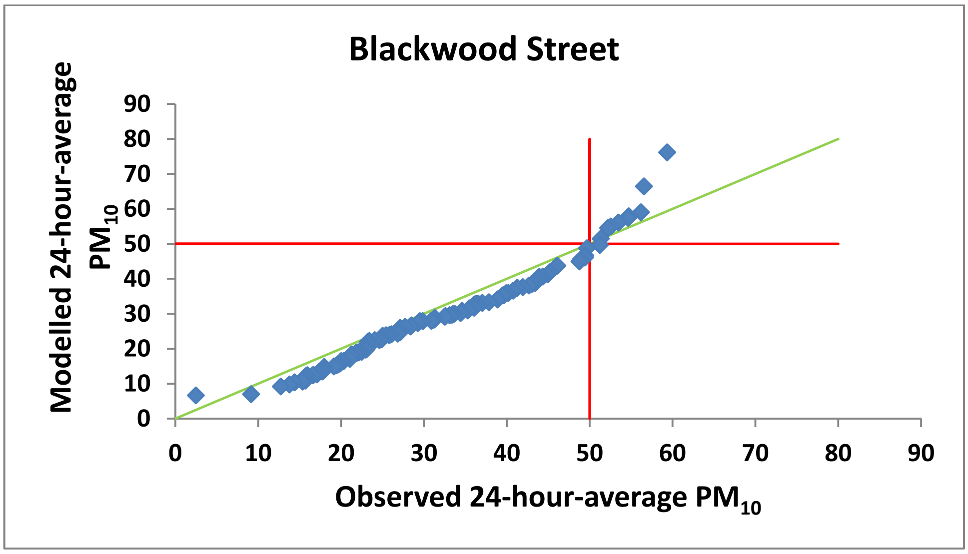

Figure 14(b) Quantile-Quantile plot for Blackwood Street.

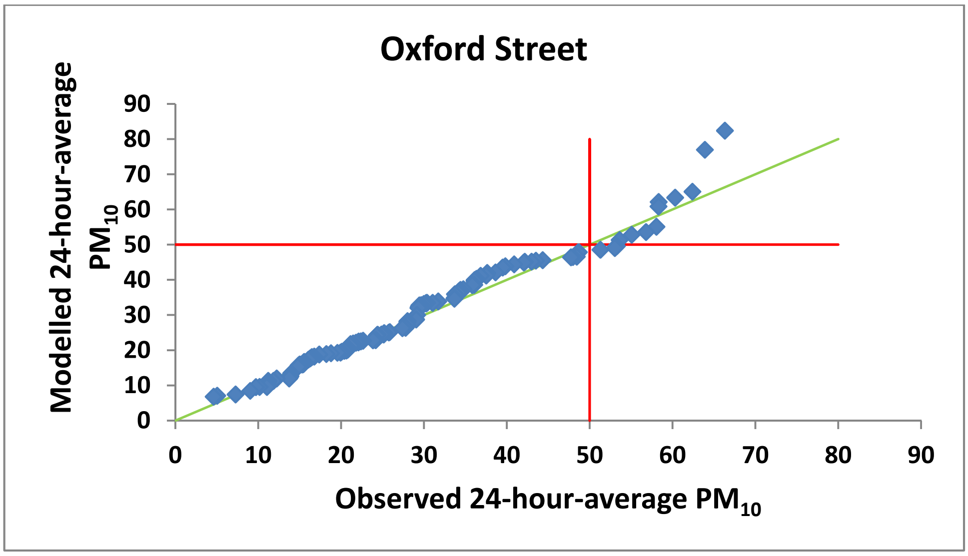

Figure 14(c) Quantile-Quantile plot for Oxford Street.

Figure 14: Quantile-quantile plots of winter (May, June, July, August) PM_{10} at the three monitoring sites: (a) St Vincent Street, (b) Blackwood Street, (c) Oxford Street. The '1:1' line is shown in green. The plots are divided into quadrants by the 'observed = 50 $\mu g/m^3$' and the 'modelled = 50 $\mu g/m^3$' lines.

Table 4: High-ranked 24-hour PM_{10} concentrations and exceedence numbers at the monitoring sites ("St V" St Vincent Street, "Blk" Blackwood Street, "Oxf" Oxford Street). Units are $\mu g/m^3$.

Parameter	St V - Obs	St V - Model	Blk - Obs	Blk - Model	Oxf – Obs	Oxf - Model
Maximum	74	74	59	76	66	82
2nd-highest	67	71	57	66	64	77
3rd-highest	67	70	56	59	62	65
Mean (winter)	36	33	31	29	29	30
Exceedences	23	14	10	9	14	10

4.6 Source-apportioned Time Series of Modelled Winter PM_{10}

This section examines the time series of modelled PM_{10} over the winter months at air quality monitoring sites, apportioned according to source contribution as defined by the emissions inventory information. As the model has been run for each source type separately, the resulting PM_{10} concentrations can easily be attributed to their source. This provides useful information for air quality management, and can show which sources may need to be targeted for emissions reduction, for more effective reductions of ambient PM_{10}. Figure 15, Figure 16 and Figure 17 show time series of PM_{10} by source from St Vincent Street, Blackwood Street and Oxford Street respectively. The upper panels of each figure show 24-hour-averaged PM_{10} concentrations in $\mu g/m^3$ for each source, and lower panels show proportions for each source of the total PM_{10}.

For most winter days, the 24-hour averaged PM_{10} is predominantly due to domestic heating, with small industry, transport and sea spray components. Windier days are characterized by much lower total PM_{10} concentrations, and a much larger sea spray proportion (although the sea spray concentration can also be many times higher than on calm days).

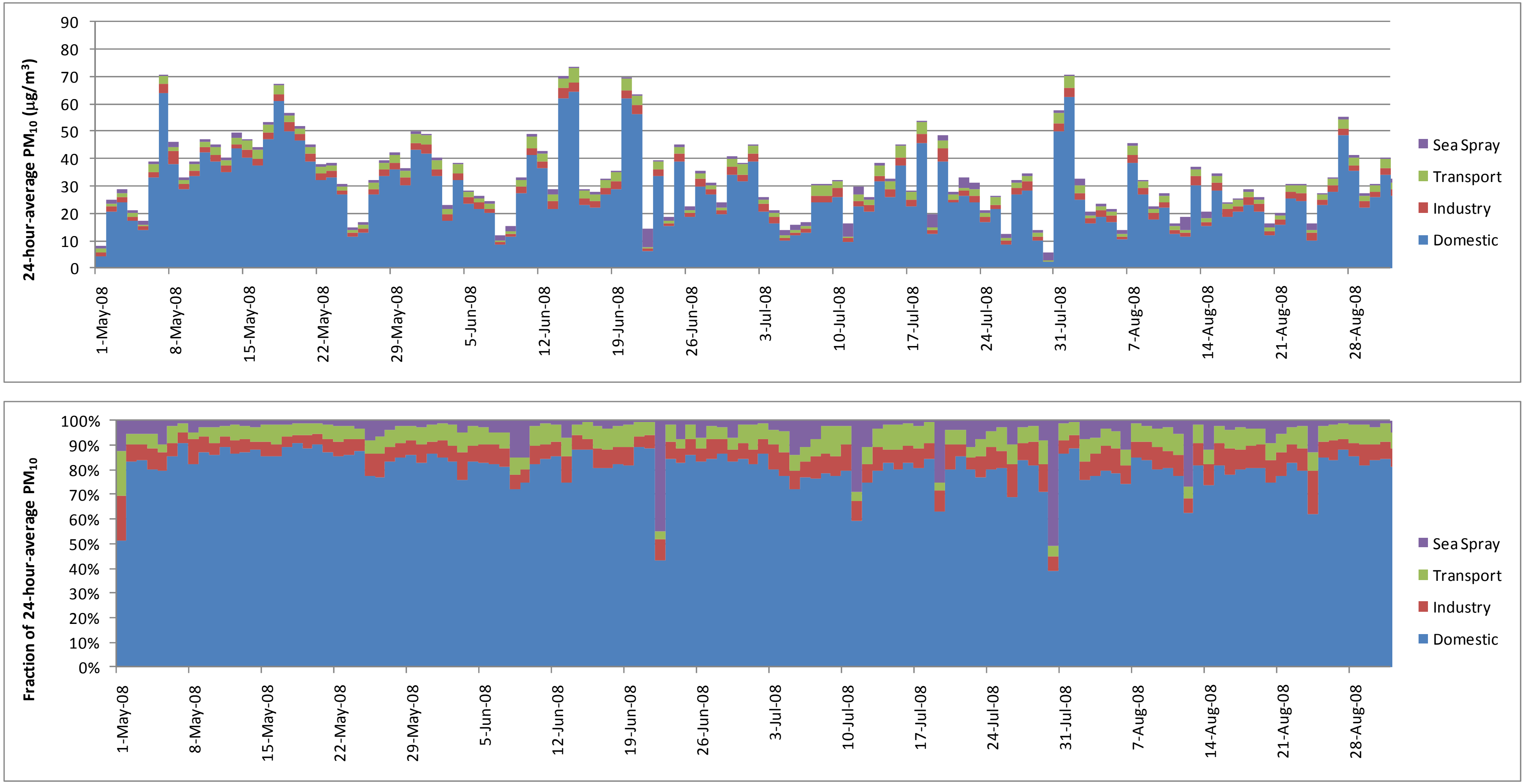

Figure 15: Winter time series of modelled PM_{10} at St Vincent Street, Nelson, partitioned according to modelled emission source. The upper chart shows 24-hour average concentration; the lower chart shows the source proportion of each daily total.

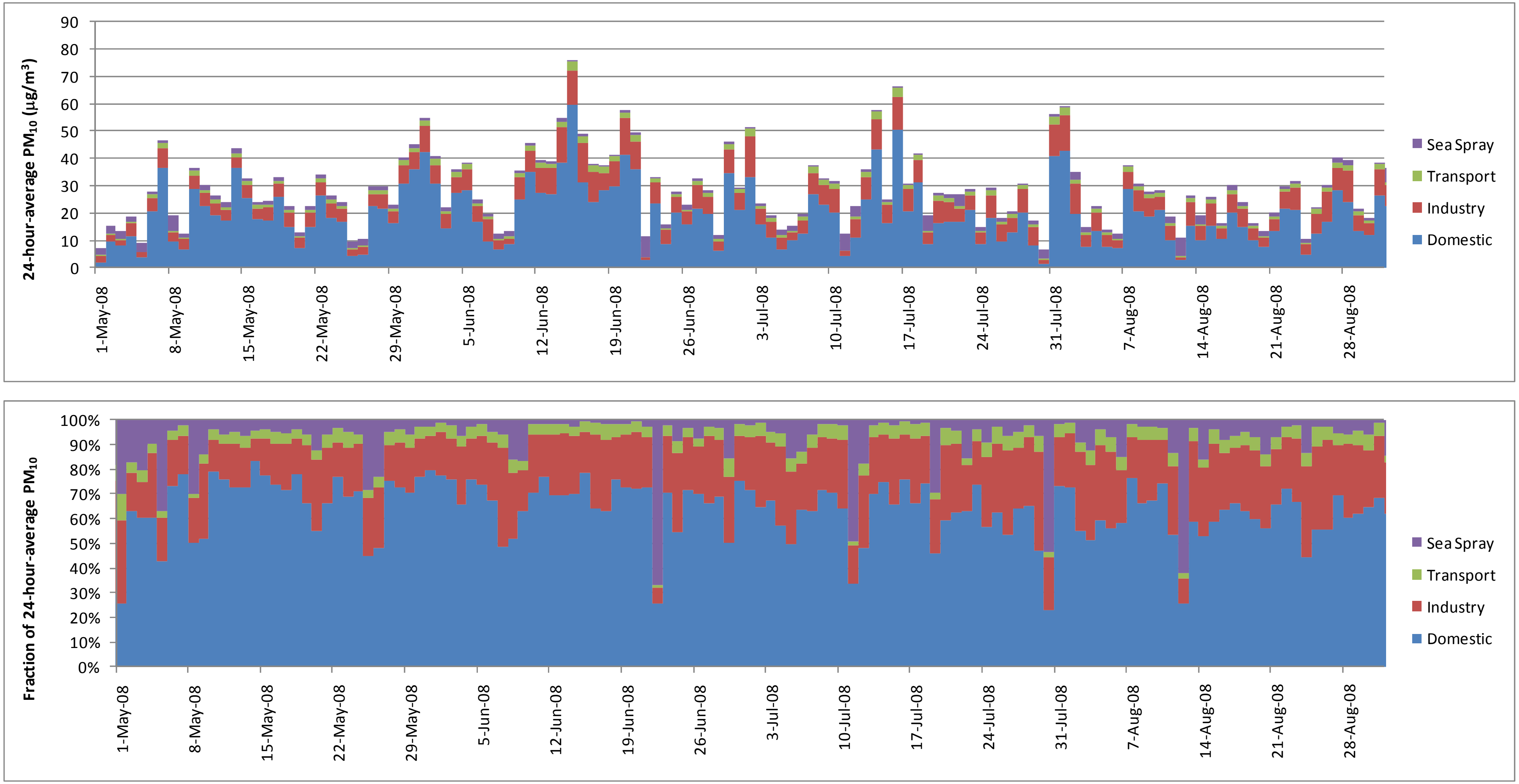

Figure 16: Winter time series of modelled PM$_{10}$ at Blackwood Street, Nelson, partitioned according to modelled emission source. The upper chart shows 24-hour average concentration; the lower chart shows the source proportion of each daily total.

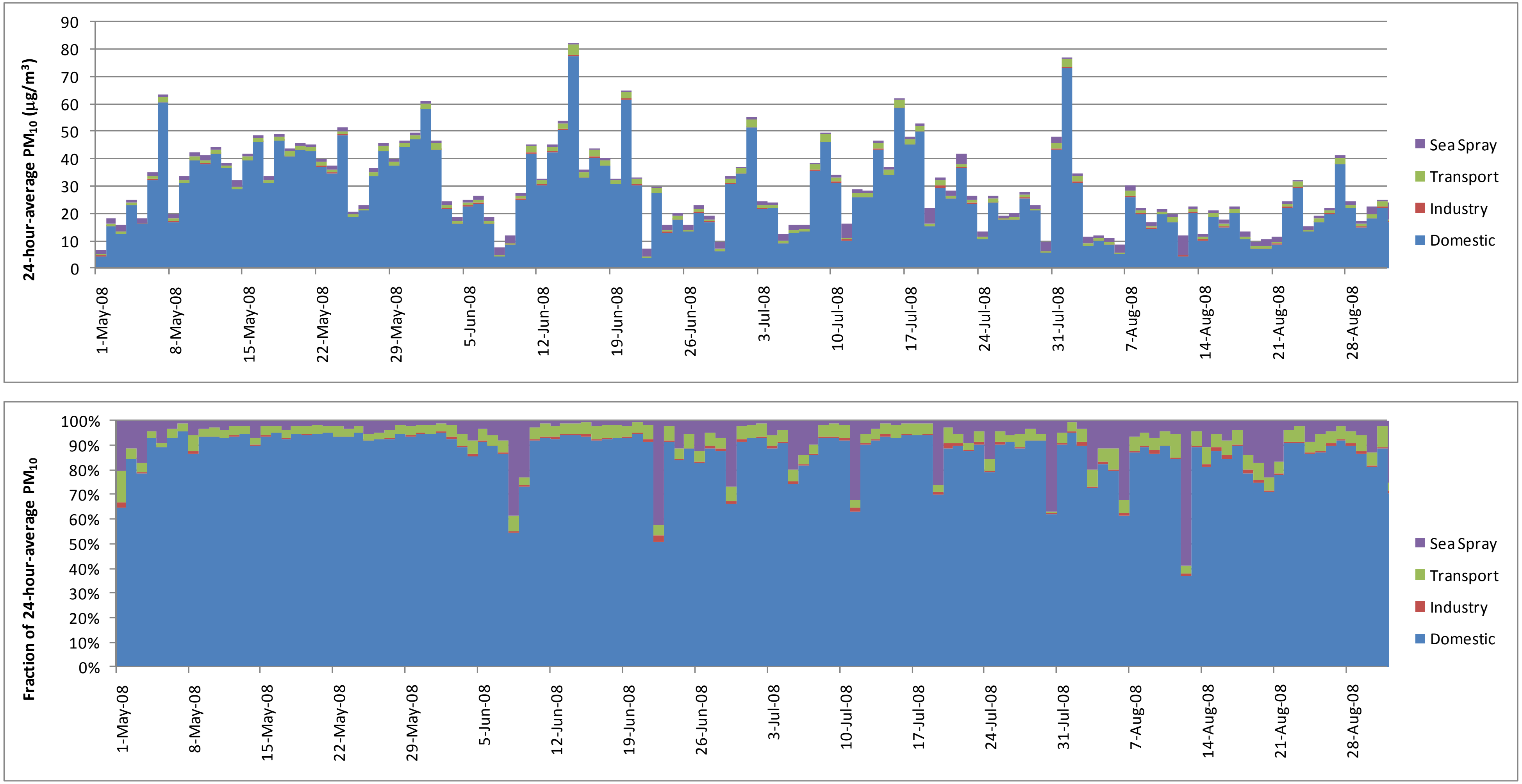

Figure 17: Winter time series of modelled PM_{10} at Oxford Street, Richmond, partitioned according to modelled emission source. The upper chart shows 24-hour average concentration; the lower chart shows the source proportion of each daily total.

There are slight variations in the source proportions between sites. Roughly speaking, PM_{10} levels at St Vincent Street on average contain 10 % transport, 10 % industry and 5 % sea spray (the rest being due to domestic sources. Similarly, PM_{10} levels at Blackwood Street on average contain 5 % transport, 20 % industry and 5 % sea spray, and at Oxford Street the proportions are 5 % vehicles, 5 % sea spray and no industry.

Due to findings in Appendix F for non-winter model results, modelled source proportions during the non-winter months are not considered reliable, and therefore are not presented in this report.

4.7 Spatial Patterns of PM_{10}

4.7.1 Introduction

Having examined the airshed model results and compared them with PM_{10} measurements at air quality monitoring sites, the model results are examined over the region as a whole. This section shows two-dimensional maps of PM_{10} over the Nelson/Richmond area during pollution events. Such maps draw on one of the strengths of the modelling process, in that the model can predict pollution levels at locations other than monitoring sites. Also, it can be used to examine the physical processes which have led to those levels, and make predictions of pollution levels under different emissions scenarios.

It is common practice to present “composite” results of the maximum pollution levels which may occur at each point on the map. Accordingly, composite maps of maximum 24-hour-averaged PM_{10} concentrations are shown in this section. However, the maximum concentration may occur at different locations on different occasions, and therefore maps of modelled 24-hour-average PM_{10} concentration for specific events are also presented and discussed here. The following sub-sections discuss spatial patterns of winter-time PM_{10} events, summer PM_{10}, number of PM_{10} exceedences, and compare patterns with current airshed boundaries and recent mobile monitoring results (Sections 4.7.2, 4.7.3, 4.7.4, 4.7.5 and 4.7.6 respectively).

4.7.2 Modelled wintertime PM_{10} events

This section shows maps of the peak 24-hour-average PM_{10} for the modelled year 2008. These peak events occur during winter. The composite-maximum modelled PM_{10} concentration in Figure 18 shows peak concentrations in Richmond, Tahunanui and Nelson City, as expected from the emissions pattern. The area bounded by the red contour (50 $\mu g/m^3$) identifies areas predicted by the model to be in breach of the NES for PM_{10}. Other contour levels are in multiples of one-third of the NES (16.7$\mu g/m^3$) to coincide with MfE-defined environmental performance indicator levels.

A small area in the southern part of Nelson (Stoke) has modelled concentrations which are twice the NES (the thick white line shows concentrations of 100 $\mu g/m^3$). Also, due to pollution dispersion from the source region, air quality effects extend beyond the urban boundaries, with levels up to two-thirds of the NES (33.3 $\mu g/m^3$) spreading to rural areas and around 3 km out to sea.

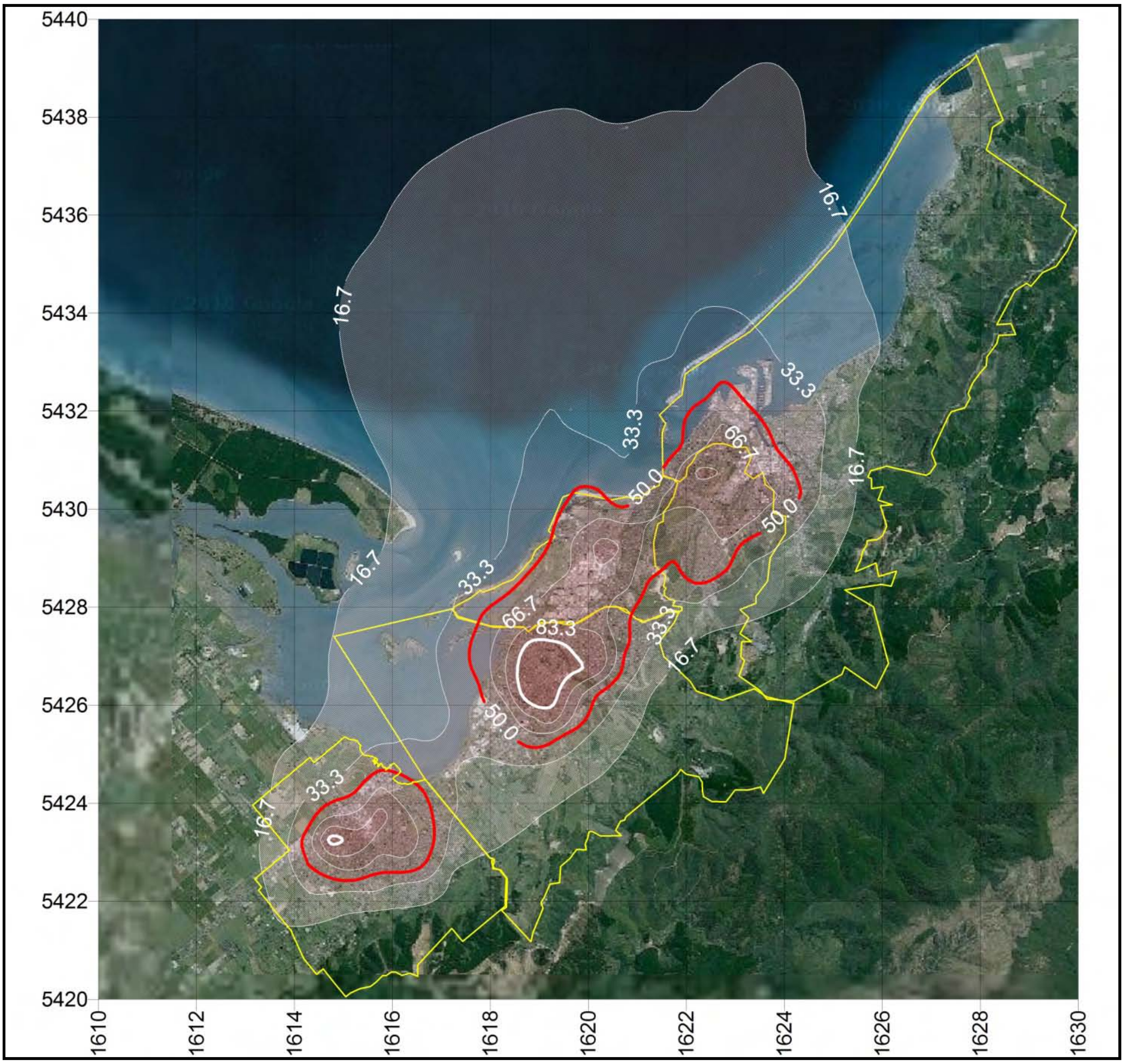

Figure 18: Composite maximum modelled 24-hour-average PM$_{10}$ concentration on the CALPUFF sampling grid. Contour levels are in multiples of one-third of the NES for PM$_{10}$ (the thick red line represents the NES, 50 μg/m^3). Airshed boundaries are in yellow[6].

Spatial patterns of modelled 24-hour-average PM$_{10}$ for four of the case-days discussed in Section 4.2 are shown in Figure 19. The modelled highest PM$_{10}$ occurs at each monitoring site on 15 June (see Figure 19(a)), with the results for this date being consistent with the composite maximum PM$_{10}$ for 2008 occurring over a large area on this date (Figure 18). The other case-days have differing levels of PM$_{10}$ between the urban centres, so that elevated PM$_{10}$ levels are not uniform over the area on a given date (and separate urban centres do not share the same peak PM$_{10}$ levels). Figure 19(b) and Figure 19(d) show lower PM$_{10}$ at

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[6] Approximate Nelson airshed boundaries have been determined by digitizing maps contained in the Nelson emissions inventory. The Richmond airshed outline was supplied by TDC as a GIS shape file.

Tahunaui, and Figure 19(c) shows lower PM_{10} in Nelson city (relative to the rest of the domain on those occasions).

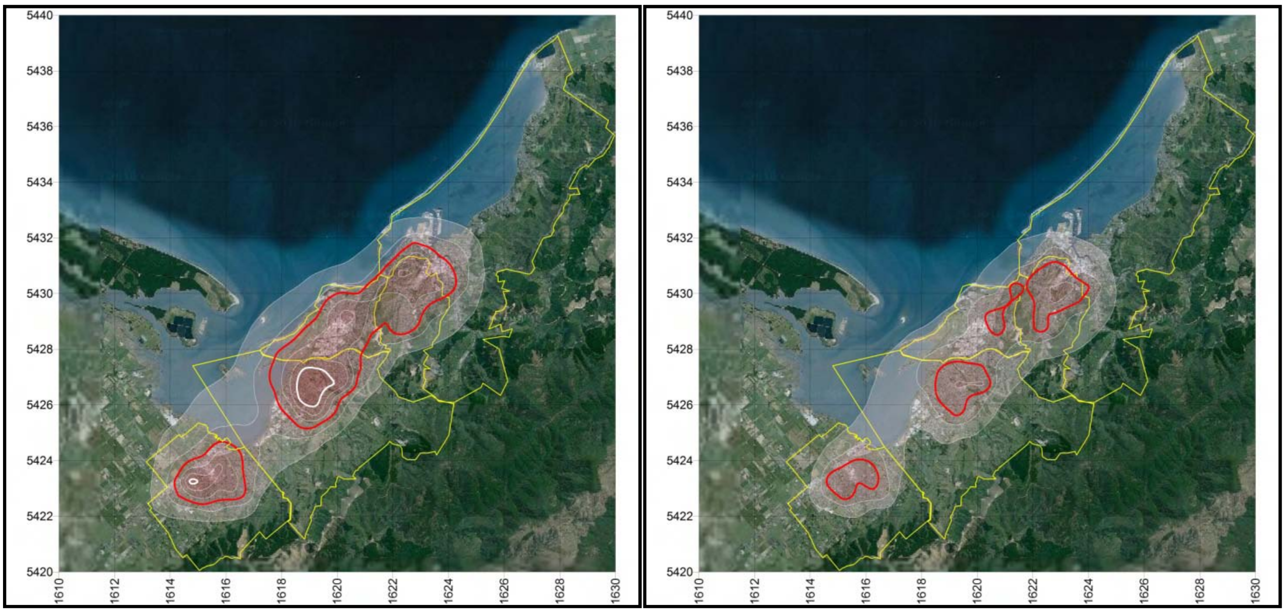


Figure 19(a) 15 June 2008 (case W1) Figure 19(b) 7 May 2008 (case W2)

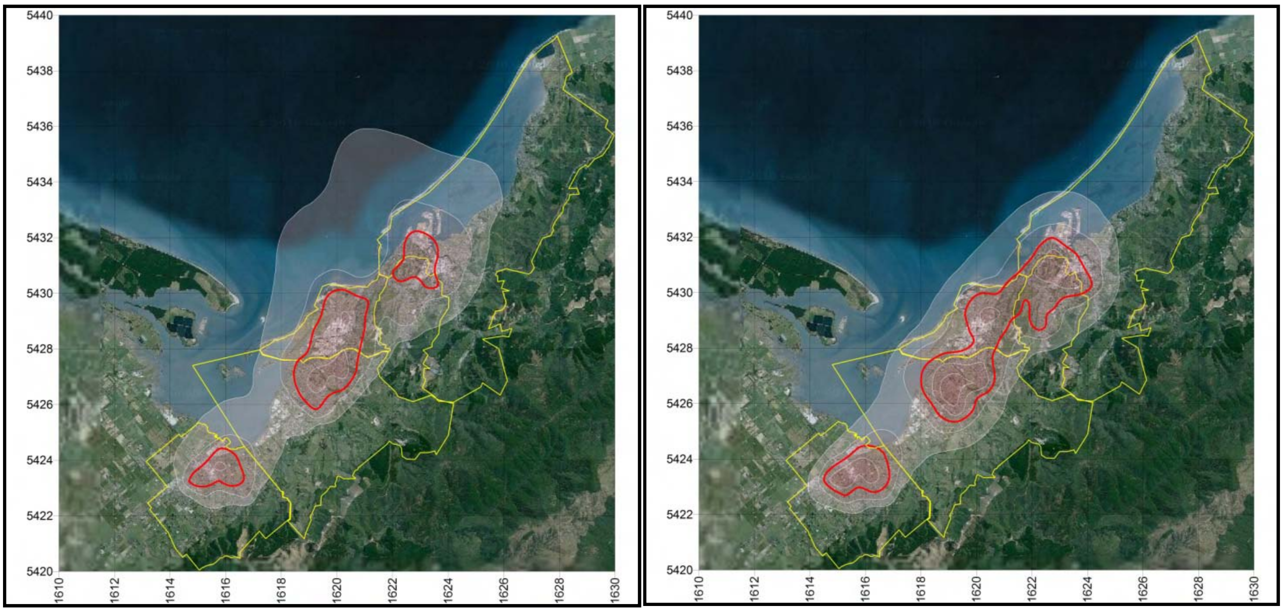


Figure 19(c) 16 July 2008 (case W3) Figure 19(d) 1 August 2008 (case W4)

Figure 19: Modelled 24-hour-average PM_{10} concentration on the CALPUFF sampling grid for selected days. Contour levels are in multiples of one-third of the NES for PM_{10} (the thick red line represents the NES, 50 $\mu g/m^3$). Airshed boundaries are in yellow.

In the examined cases of highest modelled PM_{10}, the wind speed was low. For this reason, the highest impacts occurred over the urban sources, with little dispersion away from them. Hour by hour, the modelled PM_{10} varies within the urban areas due to changes in emissions, with little being visibly transported out of the urban areas. Hence the maximum modelled PM_{10} outside the urban areas, as seen in Figure 18, occurs under more mobile conditions, rather than calm, on days other than those shown here.

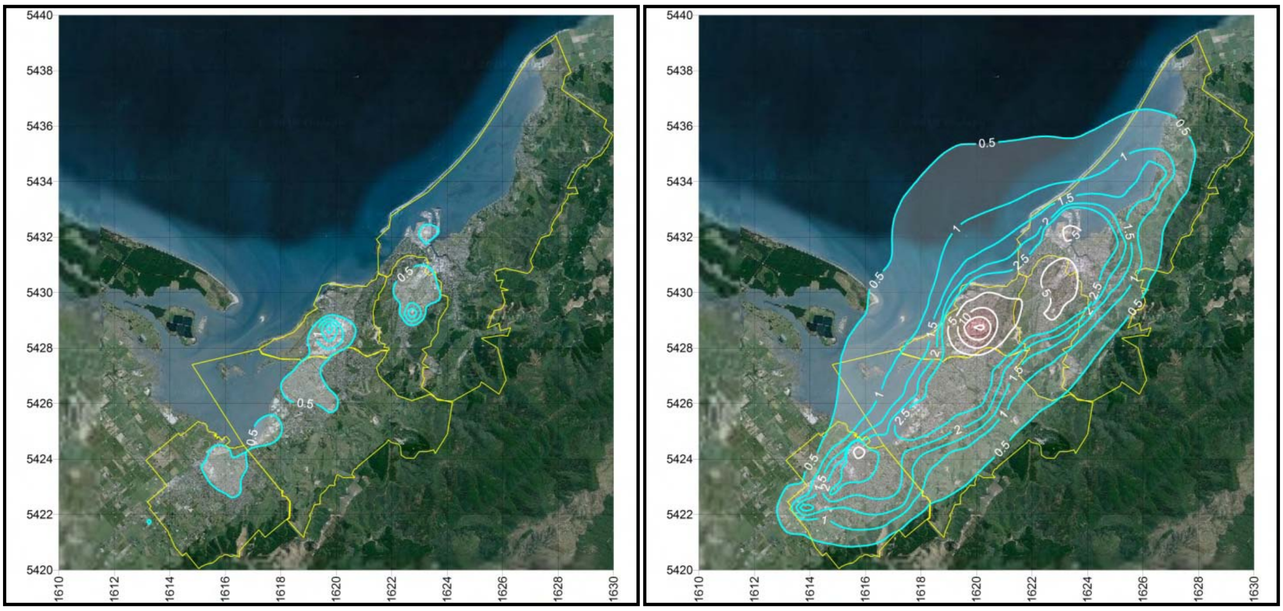
Note that the maps shown in this section do not include naturally occurring PM_{10}. This component of PM_{10} is usually negligible during calm conditions.

4.7.3 Modelled summertime PM_{10}

Examples of spatial maps of summer PM_{10} levels are presented in this section. These maps have been included for completeness at the request of Tasman District Council, despite the relatively poor airshed model performance during the non-winter months (see Appendix F).

As the case studies presented in Section 4.3 have indicated, it is possible that peak PM_{10} levels during summer can occur due to either anthropogenic or natural sources (or a combination of both). Thus the spatial pattern of PM_{10} modelled by CALPUFF only may misrepresent the total modelled PM_{10} (which includes an additional natural component), and care should be taken in the interpretation of the modelled spatial distributions of summertime PM_{10}.

Maps of the 24-hour-average modelled PM_{10} on two of the case study days discussed in Section 4.3 are shown in Figure 20. These maps show contributions from industry and transport sources (but not natural sources). The smallest-scale peaks are due to industrial sources, with the largest contributions from Tahunanui and Nelson hospital. The more diffuse contributions are from motor vehicles, with concentration peaks around one-quarter of the industrial concentration peaks. Note that the relative sizes of the source contributions should be treated with care, as transport emissions have been specified as airshed-wide averages, as has industry in Nelson. With the given form of the transport emissions data supplied for this work, the dispersion model is not able to realistically simulate peaks around industrial sites or roadside hot-spots. The total anthropogenic PM_{10} is different between the two case-days presented. The maximum anthropogenic concentrations shown are 2.3 μg/m^3 and 20.7 μg/m^3 on 22 January and 31 March respectively. However, at the St Vincent Street site, the total PM_{10}, including the sea spray component, is the same on both days (see Table 3).



(a) 22 January 2008 (case S1) (b) 31 March 2008 (case S2)

Figure 20: Modelled 24-hour-average PM_{10} concentration on the CALPUFF sampling grid for selected days. Blue contour levels from 0.5 to 2.5 μg/m^3 at intervals of 0.5 μg/m^3; white contour levels from 5 to 20 μg/m^3 at intervals of 5 μg/m^3.

4.7.4 PM_{10} exceedences

The modelled number of exceedences of the NES for PM_{10} (24-hour-average concentration of 50 $\mu g/m^3$) over the regions has been depicted as a spatial map in Figure 21. At the time of preparation of this report, the NES permitted one exceedence of the PM_{10} standard of 50 µg/m3 per year, with two exceedences constituting a breach of the NES. Areas experiencing two or more exceedences are shown in Figure 21 bounded by the yellow contours, and are confined to the urban areas of Richmond and Nelson. In their centres, the modelled number of exceedences can reach 25 per year.

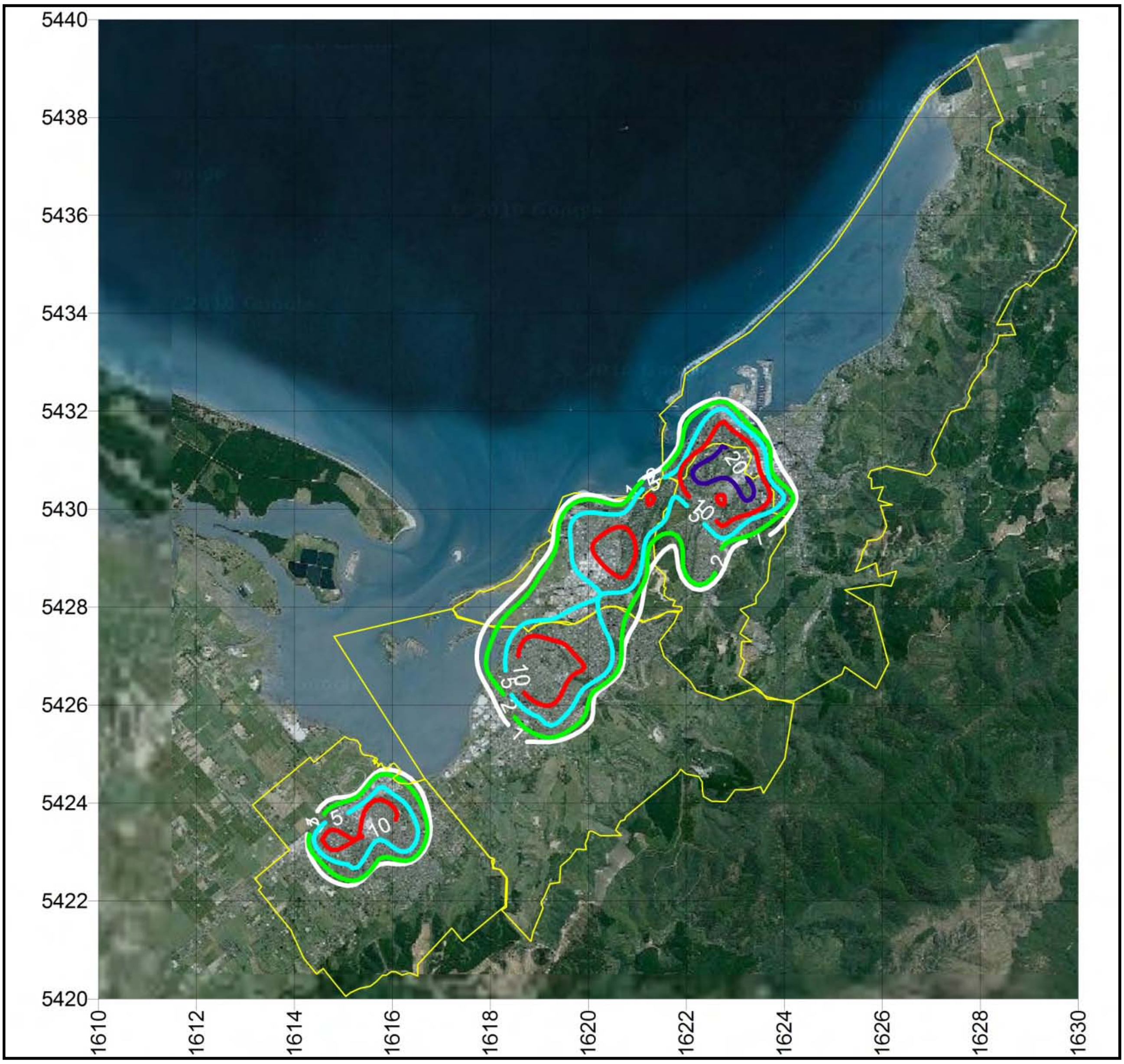


Figure 21: Modelled number of exceedences of the NES for 24-hour-average PM_{10} (concentration 50 $\mu g/m^3$) in 2008. Contours levels denote 1 (white), 2 (green), 5 (light blue), 10 (red) or 20 (dark blue) events.

Section 4.5.3 (above) compares the modelled number of exceedences with the number observed to occur in 2008 at the monitoring sites, with results presented in Table 4. Although in some locations there is a mismatch between the modelled and observed number of exceedences, this can be due to strong spatial gradients in the number of exceedences, as shown in Figure 21. This is especially true around Nelson City, such that the modelled grid cell locations to the southwest, northwest, northeast and southeast of the St Vincent Street location are predicted to have 9, 23, 19 and 23 modelled exceedences, respectively. The St Vincent Street site itself experiences 14 modelled exceedences, compared to 23 observed exceedences. However, at points less than one kilometre from the site the model also predicts 23 exceedences.

Given that determining the number of exceedences of the PM_{10} standard is important for air quality management, its spatial variability should be confirmed by observations and focused, higher-resolution modelling of Nelson City than has been practical for this project. It has not been practical to model the whole urban area (and surroundings, in case of recirculation of pollutants) at a resolution better than 500 m.

In general, prediction of the number of exceedences of an air quality target (per year) has proved to be a challenge for modellers, and it is not generally done well. There are a number of reasons for this, some particularly relevant to New Zealand, and a few are listed here:

i) There may be strong spatial gradients in the true number of exceedences, due to roadside hotspots, or sharp changes in wind speed and direction.

ii) Models (and their inputs) are generally tuned to reproduce 'average', rather than 'extreme', conditions.

iii) Real-life domestic heating emissions are a function of meteorology and human behaviour.

iv) There are a number of uncertainties inherent in the modelling process, which have a greater effect on the tail-ends of the concentration distribution than on mean conditions. The uncertainties can arise from the following, for example:

    (a) Emission input uncertainties and unusual emission conditions.

    (b) Meteorological data or meteorological modelling uncertainties.

    (c) Dispersion model performance, random or systematic errors.

    (d) Spatial representativeness of observations being inconsistent with model resolution.

    (e) Small-scale effects being unresolved, leading to apparent randomness in concentrations, not accounted for in the model.

There are several ways in which these may be overcome, and research is currently in progress to address some of the issues.

4.7.5 Comparison of winter modelling with current airshed boundaries

This section outlines a method by which model results may be used to define (or refine) airshed boundaries. Urban and industrial airsheds were defined by Regional Councils and Unitary Authorities at the time the NES were introduced, to delineate likely NES-compliant or non-compliant areas. As more than half a decade has passed, more information on air quality from monitoring and modelling has become available, and it may be appropriate to re-visit the original airshed definitions. Some revision of airshed boundaries has already occurred in NZ. Outlines of the airsheds of Nelson and Richmond are shown in Figure 18 to Figure 21 of this report.

The urban airshed modelling carried out here can be used to potentially refine airshed boundaries, and for domestic-heating and industry-dominated areas a first approximation may be that non-compliant areas are bounded by the 50 $\mu g/m^3$ contour in Figure 18. These may be designated as 'airsheds', in that within these bounds, the NES are not complied with under current emission levels. Figure 25 shows magnified versions of Figure 18, focussing on individual airsheds, and emphasizing the modelled 50 $\mu g/m^3$ contour as a potential airshed boundary.

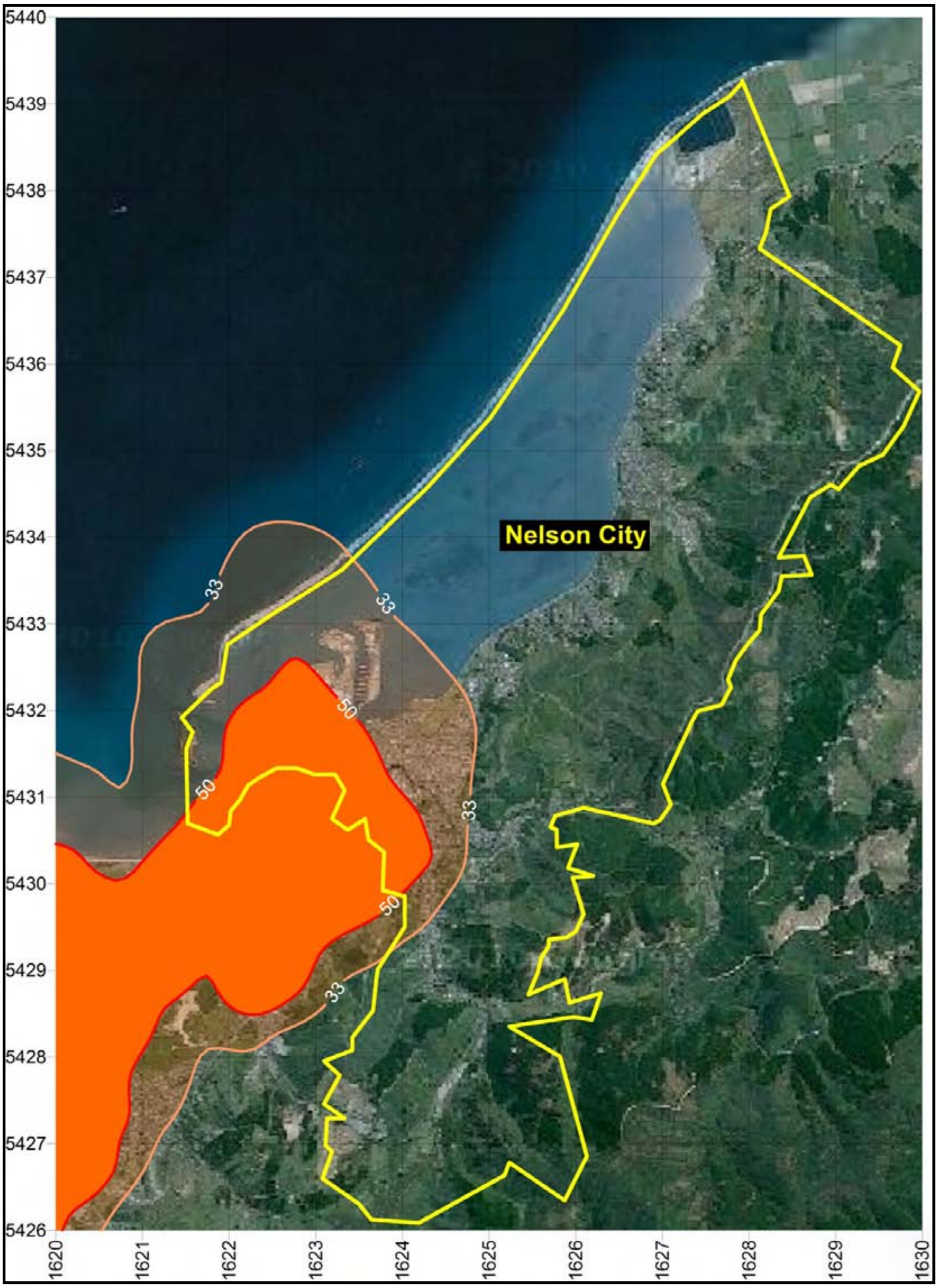


Figure 22: Comparison of Nelson City airshed boundary with modelled PM_{10} (24-hour average concentration contours 33 $\mu g/m^3$ and 50 $\mu g/m^3$).

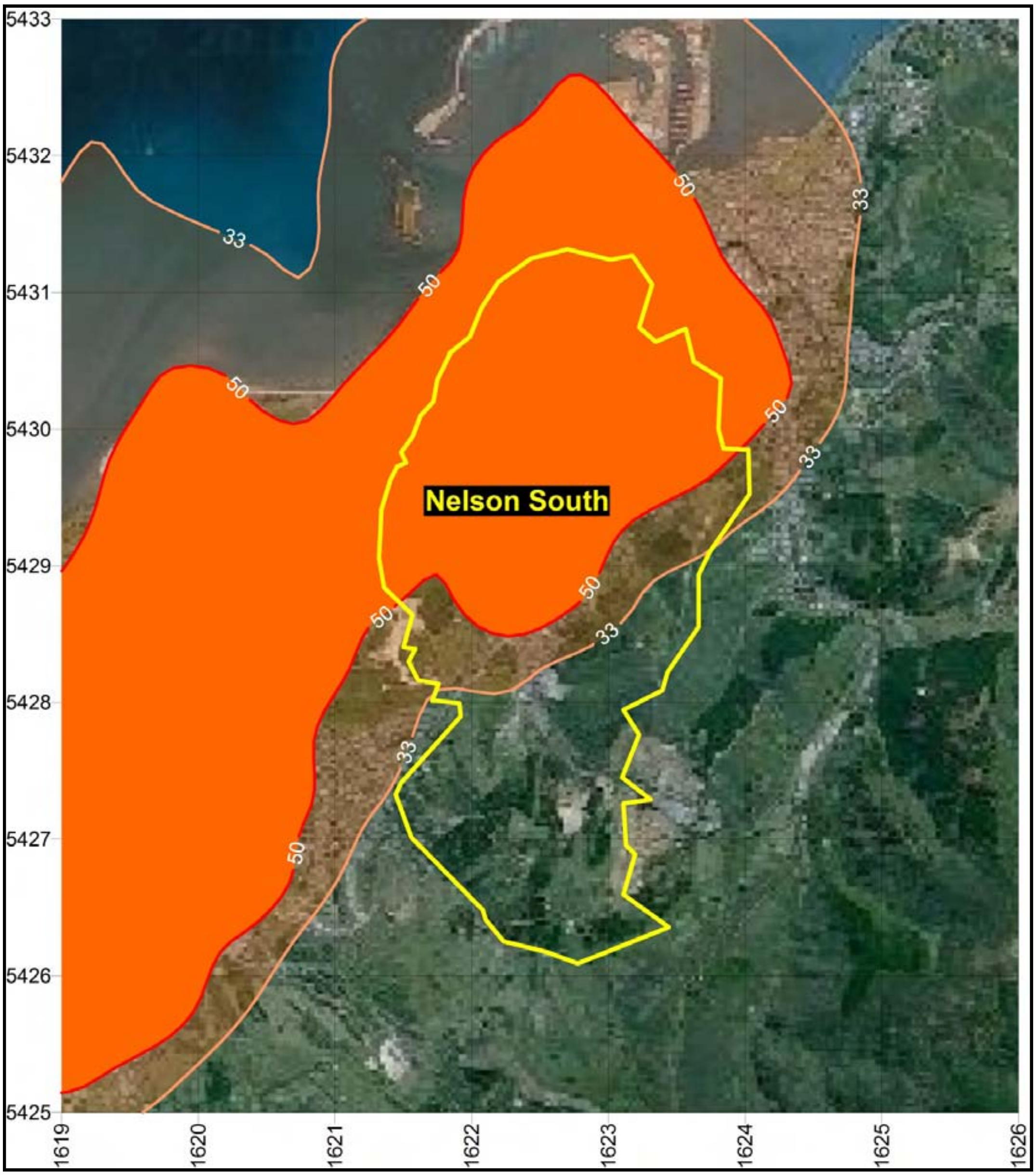


Figure 23: Comparison of Nelson South airshed boundary with modelled PM_{10} (24-hour average concentration contours 33 $\mu g/m^3$ and 50 $\mu g/m^3$).

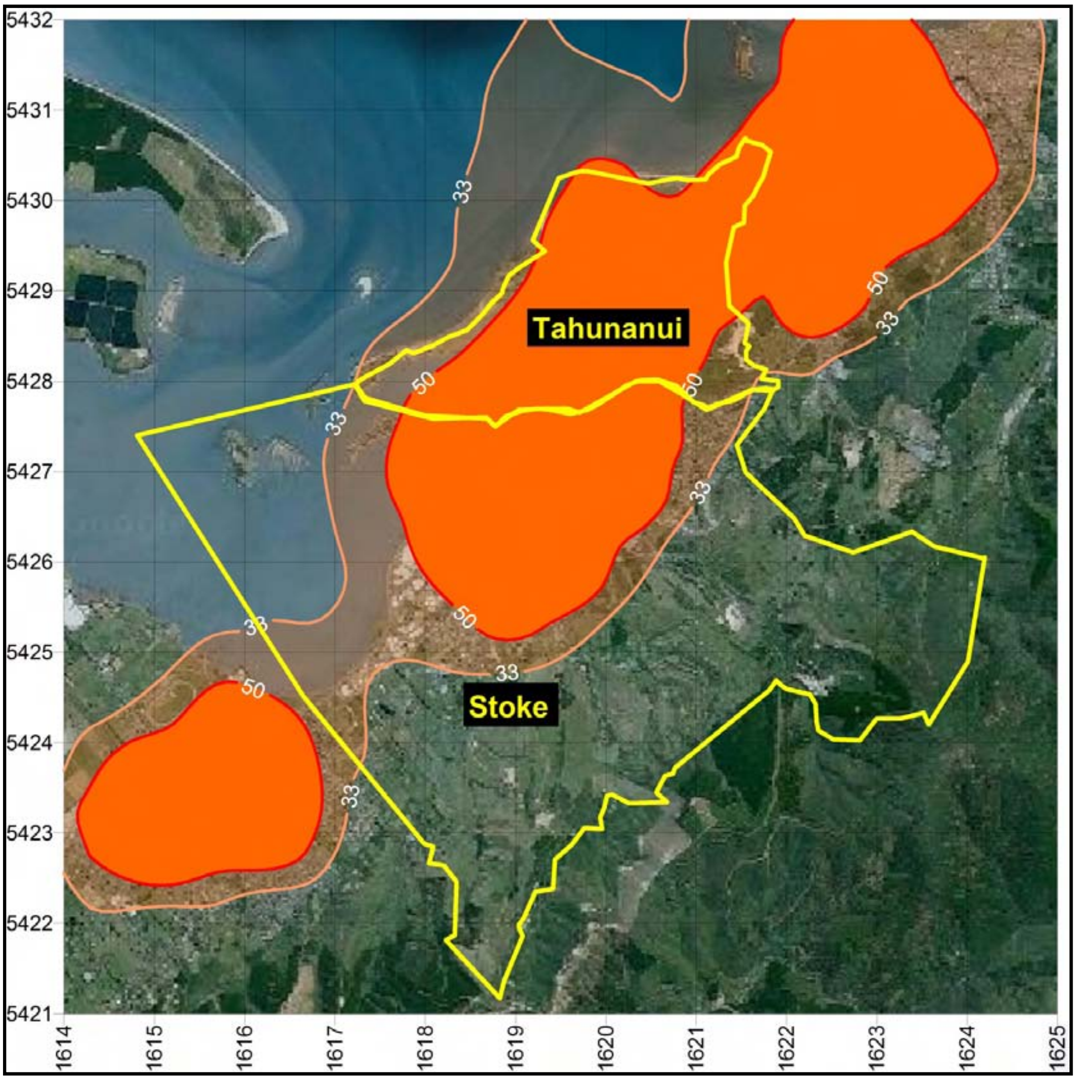


Figure 24: Comparison of Tahanui/Stoke airshed boundary with modelled PM$_{10}$ (24-hour average concentration contours 33 μg/m^3 and 50 μg/m^3).

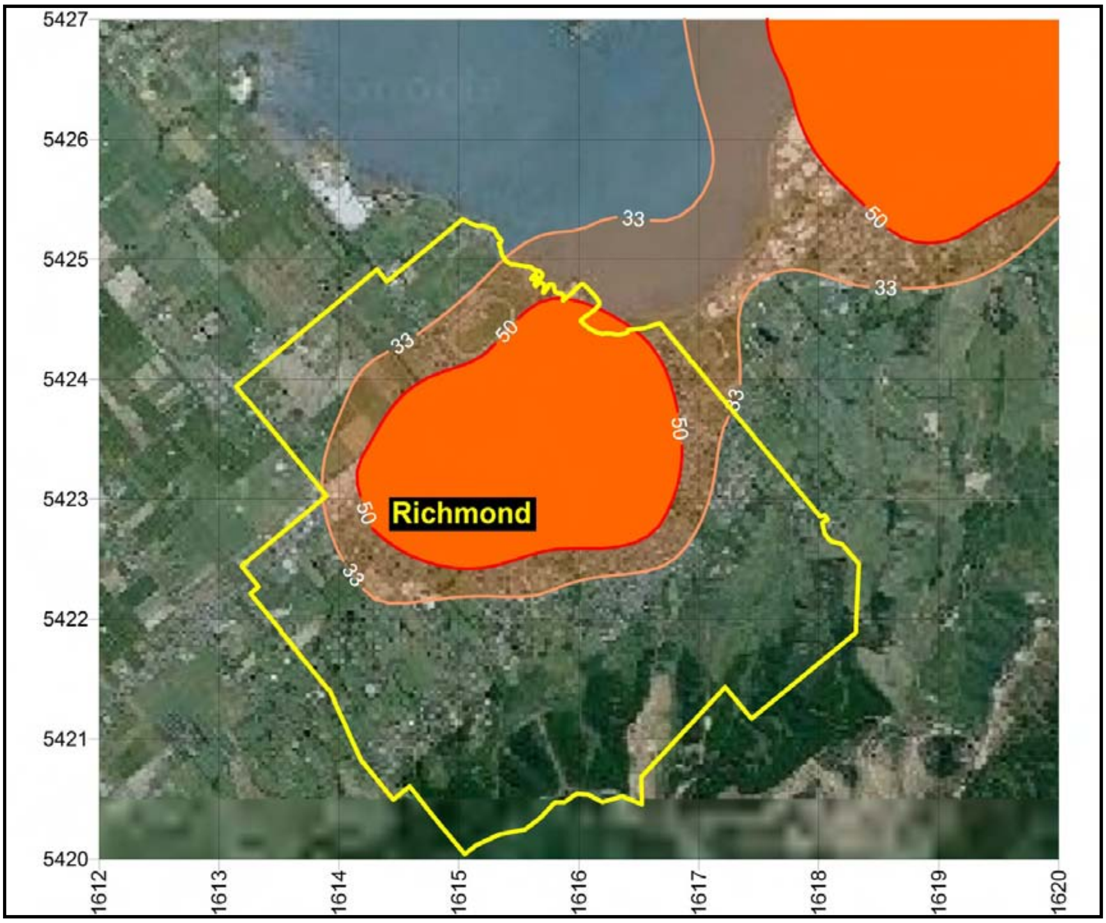


Figure 25: Comparison of Richmond airshed boundary with modelled PM_{10} (24-hour average concentration contours 33 $\mu g/m^3$ and 50 $\mu g/m^3$).

Figure 22, Figure 23, Figure 24 and Figure 25 indicate that the airsheds appear to have been conservatively defined, in that the modelled non-compliant regions (peak PM_{10} greater than 50 $\mu g/m^3$) are contained within the gazetted airshed boundaries. The current airsheds include some rural areas, but it is not simply a matter of excluding these, as there is some drift of PM_{10} away from the airsheds during peak events. In particular, most of the urban area of Nelson (that is the western portion of the Nelson City airshed) has a modelled PM_{10} peak of greater than two-thirds the NES criterion concentration, but only a small area has a modelled PM_{10} peak greater than the NES criterion itself (Figure 22). The modelling indicates that the northern coastal suburbs, such as Marybank and Atawhai, do not experience high PM_{10} concentrations; their domestic heating emissions have been represented in the model as level-2 sources.

Similarly, the modelled PM_{10} reaches more than two-thirds of the NES criterion in the northern half of the Nelson South airshed (Figure 23), such that the non-compliant area would appear to include Nelson South, but not Bishopdale. In Nelson Airshed B, the modelled levels of PM_{10} can exceed 50 $\mu g/m^3$ over most of Tahunanui (Airshed B1), but only over the urban/residential part of Stoke (Airshed B2), as shown in Figure 24.

The Richmond airshed includes the CAUs labelled Richmond North and Richmond South in the emissions inventory (Environet, 2005), and an adjacent region to the southwest of this, which is mostly rural. The region of peak modelled PM_{10} greater than 50 $\mu g/m^3$ extends over the main urban/residential area of Richmond and the industrial area along Beach Road, but not over the adjacent area to the southwest, or the rural areas to the southeast or northwest (see Figure 25). Note that no emissions information from industries to the northwest of Richmond, along Lower Queen Street, was supplied to Golder for the airshed modelling.

The modelling presented in this section indicates airshed boundaries for areas predominantly influenced by domestic heating, and should be treated as preliminary results. A refined approach should be taken for areas with a larger industrial component, and for areas potentially dominated by road-traffic effects, such as the State Highway 6 along the coast north of Nelson city. Also, there is a possibility that PM_{10} model results for Nelson are conservative. It is thought that hilltops over 100 m are clear, even on high pollution days. However, the model results indicate that a concentration of 50 µg/m^3 may be reached along hilltops as well as the valleys between (and the inventory indicates high emissions in these areas). This may be a deficiency in CALMET's simulation of terrain blocking effects, or a model-resolution issue in this locality. These would be investigated as part of a refined approach to a review of airshed boundaries which also better incorporates road-traffic and industry effects.

In addition to an assessment of likely non-compliant areas (under 2004-2006 emissions), the airshed model would have value in assessing those areas under current emissions or projected emissions for 2016 and 2020, the NES target dates.

4.7.6 Comparison of winter modelling with mobile monitoring

Mobile monitoring of winter pollution was carried out over several nights in July 2008 in Nelson and Richmond (NIWA, 2010) to examine spatial variability of particulate pollution. Real-time measurements were carried out as the vehicle was driven around the streets, and extrapolated to infer spatial patterns of pollution for the campaign nights. Ratios of concentrations (PM_{10}, PM_1, black carbon) were used to infer the sources of pollution (natural, diesel combustion, wood smoke).

The mobile monitoring results have been compared with the wintertime PM_{10} airshed modelling results presented in this report, and the result of that comparison is discussed in this section. There are obvious differences between the two approaches. The mobile monitoring was carried out over a few days, whereas the airshed modelling covers the whole season. The mobile monitoring was carried out over a set of one-dimensional paths and extrapolated to cover a two-dimensional area, whereas the airshed modelling operates on a grid of cells 500 m by 500 m. Nonetheless, there are several similarities between results presented by NIWA (2010) and those presented in this work.

The mobile monitoring identifies a number of 'hot spots' of PM_{10} in the area. These are local maximum concentrations in Nelson City, Stoke, a secondary maximum in the residential area of Tahunanui, and a maximum in the westernmost portion of Richmond's urban area. The airshed modelling also produces those local hot-spots in Nelson, which can be seen in the composite maximum 24-hour-averaged PM_{10} (Figure 18), and in several of the case-day plots of (Figure 19). These examples coincide with areas of highest emission rates, and occur under calm conditions during which emitted PM_{10} remains close to its source.

A localized peak in the modelled PM_{10} in Richmond occurs in the composite maximum Figure 18, and in case W1 (Figure 19(a)), the day on which the maximum concentration occurred at each monitoring site). This coincides with the hot spot identified by NIWA (2010). It arises in the airshed modelling due to a localized peak in emissions (a small-area modelled source which is entirely built-up with no green space), which leads to a maximum concentration under calm conditions. It is not visible in the other case studies shown in Figure 19(a), indicating that the mechanism by which it occurs in the model is not that proposed by NIWA (2010). NIWA proposed that the peak to the west of local terrain features occurs through blocking of the south-westerly flow and the accumulation of emitted PM_{10} at that location. If the mechanism suggested by NIWA is correct, then the feature should be ubiquitous, and if modelled correctly should occur on more than one occasion. The airshed model as configured here – to cover the region at 500 m horizontal resolution – does not resolve this terrain feature, so would not be expected to simulate the terrain blocking effect. However, it is arguable whether the small-scale, low hill would have such a strong influence on the meteorology, even in stable conditions. The high pollution observed may still be due to an emissions hot spot in a larger area of calm winds.

5.0 DISCUSSION ON AIRSHED MODELLING

5.1 Introduction

Airshed modelling results have been presented in Section 4.0. The following presents a summary of those results, including discussion on several aspects of the dispersion modelling. Summaries of model performance for winter and summer are given, including recommendations for further improvements in the modelling (Sections 5.2 and 5.3). Some comments on air quality in Nelson and Richmond are made in Section 5.4, related to features observed in the monitoring which have presented challenges to the modelling. A list of potential further applications of the airshed modelling to airshed management in the Nelson and Tasman regions is provided in Section 5.5, with recommendations for further investigation of urban air quality by NCC and TDC summarized in Section 5.6.

5.2 Winter-time PM_{10} Modelling

CALPUFF performs well in cases where the PM_{10} is dominated by domestic sources. Model performance statistics have been shown to be mostly good. There is some sensitivity in the modelled PM_{10} to hour-by-hour fluctuations of wind speed when it is below 1 m/s, but this is also the case for the observed PM_{10}.

Some common characteristics of PM_{10} events during winter in Nelson and Richmond have been seen in the airshed modelling results, as follows:

i) PM_{10} concentrations are sensitive to wind speed and mixing height.

ii) PM_{10} concentrations are not sensitive to wind direction, being local effects, and being at low wind speeds when direction is difficult to define. But, the maximum PM_{10} appears to occur under southerly or southeasterly conditions.

iii) PM_{10} concentrations vary between monitoring sites – and therefore between urban areas – according to the meteorology at those locations.

iv) The modelled wintertime PM_{10} events have by far the largest contribution from domestic heating sources, with some industry contribution apparent at the Blackwood Street site.

There is some variation between monitoring sites in the proportions of total PM_{10} due to individual source-types, whereby the average proportions over the whole season of domestic heating, transport, industry and sea spray are 75 %, 10 %, 10 % and 5 %, respectively, at St Vincent Street, 70 %, 5 %, 20 % and 5 % at Blackwood Street and 90 %, 5 %, 0 % and 5 % at Oxford Street.

5.2.1 Hour-by-hour domestic emissions profiles

Emission sources have been given on the mesh block or airshed scales, with given hourly distributions through the day and night. Some testing of the time-dependence of the domestic emissions information has been carried out. This was prompted by observations of PM_{10} levels remaining elevated after midnight, when emissions have supposedly ceased. However, perturbations of the hourly distribution of emissions (while keeping the same 24-hour total) have lead to only small changes to model results, and do not explain the persistence of PM_{10} levels after midnight. We suspect that there is an overnight phase of domestic PM_{10} emissions arising in addition to an evening's wood burning, rather than the known emissions occurring later. During this time it is possible that smouldering wood in a burner nearly shut down could emit large amounts of PM_{10} than is incorporated into current inventories. Golder has succeeded in deriving a reasonable configuration for the specified domestic heating sources, which leads to reasonable results for modelled ambient PM_{10}. However, we recommend that the latest NZ research from domestic heating emissions testing in 'real-life' situations be incorporated into future inventory development.

5.2.2 Modelling PM_{10} NES exceedences

The number of exceedences in a year is a difficult quantity to model. It requires the distribution of concentrations to be simulated well at the high end of the range, rather than simply the highest individual concentrations. As a result, predicting the number of exceedences is not often done well. There are a number of possible reasons for this and it is the subject of active research in the international modelling community. Golder is conducting research into this subject under the Foundation for Research Science and Technology (FRST) 'Healthy Urban Atmospheres' programme, and will focus on model performance and the specification of emissions information.

In the current work, the number of exceedences in a year has been generally underestimated for the Nelson and Richmond areas. This may be due to deficiencies in the meteorological modelling of extreme conditions, such as calm winds. Alternatively, it may be due to the observed number of exceedences occurring under extreme, rather than typical, emissions. Also, there are challenges in the modelling of the spatial distribution of concentrations, such as sharp horizontal gradients, which can mean the number of exceedences changes rapidly from location to location within varying terrain and emission rates. Finally, it is clear from a review of overseas research that uncertainties need to be accounted for in a statistical manner, as there are unresolved components of modelled and measured air pollutant levels, which have to be expressed in terms of random probability distributions. This has a particular bearing on the highest concentrations, but would also give a more robust and detailed picture of how well different parts of the modelling procedure are performing. It should then give firmer pointers to those parts whose improvement could give the best improvement overall.

5.3 Summertime PM_{10} Modelling

For the non-winter months there is a model under-prediction of total PM_{10}. There are several likely reasons for this, as follows:

i) Localized transport effects are not resolved by airshed-based transport emissions;

ii) Localized industry effects are not resolved by airshed-based industrial emissions (this applies to Nelson);

iii) Local industry specified as individual sources (in Richmond) cannot be modelled well due to the absence of most stack parameters from the available emissions information;

iv) Peaks in sea spray amounts are not accounted for in the simple linear-regression model used to predict concentrations arising from this source;

v) There may be significant wind-blown dust or re-suspended road dust which are not modelled.

These aspects would be present in winter-time, but are not apparent due to the dominance of PM_{10} from domestic heating. Improvements in the modelling of dispersion during other seasons would be achieved through addressing items (i) to (v) above.

Items (i) to (iii) are related to the way emissions have been specified for the modelling. CALPUFF is capable of modelling dispersion on small scales near localized sources, provided that emission inputs are in a suitably detailed form. The information required is available, but may not be included in emissions inventories. We would recommend that future emissions inventories should have regard to the information needs of dispersion models, if the provision of model inputs is to be one of the purposes of an inventory.

As an aside, there may be other anthropogenic sources which have not been accounted for, such as shipping emissions from the port of Nelson. Such emissions have been found to be, or are suspected to be, significant in other cities in New Zealand.

Items (iv) and (v) relate to natural sources of PM_{10}. As their contribution in the summer appears to be of the same order as the contribution from anthropogenic sources, models for these components should be more realistic. This is a challenge, as improvements would be based on empirical information, rather than simple models.

5.4 Other Air Quality Issues in Nelson and Richmond

In the course of examining environmental data from Nelson and Richmond, several questions have arisen regarding meteorological and urban air quality processes in the region. These are independent of any modelling carried out, but their examination would serve to improve model simulations. Aspects of interest include the following:

a) There are elevated levels of PM_{10} at the Blackwood Street site during the daytime, whose source is not understood. They may be due to PM_{10} from domestic emissions persisting from the previous night, a local industrial source, or peak traffic along State Highway 6 south and east of the industrial area.

b) The months of May, June and July exhibit a strong relationship between calm and cold conditions and elevated PM_{10} levels, as would normally be expected in winter. However, this relationship is not as strong in August, in that there are similar PM_{10} levels in August to the other winter months, but under windier conditions. Some investigation is needed into the reasons for this. For instance, there may be higher emissions from domestic heating, or a higher level of natural emissions.

c) There are two possible explanations for the sharp spatial gradients of PM_{10} in Richmond (according to mobile monitoring and airshed modelling). The emissions inventory suggests a local hot-spot of domestic emissions, but there may also be terrain effects. If there is a dynamical reason for the gradient, from terrain blocking for example, then it is considered by Golder that neither the mobile monitoring carried out by NIWA, nor the airshed modelling (which does not resolve the small hills in Richmond) have yet demonstrated this.

5.5 Applications to Airshed Management

The focus of this work has been the development and testing of an airshed model for the Nelson and Richmond urban areas, and their surroundings. This has been necessary to ensure that sources of data have been treated correctly in the modelling, that the model has been configured correctly, and gives realistic results, reproducing present-day air quality conditions in the region. Several potential applications have been listed in the following, along with some recommendations on how the work may be carried out. Golder notes that although mentioned in the original RFP, these applications are outside the scope of the original agreement between NCC, TDC and Golder. However, expansion of the original versions of the following items, and the further analysis contained in the results sections above, have been carried out subsequently as a variation to that agreement.

1) **State of the Environment reporting**: This possibility has been put forward by NCC and TDC, whereby information on current air quality from the modelling could be used to supplement monitoring data used in environmental reporting. While this is possible, it has not been done in New Zealand. Model results could be included for illustrative purposes, but information from monitoring would be more conclusive, and should therefore take preference. However, model results for peak PM_{10} levels may be used to identify current NES non-compliant areas, as shown in Figure 25. In addition, source-apportioned model results may be used to supplement source apportionment analysis of PM_{10} monitoring, and projections of future PM_{10} could be presented (given projections of emission levels).

2) **Ambient air quality monitoring review**: The airshed modelling may be used to identify 'hot spots' of PM_{10} pollution (high concentrations and large number of exceedences) and used to recommend new locations for monitoring sites. As can be seen in Figure 18, the modelling indicates several local maxima in PM_{10} concentration. These are reasonably close to the existing monitoring sites. Although the model maxima are not in exactly the same locations as the air quality monitoring sites, disagreement with model results would not be a strong enough reason to move the existing sites. Also,

the historical record of air quality at the current locations would be interrupted were the site to be moved. However, there is a modelled hot spot of PM_{10} over Stoke, and for a more complete picture of air quality over Nelson as a whole, establishment of a new site would be recommended. According to the model results, the hot spot would be near the intersection of Nayland Road and Songer Street.

3) **Meteorological monitoring**: Data from monitoring sites are not necessary to run CALMET, as the meteorological fields can be supplied by a weather prediction model (in this case, MM5). However, the meteorology of the region has previously been found to be quite difficult to model, and the dispersion modelling carried out here has benefited greatly from meteorological data from Nelson and Richmond. Although the urban areas are quite well-served by meteorological monitoring, any future focus on the Waimea Plains would benefit from additional monitoring there. As explained in this report, data from the Brightwater site could not be used in the modelling, and it could be advantageous to reinstate that site. It would give an enhanced picture of flows and recirculations in the area.

4) **Airshed boundary review**: This has been addressed in Section 4.7.5, where it was identified that the currently defined airsheds of Richmond and Nelson cover larger areas than those indicated by the modelling to be non-compliant with the NES. This is not to say that the current airsheds should be reduced in extent, as there may be a number of other reasons for determining their current extent.

5) **Emissions reduction scenarios and compliance with the new NES**: The effects on local air quality of policy decisions on emissions reduction can be assessed using the model, by using projections of future emissions as model inputs. The scenarios may involve changes in individual source-types, or in sub-areas of the region, or at any level of detail supplied in emissions information. This is a major strength of dispersion modelling – its ability to assess air quality in new locations, or in the future, in the absence of ambient concentration data. Given current and projected emissions, the modelling may be used to assess the potential effects on air quality under a variety of emissions scenarios. These may be ‘business as usual’ (with projected population changes), or when emissions reduction measures are taken and ultimately complied with. Reduction measures may include banning of certain home-heating types, or imposing their replacement by low-emission appliances. Compliance with the NES can then be assessed. Alternatively, the emissions reductions required for NES compliance can be determined, and compared with emissions projections, or translated into the number of appliance conversion or removal.

6) **Inter-airshed dispersion**: Running the airshed model with emissions from each airshed separately can give a measure of the amount of PM_{10} transported between airsheds. This has been reported on in Section 4.3.

7) **Baseline PM_{10}**: The airshed model results may be used to provide an estimate of the (spatially-varying) urban baseline of PM_{10}, to assess the cumulative effects of industries, as part of their resource consent applications. Depending on the level of sophistication required, the time-variation of baseline PM_{10} may also be incorporated in assessments. With the advent of the NES, accounting for baseline pollution levels has become an important component of industrial assessments, and robust, sophisticated methods are beginning to be employed – including the use of airshed modelling. Golder has reviewed several methods for incorporating baseline PM_{10} into industrial assessments (Golder, 2009(b)). A valuable extension to the current work would be the provision of baseline levels of SO_2.

5.6 Summary of Recommendations to NCC and TDC

Recommendations for further work, appearing among the discussion topics of Sections 5.0 to 5.5, have been collected together in this section for consideration by NCC and TDC. This section is divided into operational matters for the Councils (Section 5.6.1), and recommended refinements and extensions to the modelling as presented so far in this report (Section 5.6.2). Other air quality aspects for investigation, not directly related to modelling, are listed in Section 5.6.3. The aspects outlined here have already been mentioned.

5.6.1 Council operational matters

The following council operational matters were mentioned in Section 5.5, items (2) and (3).

Modelling of PM_{10} dispersion in the Nelson/Richmond produced local peaks largely consistent with locations of air quality monitoring sites. In addition to the sites already in place, Golder recommends commissioning of an air quality monitoring site (including meteorological monitoring) in Stoke.

The urban centres are well served by meteorological monitoring. However, the Waimea Plains and potential valley drainage flows may not be captured by the current monitoring. Accordingly, Golder recommends re-establishment of the Brightwater meteorological site with up-to-date monitoring equipment.

5.6.2 Suggestions for airshed modelling refinement and extension

Several applications of the modelling to air quality management have been partially addressed in this report. These are listed here, along with suggestions for further work.

Airshed boundary review: Examination of peak PM_{10} areas in relation to current airshed boundaries has been examined in Section 4.7.5.

State of the Environment reporting: Section 5.5, item (1).

Modelling emissions reduction scenarios: Section 5.5, item (5). Such work would benefit from refined emissions inventories, incorporating recent emission factors from real-life testing of domestic fires, emissions projections, and the incorporating the industries northwest of Richmond. It would also benefit from an inventory of industrial sources individually, rather than airshed totals.

Cross-boundary dispersion of PM_{10}: See Section 4.3.

Use of airshed modelling to describe baseline levels of PM_{10}, for industrial applications: See Section 5.5, item (7).

Refined modelling of industrial and transport effects, in particular to improve modelling of summer conditions: As mentioned above, such work would need an inventory of industrial sources, including all stack parameters – such as height, exit velocity and temperature – in addition to emission rates. Effects of motor vehicle emissions at the roadside would need a different modelling approach, using a transport-specific dispersion model.

Modelling of exceedences: A refined approach would include some probabilistic aspects, as discussed in Section 5.2.2.

Other natural sources of PM_{10}: The airshed modelling contained in this report has been augmented by the consideration of marine aerosol PM_{10} from sea spray. It is possible that crustal matter (or soil dust) may be a significant component under certain conditions. This has not been addressing in the current work, but Golder recommends that conditions under which crustal matter is present be determined to allow a simple model to be developed for this source, incorporating it into the modelling results.

Baseline pollution levels for industrial applications: This is mentioned above in relation to PM_{10}. The concept may be extended to examine baseline levels of sulphur dioxide (SO_2), as this is an NES criterion pollutant more usually associated with industry.

5.6.3 Other air quality aspects for further investigation

There are some aspects of air quality in Nelson and Richmond, which have arisen from examination of air quality and meteorological data from the area, which may warrant further examination. These are listed as follows:

Determination of source of PM_{10} at the Blackwood Street site during daytime: Section 5.4, item (a).

Relationship between PM_{10} levels and meteorology (August is different from the other winter months): Section 5.4, item (b).

Closer examination of the spatial gradients of PM_{10} in Richmond: Section 5.4, item (c).

6.0 METEOROLOGICAL DATA SETS

As part of this project, Golder has produced meteorological data sets for supply to consultants for use in industrial applications. The data sets are in the form of CALMET outputs over an area covering Nelson and Richmond at 250 m resolution for the years 2008 and 2009, and in form of AUSPLUME meteorological files at selected locations in the region. These files are available electronically (the CALMET outputs and AUSPLUME meteorological files may be obtained from NCC and TDC). Appendix G constitutes a guide to the use of the data files, and may be read in isolation[7] from the bulk of this report, which is concerned with airshed modelling. However, the reader is referred to detailed descriptions of the production of CALMET and AUSPLUME data sets in Appendices B and H, respectively.

The data sets themselves may be obtained on portable hard disk from Nelson City Council or Tasman District Council. The letter accompanying the data serves as a ‘readme’ file for the contents of the disk, and is attached as Appendix I to the main report.

7.0 STRATEGIES FOR MAINTENANCE OF MODELLING

This section discusses the likely needs of NCC and TDC regarding the maintenance and improvement of the meteorological and airshed modelling and resulting data sets.

7.1 Meteorological Data Sets

From Golder’s experience, although CALMET/CALPUFF is regularly updated by TRC Solutions, there have not been significant changes to CALMET itself (aside from bug fixing) for a number of years. Therefore, CALMET outputs supplied as part of this project should be relevant for some years to come. Also, we would expect that their format will be compatible with future versions of CALPUFF. Nevertheless, we would recommend a review of the meteorological modelling every two years, for the following reasons:

i) to confirm that the CALMET outputs are indeed compatible with the latest version of CALPUFF (and carry out a straightforward update if they are not);

ii) to reflect changes in best practice among the scientific community;

iii) to incorporate feedback from users.

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[7] As Appendix G may be read as a stand-alone document, there may be some duplication of text, figures and references between Appendix G and elsewhere in this report.

7.2 Airshed Model

In tandem with the meteorological model reviews, we would recommend a review of the airshed modelling every two years, or following any significant upgrade to the emissions inventory, for the following reasons:

a) to check CALPUFF model compatibility at the same time as checking the meteorological data sets;

b) to assess whether the airshed model should be updated to the latest version CALPUFF (depending on how CALPUFF has changed);

c) to incorporate updated emissions inventory information;

d) to reflect developments in science;

e) to respond to the operational policy-decision needs of TDC and NCC.

8.0 CONCLUSION

This work has been concerned with the development of an airshed model of the urban air quality of Nelson and Richmond, and with the supply of meteorological data sets to users for industrial air quality assessments.

A summary of findings is contained in the Executive Summary, with recommendations and suggestions for further work summarized in Section 5.6, and a strategy for maintenance of the data sets created outlined in Section 7.0.

The focus has been on producing good-quality, physically-realistic results. Future work will be concerned with further applications of the airshed model to air quality management issues and decision-making, for it to be used as a primary tool for assessment of current and prediction of future air quality in Nelson City and the Tasman District.

9.0 REFERENCES

(This list contains all papers, reports and books referred to in the previous sections or the Appendices to this report).

Barna, M.G. and Gimson, N.R., 2002: Dispersion modelling of a wintertime particulate pollution episode in Christchurch, New Zealand, Atmospheric Environment 36, 3531-3544.

Chilton, R.L., 1999: Meteorological influences on air pollution of a Canterbury town: Ashburton New Zealand. Master of Environmental Science Thesis, University of Canterbury.

Davy, P., Trompetter, B., Markwitz, A., 2007. Source apportionment of airborne particles in the Auckland region. GNS Science consultancy report 2007/314, December 2007.

Environet, 2005: Richmond emission inventory 2004. Report prepared for Tasman District Council by Emily Wilton, April 2005.

Environet, 2006: Air emission inventory – Nelson 2006. Report prepared for Nelson City Council by Emily Wilton, October 2006.

Gimson, N.R., 1999: Particulate pollution in Christchurch: a model for emission reduction planning. New Zealand Science Review 56(1-2): 17-25.

Gimson, N.R. and Uliasz, M., 2003: The determination of agricultural methane emissions in New Zealand using receptor-oriented modelling techniques, Atmospheric Environment 37, 3903-3912.

Gimson, N.R. 2005: Modelling the air quality of Auckland - a comparison between CALGRID and TAPM simulations based on observed and modelled meteorology. *Clean Air and Environmental Quality* 39(3): 38-46.

Gimson N., Chilton R., Xie, S., 2010: Meteorological Datasets for the Auckland Region – User Guide. Prepared by Golder Associates (NZ) Limited for Auckland Regional Council. Auckland Regional Council Technical Report 2010/022.

Golder, 2007: Dispersion Modelling in New Zealand. Part 1 – Assessment of Meteorological Models. End-user report under FRST programme Protecting NZ's Clean Air. See http://www.niwascience.co.nz/ncces/projects/air-quality/reports

Golder, 2009(a): Contributions to PM_{10} levels in Napier and Hastings from surrounding urban and rural areas - airshed modelling re-analysis. Report prepared for Hawke's Bay Regional Council, 17 April 2009.

Golder, 2009(b): Evaluation of baseline PM_{10} levels for industrial resource consent applications. Report prepared for Foundation for Research, Science and Technology, June 2009.

Golder, 2011: Population exposure to particulates in Auckland – urban airshed modelling. Report prepared for the Auckland Council, 31 March 2011.

MfE, 2002: Ambient Air Quality Guidelines. Air Quality Report No 32. May 2002.

MfE, 2004a: Resource Management National Environmental Standards relating to certain air pollutants, dioxins and other toxics regulations. September 2004, Ministry for the Environment, Wellington, New Zealand.

MfE, 2004b: Good practice guide for atmospheric dispersion modelling. June 2004, Ministry for the Environment, Wellington, New Zealand.

MfE, 2008a: Good practice guide for assessing discharges to air from industry. May 2008, Ministry for the Environment, Wellington, New Zealand.

MfE, 2008b: Good practice guide for assessing discharges to air from land transport. May 2008, Ministry for the Environment, Wellington, New Zealand.

MfE, 2011: Resource Management (National Environmental Standards for Air Quality) Regulations 2004. http://www.mfe.govt.nz/laws/standards/air-quality/review/index.html.

NIWA, 2006: Airshed modelling of PM_{10} levels in the Hawke's Bay region. NIWA Client Report WLG2006-48, September 2006.

NIWA, 2010: Spatial variation of particulate air pollution in Christchurch and Nelson/Richmond during winter 2008. NIWA Client Report CHC2010-050, April 2010.

Trompetter, W., Davy, P., Barry, B. and Markwitz, A., 2010: Ion Beam Analysis results of air particulate matter collected in Nelson. GNS Science Consultancy Report 2010/99, February 2010.

Turner, D. B., 1964. A diffusion model for an urban area. J. Appl. Meteorol., 3:83-91.

van Jaarsveld, H., Klimov, D., 2007. Modelling the impact of sea-salt particles on the exceedances of daily PM_{10} air quality standards in the Netherlands. Proceedings of the 11th international conference on harmonisation within atmospheric dispersion modelling for regulatory purposes. Cambridge, UK, July 2007.

Wang, H. and Shooter, D., 2001: Water soluble ions of atmospheric aerosols in three New Zealand cities: seasonal changes and sources. Atmospheric Environment, 35, 6031-6040.

Willmott, C. J., 1981: On the validation of models. Physical Geography, 2, 184-194.

Willmott, C.J., 1982: Some comments on the evaluation of model performance. Bulletin of the American Meteorological Society 63: 1309-1313.

Wratt, D.S., Gimson, N.R., Brailsford, G.W., Lassey, K.R., Bromley, A.M. and Bell, M.J., 2001: Estimating regional methane emissions from agriculture using aircraft measurements of concentration profiles, Atmospheric Environment 35, 497-508.

APPENDIX A

Report Limitations

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APPENDIX B

Meteorological Model Configuration

1.0 INTRODUCTION

CALMET has been run to produce the meteorological outputs on which airshed modelling using CALPUFF is based, and to produce outputs to be supplied to users for industrial applications also using CALPUFF. This Appendix describes the methodology followed to produce three CALMET data sets, for the following purposes:

1) Airshed modelling using 2008 meteorology (large domain, 75 x 76 km, resolution 500 m);

2) Industrial applications using 2008 meteorology (small domain, 26 x 26 km, resolution 250 m);

3) Industrial applications using 2009 meteorology (small domain, 26 x 26 km, resolution 250 m).

Most of the following discussion applies to all three data sets, and aside from date changes and model grid configurations, CALMET input parameters for the three runs are the same. A higher resolution was chosen for the industrial data sets, to reflect anticipated shorter-range impacts of individual industries, and a need for more terrain and land use detail closer to the source. CALPUFF modelling of either urban airshed sources or industrial stacks could be carried out using any of the CALMET data sets.

The modelled meteorology consists of three-dimensional hourly wind, temperature and humidity fields, and two dimensional surface-based parameters such as mixing height and Pasquill-Gifford stability class. The model runs cover the urban areas of Nelson and Richmond. The airshed-model run includes a large amount of the surrounding area, in order to simulate longer-range transport and possible re-circulation of air pollutants.

The following sections describe the preparation of input data, including modelled meteorology from the numerical weather prediction model MM5, geographical information such as terrain heights derived from remote sensing (LIDAR, LIght Detection And Ranging), and data from meteorological monitoring stations. Sections 2.0, 3.0 and 4.0 discuss the input data in the order in which the information is used by CALMET to calculate hourly meteorological fields. They are followed by tabulations of CALMET's model configuration parameters in Section 5.0.

The meteorological modelling has been carried out as a basis for the airshed modelling, and to produce meteorological data sets for other users. Although the two modelling exercises have resulted in outputs at different horizontal resolutions (500 m and 250 m, respectively), the modelling methodology and input information have been the same for each. The use of MM5 outputs to provide large-scale approximations to the CALMET solution (prior to the use of high-resolution geographical information and local meteorological data) is a standard practice, recommended by CALMET's developers. It has not been done frequently in NZ, as consultants using CALMET/CALPUFF do not usually have the access to high-performance computing facilities needed to run such models as MM5. For the current work, MM5 data were purchased from Lakes Environmental; for subsequent projects using CALPUFF, MM5 has been run in-house by Golder (Canada).

Appendix G of this report is a user guide to the meteorological data sets for industrial applications. It is self-contained, but the reader may be referred to this Appendix for methodological details regarding CALMET, and to Appendix H for details on the production of AUSPLUME meteorological files.

2.0 MM5 DATA USED AS CALMET'S 'INITIAL GUESS'

The CALMET meteorological processor allows for the assimilation of outputs from MM5, and these are used to generate an initial estimate of each hour's meteorological fields in CALMET. This is known as the 'initial guess'.

Modelled hourly, three-dimensional fields of wind, temperature, relative humidity from MM5 were used in the initial-guess stage of the CALMET run for each hour. MM5 solves the equations of atmospheric motion mathematically to give a physically realistic wind field. Numerical outputs from MM5 were purchased from

Lakes Environmental. These were obtained for the year 2008 (resp. 2009), covering an area 150 km by 150 km (resp. 50 km x 50 km) at 4 km resolution, centred on Nelson (41.298 S, 173.327 E). Eighteen vertical levels were used, the lowest 15 m above ground level. The larger area was purchased to ensure that no modelled pollution dispersed beyond the domain boundary, and determine the range which was actually necessary. It was found that an area 50 x 50 km would be sufficiently large, hence data over the smaller area were purchased for the 2009 modelling.

The spatial resolution of CALMET was higher than that of MM5, with the MM5 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 to produce the CALMET Step 1 wind field (see Section 3.0), and the objective analysis stage lead to the final CALMET fields. No meteorological observations were used until the objective analysis stage, at which point data from surface stations were incorporated (see Section 4.0).

3.0 GRAPHICAL INFORMATION FOR CALMET'S 'STEP 1' FIELD

CALMET requires terrain and land-use data on a regular grid of points. This 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' field.

To determine the detailed terrain elevation, aircraft flights have been carried out over Nelson and Richmond recently with on-board LIDAR remote sensing equipment. The resulting terrain height data, at 5 m contour resolution, have been provided for this project by NCC and TDC. Gridded terrain information for the surrounding area has been derived using Golder's in-house GIS procedures. Land-use data were extracted from Golder's in house database and converted to the CALMET input format.

The airshed model domain has dimensions 75 km x 76 km, consisting of 150 x 152 grid cells of size 500 m x 500 m. Maps of the terrain and land use data used in the CALMET run for airshed modelling are shown in Figure 1 and Figure 2, respectively. The colour-coding for land use categories is shown in Table 1.

The industrial-source model domain has dimensions 26 km x 26 km, consisting of 104 x 104 grid cells of size 250 m x 250 m. Maps of the terrain and land use data used in the CALMET run for airshed modelling are shown in Figure 3 and Figure 4, respectively.

Table 1: Land use categories used by CALMET.

Colour coding on Figure 2 and Figure 4	Land use category
Brown	Urban or built-up land
Yellow	Agriculture
Light green	Rangeland (e.g. shrubs)
Dark green	Forest
Blue	Water
Olive green	Wetland
White	Barren land (e.g. beaches, sand spits, dry river beds)

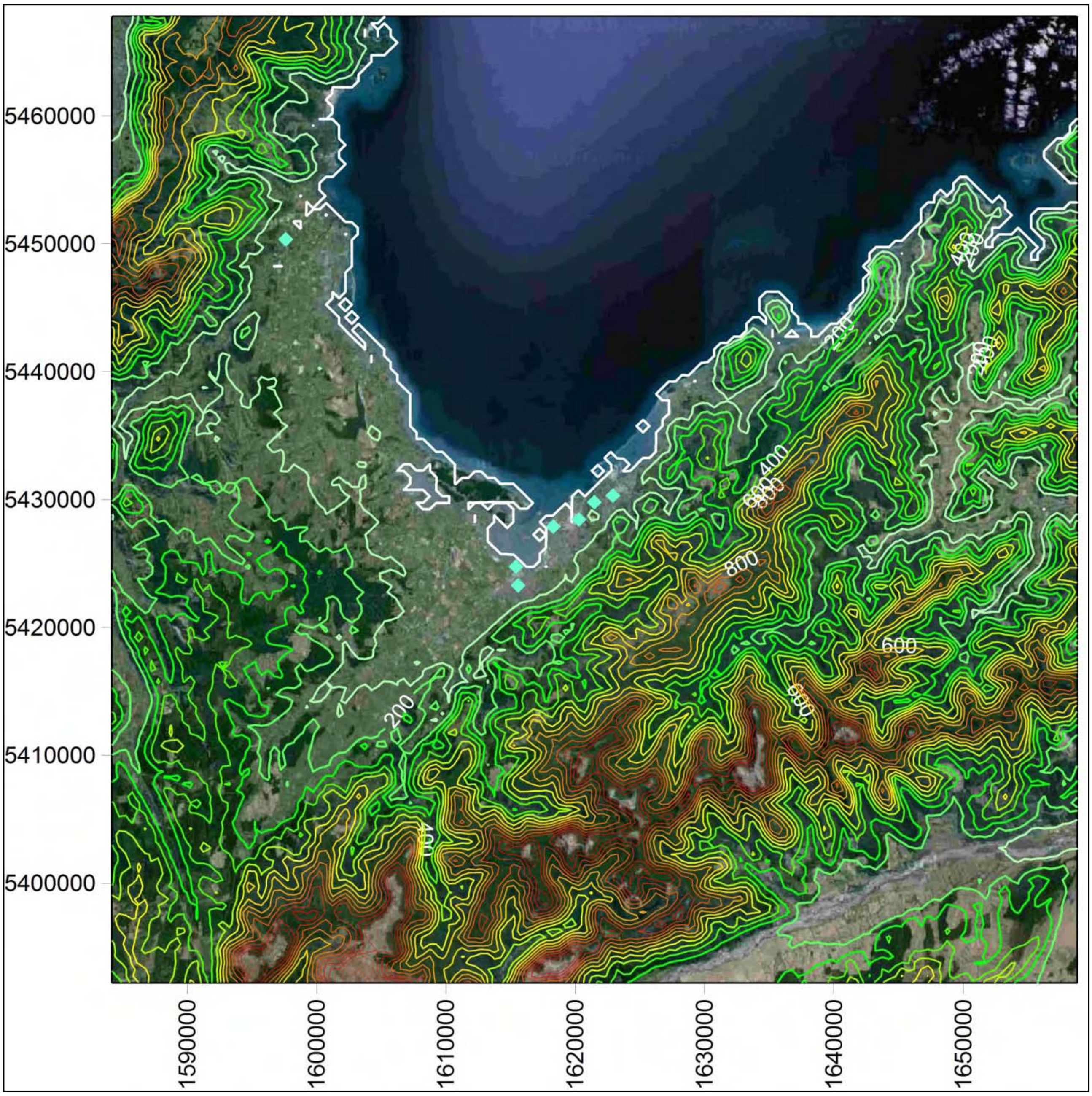

Figure 1: Contours of terrain height used by CALMET for airshed modelling (contour interval 100 m, starting at zero). New Zealand Transverse Mercator coordinates are given in metres. Meteorological stations are indicated by blue diamonds.

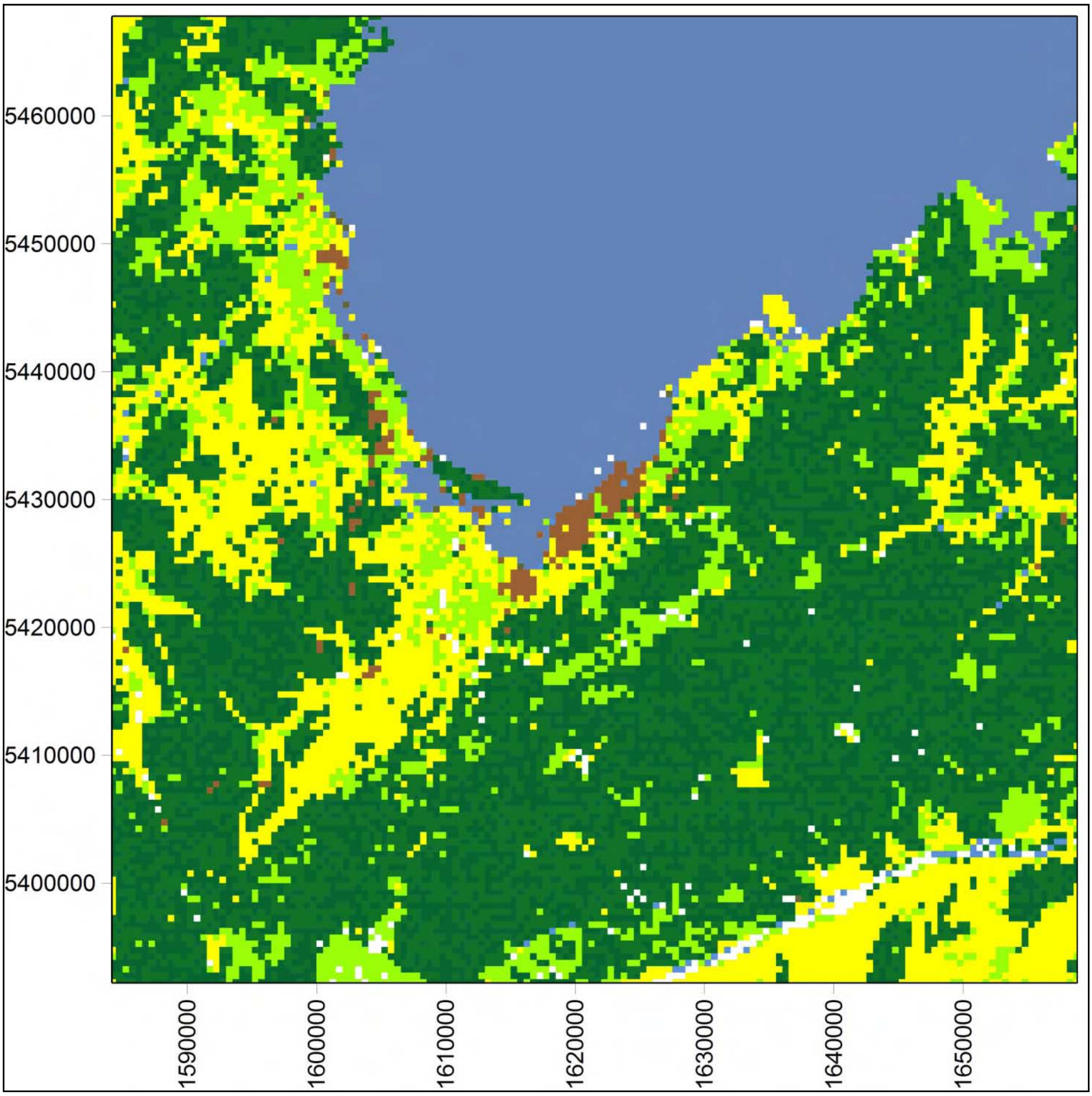

Figure 2: Land-use map for the CALMET airshed modelling domain. Colour coding as listed in Table 1.

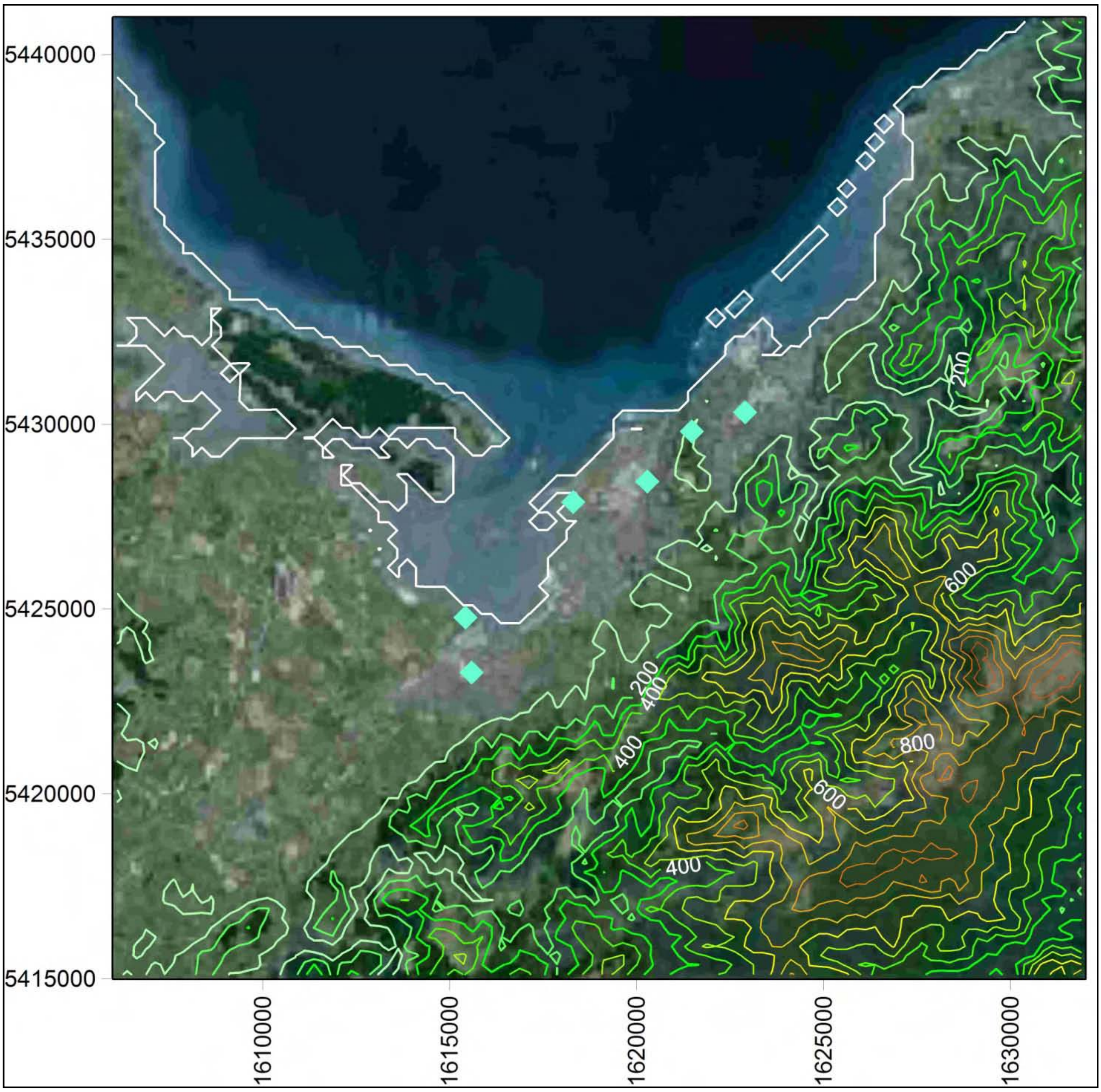

Figure 3: Contours of terrain height used by CALMET for the industrial source modelling domain (contour interval 100 m, starting at zero). New Zealand Transverse Mercator coordinates are given in metres. Meteorological stations are indicated by blue diamonds.

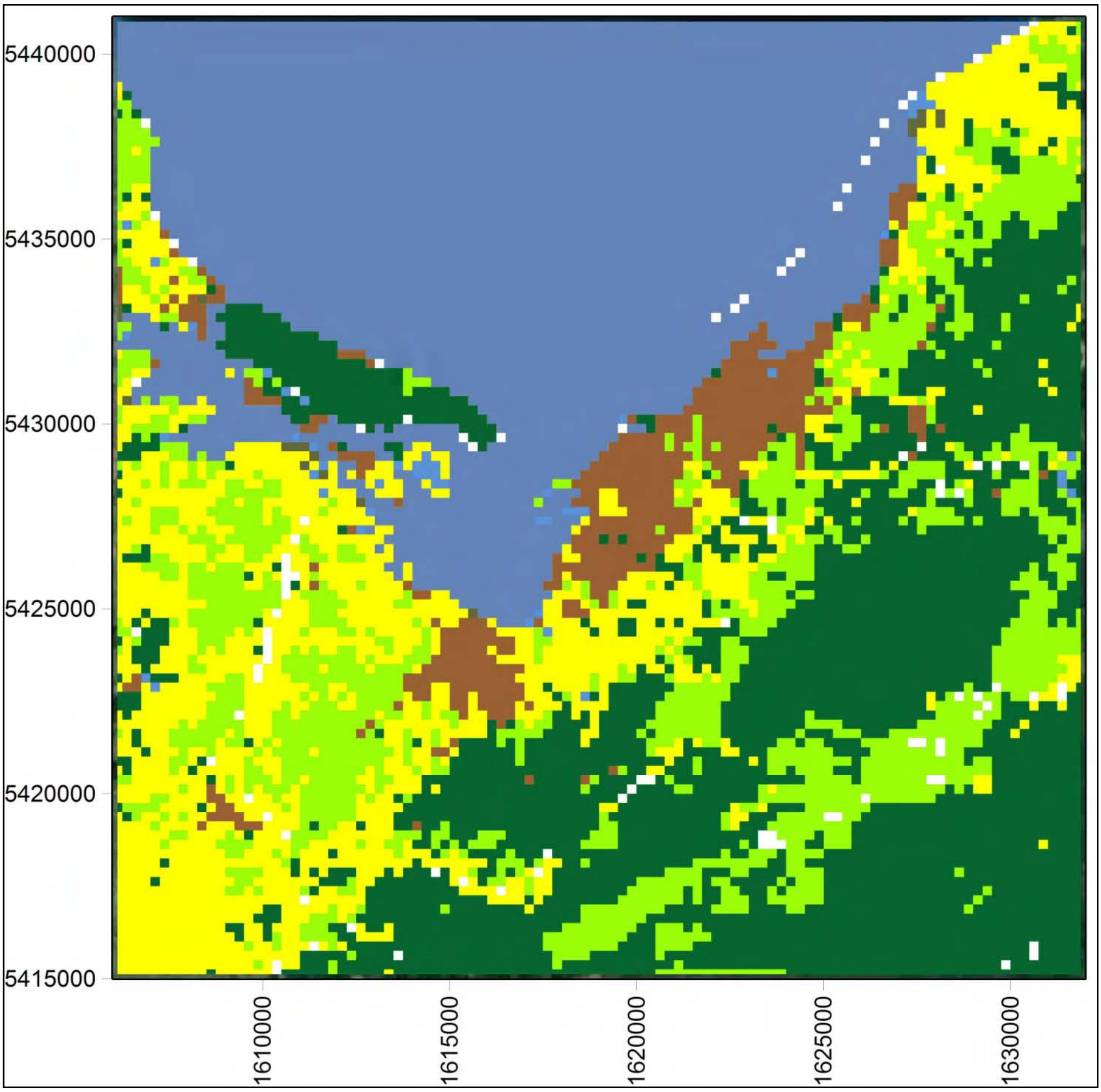

Figure 4: Land use map for the CALMET industrial source modelling domain. Colour coding as listed in Table 1.

4.0 METEOROLOGICAL STATION DATA FOR OBJECTIVE ANALYSIS

CALMET requires meteorological data from local weather stations. Local data are used to ensure that the modelled fields are consistent with observations. Incorporation of local observations leads to the final modelled meteorology, overriding the terrain-driven Step 1 field. Therefore, 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 Nelson/Richmond area operated by NCC and TDC. Data from these (and two others) have been used in the CALMET modelling, as described in this section.

Meteorological monitoring stations have been commissioned by NCC and TDC, measuring surface wind, temperature, humidity, rainfall and wind gusts. These are located at Blackwood Street, St Vincent Street and Princess Drive in Nelson, the TDC office in Richmond, Richmond Park racecourse, and Brightwater. Wind speed data from Brightwater were found to be unreliable. The instrument was old and of low quality, with measured wind speed being generally lower than that at nearby monitors by a factor of three of four. It was not considered reasonable to simply re-scale the wind speeds, and MM5 winds for that location were expected to be more realistic. Therefore, in consultation with TDC, it was decided to not use the wind data from that site. Although the wind *direction* data were reliable, resolution is quite coarse (bearings to the nearest 22.5^0), and the CALMET model requires *both* speed and direction. The site data from NCC and TDC were supplemented by data from stations at Nelson Airport and Motueka (Riwaka), obtained from the National Climate Database (CLiDB).

A summary of the data availability from the meteorological stations is shown in Table 2. Wind speed and direction are available at all seven sites, temperature and relative humidity is measured at six of the seven sites, while rainfall is only available at two sites and pressure at one site. CALMET has been run with a time step of one hour. Hence data provided by NCC and TDC at shorter time intervals have been averaged to one hour.

Wind roses are shown for each of the stations in Figure 5 to Figure 11. Many of the sites show the predominance of northeast or southwest winds parallel to the coastline. However, some show local features such as drainage from nearby hills (for example, Blackwood Street, St Vincent Street and Nelson Airport). The wind rose from Motueka displays quite different features – this site is in a different location relative to the surrounding hills and the orientation of the coastline, and is more sheltered with calmer winds. The differences between wind roses demonstrate clearly the variability in meteorology across the region, and the availability of station data is crucial for the modelling. It is unlikely that a purely model-based approach (which uses no wind measurements) would produce a realistic picture of the complex meteorology of the area[1].

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[1] A sophisticated prognostic model such as MM5 should be able to produce reasonable meteorology of the region. However, it would need to be run at high resolution, and this would be computationally demanding and beyond most resources available in New Zealand.

Table 2: Summary of surface meteorological station data used by CALMET. For National Climate Database (CliDB) stations the ID is the agent number.

Station name	**Station ID**	**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)**
Nelson Aero AWS	4271	MetService	(1618.305, 5427.896)	Wind speed, wind direction, air temperature, relative humidity, pressure, rainfall [2]	01/01/2007 00:00 01/01/2010 00:00	2.36%	99.6%
Motueka, Riwaka EWS	12429	Not found	(1597.621, 5450.361)	Wind speed, wind direction, rainfall	01/01/2007 00:00 01/01/2010 00:00	4.38%	100%
Nelson A&P showgrounds/ Racecourse	1001	TDC	(1615.421, 5424.768)	Wind speed, wind direction, air temperature, relative humidity	01/01/2007 00:00 01/01/2010 00:00	0.37%	100%
Tasman District Council (TDC) building	1002	TDC	(1615.590, 5423.283)	Wind speed, wind direction, air temperature, relative humidity	01/01/2007 00:00 01/01/2010 00:00	1.2%	100%
Blackwood St reserve	1011	NCC	(1620.291, 5428.451)	Wind speed, wind direction, air temperature, relative humidity	01/01/2008 00:10 01/01/2010 00:00[3]	4.72%	84%
Princess Dr	1012	NCC	(1621.478, 5429.803)	Wind speed, wind direction, air temperature, relative humidity	01/01/2008 00:10 01/01/2010 00:00	1.11%	100%
117 St Vincent St	1013	NCC	(1622.902, 5430.321	Wind speed, wind direction, air temperature, relative humidity	01/01/2008 00:10 01/01/2010 00:00	2.57%	100%
Brightwater	1003	TDC	(1608.997, 5419.834)	Wind speed, wind direction, air temperature, relative humidity	*DATA NOT USED*	***DATA NOT USED***	***DATA NOT USED***

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[2] Cloud data were also available from Nelson Airport. However, cloud parameters in CALMET have been diagnosed from the relative humidity in MM5.

[3] There is a gap of 117 days from Feb 2008 to Jun 2008.

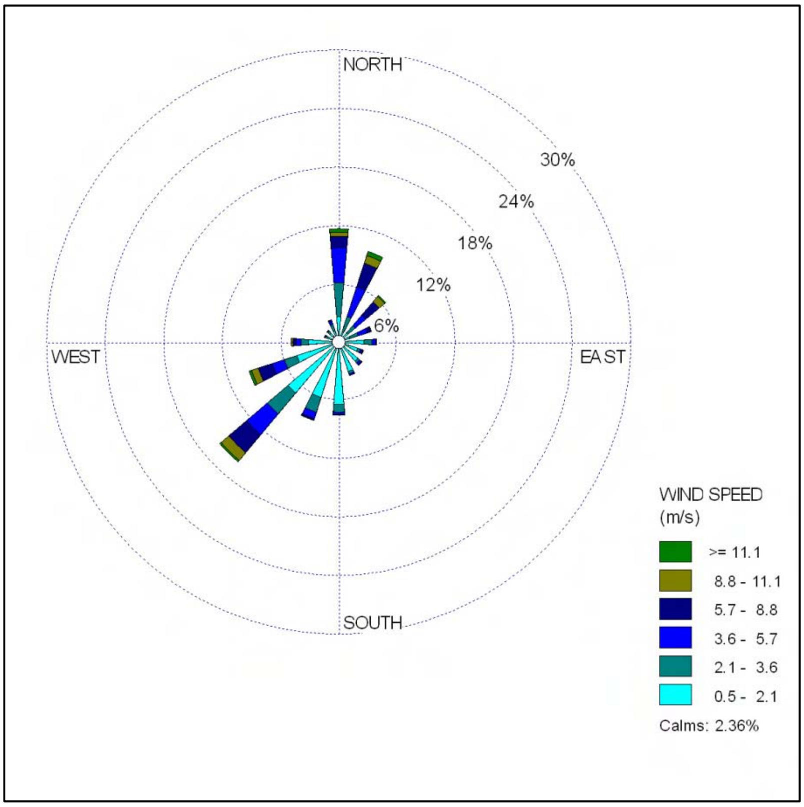


Figure 5: Wind rose, Nelson Aero AWS (CliDB), January 2007 to December 2009.

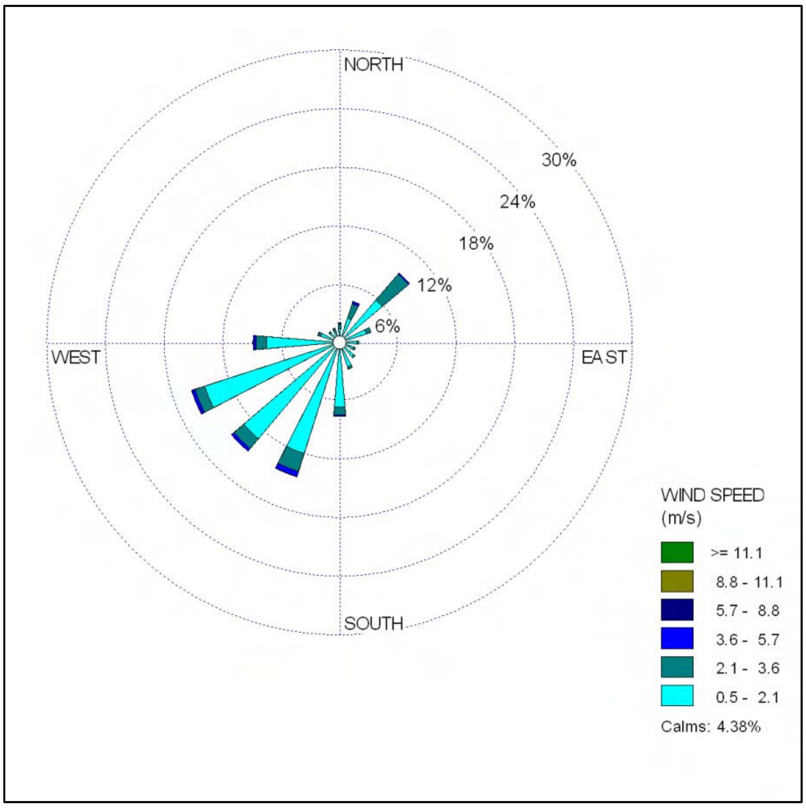


Figure 6: Wind rose, Motueka EWS (CliDB), January 2007 to December 2009.

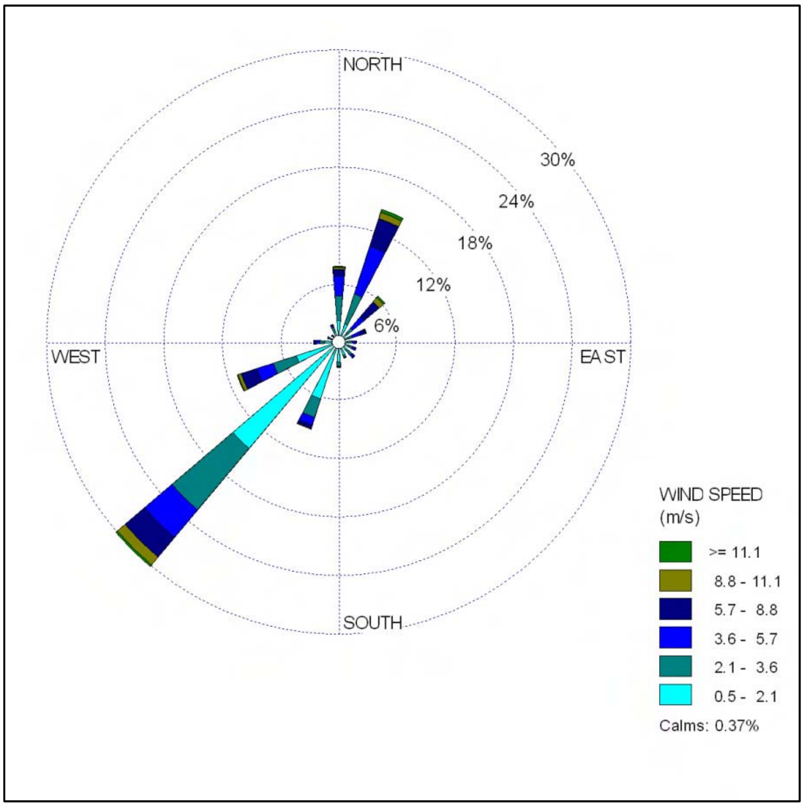


Figure 7: Wind rose, Racecourse (TDC), January 2007 to December 2009.

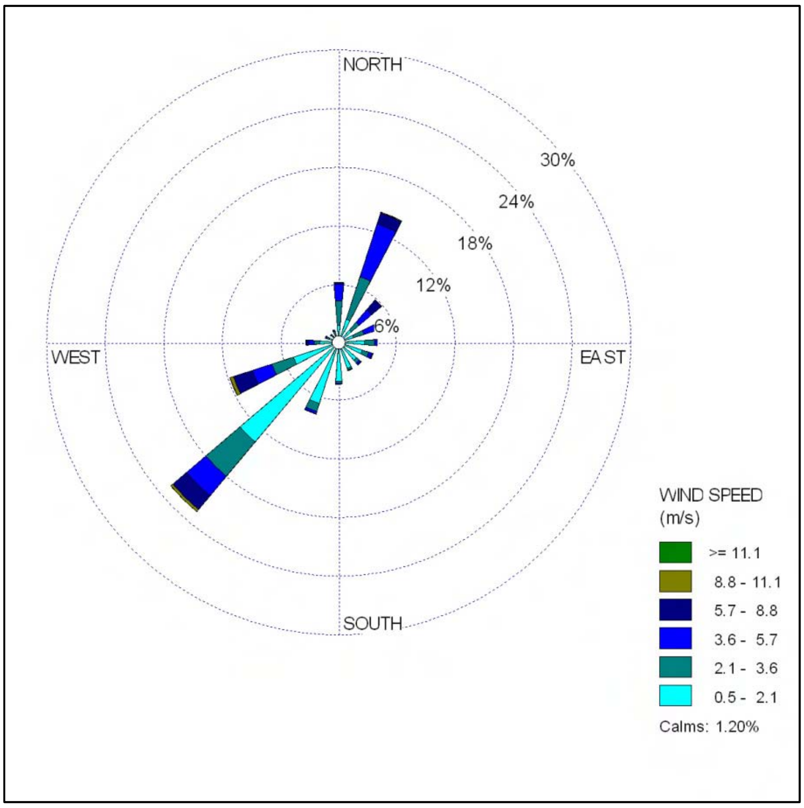


Figure 8: Wind rose, TDC building (TDC), January 2007 to December 2009.

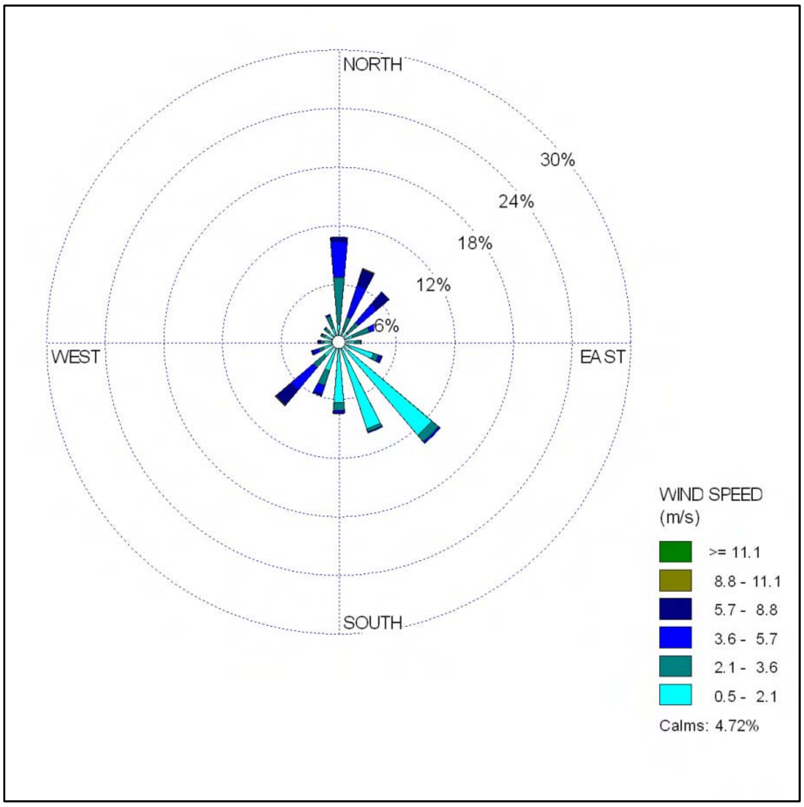


Figure 9: Wind rose, Blackwood St Reserve (NCC), January 2008 to December 2009.

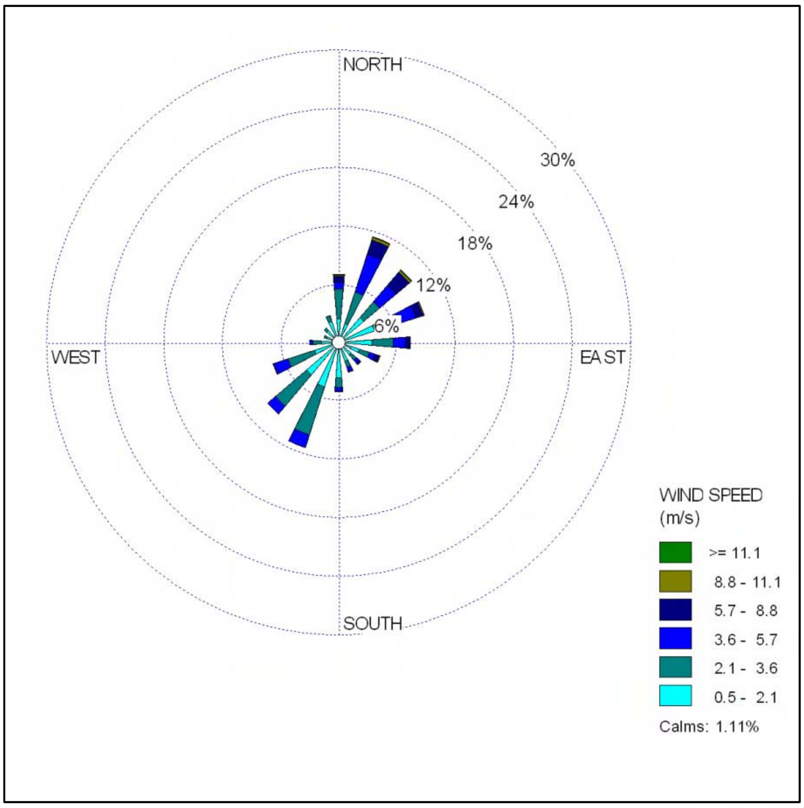


Figure 10: Wind rose, Princess Dr (NCC), January 2008 to December 2009.

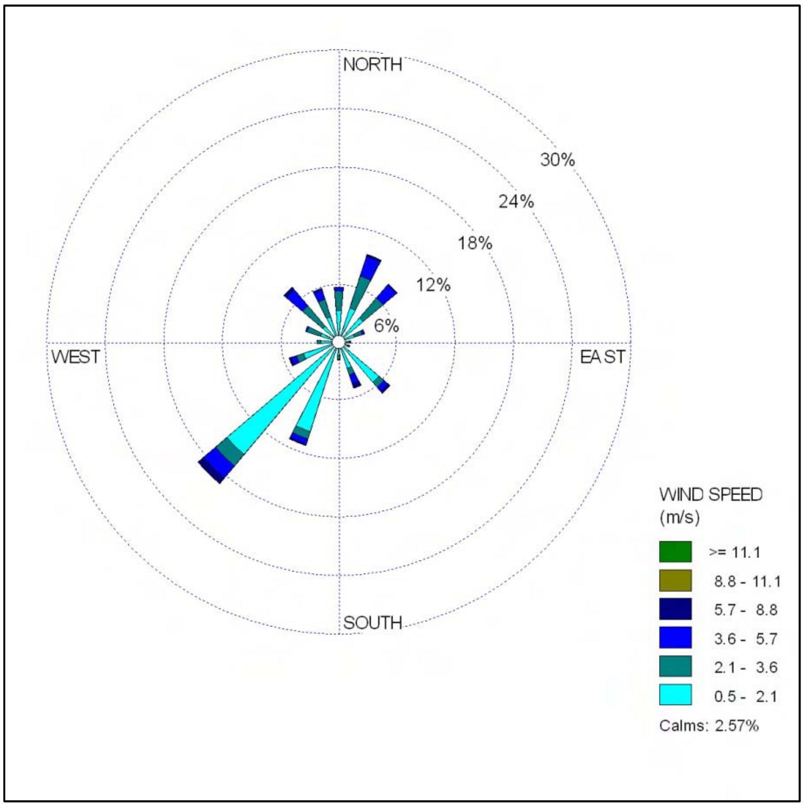


Figure 11: Wind rose, St Vincent St (NCC), January 2008 to December 2009.

Air temperature is measured at a height of 15 m above ground at the TDC office (data have been available since 1995). In 2009, temperature was also measured at 2.5 m and 12 m above ground level. The additional monitoring was carried out to gain an understanding of the structure of the atmospheric surface layer during winter-time inversion conditions. It was also suggested as a source of information for validating meteorological models. Multi-level measurements of temperature and wind can indeed be used to infer some properties of the nocturnal boundary layer (such as stability and turbulence levels) in the absence of direct measurements. Temperature measurements may also be used to evaluate the temperatures determined by a prognostic meteorological model, but it would be unusual for the model to resolve levels so close together. Moreover, CALMET, being a diagnostic model, takes temperature data as input, and therefore those data cannot also be used for validation purposes. In CALMET, the lowest model layer is hard-coded with a depth of 20 m. Consequently, only temperature data from the TDC office at the 15 m level have been used in the CALMET modelling.

5.0 CALMET CONFIGURATION PARAMETERS

The following tables provide details of user-specified parameters for generating hourly, three-dimensional meteorological data sets with CALMET. Parameters which vary between the three CALMET runs are indicated below. Parameters not mentioned here take default values, or they relate to a particular feature of the model that is not used.

Table 3: Run control.

Parameter	Value
Start date/time (2008 runs)	1 January 2008 00:00
Finish date/time (2008 runs)	1 January 2009 00:00
Start date/time (2009 runs)	1 January 2009 00:00
Finish date/time (2009 runs)	1 January 2010 00:00
Time zone	UTC+1200
Time step	3600 s

Table 4: Map projection.

Parameter	Value
Map projection	Tangential Transverse Mercator (TTM) assumed[4]
Datum region	WGS-84
Projection origin	41.298S, 173.237E
False origin (NZTM coordinates)	(1619.842, 5428.134) km

Table 5: Grid control – CALMET for airshed modelling.

Parameter	Value
SW corner of grid cell (1,1)	(1584.000, 5392.000) (km, NZTM)
Grid dimensions	150 x 152 grid cells of size 500 x 500 m
Vertical grid, number of layers	10
Cell-face heights for vertical grid (m)	0, 20, 40, 80, 120, 200, 400, 800, 1200, 2000, 3000

Table 6: Grid control – CALMET for industrial applications.

Parameter	Value
SW corner of grid cell (1,1)	(1606.000, 5415.000) (km, NZTM)
Grid dimensions	104 x 104 grid cells of size 250 x 250 m
Vertical grid, number of layers	10
Cell-face heights for vertical grid (m)	0, 20, 40, 80, 120, 200, 400, 800, 1200, 2000, 3000

---

[4] The coordinate system used in the modelling is not TTM, but NZ Transverse Mercator (NZTM). TTM is chosen in CALMET, as it allows any rectangular coordinate system to be used. The projection origin allows the rectangular coordinate system to be linked to a latitude/longitude system, in order to correctly obtain the sun angle and its influence on the meteorology.

Table 7: Prognostic model options.

Parameter	Value
Use of MM5 for surface or upper-air information	NOOBS = 1; use MM5 for upper-air only
Use of MM5 for wind information	IPROG = 14; use MM5 as initial-guess wind field
Use of MM5 for temperature information	ITPROG = 1; use MM5 for upper-air only
Use of MM5 for relative humidity information	IRHPROG = 0; use surface observations
Use of MM5 for cloud information	ICLOUD = 3; diagnose cloud cover from MM5 relative humidity at 850mb
Use of MM5 for precipitation information	NPSTA = 0; precipitation included in the surface file

Table 8: Wind field options.

Parameter	Value
Extrapolation of surface wind observations	IEXTRP = -4; similarity theory used; only surface station data used in model layer 1 (not MM5 outputs)
Layer-dependent biases	-1, 9x0
Vertical extrapolation of surface winds (RMIN2)	-1.0; extrapolate all surface stations
Maximum radius of influence of meteorological data	RMAX1 = RMAX2 =10 km; RMAX3 = 30 km
Relative weighting of first-guess field and observations (that is, distance from site at which they are equally weighted)	R1 = R2 = 1.0 km
Radius of influence of terrain features	TERRAD = 2 km

6.0 EVALUATION OF THE CALMET MODEL

Evaluation of results from the CALMET model is less straightforward than evaluation other models. Ideally, meteorological model outputs would be compared with observations of wind, temperature, humidity and rainfall, for instance. Many measures of model performance are available, and these have been used for the CALPUFF results in the main body of this report, in the comparison of modelled PM_{10} with measurements of ambient PM_{10}. In the case of CALMET, the observations at monitoring stations have been used as model inputs, and the model automatically reproduces those at those sites. A quantitative performance assessment of CALMET is not possible, and the evaluation consists mainly of an inspection of the output fields from CALMET (in two horizontal dimensions, at several levels) and their evolution with time.

In this work, CALMET is driven by a combination of large-scale, modelled meteorology (generated by the prognostic model MM5) with data from several climate monitoring sites in the Nelson/Richmond area. The climate monitoring sites are presumed valid over a pre-specified range (given by parameters R1 and R2 in Table 8), outside of which the CALMET solution is given over to the MM5 results. The CALMET model evaluation consists of ensuring that (a) the two dimensional fields, especially of wind, give realistic patterns, in the coastal and orographic settings of Nelson and Richmond, and (b) that there is a reasonable and smooth transition at the edges of the influence of the local observations to the MM5 solution. With the models configured in this way, (a) and (b) are as much criteria on the performance of MM5 as CALMET.

We have visually examined some of the CALMET results, especially over the winter months, and are confident that the meteorological solution provided by MM5 and CALMET is reasonable. The potential disparity between MM5 and observations could lead to rapid changes in wind speed and direction over short distances (close to monitoring sites), and the radius of influence parameters have been chosen so that the wind fields in the areas around and between the monitoring sites vary smoothly. There may then be changes in meteorology between the Nelson/Richmond area and the rest of the computational domain, but this should still produce realistic PM_{10} dispersion with CALPUFF.

Some examples of surface wind fields from CALMET are presented in Figure 12 (the lowest model layer, at the surface, is 20 m deep). These are not the full CALMET domain, but a 40 km by 40 km area.

Figure 12(a) shows a daytime northeasterly wind flow over whole area. The flow over the urban areas is also northeasterly, therefore the wind field is visually smooth. Figure 12(b) shows a southeasterly flow at the end of the day. Again, the wind field is smooth as the large-scale flow and most of the local flows are southeasterly. The wind direction over Nelson City more directly from the east. Figure 12(c) shows a large-scale southwesterly flow in the early morning. Under stable night-time conditions, the local terrain blocks the wind in uphill directions, to pass around southwest-facing slopes, flow down valley-side slopes and be channelled along valleys in their downhill directions. Figure 12(d) shows a northwesterly flow at night, being blocked and diverted by the terrain to the southeast in a similar way to the terrain-blocking effects shown in Figure 12(c). However, the flow over the urban area is from the northeast. This may reflect a discrepancy between the large-scale MM5-modelled winds and the local observed flow, where the MM5 results *should* be northeasterly. However, local flow may well be blocked by the higher terrain to the southeast, and diverted to the southwest as a result. As MM5 runs at 4 km resolution, this process may not be resolved by that model.

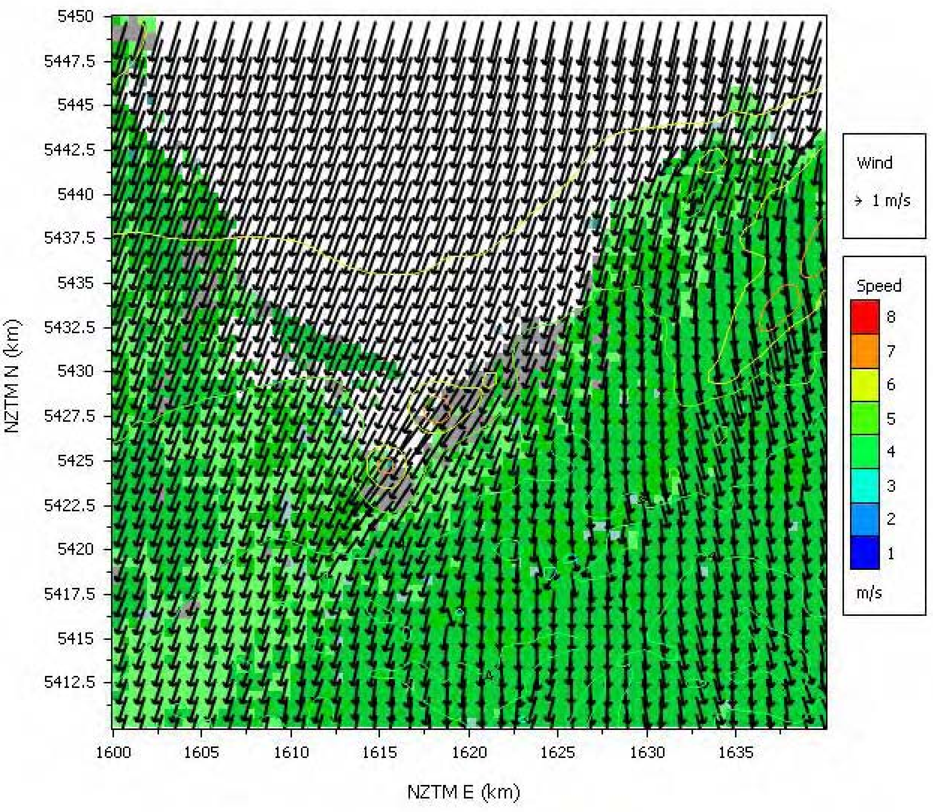


Figure 12 (a)

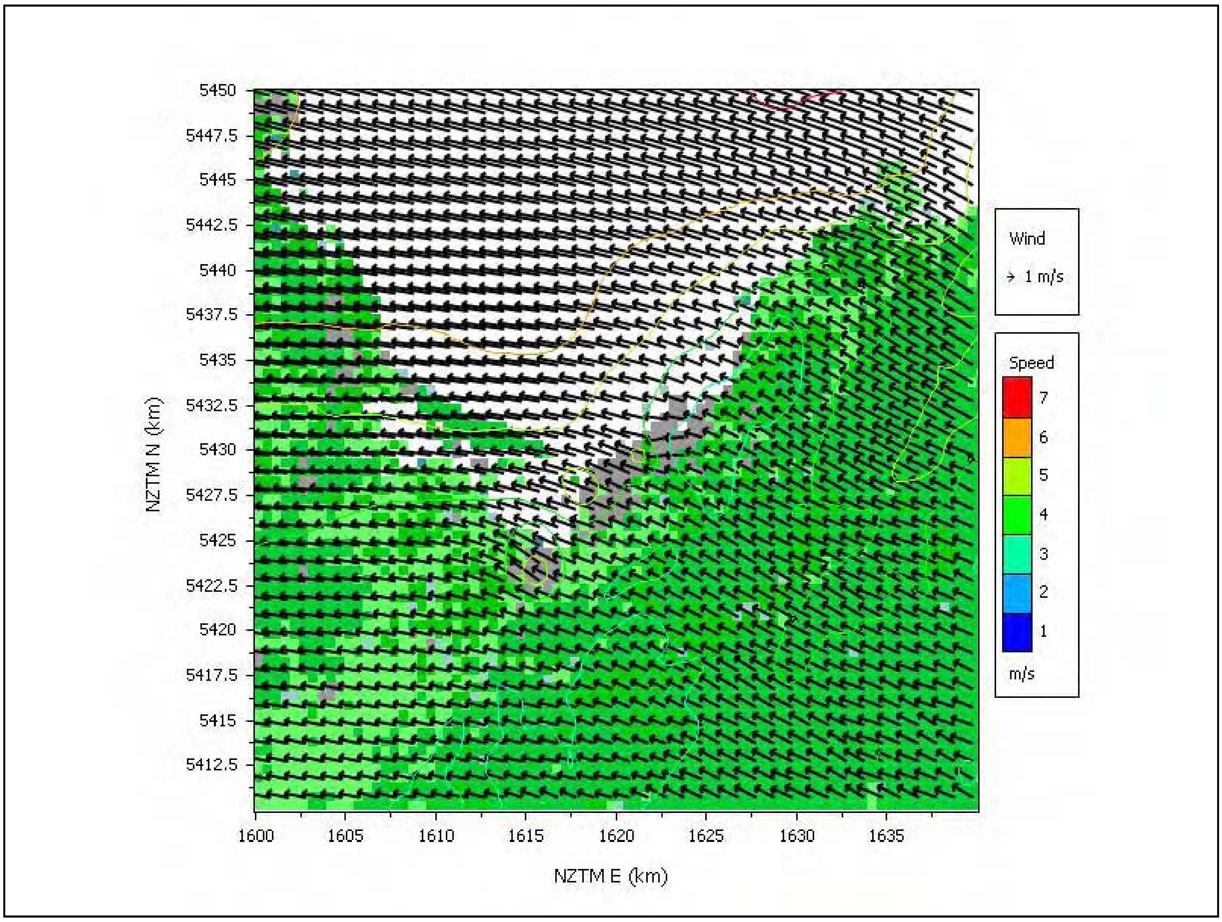
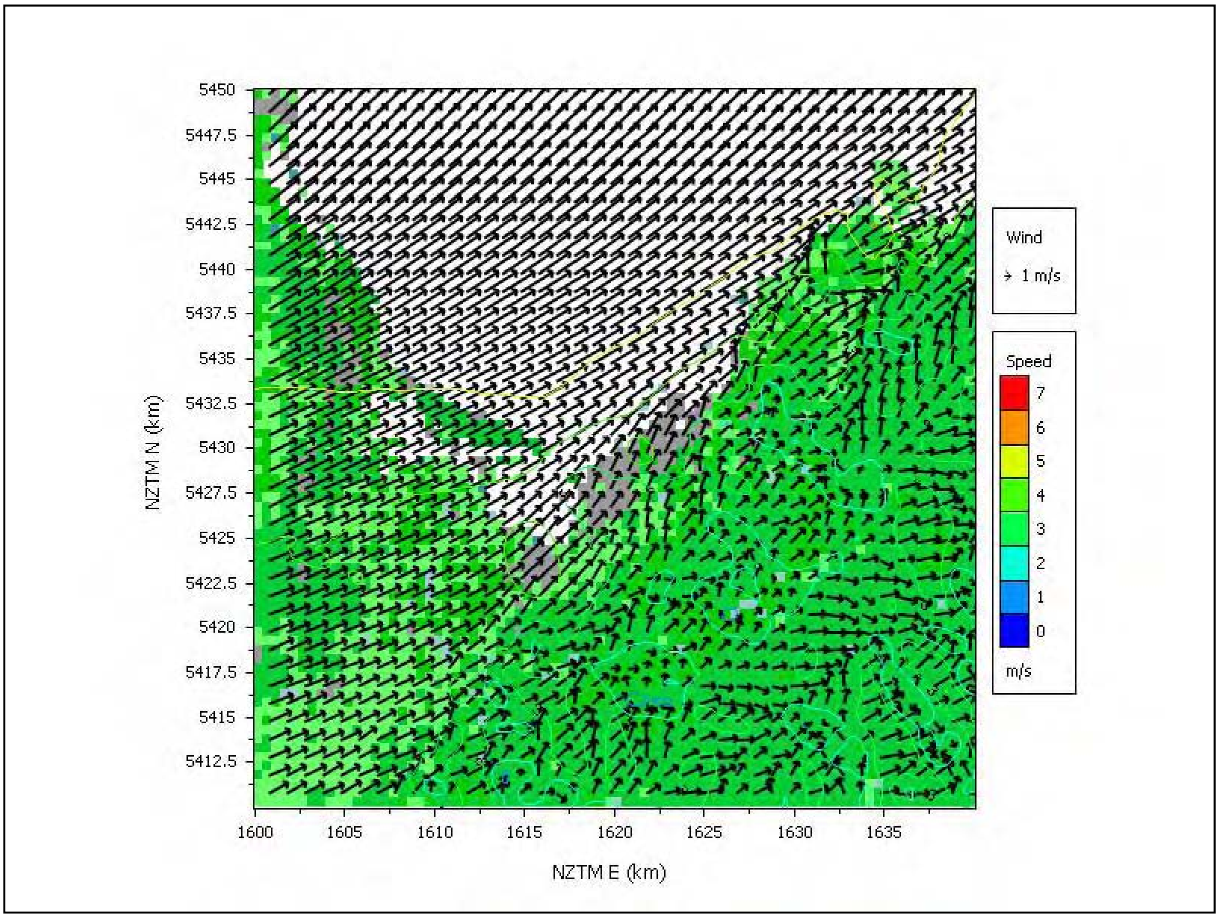

5450
5447.5
5445
5442.5
5440
5437.5
5435
5432.5
5430
5427.5
5425
5422.5
5420
5417.5
5415
5412.5
NZTM N (km)
1600
1605
1610
1615
1620
1625
1630
1635
NZTM E (km)
Wind
1 m/s
Speed
7
6
5
4
3
2
1
m/s

Figure 12 (b)


5450
5447.5
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5432.5
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5427.5
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5422.5
5420
5417.5
5415
5412.5
NZTM N (km)
1600
1605
1610
1615
1620
1625
1630
1635
NZTM E (km)
Wind
1 m/s
Speed
7
6
5
4
3
2
1
0
m/s

Figure 12 (c)

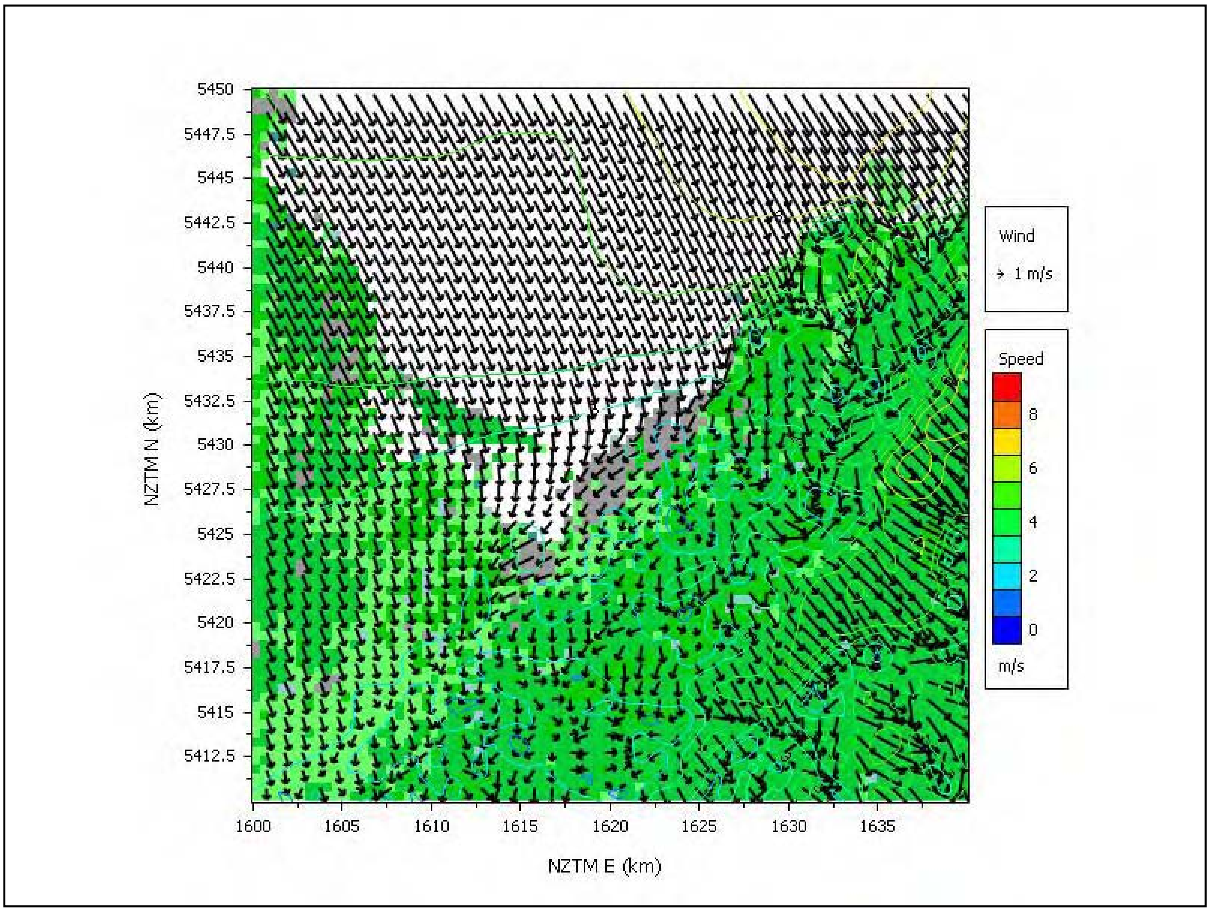


Figure 12 (d)

Figure 12: Modelled surface-layer wind fields from CALMET for several hours during the winter of 2008. Grid resolution is 500 m, but every second wind vector in each direction is shown. Urban areas are shaded grey, rural areas green, and sea unshaded. Contours are shown to highlight gradients in wind speed.

APPENDIX C

Dispersion Model Configuration

1.0 INTRODUCTION

This Appendix describes the configuration of CALPUFF to simulate the dispersion of PM_{10} around the Nelson and Richmond airsheds. There are three main aspects which must be addressed regarding the set-up of CALPUFF for this purpose, as follows:

a) Production of wind and other meteorological fields using CALMET (described in Appendix B);

b) Processing of emissions data to specify sources in the model;

c) Selection of other parameters in CALPUFF related to the dispersion of air pollutants.

The specification of emissions and selection of other dispersion parameters are described here in Sections 2.0 and 3.0, respectively.

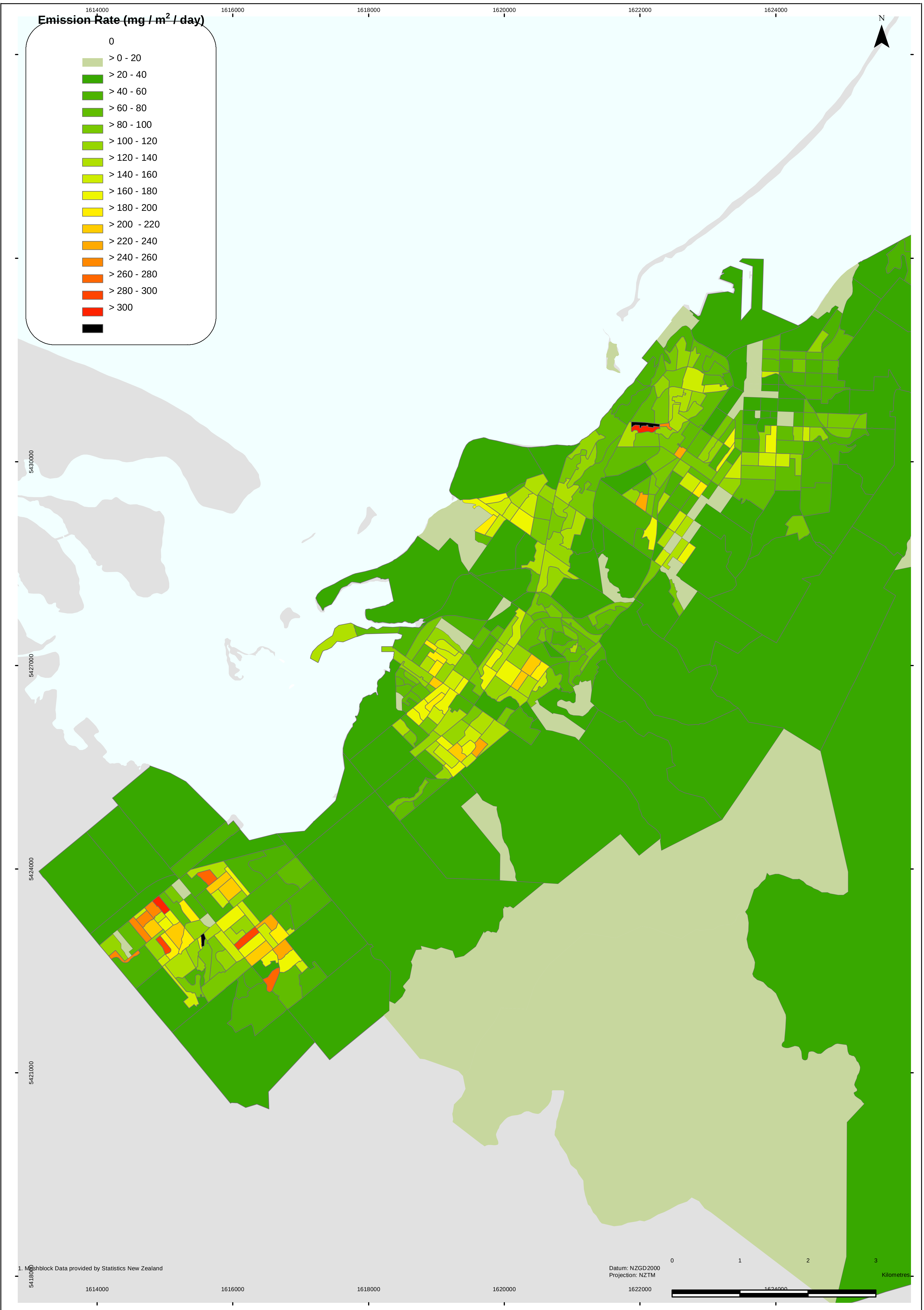
2.0 PROCESSING OF EMISSIONS DATA

Emissions data from inventories compiled by Environet (Environet 2005, 2006) have been supplied to Golder for the three main anthropogenic source sectors: domestic heating, industrial and transport emissions. These have been modelled as area sources of PM_{10} in CALPUFF, whereby sources are specified as small (10 m by 10 m), four-sided, surface-level polygons with hourly-varying emissions. The three source types have been modelled separately and combined as a post-processing step to produce the total modelled ground-level concentrations of PM_{10}. This is convenient computationally, and also enables calculation of the contributions from individual source-types to the total modelled PM_{10}.

2.1 Domestic Emissions

Domestic PM_{10} emissions have been provided by Environet on a mesh block basis. Mesh blocks vary in size based on the number of people and the area covered. In general, there are approximately 60 people in a rural block and 110 in an urban block (according to Statistics New Zealand). The Nelson city and Tasman district contain 473 mesh blocks in the modelling region.

The daily PM_{10} area emissions for each mesh block are shown in Figure 1. The daily area emission rates range from 0 mg/day/m² to around 300 mg/day/m². There are two areas with domestic area emission rates of more than 300 mg/day/m², having values of 484 mg/day/m² and 764 mg/day/m². Higher area emission rates are observed in regions with higher population density and a larger proportion of high emission domestic appliances. The two high values have been confirmed with Environet. These two mesh blocks are built up, with no parks or low population density land, and contain a large number of higher emission appliances, such as older wood burners. The distribution of mesh block emission rates is shown in Figure 2. The mean PM_{10} area emission rate is 70 mg/day/m² and the median is 56 mg/day/m².



1. Meshblock Data provided by Statistics New Zealand

Datum: NZGD2000
Projection: NZTM

TITLE NELSON AND RICHMOND MESHBLOCK PM$_{10}$ EMISSION RATES

MAY 2011
PROJECT 0978104449

C1

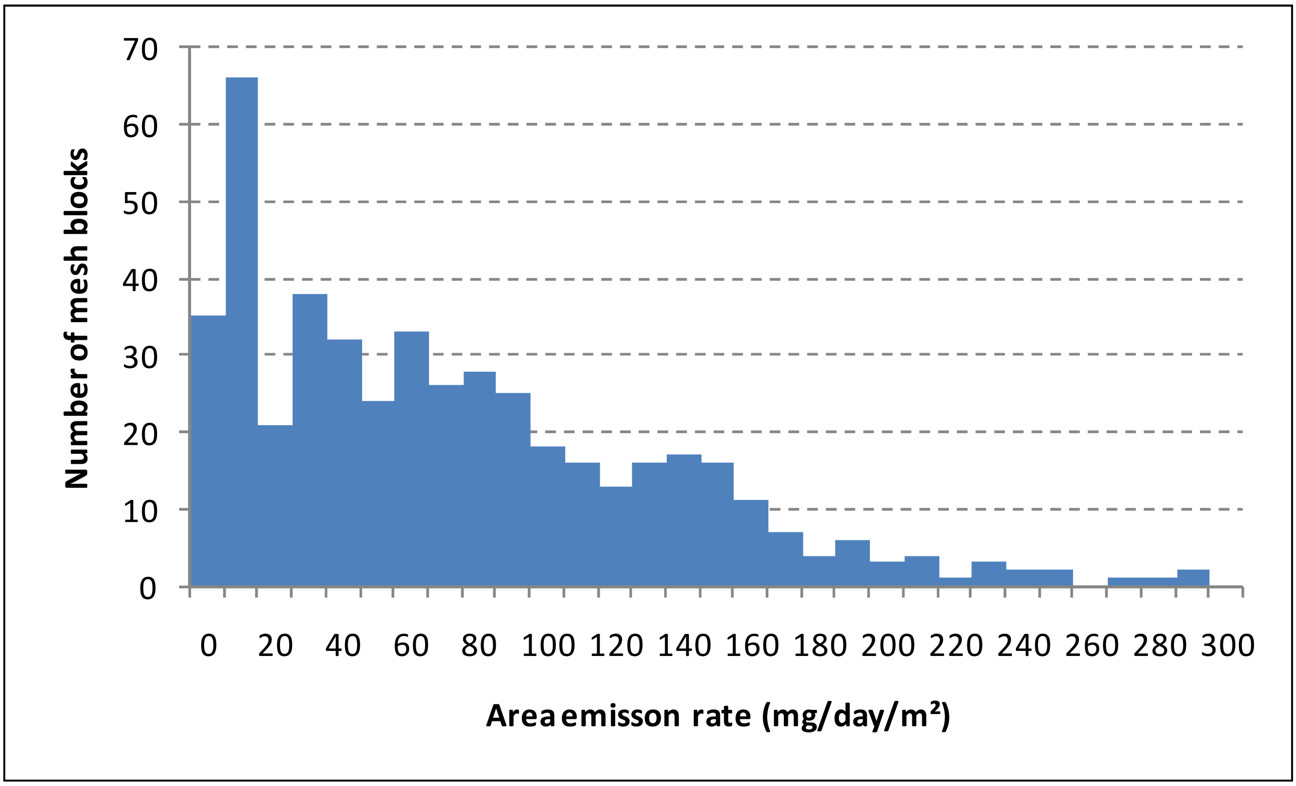


Figure 2: Domestic area emissions by mesh block. Note that there are two areas with emission rates of 484 mg/day/m² and 764 mg/day/m², not shown in the figure.

Using CALPUFF to model area sources has some limitations. The mesh blocks constitute too many area sources to be able to practically model. To reduce the number of area sources, the mesh blocks have been combined into larger area sources, where neighbouring mesh blocks have similar emissions. A further restriction is also imposed by the model which requires all area sources to be represented by four-sided polygons.

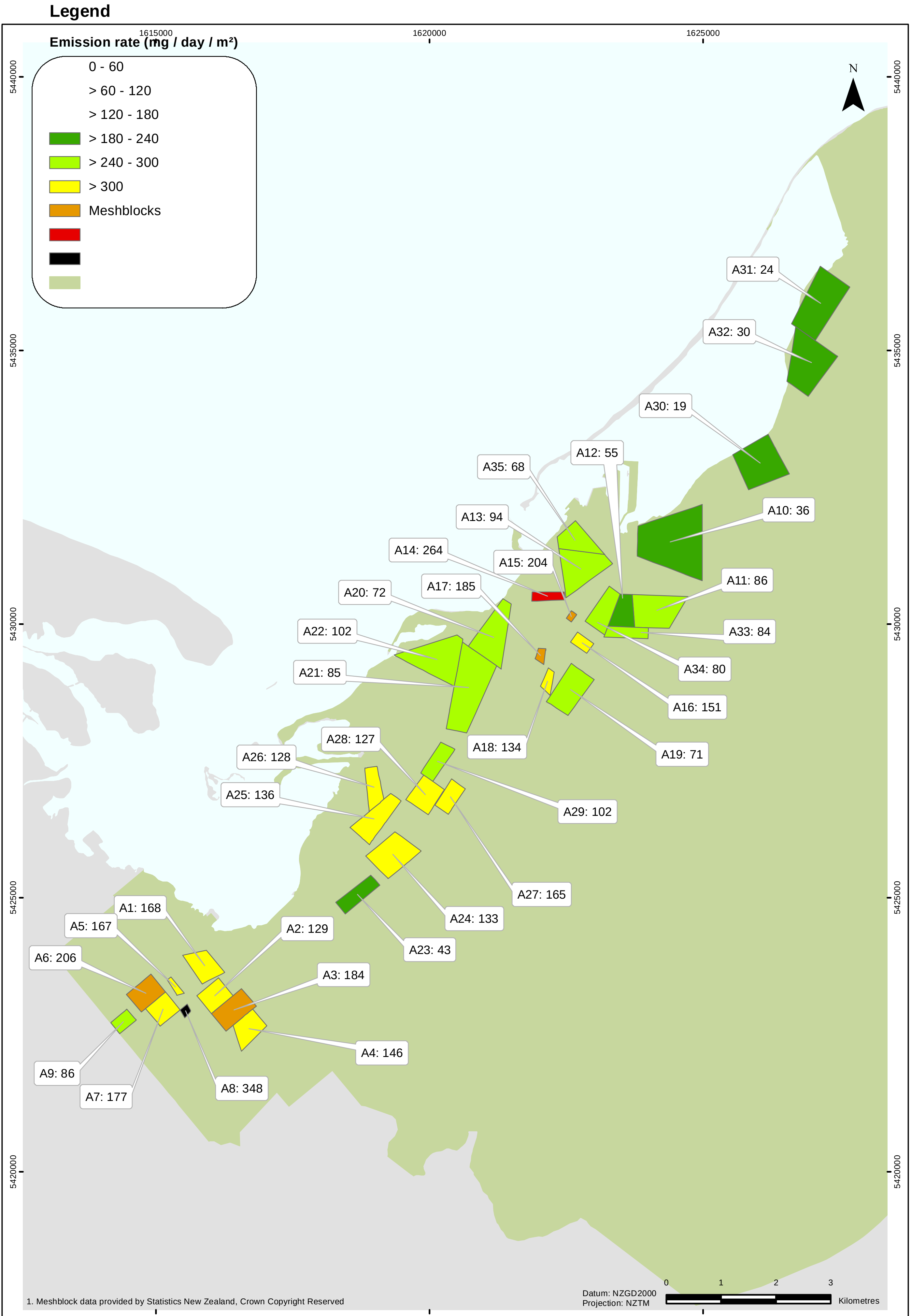
Mesh blocks with an emission rate of greater than 20 mg/day/m² have been separated into “level-1” and “level-2” sources.

The dominant, higher emission mesh blocks have been combined into small groups to allow them to be resolved by the model and to retain most of the original detail in the mesh blocks. These are labelled “level-1” sources and are shown in Figure 3. These were created by drawing new four-sided polygon boundaries over top of the high-emission mesh blocks. A new emission rate, based on the conservation of total emission (in kg/day of PM_{10}), was then calculated for each of the mesh blocks.

The level-2 sources represent the majority of the remaining mesh blocks with emission rates of greater than 20 mg/day/m² and are shown in Figure 4. The level-2 sources contain lower emission rate mesh blocks and, as their contribution to PM_{10} levels are expected to be lower than the level-1 sources, they do not need to be as well-resolved spatially as the level-1 sources. As a result, the level-2 sources tend to cover larger areas than the level-1 sources.

The specification of domestic emissions as level-1 and level-2 modelled area sources as described here means that some level-1 sources are embedded spatially in the level-2 area sources. No emissions are counted twice, but having the level-2 sources spread over areas covered by level-1 sources is unavoidable – the sources have to be specified as four-sided polygons and are not allowed to have ‘holes’. In effect, some of the level-2 emissions may be assigned to the wrong location (that is, the location of an embedded level-1 source). But, they are somewhat diffused already as the spatially variability between mesh blocks is smoothed to be a single uniform source, and they represent the less significant area sources such that the error is a small part of the total domestic emissions.

Mesh blocks with 20 mg/day/m² or less were grouped into a single large area source, called “level-3”, covering the majority of the modelling region. The resultant emission rate was approximately 0.5 mg/day/m².



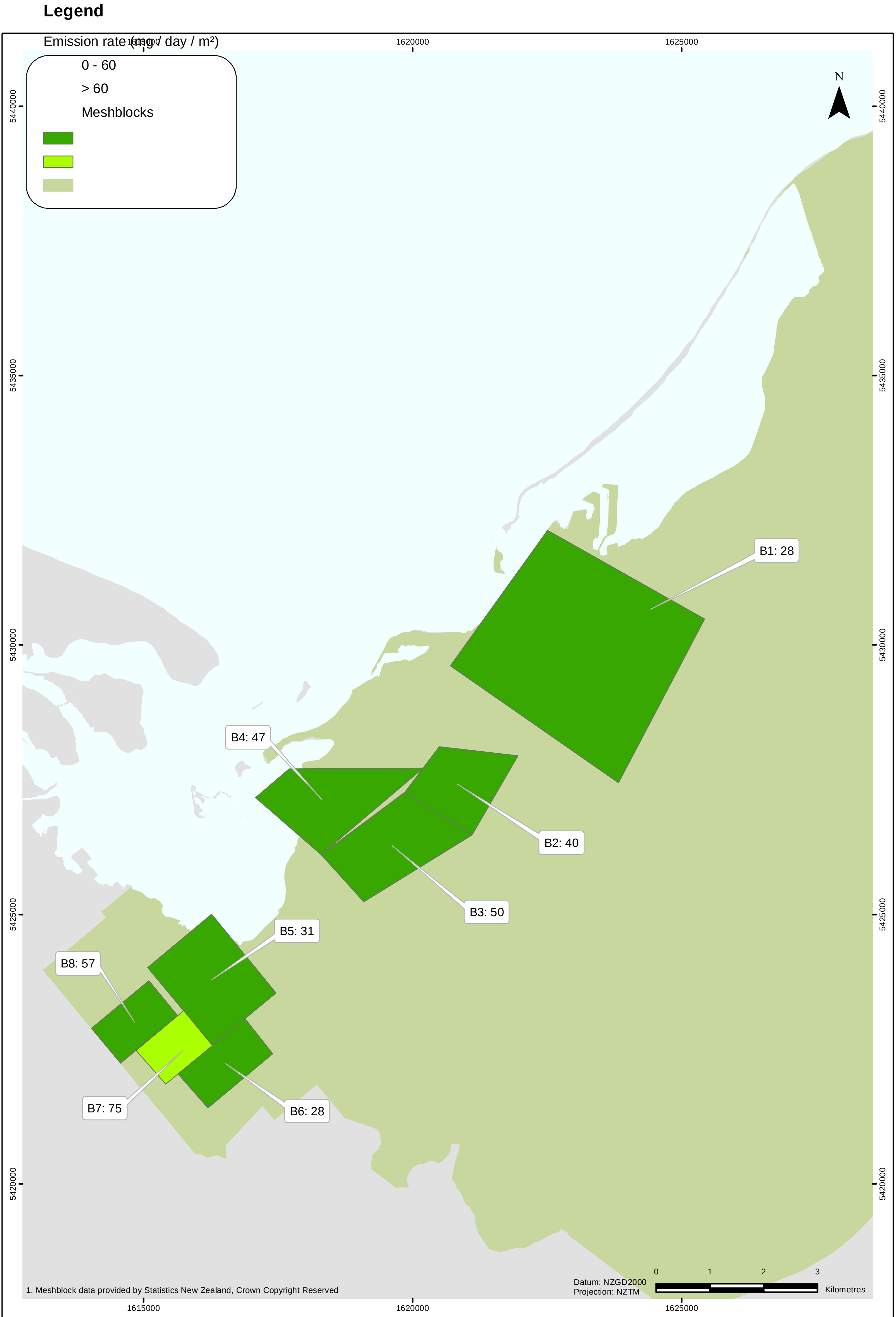
1. Meshblock data provided by Statistics New Zealand, Crown Copyright Reserved

TITLE LEVEL 1 AREA SOURCES

MAY 2011

PROJECT 0978104449

C3



1. Meshblock data provided by Statistics New Zealand, Crown Copyright Reserved

Golder Associates

TITLE **LEVEL 2 AREA SOURCES**

MAY 2011

PROJECT 0978104449

C4

Emissions discussed in this section are daily totals. Variations in domestic emissions hour by hour and between months are discussed in Sections 2.4 and 2.5.

The proportion of the total PM_{10} mass emitted per day is one quarter from level-1 sources in Nelson, one quarter from level-1 sources in Richmond, one quarter from all level-2 sources and one quarter from the level-3 source. However, that level-1 sources are more confined spatially and the local ground level concentration arising from these is at least an order of magnitude greater than that arising from the region-wide level-3 source.

2.2 Industrial Emissions

Industrial PM_{10} emissions have been provided by Environet for each of the four airsheds in Nelson and for eight industrial sites in Richmond.

Within the Nelson airsheds, there are four main industrial areas. These have been identified in consultation with NCC on industrial zoning, and the total airshed emissions have been assumed to be confined to the industrial areas, and the hospital. Emissions from each of the five sources in Nelson are contained in the inventory data, and the area over which they are confined has been defined by drawing a four-sided outline around them. Emissions in terms of PM_{10} mass per area are calculated by dividing the mass emission rate by the area of the industrial zones (*not* the whole airsheds within which they are contained). The modelled emissions from industrial areas within Nelson's airsheds are given in Table 1.

Emissions information from the eight industrial sites in Richmond has been supplied by Environet, and contains more up-to-date data than the 2004 emissions inventory for Richmond. However, most stack parameters are not known, therefore the sites have been modelled as area emission sources of 100 m². The total emission from these sources in Richmond is also shown in Table 1.

Table 1: Summary of industrial sources in Nelson and Richmond.

Airshed	**Area of industrial regions within airshed (m², as modelled)**	**Total PM_{10} emission (kg/day)**	**Area emission rate (in mg/day/m²)**
A – Nelson South (Hospital only)	19,900	4.1	206
A – Rest of Nelson South	148,400	4.9	33
B1 – Tahunanui	1,080,000	63.0	58
B2 – Stoke	853,000	9.0	11
C – Nelson City	886,000	9.0	10
Richmond	800 (eight individual sources, 100 m^2 each)	8.43	Varies among sources

The emission rates discussed in this section are daily totals. Variations in industrial emissions between months and during the day are discussed in Sections 2.4 and 2.5.

2.3 Motor Vehicle Emissions

Motor vehicle PM_{10} emissions have been provided by Environet for the four airsheds in Nelson and the Richmond airshed. The total PM_{10} emissions for each of the airsheds are given in Table 2.

Each source area is represented in CALPUFF by a four-sided polygon. The polygons have been chosen to cover the areas containing the main roads within the airshed. These may not extend to the whole airshed. Airshed C, Nelson City, has been represented by two area sources (with equal emissions per area), so as not to include an area over the harbour as a motor vehicle source.

There is no modelled variation in motor vehicle sources between months. Variations during the day are discussed in Section 2.5.

Table 2: Summary of motor vehicle sources.

Airshed	Total PM_{10} emission (kg/day)	Area of main traffic regions within airshed (m^2)	Emission rate ($mg/day/m^2$)
A – Nelson South	27	5,310,000	5.1
B1 – Tahunanui	23	5,610,000	4.1
B2 – Stoke	42	9,030,000	4.7
C(1) – Nelson City 1	42	6,490,000	4.6
C(2) – Nelson City 2		2,490,000	4.6
Richmond	39	7,460,000	5.2

A map of showing the locations of industry and motor vehicle sources as used in the airshed model is shown in Figure 5.

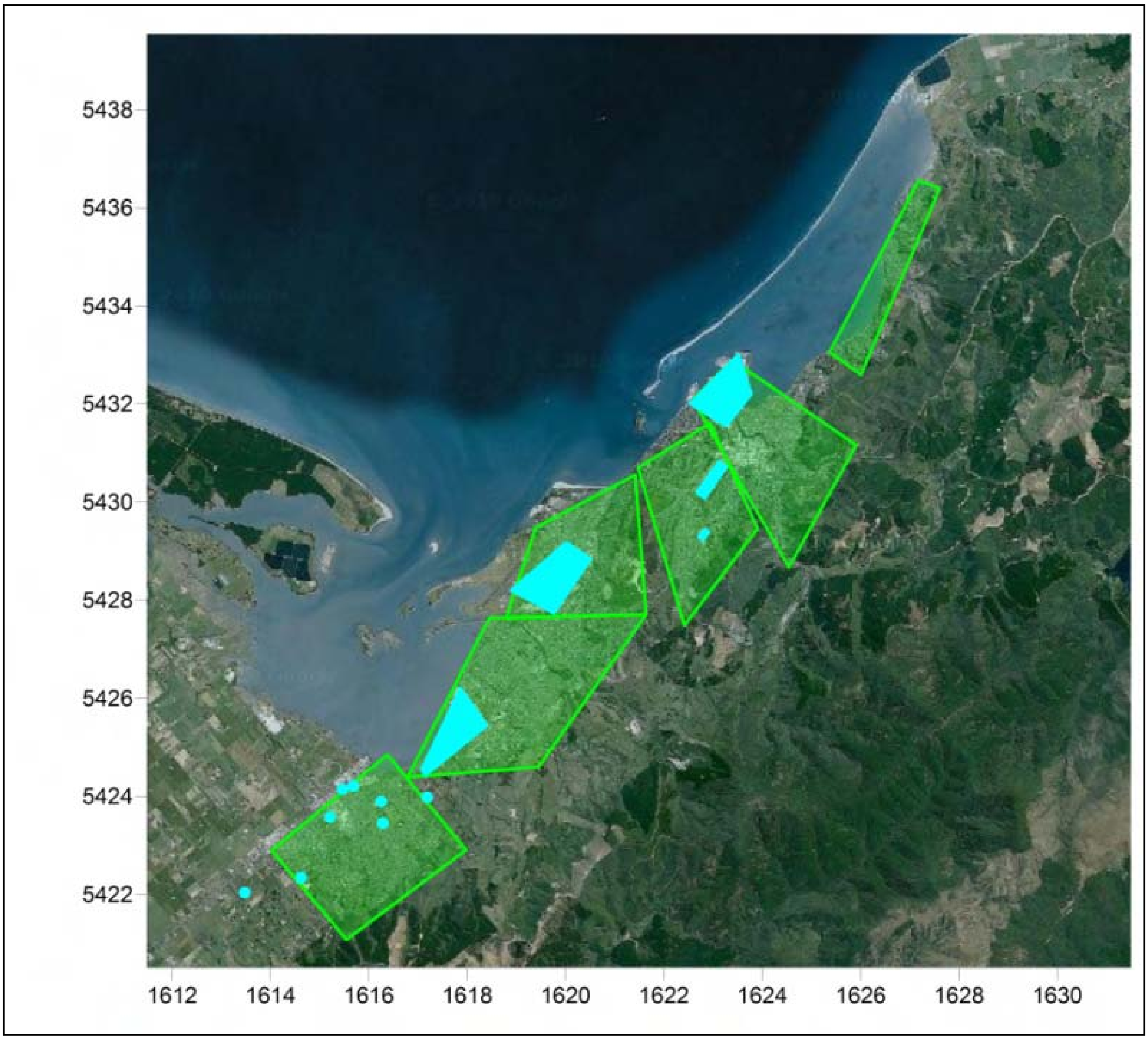


Figure 5: Locations of modelled area sources: industry (blue) and transport (green).

As mentioned in the main report, the representation of motor vehicle emissions as large area sources in CALPUFF will not lead to realistic estimates of PM_{10} concentrations from vehicles, whose main impacts would be confined close to the roadside. CALPUFF is not designed to model dispersion from vehicles, and a more specialized model should be used for such purposes (for example, CALINE4, AUSROADS, CAR-FMI or ADMS-Roads). Such a model would require vehicle emissions data to be associated with individual road links, rather than an airshed. However, this source sector has been included in the modelling for the sake of completeness, and should be thought of as a representation of vehicle effects due to the urban baseline, away from the roadside.

2.4 Variation in Emissions Between Months

The monthly variations in the PM_{10} emissions have been provided by Environet for each sector. Figure 6 shows the emissions in each month as a percentage of the July's emissions for the three source types.

Domestic heating emissions show the largest variation, being highest during the winter months and zero during summer. Industrial emissions outside winter are assumed to be 95% of the winter emissions. Motor vehicles are presumed not to change from month to month.

The monthly variations in PM_{10} as provided by Environet lead to an under-estimate of ambient PM_{10} in the early part of winter, and an over-estimate later in the season. As a model calibration exercise, the monthly scaling factors domestic emissions have been revised, as described in Appendix D. The justification for the scaling process is also described in that Appendix.

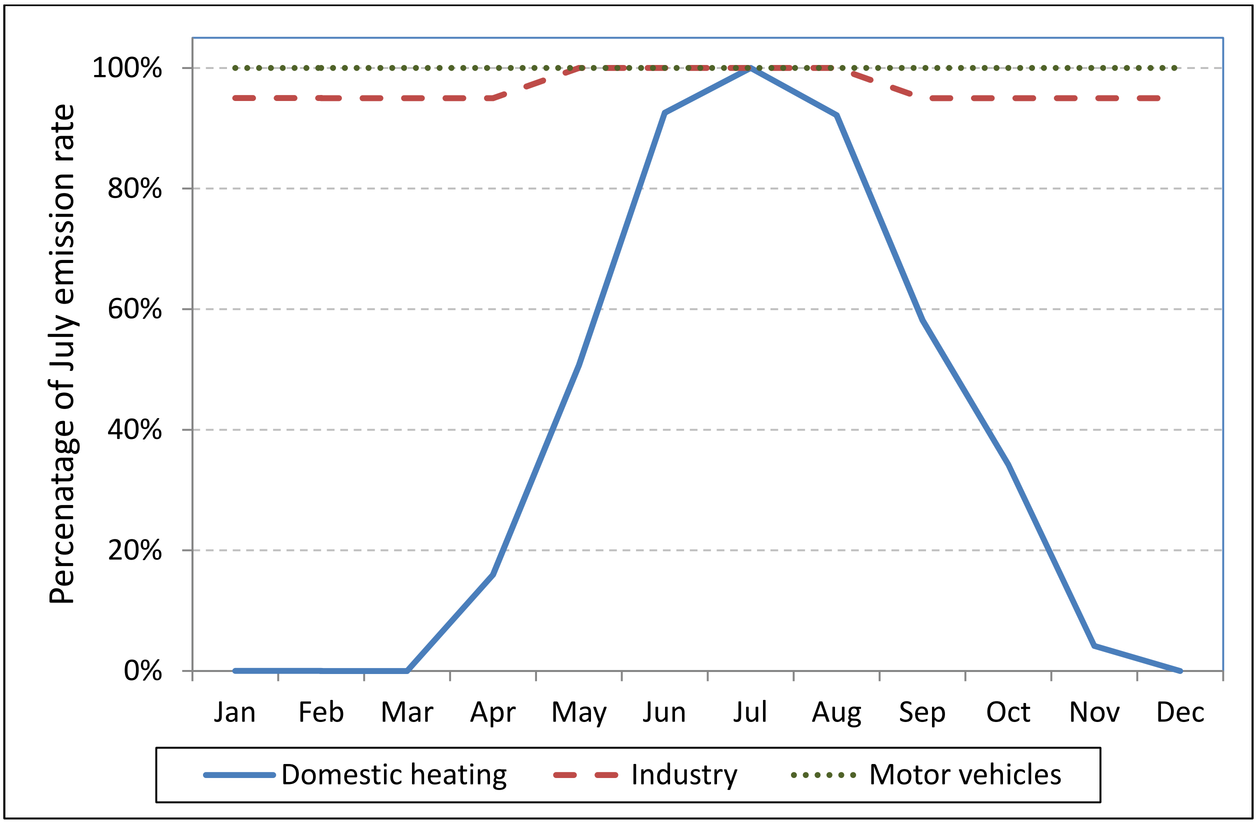


Figure 6: Monthly variation in emission rates for domestic sources, industry and motor vehicles. (Data supplied by Environet).

2.5 Variation in Emissions during the Day

The hourly variations in the PM_{10} emissions through the day have been provided by Environet for each source sector. Hour by hour emission rates as a fraction of the daily total are assumed the same for each modelled source. Figure 7 shows the hourly emission rate as a percentage of the daily emission rate. The domestic emissions peak in the evening, while motor vehicle emissions increase during the day time with peaks for morning and evening rush hours. Industrial emissions have a peak for several hours in the morning, before reducing to a lower rate for the rest of the day, then reducing to a yet lower rate during the night.

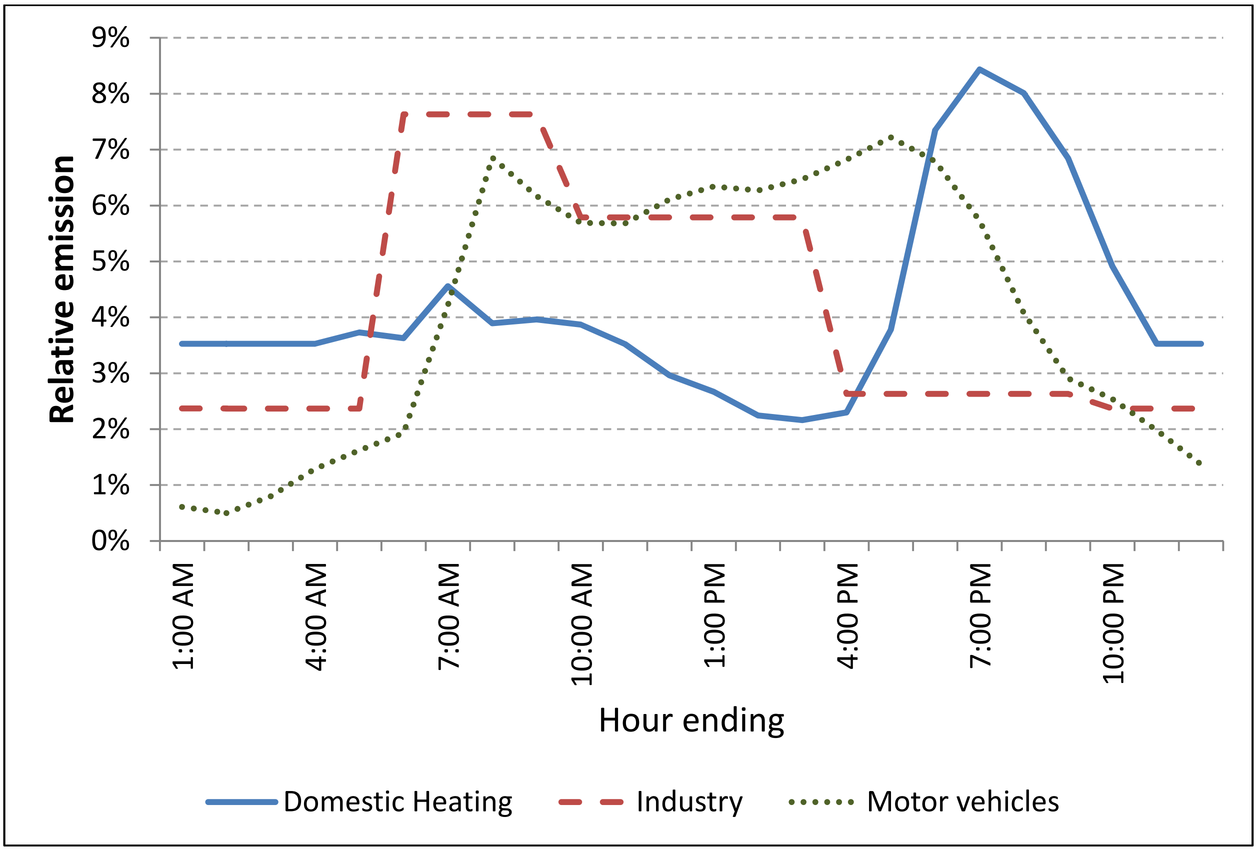


Figure 7: Hourly variation in emissions as a percentage of the total daily emission for domestic sources, industry and motor vehicles.

3.0 OTHER CALPUFF CONFIGURATION PARAMETERS

CALPUFF simulates the emission of PM_{10} as a stream of ellipsoidal puffs of material released from each source. The released puffs are transported by the wind field calculated by CALMET, expanding and diluting due to the modelled turbulent-diffusion processes. Ground-level concentrations are then calculated by the model at selected receptor locations, by summing the puff concentrations at those locations.

CALPUFF was run over an area 75 km by 76 km, for the year 2008, using air emissions data for the three main source-types as described. The area matches that covered by CALMET. An inner grid of receptor points at 500 m resolution, congruent to the meteorological grid points has been defined, centred on the urban areas. This covers an area 40.5 km by 39.5 km. Also, some discrete receptors have been specified, at the coordinates of the ambient air quality monitoring sites. The receptor points are defined in the model as points on a smaller grid at which the concentration is output. The larger meteorological grid permits dispersion beyond the receptor grid, and possible re-circulation of pollutants.

The following tables provide details of user-specified parameters used as inputs to the CALPUFF dispersion model. Note that the emissions are described above and in Appendix D. Other parameters not mentioned in this Appendix should be assumed to take default values, or they relate to a particular feature of the model that is not used.

Table 3: General run control parameters.

Parameter		Value	
Start date/time		1 January 2008	00:00:00
End date/time		1 January 2009	00:00:00
Base time zone	XBTZ	-12 (negative for east of Greenwich)	
Time step	NSECDT	3600 seconds	

Table 4: Pollutant specifications.

Parameter		Value
Number of chemical species	NSPEC	1
Number of emitted species	NSE	1
Species; modelled; emitted; deposited?		PM_{10}; Yes; Yes; No
Chemical mechanism	MCHEM	0 (No chemistry modelled)
Dry deposition	MDRY	0 (No dry deposition modelled)
Wet deposition	MWET	0 (No wet deposition modelled)

Table 5: Technical options.

Parameter		Value
Dispersion coefficient calculation	MDISP	2 use micrometeorological variables
PDF formulation for dispersion under convective conditions	MPDF	0 (Off)
Building downwash	MBDW	2 PRIME algorithm (but not used for area sources)
Check parameters for regulatory settings		No

Table 6: Map projection (parameters match those for CALMET).

Parameter	Value
Map projection	Tangential Transverse Mercator (TTM)
Datum region	WGS-84
Projection origin	41.298 S, 173.237 E
False origin *(for NZTM coordinates)*	(1619.842, 5428.134) km

Table 7: Grid control (parameters match those for CALMET).

Parameter		Value
SW corner of grid cell (1,1)		(1584, 5392) km
CALMET grid dimensions	NX x NY; DGRIDKM	150 x 152 points at spacing 0.5 km
Vertical grid, number of layers		10
Cell-face heights for vertical grid (m)		0, 20, 40, 80, 120, 200, 400, 800, 1200, 2000, 3000

Table 8: Grid (used by CALPUFF – subset of CALMET grid).

Parameter		Value
CALPUFF computational grid range E-W		1 to 150 out of NX=150
CALPUFF computational grid range S-N		1 to 152 out of NY=152
Use of gridded receptors?		Yes
Receptor grid range E-W		36 to 116
Receptor grid range S-N		38 to 116
Receptor grid nesting	MESHDN	1 (grid spacing 0.5 km)

Table 9: Discrete receptors.

Parameter	Value
Number of receptors	6

ID	X (km)	Y (km)	Ground Elev. (m)	Height AGL (m)
1	1622.904	5430.323	17.0	0
2	1620.293	5428.453	8.0	0
3	1615.328	5423.524	10.0	0
4	1624.351	5429.906	62.0	0
5	1615.887	5423.694	10.0	0
6	1614.923	5423.165	15.0	0

APPENDIX D

Calibration of Monthly Domestic Emission Factors

1.0 INTRODUCTION

This Appendix describes a method for updating airshed model inputs so that its results more closely match observations of PM_{10}. This has been achieved through an adjustment of the domestic emissions by a scale factor which varies between months. Although there may be uncertainties in the home heating emissions, the procedure followed here is based on the need to produce a more useful tool for air quality management. The updates have been carried out for the mid-year months, when PM_{10} from domestic fires dominates the total ambient PM_{10}. Therefore the rescaling of those emissions is not unreasonable.

Initial runs of the CALPUFF airshed model have been carried out for 2008 meteorology over the Nelson and Richmond area according to the model configurations described in Appendices B and C. From the model runs, time-series of ground-level concentrations of PM_{10} on a regular grid of points, plus several discrete receptors at the locations of air quality monitoring sites were produced. The model results at the monitoring sites, combined with the sea spray component of PM_{10} calculated in Appendix E have been compared with a year-long time series of measured PM_{10} at three of the monitoring sites, namely St Vincent Street (Nelson), Blackwood Street (Nelson) and Oxford Street (Richmond).

Given that the sources of PM_{10} in the airshed model are specified as area sources of size at least as large as mesh block units, the model should perform best when sources which are also at those spatial scales in reality dominate PM_{10} levels in the urban boundary layer. Provided that air quality monitoring sites are not close to individual dwellings, the modelled PM_{10} from domestic heating should match observations reasonably. Although composed of individual discharges through chimneys, PM_{10} from domestic heating can be modelled reasonably well as a set of area sources. This has been found to be the case elsewhere using CALPUFF (Barna and Gimson, 2002) or other airshed models such as CALGRID or TAPM (Gimson, 2005; NIWA, 2006; Golder, 2009(a), 2011). Further, it can also be reasonable in relative simple environments (flat land, compact urban areas, spatially uniform emissions and meteorology) to predict PM_{10} from domestic sources using a box model which has no spatial detail (Chilton, 1999; Gimson, 1999). Presuming these arguments apply to Nelson and Richmond, CALPUFF *should* model wintertime PM_{10} – dominated by domestic heating sources – reasonably well.

However, an examination of results has found a general tendency for the model to under-estimate PM_{10} in the early winter months (May, June and July), and over-estimate PM_{10} in the later months (August and September). The emissions inventory reports (Environet, 2005; Environet 2006) presented emissions data for July, with a monthly factor to be used to rescale the emissions for other months of the year. Thus, domestic emissions have been assigned a 100% factor to July, with a decreasing percentage for other winter months, falling to zero in summer (December, January and February)[1]. The monthly factors were derived from the responses of householders to a telephone questionnaire on home heating appliance use in Nelson and Richmond. Householders were asked for the number of days per week on which the appliance was used, for each month of the year.

In the following, Section 2.0 presents the airshed model results for PM_{10} at the air quality monitoring sites, with monthly scale factors as used in the inventory data. Section 3.0 describes the process of adjusting the monthly scale factors for domestic emissions to improve the general magnitude of PM_{10} during each month. Updated airshed model results are also presented in this section. Discussion and concluding remarks are contained in Section 4.0.

2.0 INITIAL AIRSHED MODEL RESULTS

A time series of the modelled PM_{10} ground-level concentration at St Vincent Street, Nelson, is shown in Figure 1. The portion due to each modelled source is identified, and the concentration also includes the wind- and season-dependent sea-spray PM_{10}. Each column is a daily average. Levels of PM_{10} are largest

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[1] Therefore domestic emissions during these months have not been modelled using CALPUFF.

during the winter, when the domestic component dominates. The transport and industry components are small throughout the whole year, and are a similar size to each other. During the summer, the sea-spray component is roughly the same size as the transport and industry components, and is generally lower during winter than summer. Peaks in sea spray PM_{10} during the winter generally occur on days of low anthropogenic PM_{10}, as the two components depend on the wind speed in different ways: anthropogenic PM_{10} is larger during calm conditions, and sea spray PM_{10} is larger under windier conditions.

A time series of the total modelled PM_{10} plotted alongside a time series of 24-hour averaged PM_{10} observations from St Vincent Street is shown in Figure 2. This figure shows that the model under-predicts the observed PM_{10} in early winter but over-predicts in late winter. We postulate that this is due to over- or under-prediction of the domestic component of PM_{10}, which dominates during the winter time, and adjustments to this component could be made to improve the comparison between modelled and observed PM_{10}. In addition, the model under-predicts the observed PM_{10} at the ends of the year. This cannot be improved by a recalibration of domestic emissions, as there are none during the summer. The under-prediction must therefore be due to an under-estimate of other emissions, such as transport or industry, sea spray or some as yet unaccounted-for source. In the case of transport, the model cannot resolve small-scale dispersion next to the roadside. In the case of industry, the same is true, as the industrial sources are represented by large areas rather than point sources, and information on most stack parameters has not been available for this work.

The same features of the comparison between modelled and observed PM_{10} appear at the other air quality monitoring sites (figures not shown here).

The model performance can be shown more clearly with results presented as quantile-quantile plots. The modelled and observed concentrations are ordered separately before plotting. This gives a comparison of the distribution of concentrations between model and measurements, and determines the model's ability to predict worst-case concentrations (even if the date of their occurrence in the model is different from the date on which they occurred in reality). Figure 3 shows quantile-quantile plots of modelled 24-hour PM_{10} against observed PM_{10} at St Vincent Street, Nelson, for each of six months in the middle of 2008. The 1:1 line is shown. If the data points are under (respectively above) this line, the model is generally under- (respectively over-) estimating the true PM_{10} ground-level concentration. The monthly trend is clear, with the model underestimating concentrations in May and June, giving reasonable results in July, then over-estimating concentrations in August and September (then October's results are reasonable).

The following section describes the procedure used to improve the model results.

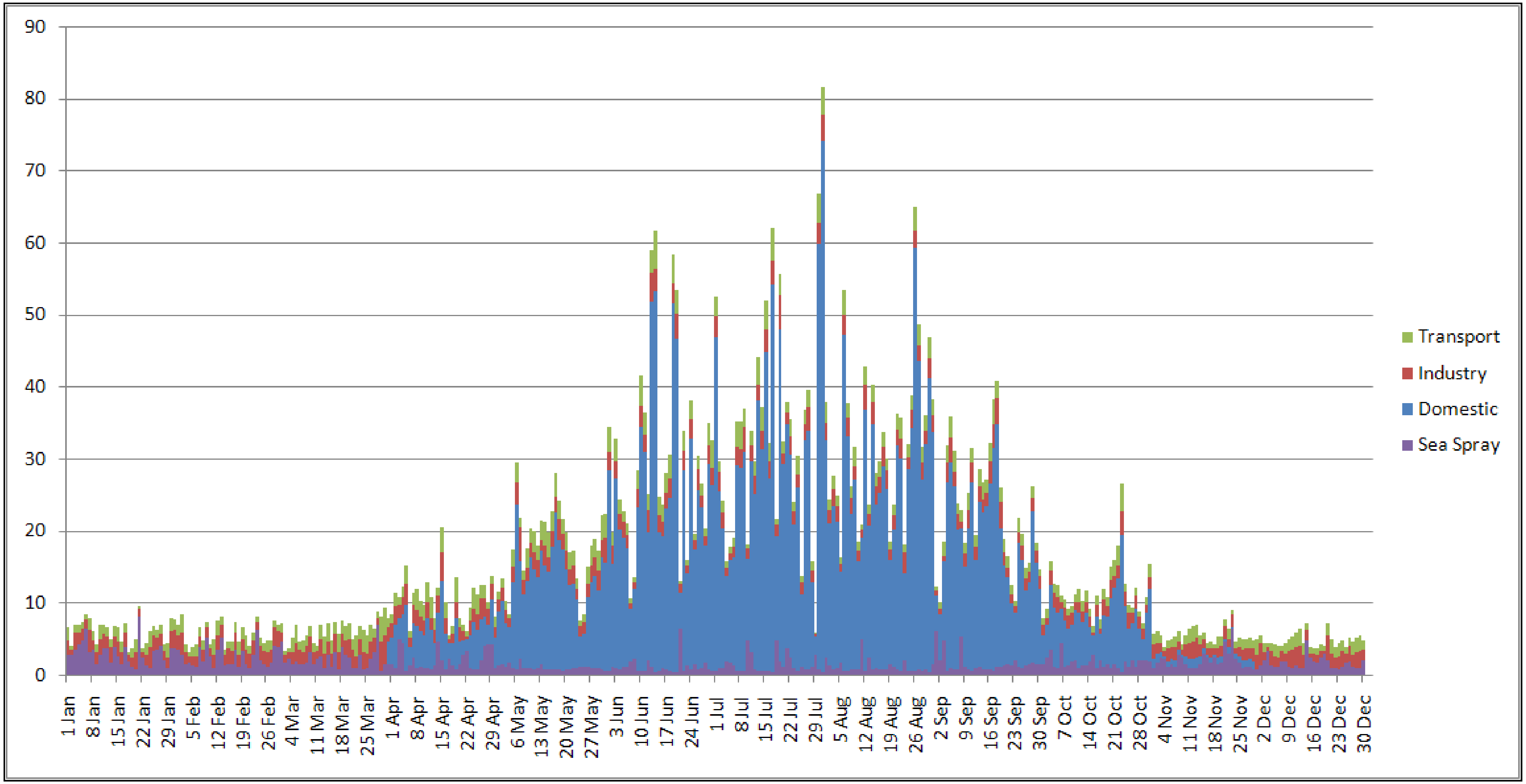


Figure 1: Airshed model results for 2008. 24-hour averaged PM_{10} concentration (in µg/m^3) at St Vincent Street, Nelson, partitioned according to source.

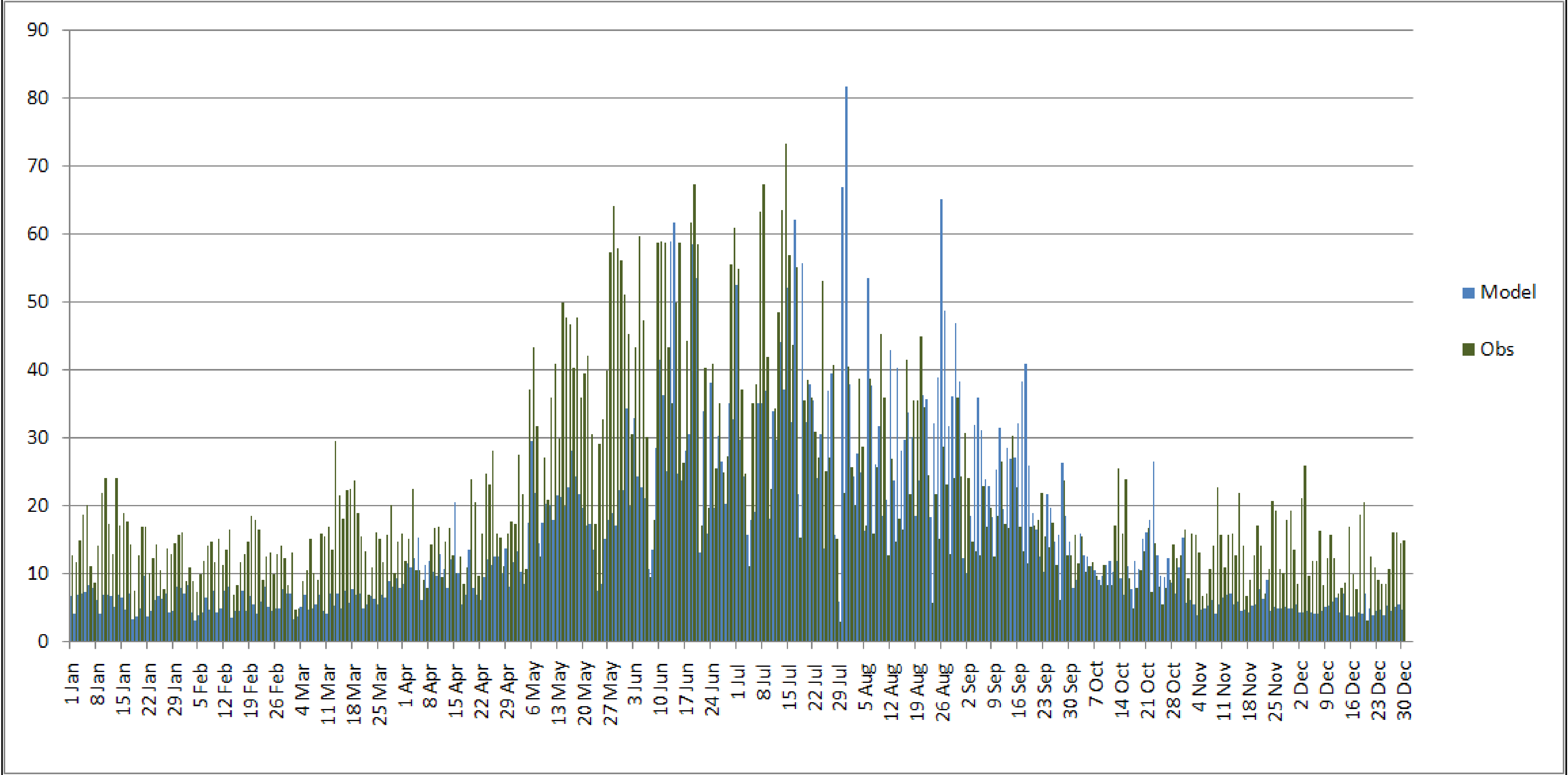
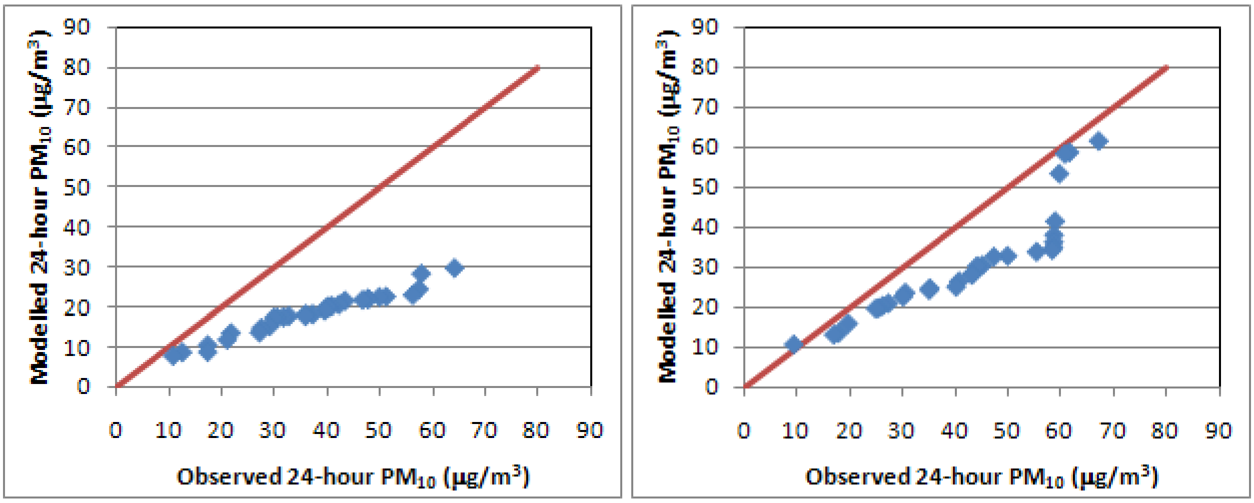
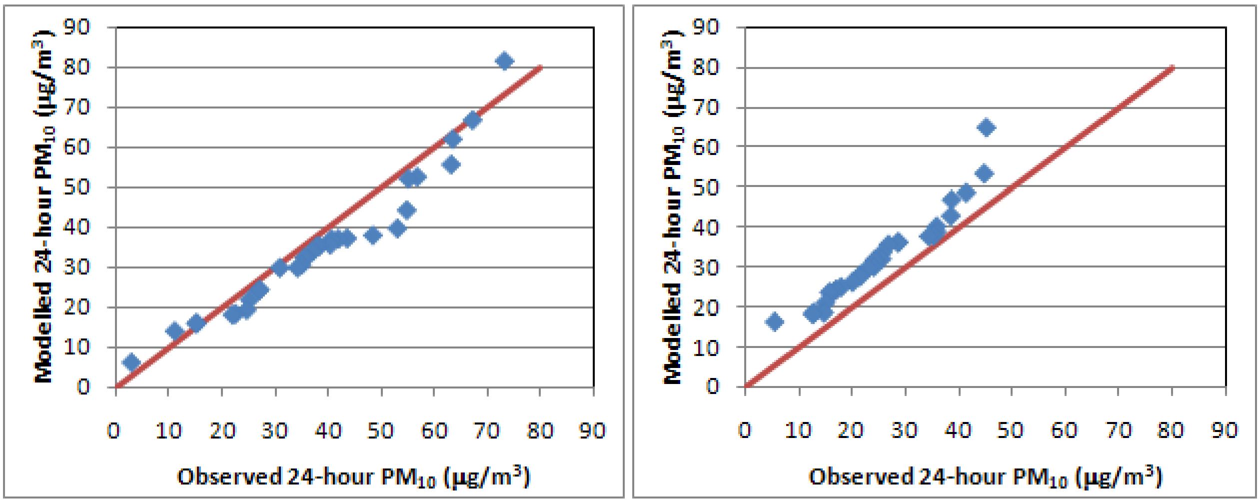


Figure 2: Comparison of airshed model results for 2008 with observations. 24-hour averaged total PM_{10} concentration (in µg/m^3) at St Vincent Street, Nelson, modelled and measured.



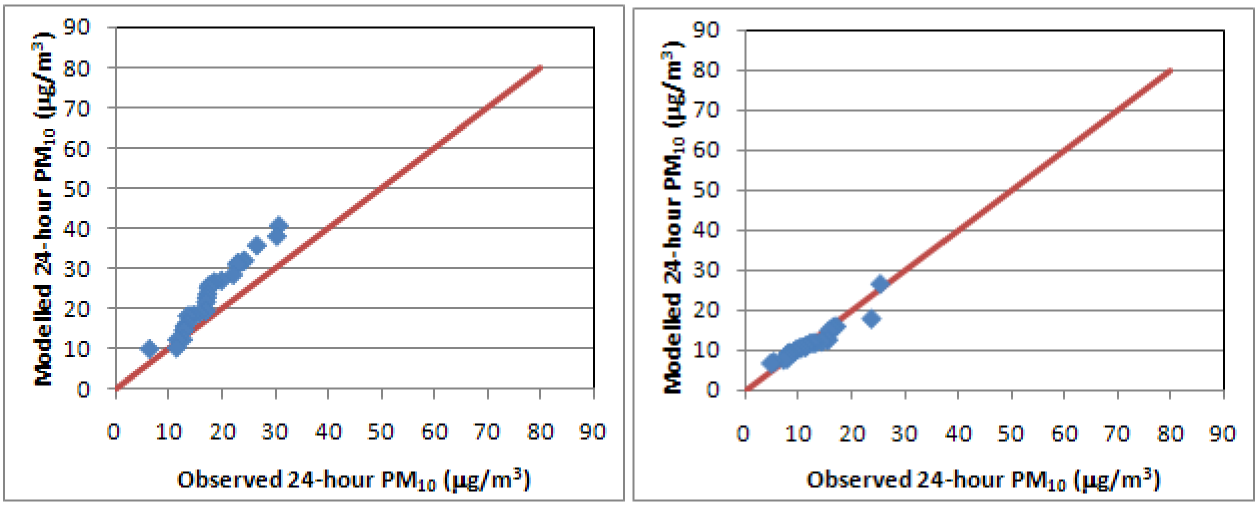
(a) May

(b) June



(c) July

(d) August



(e) September

(f) October

Figure 3: Monthly quantile-quantile plots of modelled versus observed PM$_{10}$ for 2008. (a)-(f) for months May to October.

3.0 CALIBRATED AIRSHED MODEL RESULTS

3.1 Adjustment of Monthly Scale Factors for Domestic Emissions

The monthly quantile-quantile plots have been used to derive new monthly emissions scaling factors. Adjustments have been made to the domestic emission scale factors only, to move the data points on those plots closer to the 1:1 line. They cannot be aligned exactly on the 1:1 line, as (i) only one source sector has been changed, and (ii) the original data points in Figure 3 do not all lie along straight lines initially. In other words, there is some subjectivity in the choice of new scaling factor. Also, scale factors for Richmond emissions are allowed to be different to those for Nelson. In addition, the comparison has been carried out for two sites in Nelson (St Vincent Street and Blackwood Street) to derive a single set of scale factors.

Figure 4 shows the adjusted monthly scale factors for domestic emissions for Nelson and Richmond, along with the original factors from the inventories (which are also presented in Section 2.4 of Appendix C). For both urban areas, the new factors show a peak in May, decreasing through the winter, rather than a maximum in July. Note that the percentages for each urban area are relative to July designated as 100%, although the total emissions in July differ between Nelson and Richmond). The factors for April, October and November have not been altered; these months are not dominated by domestic emissions, and there would be a large uncertainty in the factors chosen.

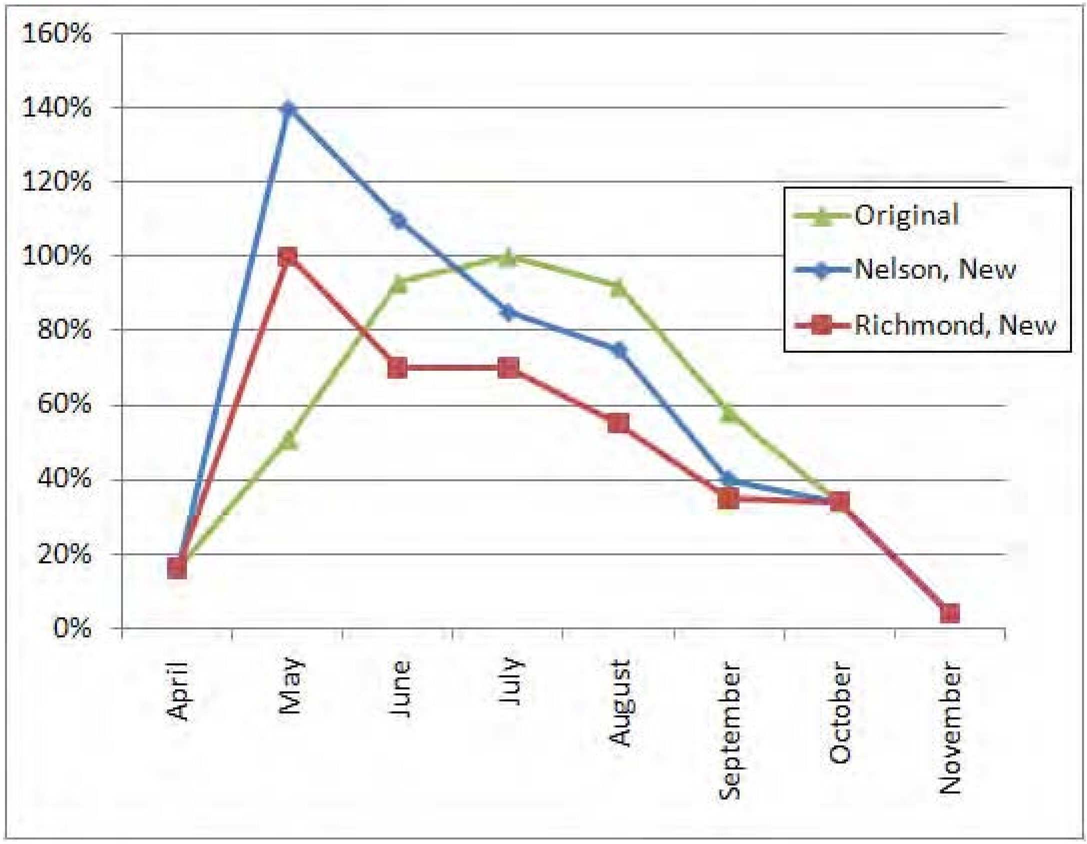
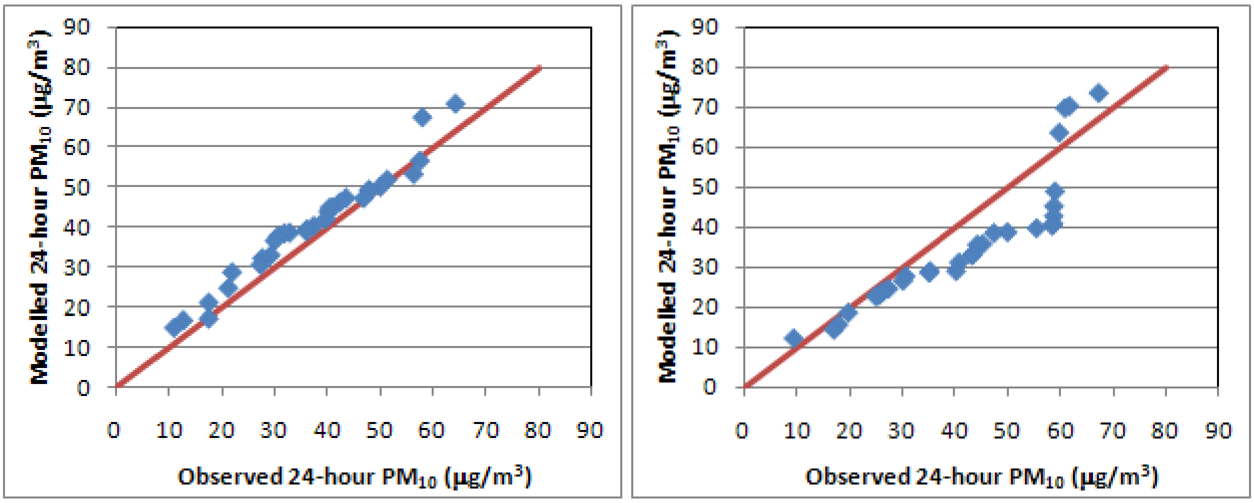


Figure 4: Domestic emissions: scale factors for each month, relative to the original July inventory designated as 100%.

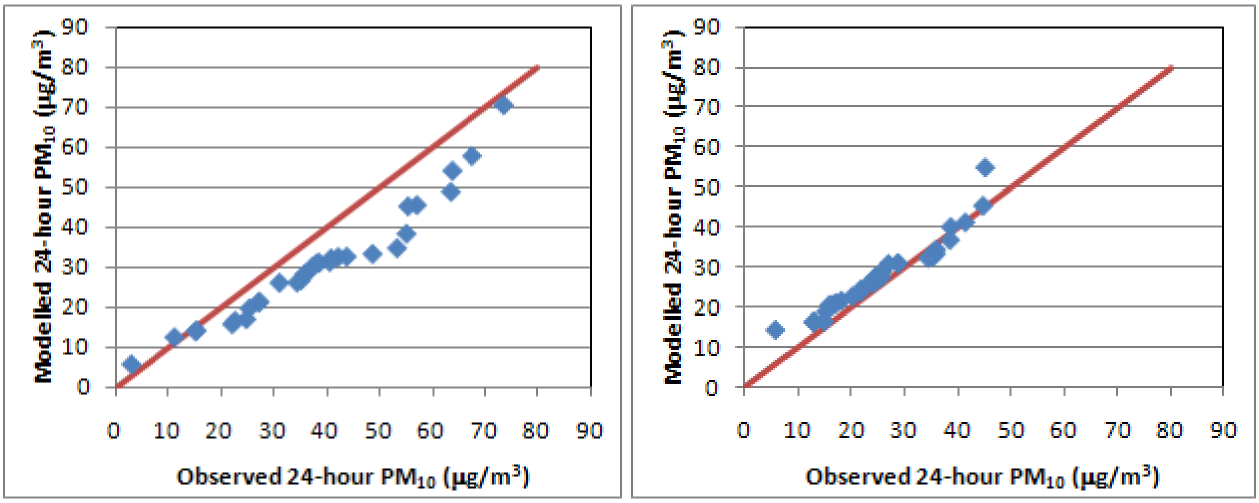
3.2 Model Results at St Vincent Street, Nelson

Figure 5 shows monthly quantile-quantile plots of PM_{10} concentrations at St Vincent Street, using the new domestic emission scale factors shown in Figure 4. It shows that most data points are now closer to the 1:1 line than they were using the factors provided in the inventories (compare Figure 5 and Figure 3). As pointed out in the previous section, the factor for October remains unchanged, so Figure 5(f) and Figure 3(f) are identical. The results for July appear worse, as the July factor was changed from 100% to 85% in Nelson and the updated model results for July under-estimate the observations. However, the model results at Blackwood Street over-estimated the observations, and the factor of 85% is a compromise between the ideal factors of 100% for St Vincent Street and 70% for Blackwood Street. As the emissions data are part of the same inventory, the factors should be the same for each location.

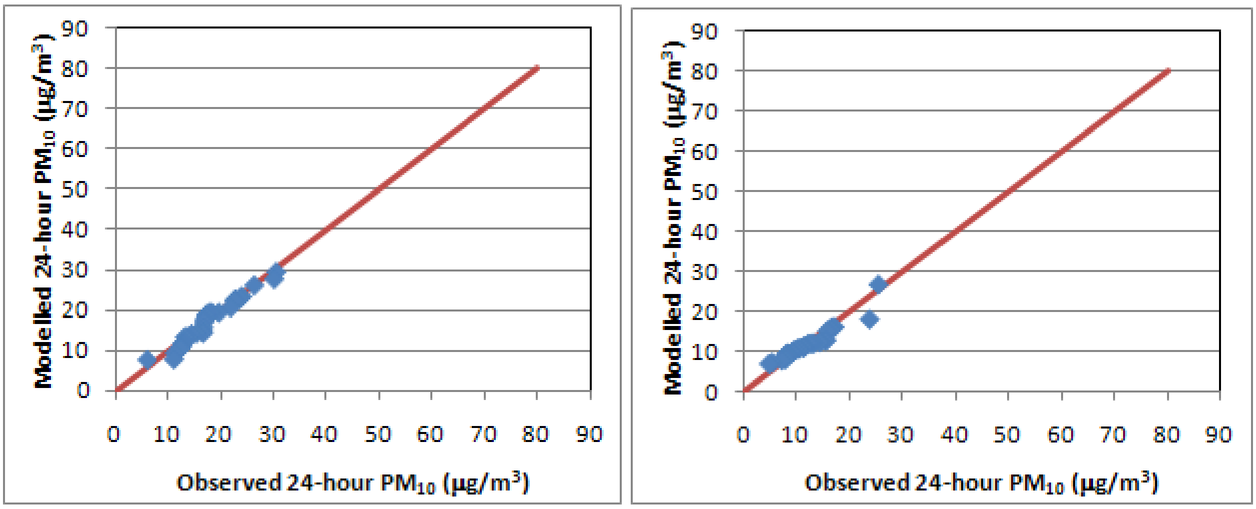
The time series of PM_{10} for the whole year at St Vincent Street using the modified scaling factors is shown in Figure 6, and is comparable with the time series in Figure 2 which used the original scaling factors. A visual inspection shows that the modelled PM_{10} concentrations are in general significantly closer to those observed, particularly in May 2008.



(a) May (b) June



(c) July (d) August



(e) September (f) October

Figure 5: Updated monthly quantile-quantile plots of PM_{10} at St Vincent Street for 2008. (a)-(f) for May to October.

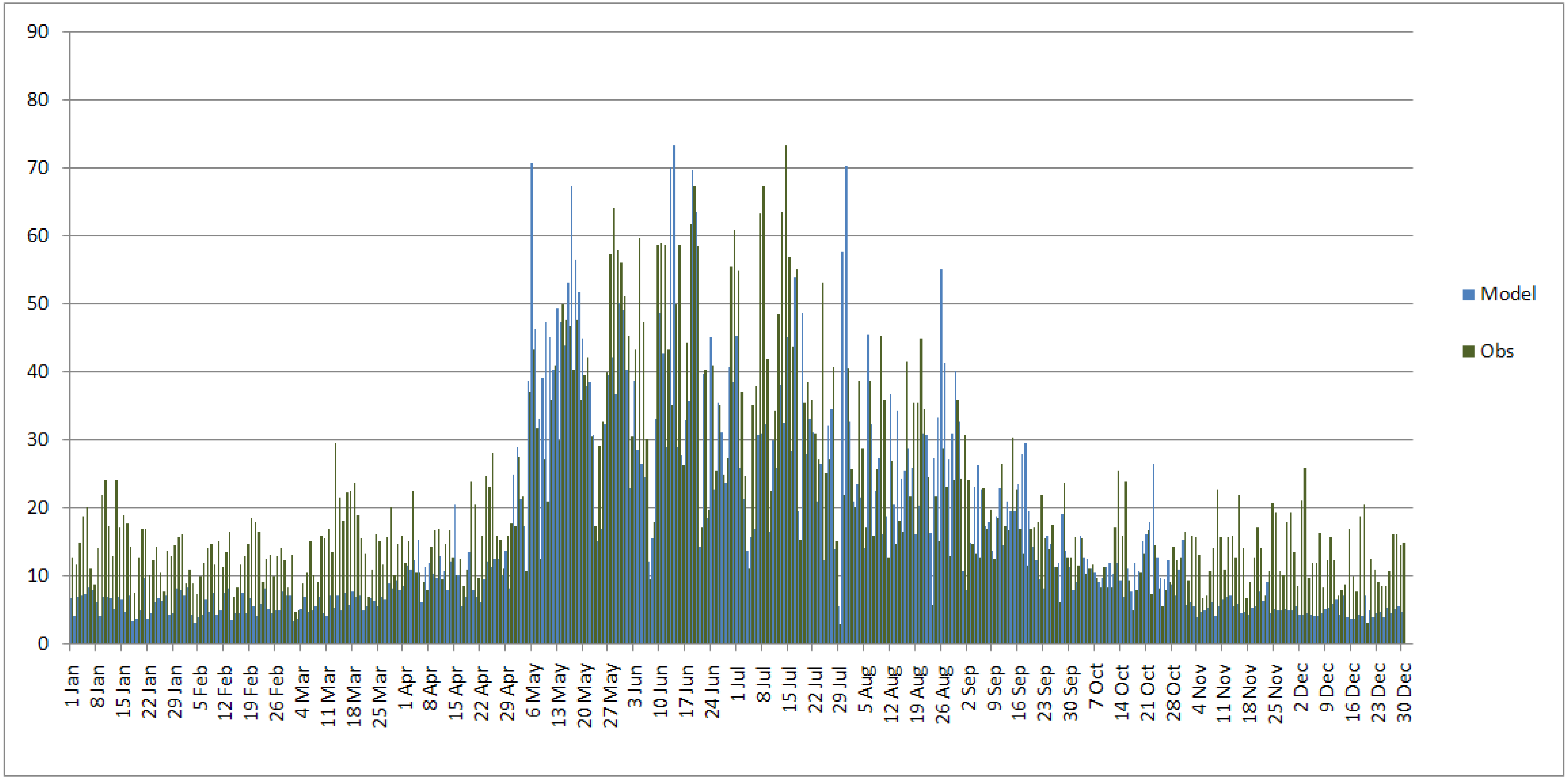


Figure 6: As Figure 2, but for updated airshed model results.

4.0 RELATIONSHIP BETWEEN EMISSION FACTOR ADJUSTMENT AND INVERSE MODELLING

The re-scaling of the monthly domestic emission factors became a subject for debate among air quality scientists at a recent meeting[2]. It was argued that (i) there was no scientific basis for altering the model inputs to make outputs match observations and (ii) leaving the original emissions factors unchanged made the mismatch between model results and observations actually more informative. To respond to (i), the adjustment of the emission factors is akin to the use of "inverse modelling" techniques, where observed concentrations are used to infer emissions (for example, see Wratt *et al*., 2001; Gimson and Uliasz, 2003). As an infinite number of possible locations and timing of sources may lead to the *same* observed concentrations, inverse modelling requires prior knowledge of emissions, which is provided by the inventories for Nelson and Richmond. Strictly speaking, inverse modelling is also a *statistical* technique, where statistical uncertainties placed on the prior information (the spatial and hourly emissions information and the observed PM_{10}) lead to results – monthly emissions factors and consequent modelled PM_{10} – which include confidence intervals around their central values. It is acknowledged that some of the information needed in advance of the process is unavailable here, precluding a formal inverse-modelling analysis.

The airshed modelling results have been presented in this report *after* adjustment of the monthly domestic emission factors, for the following reasons:

1) The monthly scale factors given in the emissions inventories are themselves estimates. These have been inferred from telephone surveys of fuel usage, which may vary from year to year. The surveys were carried out for reporting in 2005 and 2006; the modelling has been carried out for 2008.
2) The process requires the setting of only one parameter per month, applying it to all hours of the day. The best estimates of five factors have been set for five months of the year.
3) The adjusted factors are within a factor of two of the inventory factors.
4) The closer agreement with observed PM_{10} should make the airshed model a better tool for assessing current levels of PM_{10} and for examining emissions-reduction scenarios (provided the modelling has regard to the fact that the alterations have taken place).

Regarding the information obtainable from examination of the initial mismatch between observed and modelled PM_{10} concentrations (point (ii) above), it is worth pointing out the following:

a) Running the airshed model with given monthly emissions and allowing the mismatch between modelled and observed PM_{10} concentrations to remain (as suggested at the meeting) *is mathematically equivalent to* running the airshed model with regard to observed PM_{10} concentrations and allowing the mismatch between inferred monthly emissions factors and the inventory monthly emissions factors to remain.

b) Information which could be gleaned from the mismatch should therefore be the same in each case.

Finally, the trend through the year of PM_{10} emissions implied by its observed concentrations is somewhat at odds with the trend given in the emissions inventory. Cutting through the mathematics and the modelling, it is this aspect which begs some closer scrutiny.

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[2] Workshop held at Golder Associates, Christchurch, New Zealand. 28 January, 2011.

5.0 CONCLUSION

A procedure has been detailed in this Appendix, by which changes to monthly emissions factors for domestic heating have been used to allow the airshed model to produce ground-level concentrations closer to those observed at air quality monitoring sites in Nelson and Richmond. The validity of the procedure is discussed in Section 5.1 of the main report, and the model results are more useful for air quality management in their form as presented after re-scaling.

APPENDIX E

Sea Spray Component of PM_{10}

1.0 INTRODUCTION

To obtain a picture of the total PM_{10} in the coastal urban airsheds from anthropogenic and natural sources, it is necessary to account for sea spray quantitatively. It has been found overseas that sea spray PM_{10} can contribute significantly to exceedences of PM_{10} targets (van Jaarsveld and Klimov, 2007), and measurements in New Zealand have shown significant levels of marine PM_{10}, even inland (Wang and Shooter, 2001). This Appendix describes a simple model for the sea spray component of the PM_{10} concentration over Nelson and Richmond, based on source apportionment analyses carried out in the region.

2.0 SOURCE APPORTIONMENT STUDY

Monitoring of PM_{10} for source apportionment analysis carried out Nelson by GNS Science from 3 September 2008 to 22 September 2009 (Trompetter *et al*., 2010). Measurements of PM_{10} were made at Tahunanui for 24-hour periods approximately every second day. This resulted in a total of 185 samples. The samples were analysed to determine their elemental composition. Then, a statistical analysis was carried out, in which positive matrix factorisation was used to determine the sources of the measured elements. Seven source types were found by the statistical analysis, including soil, motor vehicles, biomass burning and sea spray.

3.0 SEA SPRAY MODEL

Sea spray PM_{10} studies have shown that higher sea spray concentrations often occur on days with higher wind speeds (see Davy *et al*., 2007). For the Nelson region the sea spray PM_{10} concentration – sampled as a 24-hour average – depends on season, wind speed and wind direction (data supplied by GNS, August 2010). Scale factors for the sea spray PM_{10} concentration are based on meteorological data from Nelson Airport, as this is the closest station to the Tahunanui site.

Sea spray PM_{10} concentration has been given a 24-hour-average concentration based on the following parameters:

- Daily scalar-averaged wind speed;
- Mode[1] of wind direction, rounded to the nearest 10° - either between (a) 350° and 50° (including 0°) (onshore) or (b) 60 and 340° (offshore);
- Season – either (a) spring/summer/autumn or (b) winter.

The dependence of sea spray PM_{10} on season is related to the different frequency in wind direction between winter and the other seasons, rather than the season *per se.* However, allowing a season-dependence of the PM_{10} in addition to wind dependence leads to a slightly better explanation of the observed variance, therefore this has been retained in the sea spray model.

The measured sea spray PM_{10} is partitioned into the season and wind direction categories, so that the data set is divided into four subsets. In each subset, the sea spray PM_{10} is plotted against daily-average wind speed, and a best-fit straight line drawn through the data points. The slope of the straight line uses a scaling factor (SF) to link wind speed (WS) and modelled PM_{10}, with one SF for each of the season/wind-direction

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[1] Daily mode: the most frequent value occurring in the 24-hour period from midnight to midnight.

combinations. These are shown in Table 1, and used in the following formula for the modelled 24-hour average PM_{10} from sea spray:

$$PM_{10\ (\text{sea spray})} = SF \times WS.$$

In Table 1, PM_{10} is calculated in µg/m^3 from WS in m/s. SF therefore has units of µg.s/m^4. There is some scatter around the best-fit linear relationship between PM_{10} and WS. However, the relationship is reasonable during onshore conditions, with correlation coefficient R^2=0.5. During offshore conditions, R^2=0.1, but levels of PM_{10} are much smaller.

Table 1: Scaling factors (SF) according to season and wind direction category used to calculate the sea spray 24-hour average PM_{10} concentration.

Wind direction to nearest 10°	**Season**	
	Spring-Summer-Autumn	**Winter**
350°, through 0°, to 50°	1.7567 µg.s/m^4	1.4397 µg.s/m^4
60° to 340°	0.7047 µg.s/m^4	0.5671 µg.s/m^4

4.0 COMPARISON OF MODELLED SEA SPRAY PM_{10} WITH OBSERVATIONS

As a check on the appropriateness of the sea spray PM_{10} scaling factors, the modelled sea spray PM_{10} has been compared back to the measured sea spray PM_{10} (from which the model was derived). The two time series of sea spray PM_{10} are presented in Figure 1, and as a quantile-quantile plot in Figure 2.

The time series in Figure 1 show that most of the peak concentrations are captured by the sea spray model. Some of the peak concentrations as missed by the model, as are some of the lowest concentrations. This is expected from a linear regression model, whose regression line passes through the bulk of the data points but does not touch the extremes in the data. Given that the model is quite simple, the agreement between the measured and modelled sea spray PM_{10} concentrations is good.

The quantile-quantile plot in Figure 2 compares modelled and observed concentrations after they have been ordered separately. There is some under-prediction of the higher concentrations, but in general the match of modelled PM_{10} to measurements is reasonable. Concentrations are fairly low in general; the maximum calculated concentration of 16.6 µg/m^3 is only a few µg/m^3 below the observed concentration of 21.4 µg/m^3.

5.0 CONCLUSION

Observed PM_{10} from sea spray is strongly dependent on wind speed and wind direction in onshore conditions, and indirectly depends on season. In particular, high sea spray PM_{10} concentrations coincide with frontal systems from the northwest (pers. comm. Perry Davy, August 2010) with the high levels of PM_{10} due to the long fetch over open ocean. Daily concentrations of sea spray PM_{10} have been calculated using the wind- and season-dependent model derived above, with meteorology extracted from CALMET at the air quality monitoring sites (St Vincent Street, Blackwood Street and Oxford Street) for the modelled year 2008. These have been added to the output anthropogenic PM_{10} from the airshed model to account for the main natural component of modelled PM_{10} at those sites.

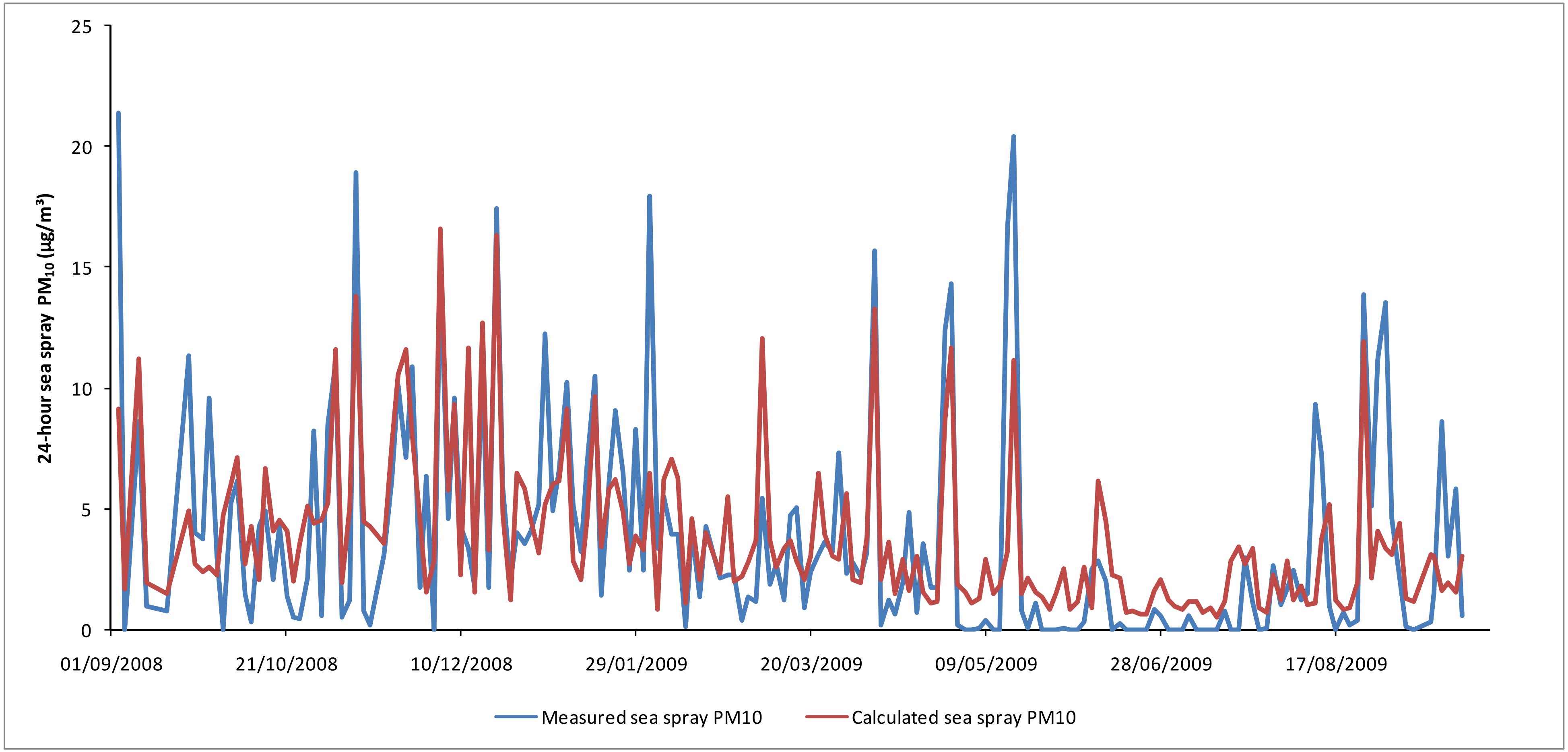

Figure 1: Time series for measured and calculated sea spray PM$_{10}$.

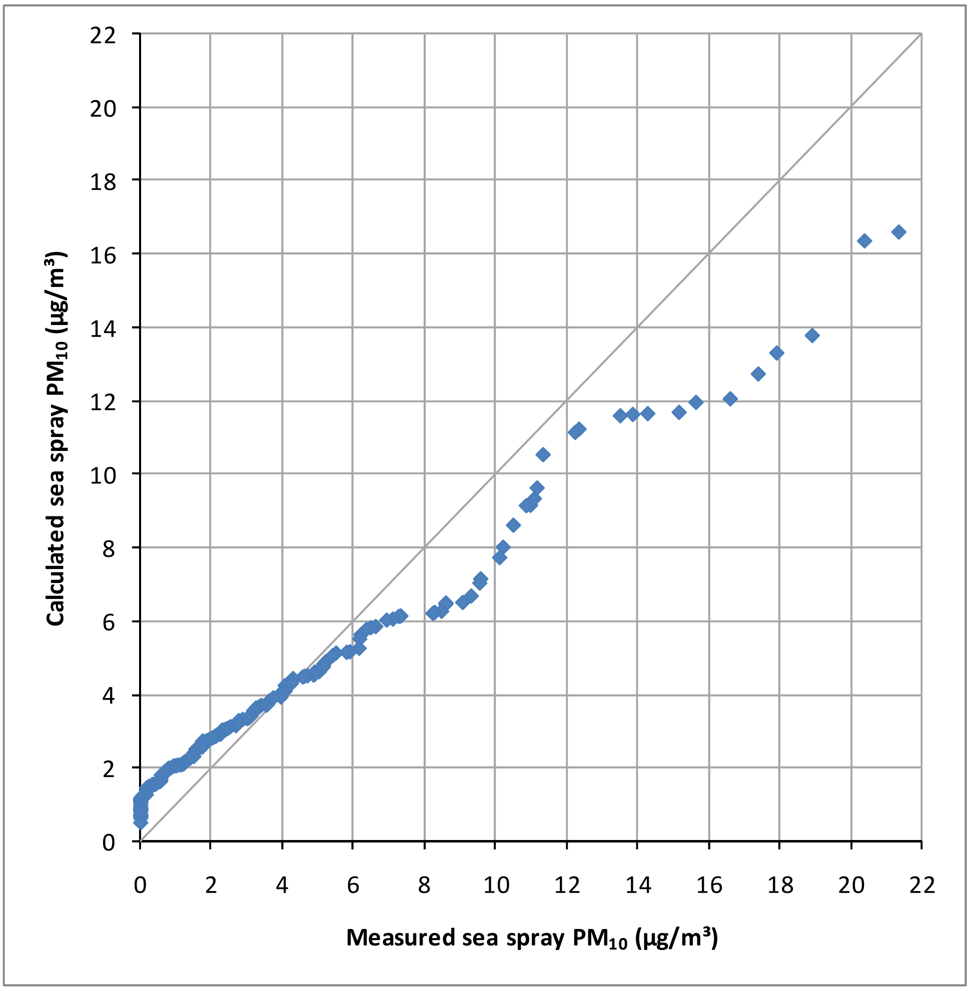

Figure 2: Ranked quantile-quantile relationship for measured and calculated sea spray PM_{10}.

APPENDIX F

CALPUFF Model Performance Statistics

1.0 INTRODUCTION

This Appendix discusses the performance of CALPUFF with respect to commonly-used model performance statistics, which compare time series of observed and modelled 24-hour-average PM_{10} concentrations. The performance statistics have been applied at the locations of the air quality monitoring sites – St Vincent, Blackwood and Oxford Streets. A logical split for the year is to consider the four winter months (May, June, July and August) separately from the other months. The performance measures are able to show how well the model reproduces means and variability in PM_{10}, to separate random from systematic errors, and to compare the model errors with observed variability. The remainder of this Appendix discusses the performance of CALPUFF for the winter and non-winter months (Sections 2.0 and 3.0, respectively).

2.0 WINTER MODEL-PERFORMANCE STATISTICS

Statistics for 24-hour-average winter PM_{10} concentrations are shown in Table 1. Mathematical formulas for the statistical measures may be found in many references (for example, Willmott, 1981, 1982; Golder, 2007). However, brief explanations of their meanings are given in the following text.

Means and standard deviations (lines 2 to 5): The table presents statistics for a 123-day period in mid-2008 (May to August). At the location of the three ambient monitoring sites, the modelled mean and standard deviation of the 24-hour-average PM_{10} are reasonably close to the observed values (lines 2 to 5).

Mean absolute error (line 6): The mean absolute error (MAE) is the average of the absolute difference between modelled and observed PM_{10}. This ranges between 10 $\mu g/m^3$ and 12 $\mu g/m^3$, and is small compared with the observed mean PM_{10}.

Overall agreement between modelled and observed time series (line 7): A measure of overall agreement is provided by the index of agreement (IOA, line 7). This ranges between zero for no agreement, and 1 if the two time series are the same. The IOA shows no agreement if the time series are different orders of magnitude, even if they happen to be correlated. IOAs of 0.7-0.8 are obtained here, showing good airshed-model performance. This is enhanced by the use of data from local climate stations; lower IOAs would probably be obtained if the meteorology were based wholly on a numerical weather model.

Linear regression of the modelled time series on the observed time series (lines 8 to 11): A linear regression has been carried out to identify and partition systematic and non-systematic model errors. These are quantified by the slope and intercept of the regression line, the correlation between observed and modelled PM_{10} (embodied in the correlation coefficient, R), and the variance explained by the regression (lines 8 to 11).

For a perfect fit of model to observation, parameter values would be R = 1, slope = 1 and intercept = 0 $\mu g/m^3$. The next-best situation would be slope = 1 and intercept = 0 $\mu g/m^3$, but R < 1, indicating that there is some random scatter, but no bias (that is, no systematic error). More realistically, the slope and intercept parameters are not 1 and 0, respectively, meaning there is a systematic error in the model results. That is, there is a linear relationship which explains some of the error, but the relationship is not "'modelled = 1 x observed + 0". The variance explained by the regression is a measure of how far away the regression line is from ideal, and should be as low as possible, leaving the random component as high as possible.

In Table 1, the regression slope is less than 1, and the intercept is positive, meaning that the model tends to miss extremes of concentration. This is not surprising – extremes are likely to occur under unusual emissions conditions, which are not simulated by the model. However, the variance explained by the linear regression is 33% or lower, depending on the site, meaning most of the model error is random, rather than showing a bias. This is a desirable feature of airshed model performance.

Root mean square errors (lines 12 to 14): The relative sizes of systematic and random errors, as parts of the total root-mean-squared error, can be seen on lines 12 to 14[1]. The systematic part of the error (line 12) is lower than the random part (line 13), which is a desirable feature of the model performance.

Model skill scores (lines 15 to 17): The 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. Their formulas are shown in the table, in terms of the standard deviations and RMS errors calculated. Model errors should be small relative to the observed variability (Skill_E and Skill_R should be less than 1), and the model variability should be the same as the observed variability (Skill_V should be 1).

Results for Skill_V are acceptable, but Skill_E and Skill_R are a little too large, in that the model errors are of the same order as the observed variability. This indicates that the model is missing some of the natural variability. The missing variability could be due to a number of features. For example, it may be due to unaccounted-for variability in the emissions, or small-scale turbulent meteorological variability. The former can be improved through a more sophisticated use of emissions information, but the latter is an inherent feature of computational models.

Table 1: Airshed model performance statistics at air quality monitoring sites, winter season. Concentrations are presented to the nearest µg/m^3.

Line	Parameter	St Vincent Street	Blackwood Street	Oxford Street
1	Number of days in time series	123	123	123
2	Observed Mean PM_{10} (µg/m^3)	36	31	29
3	Modelled Mean PM_{10} (µg/m^3)	33	29	30
4	Observed St. Dev. of PM_{10} (µg/m^3)	16	12	14
5	Modelled St. Dev. of PM_{10} (µg/m^3)	14	13	15
6	Mean Absolute Error (µg/m^3)	12	10	10
7	Index of Agreement (IOA)	0.69	0.69	0.78
8	Correlation coefficient (R)	0.49	0.47	0.63
9	Slope	0.45	0.52	0.67
10	Intercept (µg/m^3)	17	12	11
11	Variance Explained	33%	23%	14%
12	Systematic RMS Error (µg/m^3)	9	6	5
13	Unsystematic RMS Error (µg/m^3)	12	12	12
14	Total RMS Error (µg/m^3)	15	13	13
15	Skill_E = Unsyst. RMSE / Obs. St.Dev.	0.80	0.97	0.82
16	Skill_R = Total RMSE / Obs. St.Dev.	0.98	1.10	0.89
17	Skill_V = Model St.Dev. / Obs. St.Dev.	0.92	1.10	1.07

In summary, the airshed model performs well for the winter months, as seen by the performance measures presented in this section.

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[1] The sum of the squares of lines 12 and 13 equal the square of line 14, so that the total variance is the sum of the systematic and the random variances.

3.0 MODEL PERFORMANCE FOR NON-WINTER MONTHS

Modelled levels of PM_{10} in summer are much lower than winter, due to the absence of domestic heating, and the total modelled PM_{10} in summer is composed of contributions from motor vehicles, industry and sea spray.

A comparison between modelled and observed PM_{10} for time series including the months of January to April, and September to December, 2008, is presented in this section. The model performance statistics for the non-winter months are shown in Table 2.

Model performance is not as good for the non-winter months. The modelled mean PM_{10} is significantly lower than the observed mean PM_{10}. The underestimation of the modelled summer PM_{10} levels is likely to be due to small-scale dispersion effects not being captured by a model based on airshed-averaged transport emissions. Most measures show poor model performance for the summer months. For instance, there is low agreement between the modelled and observed PM_{10} time series, a large amount of bias (with model results being low), and model errors exceeding the observed variability in PM_{10}.

Table 2: Airshed model performance statistics at air quality monitoring sites, non-winter seasons. Concentrations are presented to the nearest µg/m^3.

	St Vincent Street	**Blackwood Street**	**Oxford Street**
Number of days in time series	243	243	243
Observed Mean PM_{10} (µg/m^3)	14	18	13
Modelled Mean PM_{10} (µg/m^3)	9	10	8
Observed St. Dev. of PM_{10} (µg/m^3)	5	8	5
Modelled St. Dev. of PM_{10} (µg/m^3)	5	5	5
Mean Absolute Error (µg/m^3)	7	9	7
Index of Agreement (IOA)	0.48	0.41	0.48
Correlation coefficient (R)	0.21	0.01	0.25
Slope	0.21	0.01	0.27
Intercept (µg/m^3)	6	10	4
Variance Explained	65%	84%	63%
Systematic RMS Error (µg/m^3)	7	11	6
Unsystematic RMS Error (µg/m^3)	5	5	5
Total RMS Error (µg/m^3)	9	12	8
Skill_E = Unsyst. RMSE / Obs. St.Dev.	0.99	0.60	1.02
Skill_R = Total RMSE / Obs. St.Dev.	1.67	1.51	1.68
Skill_V = Model St.Dev. / Obs. St.Dev.	1.01	0.60	1.06

APPENDIX G

CALMET and AUSPLUME Data Sets for Industrial Applications

APPENDIX G
CALMET and AUSPLUME Data Sets for Industrial Applications

1.0 INTRODUCTION

This Appendix is a user guide to the use of CALMET and AUSPLUME meteorological data sets for the Nelson and Richmond area. It may be read as a stand-alone document. However, for further reference, methodological details on the production of the CALMET data sets are contained in Appendix B, and the methods used in the creation of AUSPLUME meteorological files are detailed in Appendix H.

1.1 Background

A suite of meteorological data sets has been produced for the Nelson City Council (NCC) and the Tasman District Council (TDC), for use with air dispersion models commonly used in New Zealand. These cover the urban and industrial areas of Nelson and Richmond. The data sets have been prepared primarily for CALPUFF, with subsidiary meteorological files for use with AUSPLUME.

CALPUFF and AUSPLUME are typically used for industrial applications, and CALPUFF has also been used as an airshed model of dispersion of PM_{10} in Nelson and Richmond from all urban source types.

It is intended that the data sets be promoted by NCC and TDC, and accepted as the standard data sets to be used for air quality assessments of industrial projects around Nelson and Richmond. The data sets are supplied as dispersion model inputs, so that complex meteorological models need not be run to support specific dispersion-model impact assessments. This has the advantage that consistent and accepted meteorological data are used for the assessments.

Meteorological data sets have been produced with CALMET version 6.326 (released July 2008). They are compatible with CALPUFF versions 6.112 (released 14 April 2006) and 6.262 (released 25 July 2008), and it is expected they would be compatible with CALPUFF version 6.4 (released October/November 2010).

Use of the meteorological data sets is subject to a data sharing agreement between NCC, TDC and the user.

This Appendix provides guidance on the use of the meteorological data sets and associated dispersion models. The guide provides information for each data set, such as date and location parameters, which are needed by the dispersion models. Background information on the methodology used is contained in Appendices B and H.

Several Good-Practice Guides (GPGs) have been developed by air-quality scientists in New Zealand, and published by the MfE. These include GPGs for atmospheric dispersion modelling (MfE, 2004b), and for assessing discharges to air from industry (MfE, 2008a) and land transport (MfE, 2008b). This document provides some supplementary recommendations, not covered in those guides, but most of the recommendations made here are taken from those GPGs and are therefore consistent with them. The information contained in this guide is intended to reflect current good practice.

This Appendix 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 NCC and TDC, reviewing resource consent applications which have made use of the data sets.
- Scientific researchers carrying out projects relating to NCC and TDC policy.
- Independent researchers and interested members of the general public.

In the remainder of this Appendix, Section 2.0 contains background information on meteorological and dispersion modelling. Section 3.0 outlines the methodology used for the development of the meteorological data sets. Section 4.0 contains advice on the choice of dispersion model, depending on the type of assessment being carried out. Section 5.0 contains information on the model domains available, including maps and parameter lists for dispersion model input. Section 6.0 contains recommendations on parameter choices in CALPUFF which differ from ‘default’ settings.

The data sets themselves may be obtained on portable hard disk from Nelson City Council or Tasman District Council. The letter accompanying the data serves as a ‘readme’ file for the contents of the disk, and is attached as Appendix I to the main report.

2.0 AIR DISPERSION MODELS AND METEOROLOGICAL DATA

2.1 Air Dispersion Models

Air dispersion models are computational tools used to calculate air pollutant concentrations downwind of an emission source, or concentration variations within an airshed due to the cumulative effects of different sources. They require information on the contaminant emission rate, other characteristics of the source, the local topography and meteorology of the area, and in some situations ambient or background concentrations of pollutants.

Air dispersion models are frequently used as a tool for assessing potential environmental effects which arise from pollutant discharges to air. The key advantage of dispersion modelling is that detailed predictions of contaminant concentrations may be made over a wide area, as a supplement to ambient monitoring or other methods, which are usually only available at isolated locations.

2.2 Meteorological Data

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 to overcome these limitations.

The Nelson/Tasman region contains complex terrain, and experiences complex land-sea breeze circulations and periods of calm or light wind. Therefore, the use of steady-state Gaussian plume models in this region is not ideal. Complex dispersion models, such as CALPUFF, have significantly greater meteorological data requirements than the steady-state models. In particular, they can use spatially-varying meteorological fields.

CALPUFF’s meteorological pre-processor, CALMET, is a diagnostic meteorological model, which can use data from many monitoring stations. From such information, CALMET produces an hourly three-dimensional grid of meteorological variables, which are directly input to CALPUFF.

The meteorological data sets produced here as key inputs to CALPUFF have been developed using CALMET. Golder envisages that CALPUFF will be the preferred dispersion model for the assessment of industrial discharges that require resource consents.

3.0 OVERVIEW OF DATA SET DEVELOPMENT

CALMET meteorological data sets which cover the Nelson and Richmond urban areas in a single domain have been developed for use with CALPUFF. As discussed earlier, these data sets are compatible with CALPUFF versions 6.112 onwards.

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 can also be used to develop meteorological inputs for other models, such as AERMOD, CALINE4, AUSROADS and ADMS-Roads.

Several stages were involved in the development of the CALMET data sets. The methodology is detailed in Appendix B and outlined as follows.

a) Model years 2008 and 2009 were selected in consultation with NCC and TDC. The decision was based on the availability of monitoring data from relatively new meteorological sites in Nelson and Richmond (run by the respective councils). The site data are required inputs to CALMET. It is intended that dispersion modelling is undertaken for both 2008 and 2009, with results presented for each year separately.

b) The data for the two years at the council-run sites, plus data from local sites on the National Climate Database (CliDb), were formatted for input into CALMET. The modelling described below was carried out for each of 2008 and 2009.

c) Outputs from the weather prediction model MM5 were purchased from Lakes Environmental for a region centred on Nelson, to provide large-scale and upper-air information for input to CALMET. This supplemented the surface-based measurements from the meteorological sites. MM5 was run by Lakes to a 4-km grid resolution over an area 150 x 150 km for 2008 and 50 x 50 km for 2009. (The larger area for 2008 was chosen for testing purposes, to define the range needed for the CALMET modelling. It was found that 50 x 50 km would be sufficient and hence the smaller area was purchased subsequently for the 2009 modelling).

d) CALMET was run over an area covering Nelson and Richmond at a 250-m grid resolution. The output data sets are those intended for industrial applications in the area which require the use of CALPUFF.

e) Several single-point meteorological data sets were extracted from the CALMET results for use with AUSPLUME. These were chosen to be representative of the key industrial areas of Nelson and Richmond.

A similar methodology to that outlined above was followed to produce CALMET, AUSPLUME and CALINE4 data sets for the Auckland Region (Gimson *et al.,* 2010). The main difference is that the meteorological component of TAPM (The Air Pollution Model) was used in Auckland to produce the large-scale and upper-air information for CALMET. In the present work, MM5 was used. The use of MM5 is more straightforward, because CALMET is able to directly incorporate the MM5 outputs

4.0 CHOICE OF DISPERSION MODEL – CALPUFF OR AUSPLUME

4.1 Model Applicability to Physical Scenarios

CALPUFF, with three-dimensional meteorology provided by CALMET, is likely to be the most appropriate dispersion for most industrial applications in the Nelson and Tasman districts, for reasons discussed above. However, for ‘screening’ assessments, or for near-field effects in flat terrain, the use of a steady-state plume model with a single-point meteorological file may sometimes be justified.

The dispersion modelling GPG produced by MfE (2004b) 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 bullet points summarise 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 Nelson/Tasman 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 often provide the necessary analysis for this.

Also it should be noted that 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 – for example, there would be no significant difference in the configuration time or effort in using CALPUFF compared to AUSPLUME.

4.2 Tiered Assessment Levels

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, the model 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 DETAILS OF THE METEOROLOGICAL DATA SETS

5.1 Introduction

A high-resolution (250 m) three-dimensional CALMET meteorological data set has been developed for areas of significant industrial activity around the Nelson and Richmond urban areas, for each of 2008 and 2009. Several data sets have been extracted from the high resolution CALMET data sets at single points for use with AUSPLUME. The location and extent of the high resolution CALMET domain and the location of the single-point data sets are shown in Figure 1. All data sets contain hourly meteorological parameters.

The remainder of this section details the information specific to each data set, which is required for the configuration of the dispersion model.

5.2 CALMET Configuration Details Required by CALPUFF

5.2.1 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. The latitude and longitude, along with a corresponding easting and northing (in NZTM coordinates) for the projection origin are listed in Table 1[1].

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 CALPUFF parameter names are in square brackets. The range of the CALMET domain is [NX] [DGRIDKM] = 26 km east to west, and also 26 km north to south.

Table 1: Grid control parameters for the CALMET domain.

Parameter	**Value**
Latitude [RLAT0]	41.298S (decimal degrees)
Longitude [RLON0]	173.237E (decimal degrees)
False Easting [FEAST]	1619.842 (NZTM km)
False Northing [FNORTH]	5428.134 (NZTM km)
South west corner x-coordinate [XORIGKM]	1606.000 (NZTM km)
South west corner y-coordinate [YORIGKM]	5415.000 (NZTM km)
Number of grid cells west to east [NX]	104
Number of grid cells south to north [NY]	104
Grid spacing [DGRIDKM]	0.25 km

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[1] Although NZTM is not a Tangential Transverse Mercator projection, choice of this option allows any rectangular grid system to be specified, provided the grid coordinates are linked to the correct latitude and longitude.

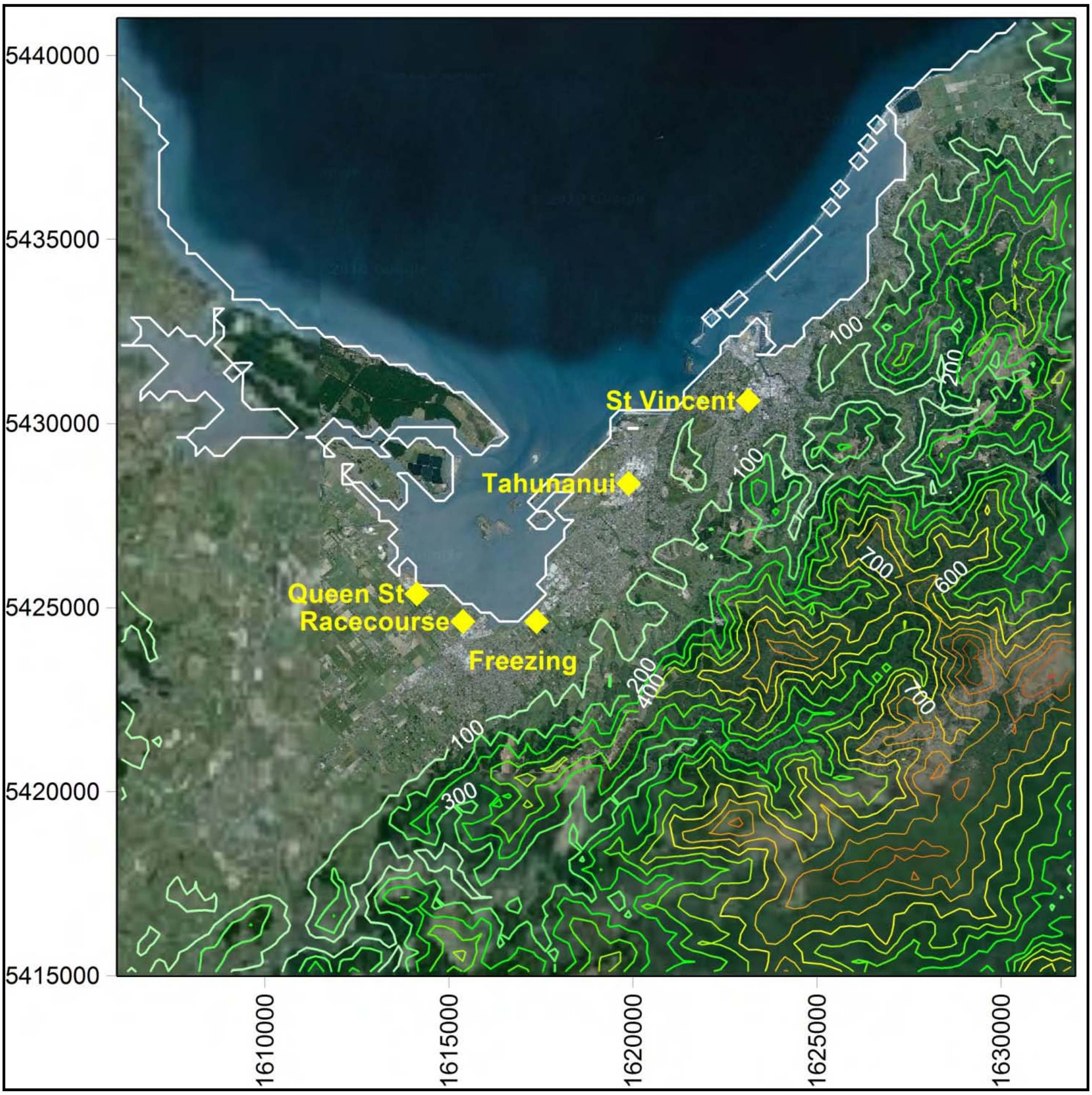


Figure 1: High resolution CALMET domain area, and AUSPLUME data point locations. The model terrain is shown at a 100 m contour interval.

CALPUFF also requires the vertical grid structure used in CALMET. Ten vertical layers ([NZ] = 10) were used with the height of each layer face [ZFACE], in metres, as follows:

[ZFACE] = 0.,20.,40.,80.,120.,400.,800.,1200.,2000.,3000.

For ten layers, there are eleven values of [ZFACE].

5.2.2 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 (not each month), and these are listed in Table 2.

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

Parameter	Year 2008	Year 2009
Start date - year [IBYR]	2008	2009
- month [IBMO]	1	1
- day [IBDY]	1	1
- hour [IBHR]	0	0
- second [IBSEC]	0	0
End date - year [IEYR]	2009	2010
- month [IEMO]	1	1
- day [IEDY]	1	1
- hour [IEHR]	0	0
- second [IESEC]	0	0
UTC time zone [ABTZ]	UTC+1200	UTC+1200

5.2.3 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, CALPUFF requires [NMETDAT] = 12. Then the filenames are specified using the parameter [METDAT]. For 2008, this means a list of names as follows, each line completed by “!END!”:

```
!  METDAT=D:\CALMET\2008\2008_01.MET !    !END!
!  METDAT=D:\CALMET\2008\2008_02.MET !    !END!
!  METDAT=D:\CALMET\2008\2008_03.MET !    !END!
```

etc., until

```
!  METDAT=D:\CALMET\2008\2008_12.MET !    !END!
```

The pathname has been included here by way of example. An analogous list would be used for the 2009 CALPUFF run (exchanging ‘2008’ for ‘2009’ in the filenames).

5.3 AUSPLUME Meteorological File Details

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 filename and folder location. For reference, the coordinates at which each AUSPLUME file was extracted are shown in Table 3, in addition to the filename for each data set.

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

Filename	Location	X (km, NZTM)	Y (km, NZTM)
Tahunanui.csv	Middle of Tahunanui industrial area, end of Vivian place, about 600m west of the Blackwood St meteorological site	1619.875	5428.375
StVincent.csv	Slightly down valley of the St Vincent Street meteorological site	1623.125	5430.625
Freezing.csv	Nelson/Tasman border – at freezing works	1617.375	5424.625
Racecourse.csv	Richmond Park Racecourse – meteorological site	1615.375	5424.625
QueenSt.csv	Lower Queen Street, Richmond – 2km north west of Racecourse	1614.125	5425.375

The coordinates given in Table 3 are those of the centre of the grid cell containing the chosen site. The sites have been chosen in consultation with NCC and TDC, to be relevant to industrial areas or up-coming industrial resource consent applications, rather than being at the location of a meteorological site. AUSPLUME files generated at the location of a meteorological site would contain the observed wind and temperature. In the case of the St Vincent Street file, the meteorology is noticeably different from the meteorology at the monitoring site (a few 100m away from the AUSPLUME location). This indicates a variability in meteorological conditions with location, implying that it may not be appropriate to model with AUSPLUME in that particular vicinity. The list of sites may be extended if more are requested by NCC or TDC.

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 H.

6.0 RECOMMENDED ‘NON-DEFAULT’ CALPUFF SETTINGS

This section is taken *verbatim* from Gimson *et al.* (2010).

Most input parameters to CALPUFF have recommended default values. Many of these are switches, relating to a choice of schemes for the physical processes included in the model. Some of the default parameters are defined by the USEPA for regulatory usage of CALPUFF.

Due to the incorporation of more modern schemes into dispersion models, the most realistic results may be obtained with ‘non-default’ settings which select the latest schemes. Most of these are discussed in the modelling GPG (MfE, 2004b). Those key parameters which should differ from the default or regulatory settings in CALPUFF are discussed in this section.

6.1 Choice of Building-Wake Downwash Algorithm

The PRIME algorithm (“Plume-Rise Model Enhancements”) has been shown to be superior to other building-wake downwash schemes and is now included in AUSPLUME, CALPUFF, TAPM and others. It is recommended that the PRIME option be used. [CALPUFF parameter: MBDW=2].

CALPUFF default: [MBDW=1] (ISC method) *USEPA default: no default.*

MfE GPG recommendation: MBDW=2 (PRIME method).

6.2 Calculation of Dispersion Coefficients

Dispersion coefficients, which determine the horizontal and vertical spread of pollution, can be derived in a variety of ways. In the CALPUFF configuration file, the dispersion coefficient computation method is represented by the parameter [MDISP]. The default method relies on a simpler approach of deriving dispersion coefficients from stability class [MDISP=3]. However, to take full advantage of the CAMET data sets it is recommended that the method of deriving "dispersion coefficients using turbulence calculated from micrometeorology" be used [MDISP=2].

CALPUFF default: [MDISP=3] *USEPA default: [MDISP=2 or 3].*

MfE GPG does not make specific recommendations for CALPUFF.

6.3 Dispersion in Convective Conditions

CALPUFF includes an option for using the probability density function (PDF) method for vertical dispersion in convective conditions. In the CALPUFF configuration file, the PDF method is represented by the parameter [MPDF]. The PDF method is also available in the most recent version of AUSPLUME (version 6), but is not mentioned by MfE (2004b).

The PDF method recognises that the turbulence may not be Gaussian under convective conditions, with vertical dispersion being asymmetrical. This is particularly relevant for dispersion from tall stacks, bringing the plume centreline downwards and leading to higher GLCs. The PDF method has been verified by scientists at CSIRO using standard model-validation data sets and is applied in AUSPLUME (version 6) to stacks greater than 100 m in height. It is recommended that the probability density formulation for convective conditions is used in CALPUFF, particularly for tall stacks [MPDF=1]. For all other situations, the sensitivity of the model when using the PDF method should be assessed.

CALPUFF default: [MPDF=0] *USEPA default: [MPDF=0] if [MDISP=3] or*

[MPDF=1] if [MDISP=2].

7.0 REFERENCES

Gimson N., Chilton R., Xie, S., 2010: Meteorological Datasets for the Auckland Region – User Guide. Prepared by Golder Associates (NZ) Limited for Auckland Regional Council. Auckland Regional Council Technical Report 2010/022.

MfE, 2004b: Good practice guide for atmospheric dispersion modelling. June 2004, Ministry for the Environment, Wellington, New Zealand.

MfE, 2008a: Good practice guide for assessing discharges to air from industry. May 2008, Ministry for the Environment, Wellington, New Zealand.

MfE, 2008b: Good practice guide for assessing discharges to air from land transport. May 2008, Ministry for the Environment, Wellington, New Zealand.

APPENDIX H

Creation of AUSPLUME Meteorological Files

1.0 INTRODUCTION

This Appendix describes the methods used to create meteorological files for AUSPLUME, applicable to locations around Nelson and Richmond. 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). It has undergone several peer-reviews 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 the dispersion modelling. However, in some cases, it is sufficient to use AUSPLUME, and 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 (see Gimson *et al*., 2010).
(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

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 are not realistic and 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.

2.1 Wind speed

Gaussian-plume models 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.

2.2 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 VicEPA, the developers of AUSPLUME and AUSROADS. VicEPA uses a solar radiation method for daytime and a modified Pasquill-Gifford scheme for night-time to define stability class. A summary of the 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 VicEPA 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^{o}) 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 Pasquill-Gifford, 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 VicEPA. 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 VicEPA.

	Day time				**1h before sunset and after sunrise**	**Night time**		
Wind Speed (m/s)	**Solar Radiation (W/m^2)**					**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

2.3 Mixing height

The minimum mixing height in CALMET is set to 50 m. This is the default value and is recommended in the modelling GPG (MfE, 2004b). 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 100m. 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 100m. 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

2.4 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.

APPENDIX I

Letter Accompanying Meteorological Data Sets

23 November 2010 Project No. 0978104449

Trevor James and Paul Sheldon

Tasman District Council
Private Bag 4
Richmond 7031

Nelson City Council
PO Box 645
Nelson 7040

NELSON AND RICHMOND CALMET AND AUSPLUME METEOROLOGICAL DATA SETS – READ ME

The data sets supplied on portable hard drive have been produced as part of a contract between Golder Associates (NZ) Limited (Golder) and Nelson City and Tasman District Councils. The project includes airshed modelling and meteorological modelling components.

The project is still in progress. This means that the final report is not yet available, and the data supplied should be considered to be in draft form. However, Golder does not envisage any changes being made.

The final report will contain fuller guidance on the use of the data sets. This note provides a brief description of the data files which have been produced by Golder. They (along with this readme file) are contained in the directory F:\met_files.

Folder Structure

There are six subdirectories, *viz.,* 2008_AUSPLUME, 2008_CALMET, 2008_CALPUFF, 2009_AUSPLUME, 2009_CALMET and 2009_CALPUFF.

Data sets have been supplied for the years 2008 and 2009, as indicated in the folder names.

*_CALMET contains the meteorological outputs for each year, as monthly files.

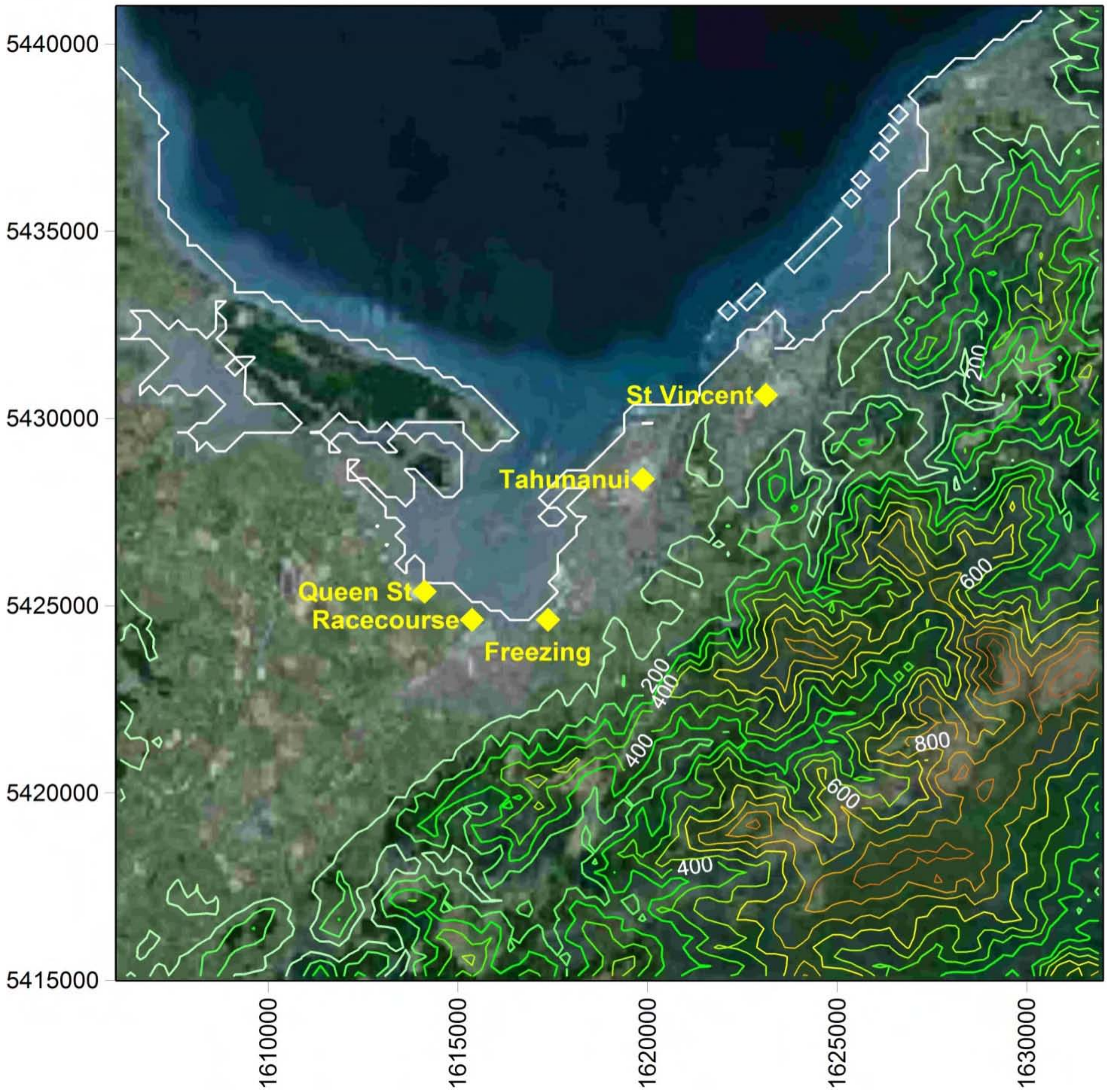
*_CALPUFF contains test runs with CALPUFF and CALPOST to ensure that the CALMET files can be read. These simulate a single point source with four discrete receptors.

*_AUSPLUME contains meteorological files extracted from CALMET for five locations in the Nelson/Richmond area.

The data sets have been produced using CALMET version 6.326 (released July 2008).

CALMET model domain

The following figure shows the extent of the CALMET model domain (at 250 m resolution), with terrain height at 100m intervals. The locations for the AUSPLUME files are marked.



CALPUFF parameters (related to meteorological inputs)

The following table lists the grid control parameters used in CALPUFF. Note the use of NZTM coordinates. Although CALMET does not have an NZTM option, the TTM projection can be used, which allows a regular grid of points. These parameters are contained in the indareas.cmn file which can be read into the CALPUFF GUI (without needing to be re-typed). A copy of indareas.cmn is contained in each _CALPUFF folder, which also includes the vertical grid dimensions. Alternatively, the input files used for CALPUFF testing include these parameters and may be used as a template.

Parameter	**Value**
Projection [PMAP]	TTM
Latitude [RLAT0]	41.298S (decimal degrees)
Longitude [RLON0]	173.237E (decimal degrees)
False Easting [FEAST]	1619.842 (NZTM km)
False Northing [FNORTH]	5428.134 (NZTM km)
South west corner x-coordinate [XORIGKM]	1606.000 (NZTM km)
South west corner y-coordinate [YORIGKM]	5415.000 (NZTM km)
Number of grid cells west to east [NX]	104
Number of grid cells south to north [NY]	104
Grid spacing [DGRIDKM]	0.25 km

The date and time range for the 2008 run is HH:MM:SS = 00:00:00 on 1 January 2008 to 00:00:00 on 1 January 2009.

The date and time range for the 2009 run is 00:00:00 on 1 January 2009 to 00:00:00 on 1 January 2010.

The CALMET runs have been divided into month-long segments, hence 12 meteorological file names need to be supplied for year of CALPUFF run. These are specified in the following form:

```
! METDAT= F:\met_files\2008_CALMET\2008_01.MET !   !END!
! METDAT= F:\met_files\2008_CALMET\2008_02.MET !   !END!
! METDAT= F:\met_files\2008_CALMET\2008_03.MET !   !END!
```

etc., until

```
! METDAT= F:\met_files\2008_CALMET\2008_12.MET !   !END!
```

All other configuration parameters for CALPUFF are at the discretion of the user.

AUSPLUME meteorological files

Meteorological files have been extracted from CALPUFF, with some post-processing to make them suitable for input to AUSPLUME. The details of this will be given in the final report. The site locations are shown on the figure above, and a description is given in the following table.

Filename	Location	X (km, NZTM)	Y (km, NZTM)
Tahunanui.csv	Middle of Tahunanui industrial area, end of Vivian place, about 600m west of the Blackwood St meteorological site	1619.875	5428.375
StVincent.csv	Slightly down valley of the St Vincent Street meteorological site	1623.125	5430.625
Freezing.csv	Nelson/Tasman border – at freezing works	1617.375	5424.625
Racecourse.csv	Richmond Park Racecourse – meteorological site	1615.375	5424.625
QueenSt.csv	Lower Queen Street, Richmond – 2km northwest of Racecourse	1614.125	5425.375

The files are contained in the _AUSPLUME folders. The AUSPLUME run configuration requires only the filename and the start and end dates (which are given above).

All other configuration parameters for AUSPLUME are at the discretion of the user.

List of files supplied by Golder

F:\met_files\2008_AUSPLUME
F:\met_files\2008_AUSPLUME\Freezing.met
F:\met_files\2008_AUSPLUME\QueenSt.met
F:\met_files\2008_AUSPLUME\Racecourse.met
F:\met_files\2008_AUSPLUME\StVincent.met
F:\met_files\2008_AUSPLUME\Tahunanui.met
F:\met_files\2008_CALMET
F:\met_files\2008_CALMET\2008_01.MET
F:\met_files\2008_CALMET\2008_02.MET
F:\met_files\2008_CALMET\2008_03.MET
F:\met_files\2008_CALMET\2008_04.MET
F:\met_files\2008_CALMET\2008_05.MET
F:\met_files\2008_CALMET\2008_06.MET
F:\met_files\2008_CALMET\2008_07.MET
F:\met_files\2008_CALMET\2008_08.MET
F:\met_files\2008_CALMET\2008_09.MET
F:\met_files\2008_CALMET\2008_10.MET
F:\met_files\2008_CALMET\2008_11.MET
F:\met_files\2008_CALMET\2008_12.MET
F:\met_files\2008_CALPUFF
F:\met_files\2008_CALPUFF\CPOST_08.INP
F:\met_files\2008_CALPUFF\CPOST_08.LST
F:\met_files\2008_CALPUFF\CPUFF_08.INP
F:\met_files\2008_CALPUFF\CPUFF_08.LST
F:\met_files\2008_CALPUFF\CPUFF_08.PUF
F:\met_files\2008_CALPUFF\INDAREAS.CMN
F:\met_files\2008_CALPUFF\luse.clr
F:\met_files\2008_CALPUFF\POSTTEST2008.BAT
F:\met_files\2008_CALPUFF\PUFTEST2008.BAT
F:\met_files\2008_CALPUFF\qagrid.bna
F:\met_files\2008_CALPUFF\qaluse.grd
F:\met_files\2008_CALPUFF\qapnts.dat
F:\met_files\2008_CALPUFF\qarecd.dat
F:\met_files\2008_CALPUFF\qarecg.dat
F:\met_files\2008_CALPUFF\qaterr.grd
F:\met_files\2008_CALPUFF\TSERIES_SO2_1HR_CONC__.DAT

F:\met_files\2009_AUSPLUME
F:\met_files\2009_AUSPLUME\Freezing.met
F:\met_files\2009_AUSPLUME\QueenSt.met
F:\met_files\2009_AUSPLUME\Racecourse.met
F:\met_files\2009_AUSPLUME\StVincent.met
F:\met_files\2009_AUSPLUME\Tahunanui.met
F:\met_files\2009_CALMET
F:\met_files\2009_CALMET\2009_01.MET
F:\met_files\2009_CALMET\2009_02.MET
F:\met_files\2009_CALMET\2009_03.MET
F:\met_files\2009_CALMET\2009_04.MET
F:\met_files\2009_CALMET\2009_05.MET
F:\met_files\2009_CALMET\2009_06.MET
F:\met_files\2009_CALMET\2009_07.MET
F:\met_files\2009_CALMET\2009_08.MET
F:\met_files\2009_CALMET\2009_09.MET
F:\met_files\2009_CALMET\2009_10.MET
F:\met_files\2009_CALMET\2009_11.MET
F:\met_files\2009_CALMET\2009_12.MET
F:\met_files\2009_CALPUFF
F:\met_files\2009_CALPUFF\CPOST_09.INP
F:\met_files\2009_CALPUFF\CPOST_09.LST
F:\met_files\2009_CALPUFF\CPUFF_09.INP
F:\met_files\2009_CALPUFF\CPUFF_09.LST
F:\met_files\2009_CALPUFF\CPUFF_09.PUF
F:\met_files\2009_CALPUFF\INDAREAS.CMN
F:\met_files\2009_CALPUFF\luse.clr
F:\met_files\2009_CALPUFF\POSTTEST2009.BAT
F:\met_files\2009_CALPUFF\PUFTEST2009.BAT
F:\met_files\2009_CALPUFF\qagrid.bna
F:\met_files\2009_CALPUFF\qaluse.grd
F:\met_files\2009_CALPUFF\qapnts.dat
F:\met_files\2009_CALPUFF\qarecd.dat
F:\met_files\2009_CALPUFF\qarecg.dat
F:\met_files\2009_CALPUFF\qaterr.grd
F:\met_files\2009_CALPUFF\TSERIES_SO2_1HR_CONC__.DAT

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Africa	+ 27 11 254 4800
Asia	+ 852 2562 3658
Australia & New Zealand	+ 61 7 3721 5400
Europe	+ 44 356 21 42 30 20
North America	+ 1 800 275 3281
South America	+ 55 21 3095 9500

solutions@golder.com
www.golder.com

AUCKLAND

Tel +64 9 486 8068
Fax +64 9 486 8072

Level 2
Takapuna Business Park
4 Fred Thomas Drive
Takapuna
Auckland 0622

PO Box 33-849
Takapuna 0740

TAURANGA

Tel +64 7 928 5335
Fax +64 7 928 5336

78 Maunganui Road
Tauranga 3116

PO Box 13611
Tauranga Central
Tauranga 3141

HAMILTON

Tel +64 7 928 5335
Fax +64 7 928 5336

Ruakura AgResearch Centre
Room 31 in the Homestead
East Street
Hamilton 3214

PO Box 19-479
Hamilton 3244

NELSON

Tel +64 3 548 1707
Fax +64 3 548 1727

Level 3
295 Trafalgar Street
Nelson 7010

PO Box 1724
Nelson 7040

CHRISTCHURCH

Tel +64 3 377 5696
Fax +64 3 377 9944

Level 1
132 Tuam Street
Christchurch 8011

PO Box 2281
Christchurch 8140

DUNEDIN

Tel +64 3 479 0390
Fax +64 3 474 9642

Level 9A
John Wickliffe House
265 Princes Street
Dunedin 9016

PO Box 1087
Dunedin 9054

ARROWTOWN

Tel +64 3 409 8106
Fax +64 3 409 8106

11 Arrow Lane
Arrowtown 9302

Golder Associates