Determination of airshed boundaries for Masterton, the Waingawa industrial area and Carterton
Wairarapa airshed study 2014

A report prepared for Greater Wellington by Golder Associates

Greater Wellington
Te Pane Matua Taiao

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DETERMINATION OF AIRSHED BOUNDARIES FOR MASTERTON, THE WAINGAWA INDUSTRIAL AREA AND CARTERTON

Wairarapa Airshed Study

Submitted to:
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REPORT

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Table of Contents

TABLES

FIGURES

APPENDICES

Abbreviations and Units

AAQG	Ambient Air Quality Guideline
AUSPLUME	Gaussian Plume Model
AWS	Automatic Weather Station
BPIP	Building Profile Input Program
CALMET	California Meteorological Model
CALPUFF	California Puff Model
CAU	Census-Area Unit
°C	degrees Celsius
CliFlo	National Climate Database
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EIL	Emission Impossible Limited
EPA	(United States) Environmental Protection Agency
ESESM	Emissions and Socio-Economic Spatial Model
EWS	Electronic Weather Station
GLC	Ground-Level Concentration
Golder	Golder Associates (NZ) Limited
g/ha/day	gram(s) per hectare per day
g/ha/hr	gram(s) per hectare per hour
g/s	grams per second
GLC	Ground-Level Concentration
GWRC	Greater Wellington Regional Council
IOA	Index of Agreement
JNL	Juken New Zealand Limited
K	Kelvins
kg/h	kilograms per hour
KL	Kiwi Lumber
km	kilometre(s)
m	metre(s)
MfE	Ministry for the Environment
m/s	metres per second
$\mu g/m^3$	microgram(s) per cubic metre
MWH	Montgomery Watson Harza
NES	National Environmental Standards
NSW EPA	New South Wales EnvironmentProtection Authority
NZST	New Zealand Standard Time
NZMG	New Zealand Map Grid Coordinates
NZTM	New Zealand Transverse Mercator (Coordinates)
Oldfields	Oldfield Asphalts Limited
PM_{10}	Particulate matter with aerodynamic diameter less than 10 microns
PRIME	Plume Rise Model Enhancements
QQ	Quantile-Quantile (type of scatter-plot)
RH	Relative humidity
RMS	Root mean square
RMSE	Root mean square error
RPC	Ron Pilgrim Consulting
Skill_E	Model skill score – systematic model error as a fraction of observed variability
Skill_R	Model skill score – total model error as a fraction of observed variability
Skill_V	Model skill score – model variability as a fraction of observed variability
SKM	Sinclair Knight Merz Pty Ltd
Std_O	Standard deviation of an observed meteorological parameter
Std_P	Standard deviation of a predicted (i.e. modelled) meteorological parameter
TAPM	The Air Pollution Model
TTM	Tangential Transverse Mercator (Coordinates)
T	Temperature
U	Label for the westerly component of the vector wind
USEPA	United States Environmental Protection Agency
UTC	Co-ordinated Universal Time (successor to Greenwich Mean Time)
V	Label for the southerly component of the vector wind
W or WS	Wind speed
WGS 84	World Geodetic System (established in 1984)
WHO	World Health Organization

1.0 INTRODUCTION

1.1 The Wairarapa Airshed Study

Following the recent changes to the National Environmental Standards (NES) and their consequences for industrial offsetting of PM_{10} emissions, the Greater Wellington Regional Council (GWRC) seeks to refine the boundary of the current Wairarapa Valley airshed, potentially dividing it into several smaller airsheds around the individual urban areas. The current Wairarapa Valley airshed is shown in Figure 1. Any new airsheds that are defined by GWRC will be established by notice in the *New Zealand Gazette*. To support changes to the current Wairarapa airshed boundary, GWRC requires the determination of realistic, scientifically-based airshed boundaries in the Wairarapa Valley. This project investigates and recommends boundaries based on atmospheric science (meteorology and air-pollution dispersion).

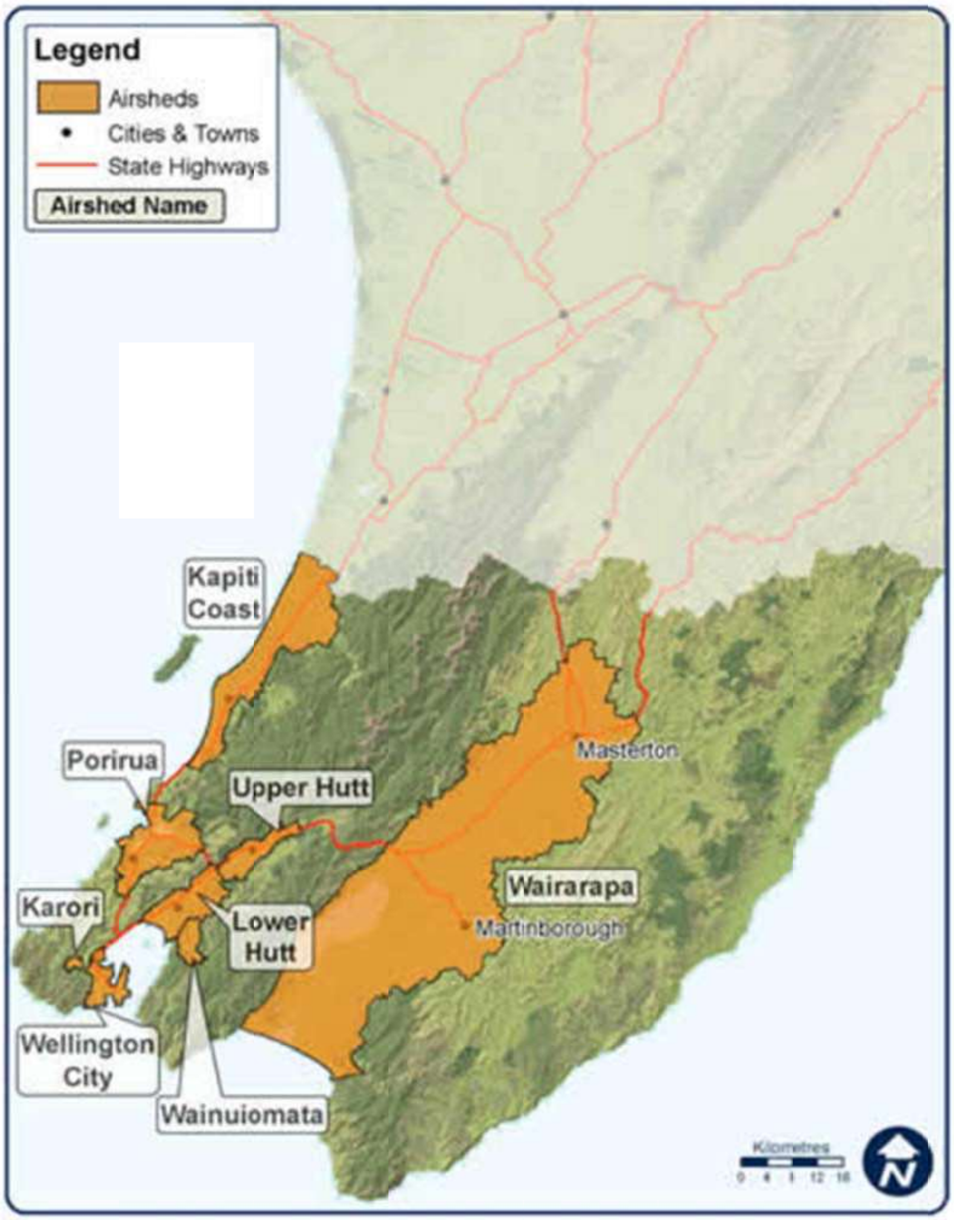


Figure 1: Defined airsheds in the Greater Wellington Region (from the MfE website).

A set of recommendations for investigation was provided to GWRC by Golder Associates (NZ) Limited (Golder) in February 2013 (Golder 2013a, the Scoping Report). The recommended investigations were aimed at providing sufficient data so that the spatial extent of airsheds could be determined. GWRC accepted several of those recommendations, and this project, the Wairarapa Airshed Study, relates to those recommendations involving meteorological modelling and dispersion modelling of PM_{10} from sources in the Wairarapa Valley. The term PM_{10} refers to particulate material with aerodynamic diameter less than 10 microns.

The main objective of this project is to provide GWRC with revised estimates of airshed boundary locations for air quality management purposes within the Wairarapa Valley.

It is important to note that the airshed boundaries determined in this report are *modelled estimates*. The eventual boundaries are yet to be determined by GWRC, and the final gazetted airsheds will take into account property boundaries and other policy requirements.

1.2 Background – Changes to the NES

When the NES for air quality were originally promulgated in 2004, GWRC gazetted a single airshed in the Wairarapa Valley for air quality management purposes. This area covered the whole of the valley, which is mostly rural, but includes five main towns. These are Masterton (the largest), Carterton, Greytown, Martinborough and Featherston. Masterton and Martinborough are labelled on Figure 1; the other towns are in the northeastern half of the airshed.

Changes to the NES in 2011 introduced the offsetting of some proposed industrial discharges of PM_{10} by reductions in PM_{10} emissions from other sources, with rules on this coming into effect in September 2012 (MfE 2011). NES Regulation 17(1) states the following:

"A consent authority must decline an application for a resource consent (the **proposed consent**) to discharge PM_{10} if the discharge to be expressly allowed by the consent would be likely, at any time, to increase the concentration of PM_{10} (calculated as a 24-hour mean under Schedule 1) by more than 2.5 micrograms per cubic metre in any part of a polluted airshed other than the site on which the consent would be exercised."

However, this does not apply if the conditions in Regulations 17(2) and 17(3) hold. Regulation 17(2) states the following:

"Subclause (1) does not apply if---

a) the proposed consent is for the same activity on the same site as another resource consent (the **existing consent**) held by the applicant when the application was made; and

b) the amount and rate of PM_{10} discharge to be expressly allowed by the proposed consent are the same as or less than under the existing consent; and

c) discharges would occur under the proposed consent only when discharges no longer occur under the existing consent."

Regulation 17(3) states the following:

"Subclause (1) also does not apply if---

a) the consent authority is satisfied that the applicant can reduce the PM_{10} discharged from another source or sources into each polluted airshed to which subclause (1) applies by the same or greater amount than the amount likely to be discharged into the relevant airshed by the discharge to be expressly allowed by the proposed consent; and

b) the consent authority, if it intends to grant the proposed consent, includes conditions in the consent that require the reduction or reductions to take effect within 12 months after the consent is granted and to then be effective for the remaining duration of the consent."

To summarize the above, in cases where the 24-hour concentration of PM_{10} may increase by 2.5 µg/m^3 or more and the activity is new or involves an increased discharge of PM_{10}, the consent authority can only grant a resource consent if any increase in industrial emissions is offset by emission reductions elsewhere in the same airshed.

1.3 Implications for the Wairarapa Valley Airshed

The current Wairarapa Valley airshed is defined as 'polluted' due to the non-compliance of Masterton with the NES for PM_{10}. Under the NES, the 24-hour PM_{10} concentration is only allowed to exceed 50 µg/m^3 once per year. Non-compliance therefore means that there are years when are two or more exceedences of that concentration. The non-compliance of Masterton with the NES has the consequence under the 2011 NES that changes in industrial activity could be affected by the emission-offset rules. The industrial focus of this study is the industry in Waingawa, which adjoins and extends approximately 2 km southwest of Masterton. The Waingawa River flows through this area. Additionally, the currently gazetted Wairarapa Valley airshed has implications for air quality management options in other locations as these may be determined by the current NES non-compliance of Masterton. Hence there is a need to refine the airshed boundaries in the Wairarapa Valley so that GWRC can effectively manage air quality issues in the area.

1.4 Project Tasks

To meet the project objective defined in Section 1.1 the Wairarapa Airshed Study aims to answer the following questions:

1) Are the Masterton urban area and Waingawa industrial areas in physically-separate airsheds, or two parts of a single non-compliant area? Where should the airshed boundaries be?

2) Are there areas other than Masterton within the Wairarapa Valley airshed that are likely to be in breach of the NES? Where should their respective airshed boundaries be?

3) What are the likely magnitudes of current PM_{10} impacts of Masterton, the Waingawa industrial area and Carterton on each other?

4) What are the potential magnitudes of future PM_{10} impacts from new industry in the Waingawa industrial area on the Masterton residential area?

The answers to these questions will help define the spatial extents of physically-based airshed boundaries around the urban areas of the Wairarapa Valley, in particular Masterton and the Waingawa industrial area, and therefore define any specific area that may potentially need to offset emissions from new or changed industrial sources. The study is composed of a number of specific tasks, outlined in Golder's proposed Scope of Services (Golder 2013d), and listed in Table 1. Tasks 1 and 2 have been reported on separately, by way of self-contained draft reports submitted to GWRC as each task was completed (Golder 2013b, 2013c). They have been incorporated as Appendices A and B of this report. The findings of Tasks 3, 4 and 5 are incorporated into Appendices C to G. The main body of the report draws together all of the findings, under Task 6. Question (2) above may be answered using the screening model of Task 1. However, the remaining questions can only be answered as part of Task 6.

The key tasks are those in which PM_{10} dispersion is modelled for the urban and industrial areas. These are Tasks 1 (for the smaller towns, Greytown, Martinborough and Featherston), 3 (for Masterton and Carterton), 5 (for the Waingawa industrial area) and 6 (which examines Masterton, Carterton and the Waingawa industrial area together).

Table 1: Wairarapa Airshed Study task list.

Task	Name	Location
1	Greytown, Martinborough and Featherston Box Model for PM_{10}	Appendix A
2	TAPM Meteorological Modelling for Masterton and Carterton	Appendix B
3	Urban Airshed Modelling of PM_{10} from Domestic Heating in Masterton and Carterton	Appendices C and D
4	CALMET Meteorological Modelling for Masterton and Carterton	Appendix E
5	Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area	Appendices F and G
6	Determination of Airshed Boundaries in the Wairarapa Valley	Main Report

1.5 Report Structure

The remainder of the report is structured as follows:

- Section 2.0 outlines Tasks 1 to 6, summarizing their findings. Further details for Tasks 1 to 5 are contained in Appendices A to G.
- Section 3.0 presents model-based airshed boundaries for Masterton and the Waingawa industrial area, and discusses results for Carterton, Featherston, Greytown and Martinborough.
- Section 4.0 examines other aspects of air quality in the Wairarapa Valley, such as PM_{10} dispersion between airsheds, emission trends, annual averages, and estimates of $PM_{2.5}$.
- Section 5.0 summarizes all of the main findings, makes suggestions for further use of the modelling reported here and provides some recommendations for future work.
- Section 6.0 contains a few concluding remarks.
- Section 7.0 introduces Golder's report limitations statement.
- Section 8.0 acknowledges the contributors to this work.
- Section 9.0 contains a list of references used in the main report (each Appendix also contains a reference list).

Appendices A to G then follow. Appendix H is Golder's report limitations statement.

2.0 METHODS

2.1 Introduction

This section contains an outline of the modelling and analytical tasks undertaken to determine the recommended airshed boundary locations. The reader is referred to the relevant Appendix for a full account of the methods and task outcomes.

In all of the modelling carried out for this study, the peak PM_{10} concentration is represented by the modelled 2^{nd}-highest. This is consistent with an exceedence of the NES being based on the 2^{nd}-highest concentration in a calendar year. The NES criterion ground-level concentration for 24-hour-average PM_{10} is 50 µg/m^3.

The scientifically-based definition of an airshed boundary used in this study is the boundary of a region not in compliance with the NES for 24-hour-average PM_{10}. That is, the boundary for a given year is the 50 µg/m^3

contour of the 2nd-highest PM_{10} concentration. Within the boundary two or more PM_{10} exceedences may occur. Outside the boundary, there is at most one exceedence, which is allowed under the NES. Note that for an area to be defined as un-polluted, it should be compliant every year. Therefore 'final' airshed is the area contained by *any* of the yearly boundaries, and so this envelops all of the yearly boundaries. For the airshed-modelling based study, the run period is five years, and final modelled airshed boundary envelops the five individual boundaries for each year's run.

2.2 Task 1 – Greytown, Martinborough and Featherston Box Model for PM_{10}

The purpose of this task is to use a simple box model to determine whether PM_{10} in any of the small towns in the Wairarapa Valley is likely to reach NES concentrations. This is a 'screening' exercise, in the absence of emissions, meteorological and ambient PM_{10} data specific to each town, and is described in Appendix A. The box model assumes a uniform concentration of PM_{10} in the layer of air above the town, up to the mixing height. This is appropriate for a small area where emissions can be reasonably thought of as spatially homogeneous. Each town is a single Census Area Unit (CAU), and the emissions from domestic heating were taken from the Emissions and Socio-Economic Spatial Model (ESESM)[1]. The model was also run for Carterton, using ESESM data, wind data and ambient PM_{10}, in order to back-calculate a suitable time series of mixing height. The Carterton wind and mixing height information was then used with the emissions information for the other towns, to estimate worst-case PM_{10} concentrations in Greytown, Martinborough and Featherston. The box-model maximum PM_{10} was calculated using 2010 meteorological data, then scaled up by 36 % to reflect inter-annual variability. This variability factor was taken from the 2nd-highest observed concentrations each year in Masterton between 2005 and 2011 inclusive[2], the largest of which was 36 % higher than the smallest.

Results for all four towns are shown in Table 2 (this is Table A4 of Appendix A).

Table 2: Estimated 2nd-highest 24-hour PM_{10} GLCs in the smaller Wairarapa towns for all winters.

Town	Box-model maximum + 36 %
Carterton	64 µg/m^3
Featherston	52 µg/m^3
Greytown	40 µg/m^3
Martinborough	30 µg/m^3

These results indicate that Martinborough and Greytown are likely to be compliant with the NES for PM_{10} by a reasonable margin.

At the time of carrying out the box modelling, ambient PM_{10} data in Carterton were only available for winter 2010, with the second-highest PM_{10} concentration being 46 µg/m^3. Subsequent to the completion of the box modelling, ambient PM_{10} have become available for winter 2013, during which the second highest 24-hour PM_{10} concentration was 47 µg/m^3. The modelled concentration of 64 µg/m^3 has not been observed, and has not resulted from the airshed modelling described later in this report, which covered a 5-year period. This indicates that PM_{10} concentrations in all of the small towns are likely to be lower than implied by the box model results shown in Table 2, and therefore Featherston is also likely to be in compliance with the NES.

[1] http://wrenz.niwa.co.nz/webmodel/emissions%20

[2] http://www.mfe.govt.nz/environmental-reporting/air/air-quality/pm10/nes/wellington/ (this page has recently become unavailable, but data are available from GWRC).

2.3 Task 2 – TAPM Meteorological Modelling for the Wairarapa Valley

2.3.1 Introduction

As mentioned already, the determination of airshed boundaries is based in this report on spatial patterns of PM_{10}, as simulated by the dispersion models TAPM and CALPUFF. Given the known exceedences of the NES in Masterton, the observed potential for exceedences in Carterton, and the low probability of exceedences in the other towns, the dispersion models were configured to focus on Masterton and Carterton. The dispersion models both require meteorological inputs. TAPM creates its own meteorological inputs. CALPUFF is based on meteorological data encapsulated in its pre-processor CALMET, which itself is based on TAPM's meteorology. The production of meteorological data sets using TAPM is described in Appendix B and outlined here.

The meteorological component of TAPM is a prognostic model, based on a mathematical representation of the laws of atmospheric dynamics and physics, similar to a weather-forecast or climate-simulation model (and TAPM can be used for weather forecasting). It is a 'limited-area' model, driven at its boundaries by the outputs from a global-scale model, within which it simulates the development of smaller-scale meteorological features such as land/sea breezes and terrain-forced flows, and the boundary-layer structure in which these features are contained.

2.3.2 Meteorological modelling procedure

TAPM was run for a five-year period, from 1 September 2008 to 31 August 2013 on a set of nested grids. The finest grid has a grid-cell spacing of 1 km, and dimensions 40 km by 40 km, covering much of the Wairarapa Valley, including Masterton, Carterton and Greytown. The model was run on 25 levels in the vertical, between 10 m and 8000 m above ground. The model's performance was evaluated with respect to meteorological data at several sites. These were Martinborough Electronic Weather Station (EWS), Masterton Airport Automatic Weather Station (AWS) and Wairarapa College in Masterton (run by GWRC). Good indices of agreement (IOAs) and other skill scores were found for wind and temperature at these sites, indicating the model was performing well.

TAPM's meteorological model component is largely a 'black box' – only the time period and locations of interest need to be chosen by the model user, the remainder of the model configuration is largely fixed[3]. There are few parameters for the user to choose, and the given defaults are usually appropriate. Aside from this, the user has the freedom to assimilate wind observations from climate sites into the TAPM run. The data are assimilated using a process known as 'nudging', in which the model wind field is driven towards the observed wind around the climate sites. This not a sophisticated technique, it is not used in the data-assimilation stages of weather forecasting, its effects are not always beneficial, and its use is discouraged by the meteorological community. Although the resulting modelled winds around the site are closer to observations – which can be of benefit on calm winter nights – the nudging technique can lead to spatial discontinuities in the wind field, and distort the boundary-layer structure. Appendix B contains an examination in some depth of the impacts of nudging. It concludes that due to its effect on other meteorological fields, wind data assimilation probably should not be used for this study. However, initial airshed modelling runs for this project were carried out both with and without nudging in the meteorological pre-processing, to examine the effect of nudging on the resulting PM_{10} concentrations. This is described in the Section 2.4.

[3] However, care must be taken over the location and resolution of the model grids, so as to properly resolve incoming meteorological features.

2.4 Task 3 – Urban Airshed Modelling of PM_{10} Emissions from Domestic Heating in Masterton and Carterton

2.4.1 Introduction

TAPM's pollution-dispersion routines were used to simulate the dispersion of PM_{10} arising from domestic heating emissions in Masterton and Carterton. Task 3 is concerned with airshed modelling of PM_{10} from home heating and is described in Appendix C. TAPM configuration parameters for Task 3 are listed in Appendix D.

Task 3 included the following sub-tasks:

1) Configure the airshed model for dispersion of PM_{10} from home heating, selecting the area to be modelled and choosing the grid resolution. Link the airshed model to the meteorological outputs obtained under Task 2 (Section 2.3), and to emissions from the inventory prepared for GWRC in winter 2013 (Sridhar & Wickham 2013).

2) Derive suitable background concentrations of PM_{10} from motor vehicles, sea spray and crustal sources for adding to the PM_{10} from home heating as a post-processing step. The background concentrations were based on source-apportionment data supplied by GWRC. This component does not include industry, which is modelled separately under Task 5 (see Section 2.6).

3) Evaluate model performance with respect to PM_{10} monitoring data at Wairarapa College and Chanel College (both in Masterton), and monitoring in Carterton. Confirm the best choice of meteorological model (with or without wind-data assimilation) with regard to dispersion model performance.

4) Devise a method for determining airshed boundaries around Masterton and Carterton. This is demonstrated in this section for domestic heating sources, and used in Sections 2.7 and 3.0 for all sources cumulatively.

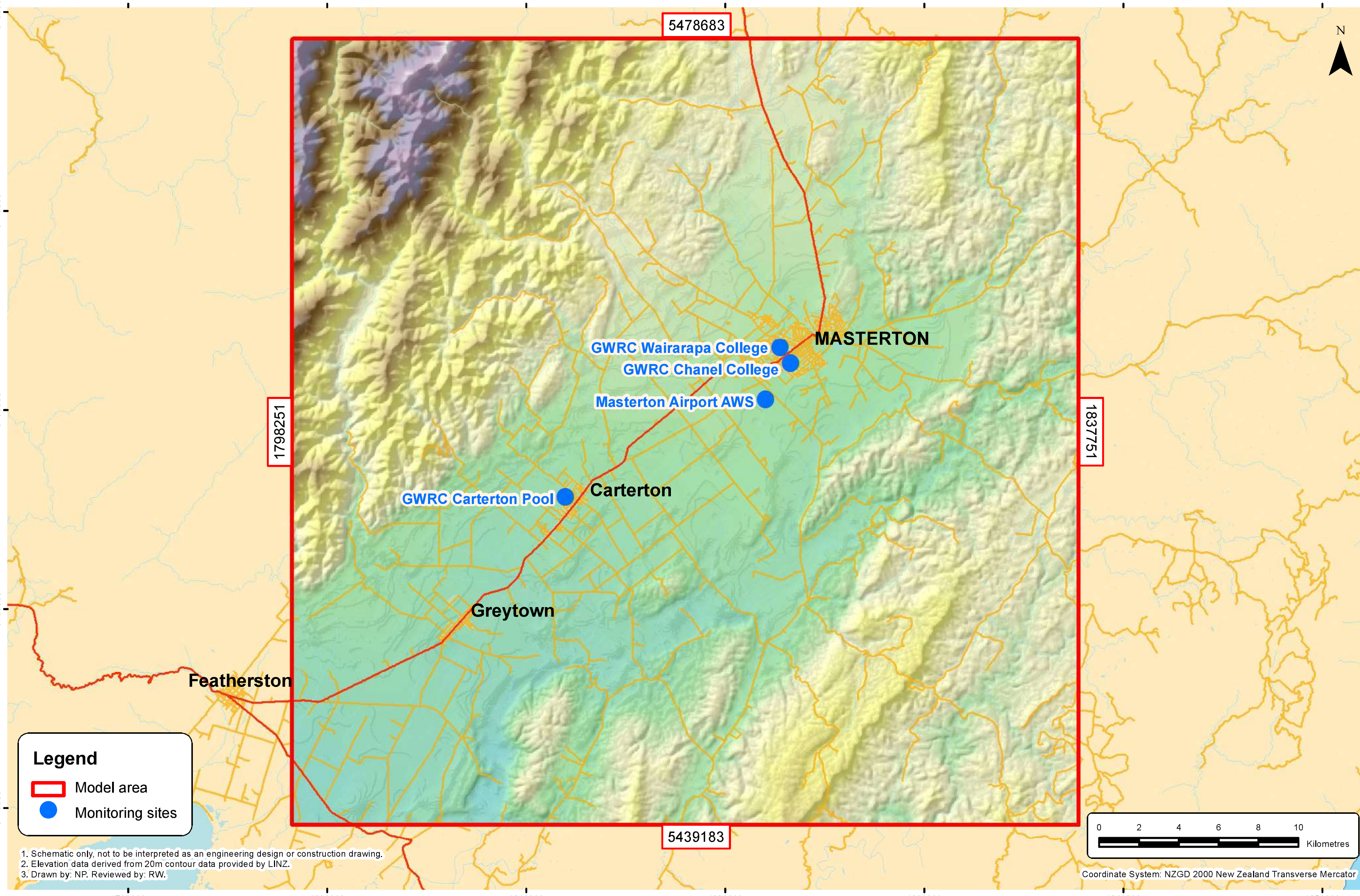
Airshed boundaries derived in this section are shown by way of example and are not to be considered the final recommendation. This is because the grid resolution used for the model testing and evaluation is 500 m, whereas final airshed model runs were carried out at 250 m resolution to provide more spatial detail in the boundary shape. The final modelled airshed boundaries also include industrial emissions of PM_{10}.

2.4.2 TAPM configuration

TAPM was run for five winter periods, namely, the months May to August in each of 2009 to 2013, on a 500 m grid covering the area of the meteorological model's 1 km grid. CAU-based emissions from domestic fires were input on a 250 m grid (TAPM averages these onto the 500 m grid for dispersion modelling). The 2013 emissions inventory was used for each modelled winter. Present-day emissions were therefore modelled over a range of years of meteorology, to capture inter-annual variability and include as wide a range as possible of meteorological conditions likely to be experienced in the region. Also, a year-by-year comparison of predicted PM_{10} concentrations with ambient PM_{10} monitoring was carried out.

Two scenarios were available from inventory data. One of these represented typical patterns of domestic fire use, with hourly, day-of-week and monthly variation in emissions. The second represented worst-case emissions, in which all domestic fires were in use 24 hours a day. An additional emission scenario was devised to model emissions from wood burners left to smoulder overnight. Smouldering emissions factors were not given in the inventory. A unit emission rate for smouldering was specified in the model, which was re-scaled to a realistic magnitude through comparison with ambient PM_{10} observations.

The meteorological model area is shown in Figure 2. This is the area covered by the finest meteorological grid of TAPM, which is at 1 km resolution. A 500 m dispersion model grid covers the same area, and this also matches the CALMET model area. Monitoring sites run by GWRC and MetService are labelled.



1. Schematic only, not to be interpreted as an engineering design or construction drawing.
2. Elevation data derived from 20m contour data provided by LINZ.
3. Drawn by: NP. Reviewed by: RW.

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TITLE METEOROLOGICAL MODEL AREA

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Source-apportionment data from the two sites in Masterton were supplied by GWRC, in order to provide concentrations of PM_{10} from other sources. These data were from the work of GNS and GWRC (see Ancelet et al. 2012.) The contribution to the total PM_{10} from motor vehicles, marine and crustal sources is generally small, and an average concentration was added to model results for domestic heating. The average PM_{10} concentration from non-domestic sources was 4 $\mu g/m^3$ at Wairarapa College and 6 $\mu g/m^3$ at Chanel College.

In summary, TAPM was run for the five-year period with three emissions scenarios and two meteorological scenarios, with testing and evaluation carried out to determine the best performing combination.

2.4.3 Model evaluation and preliminary airshed boundaries

Quantile-quantile (QQ) plots, in which modelled 24-hour PM_{10} concentrations are plotted against observed concentrations, after sorting each time series separately, were constructed for each monitoring site, for some of the years in which monitoring data were available. For example, Figure 3 shows a QQ plot for the winters of 2011 and 2012 combined at Wairarapa College, Masterton. This is a copy of Figure C4, in Appendix C, and the two sets of points are for typical and worst-case emissions from the inventory. Under the typical emissions scenario, the model significantly underestimates PM_{10} levels. Under this scenario, there would be no airshed boundary, as defined by a region of NES non-compliance, because the modelled PM_{10} never exceeds 50 $\mu g/m^3$. Under the worst-case scenario, emissions occur after midnight, leading to much higher 24-hour-average PM_{10} concentrations, which are more comparable with observed concentrations, with points closer to the 1:1 line in Figure 3. As the higher modelled PM_{10} concentrations more closely match the observed PM10 concentrations, they can be more confidently used to define the airshed boundary. The same feature in modelled concentrations was found in comparison with data from Chanel College, Masterton. In addition, more formal model-performance statistics such the IOA and skill scores were on the whole better under the worst-case emissions scenario. Therefore it is more realistic to base airshed boundaries on model results obtained under the worst-case emissions scenario.

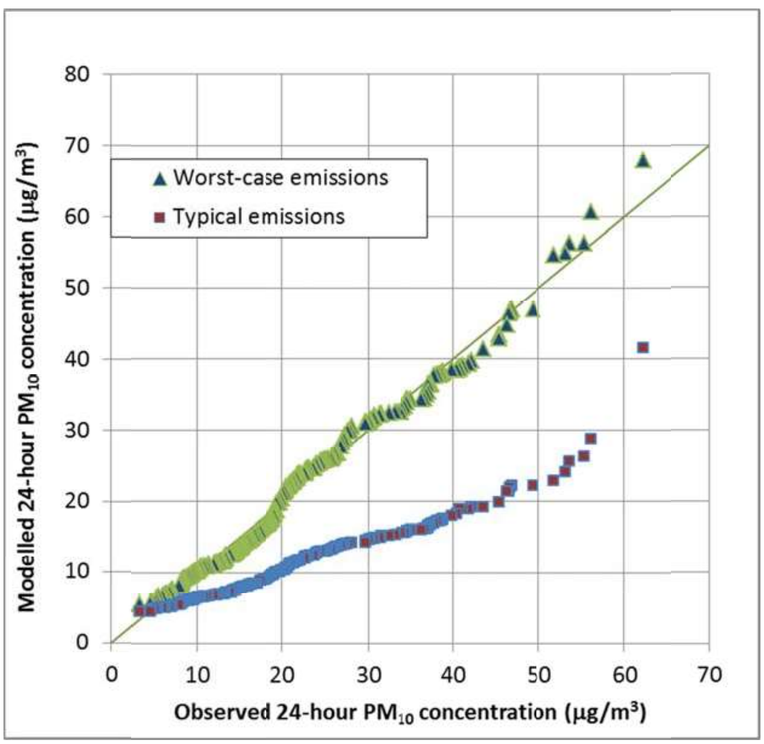


Figure 3: Quantile-quantile plot of modelled against observed 24-hour PM_{10} at Wairarapa College (modelled winters 2011 and 2012 combined). Wind observations are not assimilated in TAPM.

The QQ plots and performance statistics did not substantially differ between the meteorological-model scenarios (with and without nudging). In light of this, and due to the undesirable effects of nudging on spatial patterns of wind speed and direction, it is better practice to base the airshed modelling on meteorological modelling without nudging the model towards observed wind data.

In comparison with observations at Carterton Pool, the airshed model underestimated PM_{10} by between 20 % and 40 %, even under the worst-case emissions scenario. Reasons for this are still speculative. However, since compilation of the emissions inventory in mid-2013, data have been released from the 2013 census. These show that Carterton has experienced a higher growth in the number of residential dwellings than Masterton. This indicates that modelled PM_{10} impacts are more likely to be under-estimated for Carterton than for Masterton. No exceedences of the NES have been monitored at Carterton pool. Moreover, even adjusting the model results to account for the model under-estimation of observed PM_{10} data from 2010 and 2013 at the site, the model indicates a small likelihood of non-compliance, at any location in Carterton, or during any other modelled year.

The procedure for determining an airshed boundary for Masterton is outlined in Appendix C and summarized here. For each year, the airshed boundary is defined as the 50 µg/m^3 contour of the 2nd-highest modelled 24-hour PM_{10} concentration. The final modelled boundary then encloses all of those from the five individual years. Preliminary indications of airshed boundaries are shown in Figure 4, which is a copy of Figure C8 of Appendix C. The white boundary enclosing the shaded area should be considered a scientifically-based, though preliminary, modelled estimate of the Masterton airshed boundary.

Figure 4: Masterton airshed boundary. 50 µg/m^3 contours of 2nd-highest 24-hour PM_{10} due to domestic heating for each modelled winter (2009 orange; 2010 blue; 2011 green; 2012 yellow; 2013 purple; maximum over five years white outline with yellow shading).

The boundaries should be considered preliminary for the following reasons:

1) They are derived from model results for domestic heating sources only, with 5 μg/m^3 added to represent vehicles and natural sources. The industrial component is not included at this stage.

2) Some refinement of the boundaries may occur when the modelling is carried out on a 250 m grid.

3) The final boundaries will account for some of the uncertainties associated with the modelling, and allow for known model under- or over-estimation at the monitoring sites. This will lead to a range of possible locations for the airshed boundary.

Note that the boundaries marked in Figure 4 do not coincide with the limits of the urban area. They extend to the west, south, and east, and the modelling indicates that northern parts of Masterton do not experience NES exceedences. This is due to a general drift southwards of emissions under worst-case meteorological conditions. Worse air quality observed at Chanel College than at Wairarapa College, as Chanel College is south of Wairarapa College.

The boundaries shown here also indicate that the Masterton airshed does not include the Waingawa industrial area. However, the incorporation of the industrial component of PM_{10} may cause the cumulative PM_{10} to increase and the region of non-compliance to expand. The addition of uncertainty limits on the modelled airshed boundary would also make the region of possible non-compliance grow.

2.4.4 Smouldering emissions

Overnight emissions arise from smouldering wood burners that are loaded with fuel late at night and left on low heat. This is done to provide some overnight heating and enable easy re-lighting of the fire the next morning. It is generally accepted that emissions from smouldering fires are significantly higher that from full combustion of fuel. The New South Wales Environment Protection Authority (NSW EPA) states that '*the highest concentrations of fine particles in the air occur after midnight. This suggests that most of fine particle pollution is cause by wood heaters left to smoulder overnight.*[4]' The inventory of emissions for Masterton does not include this effect; the emissions are presumed to cease in the late evening, rather than persist overnight. If wood burners are loaded last thing at night and set to their lowest air flow setting, then emissions can persist for two or three hours[5]. It is beyond the scope of the project to investigate this process further and develop smouldering emission factors. As an alternative, some model runs were carried out which included a smouldering component. The magnitude of this component could be calculated in arrears through a comparison of model results with ambient PM_{10}. This is labelled emissions option E3. However, there are large uncertainties in the results, due to a range of choices of criteria which could be used for matching observed and modelled concentrations. The airshed model indicates around 500 kg/day of additional smouldering PM_{10} emissions in Masterton, of the same order of magnitude as the daily inventory total of 620 kg. This is consistent with the model results showing PM_{10} around half those observed when running with typical inventory emissions (option E1), and with statements made by the NSW EPA. However, it is nevertheless a rough estimate.

It is acknowledged that the combustion mechanisms by which emissions are generated differ between the worst-case inventory scenario and the smouldering scenario. In the former, the domestic fires are used to burn wood efficiently twenty-four hours a day, from a constant feed of fuel. In the latter, the fires are loaded fully with wood last thing at night, the airflow reduced, and no more wood is added for the rest of the night. However, it is noted that the worst-case emissions of 1402 kg/day for Masterton are similar to the typical daily average, plus the estimated smouldering component, and their use as inputs results in more useful model results for the purposes of airshed boundary determination than the use of typical inventory emissions only.

[4] http://www.epa.nsw.gov.au/woodsmoke/smoulder.htm (accessed 10 Jan 2014).

[5] http://www.environment.gov.au/archive/atmosphere/airquality/publications/report5/chapter6.html Report by J. Gras and co-authors for the Australian Department of the Environment, 2002.

The overnight component of the worst-case emissions are therefore treated in this project as a surrogate for smouldering emissions, and this may have an effect on the calculated location of the airshed boundary. It is therefore recommended that further research on smouldering emissions be carried out to improve emissions inventories in New Zealand.

2.5 Task 4 – CALMET Meteorological Modelling for Masterton and Carterton

Modelling dispersion of PM_{10} from industrial discharges was carried out using CALPUFF. CALPUFF requires meteorological inputs, which are supplied by CALMET. The CALMET modelling is described more fully in Appendix E. Given that outputs for industrial emissions from CALPUFF are to be combined with outputs for domestic heating emissions from TAPM, the underlying meteorological inputs to both of these models should be consistent with each other. Therefore, the meteorological modelling using CALMET is based on the meteorological modelling using TAPM (see Section 2.3 and Appendix B). Specific details of the CALMET modelling are as follows:

1) The CALMET model domain covers the same area as the TAPM 1 km resolution meteorological grid.
2) CALMET is nested to 500 m resolution, with every second grid point (1 km apart) co-located with a TAPM grid point. The same terrain and land-use data sources were used to generate the geographical information required by each model.
3) CALMET is run for the same period as TAPM, and its meteorological input fields are based on TAPM outputs fields. TAPM outputs are input as the 'initial guess' in CALMET.
4) CALMET is able to refine the TAPM fields by incorporating terrain effects among the hills next to the Wairarapa Valley. Tests were carried out with CALMET's terrain-influence parameter *terrad*, to ensure that this was done realistically. Over the Wairarapa Valley itself, the TAPM fields are essentially unchanged by CALMET.
5) The final choice of TAPM model did not assimilate observations. For consistency, neither does CALMET, which was run in no-observations mode.

These considerations ensured that the dispersion modelling (using TAPM for the urban airshed and CALPUFF for the industrial point-sources) was based on the same meteorology, and results for domestic heating sources and industrial sources could be combined with each other hour-by-hour.

2.6 Task 5 – Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area

Several industries are located in the area to the southwest of the Masterton urban area, close to the Waingawa River. Their locations are shown in Figure 5, which is a copy of Figure F1 in Appendix F. The edge of the residential area can be seen in the northeast of the figure, and the Juken New Zealand Limited (JNL) and Kiwi Lumber (KL) sites are about 1.5 km and 3 km, respectively, from the nearest houses. As part of the consenting process, dispersion modelling of discharges from JNL, Oldfield Asphalts Limited (Oldfields) and KL was carried out. No modelling was carried out for the fourth industry, Allied Concrete; modelling was not done as part of its resource consent application. The existing industrial assessments used differing meteorological inputs from those used in this project, and some carried out their dispersion modelling using AUSPLUME. Emissions, stack and building parameters were taken from the existing industrial assessments. The CALPUFF modelling is described in Appendix F, with lists of emissions and other parameters given in Appendix G.

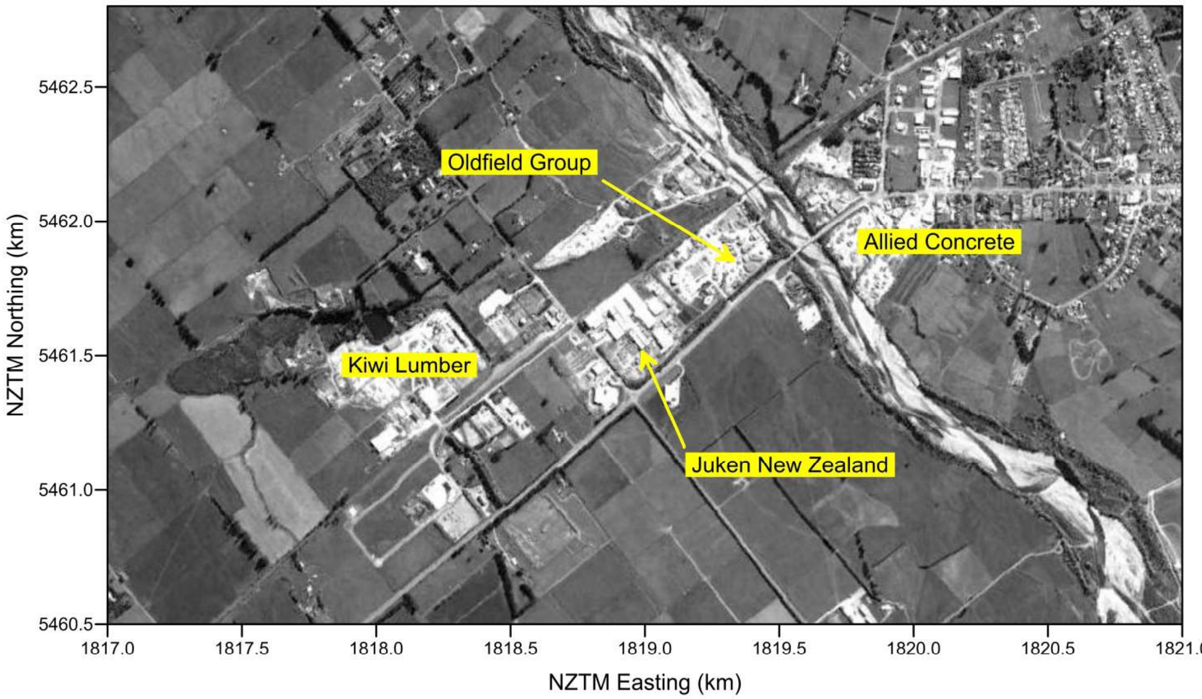


Figure 5: Industrial sites in Waingawa with air discharge permits.

Details of the CALPUFF model configuration may be summarized as follows:

1) CALPUFF was run for a five-year period from 1 September 2008 to 31 August 2013, based on the CALMET modelling outputs.

2) Discharges of PM_{10} from the three industrial sites, JNL, KL and Oldfields, were modelled.

3) Building downwash effects were included, using the PRIME algorithm.

4) Peak concentrations of PM_{10} were calculated on a sampling grid with 50 m spacing, and at a number of sensitive receptors in the residential and industrial areas.

An example of outputs from one of the modelled years, showing the peak 24-hour PM_{10} ground-level concentrations (GLCs) around the industrial sites, is given in Figure 6 (a copy of Figure F5 in Appendix F). All five years are shown in Appendix F, and they are generally similar. The highest concentration, around 80 µg/m^3, occurs over the KL site, with a smaller peak over JNL. These peak concentrations are contained within the respective site boundaries. At the edges of the residential area, the maximum-modelled 24—hour average PM_{10} concentration is approximately 4 µg/m^3 to 7 µg/m^3, due to the industrial stack sources.

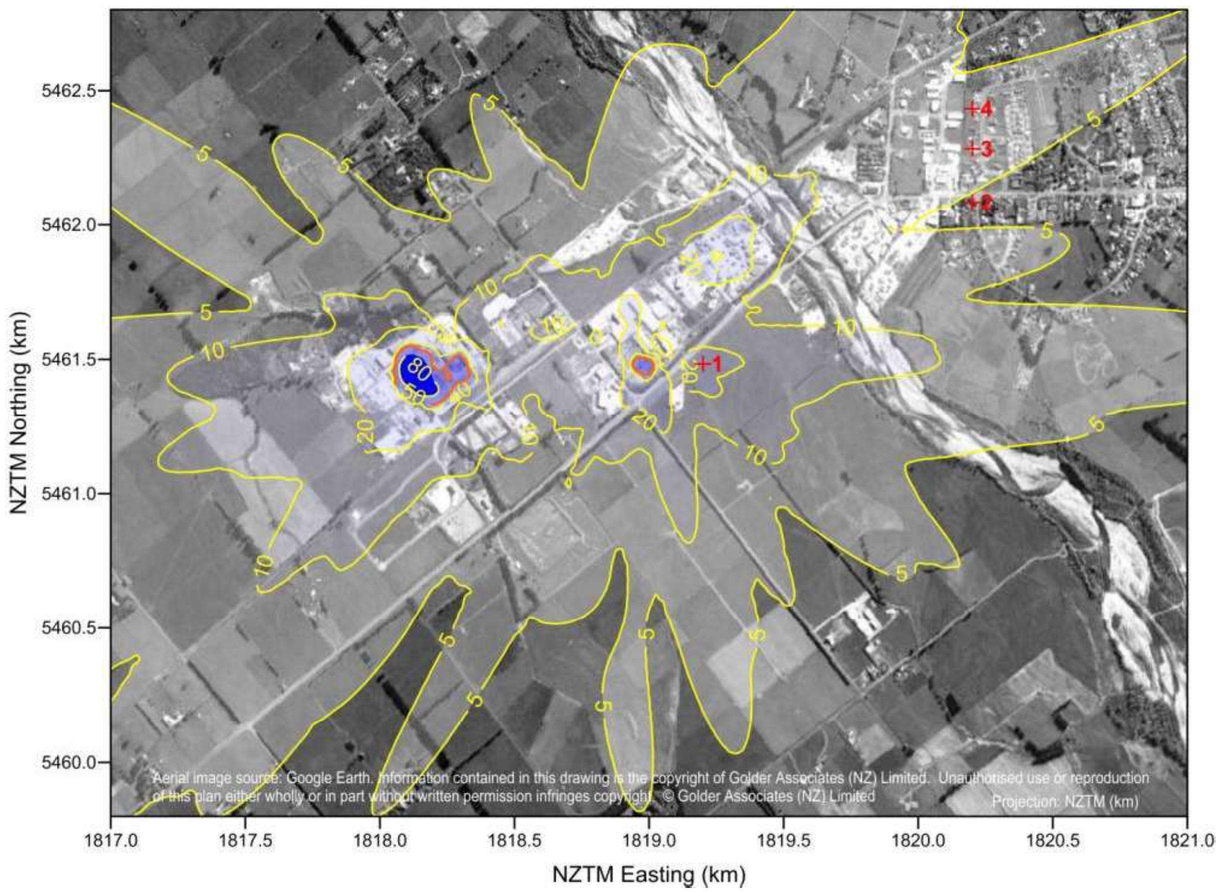


Figure 6: Maximum modelled 24-hour average PM_{10} GLCs for 1 September 2011 to 31 August 2012 inclusive. Identified receptors are labelled +1 (across the road from JNL), and +2 to +4 (residential).

2.7 Task 6 – Determination of Modelled Airshed Boundaries in the Wairarapa Valley

2.7.1 Introduction and Method

Airsheds in the Wairarapa Valley have been defined for the purposes of this report as boundaries of potential NES non-compliance, based on 24-hour-averaged PM_{10} from all sources. The cumulative PM_{10} is obtained here by combining results from the urban airshed and industrial point source models, hour-by-hour, using the following procedure:

1) Carry out the TAPM airshed modelling on the dispersion-model grid of 250 m resolution (see Figure C2 in Appendix C). Use the modelled meteorology without nudging, and worst-case emissions.

2) Map the 250 m grid airshed model results onto a 50 m grid, to match the CALPUFF grid points (used in Appendix G). This does not produce further spatial detail in the TAPM results, but allows the cumulative PM_{10} to be calculated by simply summing the TAPM and CALPUFF results, hour by hour, on the same grid of points.

3) Calculate the hour-by-hour, cumulative PM_{10} on the 50 m grid over the five modelled winters. This is based on the results of the industrial source modelling (Appendix G), the airshed modelling on the 250 m under item (1), and the background PM_{10} obtained from source-apportionment results.

4) Calculate airshed boundaries based on the 24-hour-average cumulative PM_{10} on the 50 m grid, following the procedure used in Section 2.4.3.

5) Account for uncertainties in the model-calculated boundaries in (4), by providing inner and outer limits for their location.

The resulting modelled airshed boundaries are presented below in Section 3.0. However, in the remainder of this section it is instructive to provide some discussion on uncertainties in the model results and their relation to confidence limits for airshed boundary locations.

2.7.2 Confidence limits for airshed boundary locations

The airshed model performs reasonably well in comparison with data from the Wairarapa College and Chanel College ambient monitoring sites in Masterton. That is, model concentrations are similar to observed concentrations. However, there are potential errors and uncertainties in the modelling process (from emissions calculations, model performance considerations, meteorological and ambient air quality data), which each contribute to the difference between model results and observations.

Given that there are known errors and uncertainties in modelling results in general, best estimates from models are not absolutely certain, and it can be informative to present a range of resulting pollution concentrations which reflect the uncertainties in the model estimates (some regulators require and uncertainty analysis to be carried out, although this is not required in New Zealand). For this project, the uncertainty in the modelled PM_{10} concentration translates into a range of locations for the calculated airshed boundaries.

There is some apparent randomness in observed pollution concentrations, arising through small-scale motions of the turbulent atmosphere, and this constitutes a larger component at higher concentrations (hourly observations of PM_{10} at Wairarapa College appear to quite closely follow an exponential distribution at the higher end, and there is an indication of this in 24-hour observations, too). The observed stochastic nature of air-pollution concentrations is not simulated in most models, and this contributes to their difficulty in predicting the number of guideline exceedences, for instance.

Sources of modelling uncertainty and some techniques for assessing them have been reviewed by Golder (2012). A formal uncertainty analysis has not been attempted here, as including all uncertainties would lead to such large error bars as to render the model's best estimate of concentrations meaningless. Also, some uncertainties are not easily quantified, or they would require expert judgement that is beyond the scope of this project to obtain.

The main sources of uncertainty in the current work revolve around the following issues:

1) **The use of constant worst-case inventory emissions as a surrogate for overnight smouldering emissions**. Model results at Wairarapa College and Chanel College are reasonable when worst case emissions are used. However, strictly speaking this means that errors arising from use of the worst-case inventory inputs are tending to cancel out other errors. The *residual* errors, defined simply as the difference between modelled and observed concentrations, are used here to provide error-bars on the model results. As mentioned, this translates to a range of possible airshed boundary locations.

2) **The stochastic nature of observations of the 2nd-highest 24-hour PM_{10} concentration each year that is not simulated by deterministic models**. For instance, the QQ plot in Figure 3 shows that the airshed model can give a reasonable account of PM_{10} levels in the middle of the observed range, but there is more scatter about the 1:1 line in the several highest concentrations. As airshed boundary definition is based on the 2nd-highest PM_{10} concentration, the residual errors used to provide a range of airshed boundary locations have been taken in the work to be errors in the 2nd-highest modelled PM_{10} concentration.

Put simply, item (1) indicates that the known model error can be used to generate error-bars, and item (2) specifies that the error in 2nd-highest concentration is to be used. Other sources of uncertainty, mentioned at the start of this section, are likely to be minor compared to those specifically listed.

In this work, confidence limits for the airshed boundaries make use of the model comparison with ambient data at the Masterton sites. Errors in modelled concentrations at the sites can be combined with the modelled concentrations themselves to provide a range from lowest- to highest-likely concentrations, and therefore smallest- to largest-likely airsheds.

For instance, the 2nd-highest modelled concentration in a specific year may be 68 µg/m^3 at Wairarapa College, but the observed value was 62 µg/m^3. The modelled concentration in the same year may be 72 µg/m^3 at Chanel College, but the observed value was 80 µg/m^3. This indicates a model error between -8 µg/m^3 and +6 µg/m^3. In general the model over-estimates at Wairarapa College and underestimates at Chanel College. To quantify this uncertainty, an outer airshed boundary can be determined by the 50 µg/m^3 contour of model results plus 8 µg/m^3, and an inner airshed boundary can be determined by the 50 µg/m^3 contour of model results minus 6 µg/m^3. [Equivalently, the outer and inner boundaries may be determined by the 42 µg/m^3 and 56 µg/m^3 contours of model results, respectively]. This is simple way of quantifying the known model errors, based on the difference between modelled and observed PM_{10}. Where data are unavailable (for instance, from Chanel College before 2012), the error adjustment is based on the highest observed concentration in the data. Where the model overestimates at both sites, there is no outer boundary defined. This method does not quantify all uncertainties, but gives an indication of the potential range of resulting PM_{10} concentrations and associated boundary location.

Resulting airshed boundaries for each modelled winter are shown in Figure 7. The yellow boundaries are the contours through the modelled 2nd-highest 24-hour cumulative PM_{10} of 50 µg/m^3. The red inner boundaries represent an adjustment to account for known over-estimation at a monitoring site; the blue outer boundaries represent an adjustment for under-estimation.

Worst-case inner and outer boundaries representing the full five-year period have been determined in the same way as the preliminary modelled boundaries shown in Figure 4. These boundaries are discussed below in Section 3.2 which shows the final modelled airshed boundary for Masterton.

3.0 MODELLED AIRSHED BOUNDARIES

3.1 Featherston, Greytown and Martinborough

As discussed in Section 2.2 and Appendix A, there is no indication of NES non-compliance in Greytown or Martinborough, and therefore there is no requirement to define an airshed boundary for these towns (in the sense of the definition of airshed boundary used in this study). Note that the box model cannot be used for defining an airshed boundary; more sophisticated modelling would be required to undertake this task. It is noted that the box model results for 2010, scaled up to account for inter-annual variability in the meteorology, indicate a possibility for exceedence of the NES for 24-hour PM_{10} in Featherston. However, subsequent data collected in Carterton, and further detailed modelling of Carterton and Masterton indicate that the scaling-up factor is probably conservative and therefore it is concluded that in all likelihood Featherston is also NES-compliant. Therefore there is no requirement to define an airshed boundary for this town.

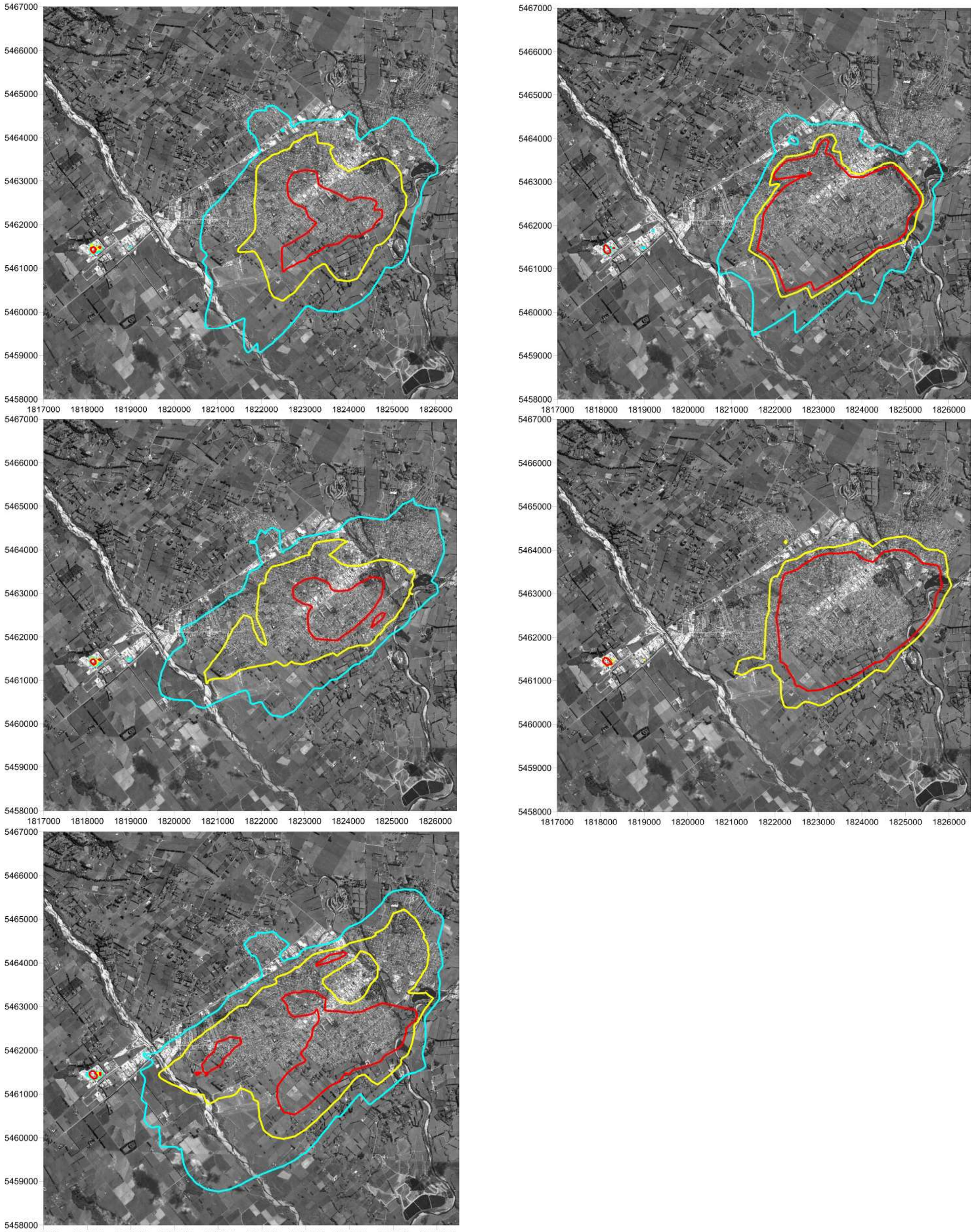


Figure 7: Modelled annual airshed boundaries shown as yellow contours. Inner and outer boundaries calculated from model uncertainties are shown in red and blue, respectively: top left 2009; top right 2010; middle left 2011; middle right 2012; bottom left 2013.

3.2 Masterton and the Waingawa Industrial Area

The modelled airshed boundary around Masterton based on model results for all five years is shown in Figure 8. The boundaries for individual years are derived following the procedure outlined above. The yellow boundary is based on modelled air quality impacts from domestic heating in Masterton, modelled impacts from the three modelled industrial sources in the Waingawa area, and source-apportioned PM_{10} observations arising from vehicles and natural sources. The outer and inner boundaries which account for modelling uncertainties are shown in blue and red, respectively. An explanation of the shading between the boundaries is given later in this section.

Figure 8: Airshed boundary around Masterton based on all years of modelling. Modelled boundary is in yellow; outer and inner boundaries accounting for modelling uncertainties are in blue and red, respectively.

As noted already, the modelled airshed boundaries do not follow the boundaries of Masterton's urban area, due to the prevalent meteorological conditions during worst-case PM_{10} events. Exceedences are predicted to occur downwind of the residential areas, in addition to directly over them. Exceedences also appear to be due to the accumulation of locally emitted PM_{10} with incoming PM_{10} emitted upwind, and exceedences are less likely to occur at upwind locations where the incoming air is clean.

The inner and outer boundaries aim to quantify uncertainties in the model's best estimate of the airshed extent (shown as the yellow curve in Figure 8). The blue and red curves do not represent a formally-derived confidence interval, and there is no numerical value on the probability of exceedence of the NES within the areas bounded by these curves. However, a qualitative description of the likelihood of exceedence of the NES can be given; assuming that the best estimate of airshed boundary is given by the model-generated yellow curve, and Table 3 provides a qualitative description. The yellow curve encloses the yellow and red areas of Figure 8.

The best estimate of the airshed boundary does not extend to the Waingawa industrial area. There are some parts of the Waingawa industrial area where PM_{10} GLCs are modelled over 50 µg/m^3. These areas are over individual stack sources and among buildings, so do not extend beyond the site boundary (as seen in Figure 6). The NES do not apply there.

Table 3: Likelihood of breach of the NES for 24-hour average PM_{10} around Masterton.

Location	Description
Area shaded red	NES breaches almost certain
Area shaded yellow	NES breaches highly likely
Area shaded grey	NES breaches possible but unlikely
Area shaded green	NES breaches highly unlikely

3.3 Carterton

The procedure for determination of an airshed boundary, as outlined in Section 2.7 was followed for Carterton. This accounted for domestic heating emissions as modelled by TAPM, based on worst-case emissions, with a background contribution of 5 µg/m^3 added to account for other sources. Additionally, the domestic heating emissions were further scaled up by 30 % to counteract the model's under-estimation relative to ambient monitoring at Carterton Pool. The modelled 24-hour peak PM_{10} concentration (defined as the 2nd-highest 24-hour GLC in any modelled year) did not reach 50 µg/m^3. This means that there is no predicted region of NES non-compliance and therefore no airshed boundary as defined in this report. This is consistent with observations of PM_{10} in 2010 and 2013 at Carterton Pool, where the 2nd highest concentration in either year was greater than 45 µg/m^3, but did not reach 50 µg/m^3.

4.0 USE OF MODELLING TO ADDRESS OTHER ASPECTS OF PM DISPERSION IN THE WAIRARAPA VALLEY

4.1 Introduction

The primary aim of this project was to provide scientifically-based estimates of airshed boundary locations around the towns in the Wairarapa Valley. As this work is based on modelling the dispersion of PM_{10} from several sources, there is a range of other aspects of air quality in the valley which can be examined in the context of the airshed and point-source dispersion modelling. Several of these are of interest to GWRC and are described in the following sections.

4.2 PM_{10} Concentrations and Dispersion between Masterton and Carterton

4.2.1 Masterton and the Waingawa industrial area

As the modelled airshed boundary is the 50 µg/m^3 contour of the worst-case PM_{10} concentration, it is informative to show *all* contours of worst-case concentrations. This is shown in Figure 9, which depicts a spatial pattern which has local maximum PM_{10} concentrations over the southeast of the urban area of Masterton[6]. These results may be useful to guide the location of future ambient monitoring sites, and they show the peak ambient PM_{10} potentially exceeding 80 µg/m^3.

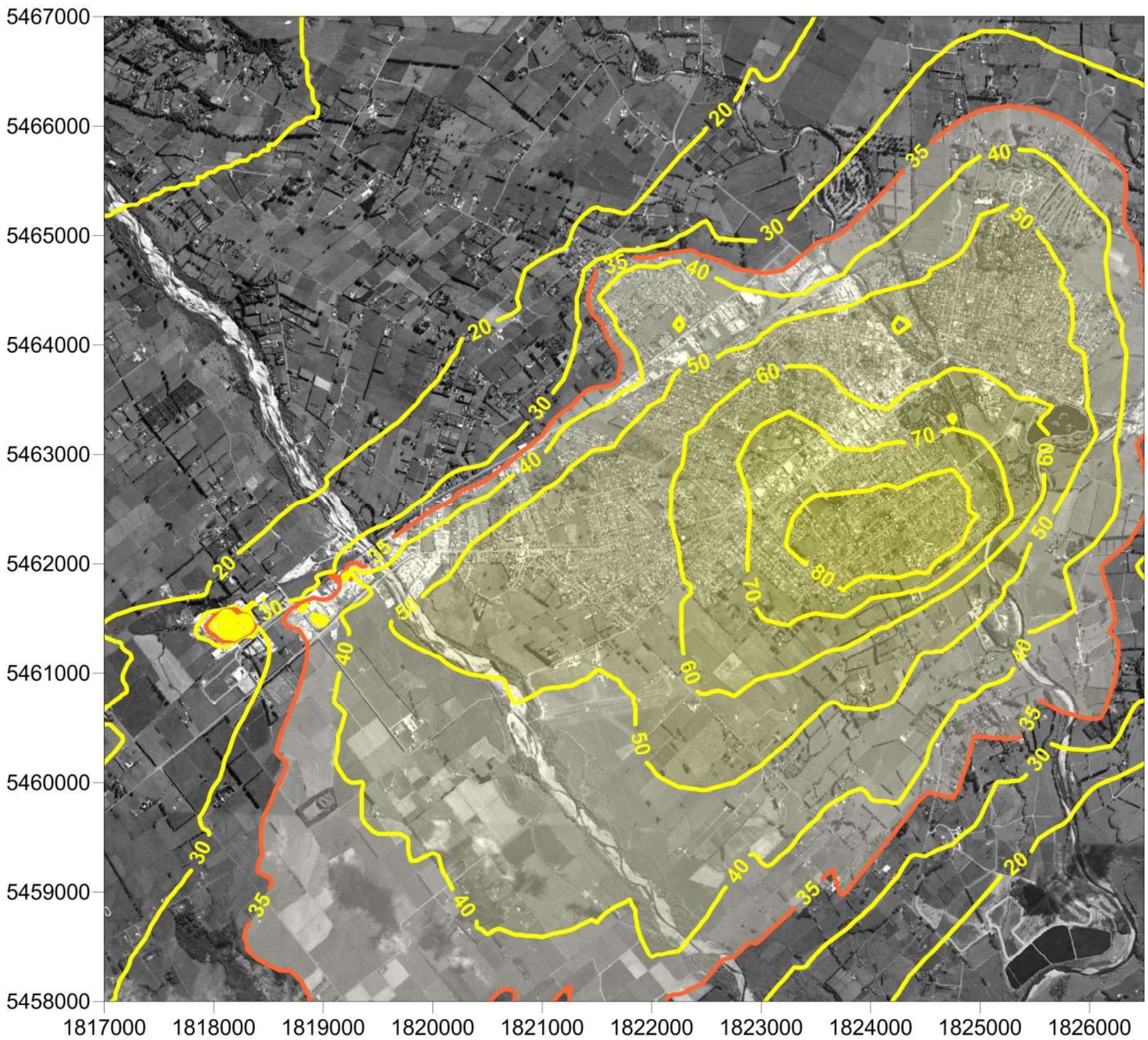


Figure 9: Modelled worst-case 2nd-highest 24-hour PM_{10} concentration around Masterton and the Waingawa industrial area (the 50 µg/m^3 contour matches the airshed boundary shown in Figure 8.

The airshed boundary locations shown in Figure 8 indicate that a region of NES non-compliance exists over and around Masterton. The airshed does not extend over the Waingawa industrial area, nor is there a separate airshed over that area. Hence if there were additional emissions from new industry or expanded industry in the Waingawa industrial area, they would not be located in a polluted airshed. However, they

[6] The significance of the 35 µg/m^3 contour is explained in Section 4.5.

could contribute significant ambient PM_{10} concentrations (that is, greater than 2.5 µg/m^3 on the 24-hour average) to the neighbouring polluted airshed of Masterton. Figure 9 depicts impacts from all sources combined and it is informative to examine the influence of the source regions on each other. The potential ambient PM_{10} in one location due to sources in another is shown in Table 4, with concentrations taken from contour plots of modelled PM_{10} due to the separate source regions (not shown). This quantifies the impacts on Masterton and the Waingawa industrial area of sources in Masterton, the Waingawa industrial area and Carterton.

Table 4: Worst-case modelled 24-hour PM_{10} impacts on Masterton from each source region.

Source	Impact on Masterton (southwestern edge)	Impact on the Waingawa industrial area
Masterton domestic heating	(see Figure 9)	15 µg/m^3 to 35 µg/m^3
Waingawa industrial area	4 µg/m^3 to 7 µg/m^3	(see Figure 6)
Carterton domestic heating	2.5 µg/m^3 to 3 µg/m^3	2.5 µg/m^3 to 5 µg/m^3

The impacts indicated in Table 4 are the potential worst-case 24-hour PM_{10} over the 5-year model run. The table shows the following:

1) Although the Waingawa industrial area is outside the non-compliant region bounding Masterton and its surroundings, there is still a substantial 'baseline' PM_{10} (potentially 15 µg/m^3 to 35 µg/m^3, depending on location) into which industrial PM_{10} may be discharged).

2) Current industry adds up to 7 µg/m^3 of PM_{10} over the southwestern edge of Masterton urban area. This serves to slightly expand the airshed in size towards the industrial area. It indicates that new industrial emissions of the magnitude of those already in place could produce ambient levels of PM_{10} above the trigger level of 2.5 µg/m^3 for emissions offsets[7].

3) There is potentially a small amount of PM_{10} in the Masterton area from sources in Carterton.

Note that it is not appropriate to calculate cumulative effect by summing the columns in Table 4. For instance, impacts on the Waingawa industrial area from Masterton and Carterton do not necessarily occur during the same day – this depends on the wind direction.

4.2.2 Carterton

In a similar way to Figure 9, contours of worst-case PM_{10} around Carterton are depicted in Figure 10. The modelled PM_{10} shown here is the cumulative GLC due to domestic heating in Carterton, estimates of 'background' PM_{10} from vehicles and natural sources, and domestic heating in Masterton (Figure 9 and Figure 10 show model results on different portions of a single model domain on which all sources have been modelled). The figure shows that there are no NES breaches in or around Carterton; the peak concentration reaches more than 45 µg/m^3 and is just under 50 µg/m^3 over the southwest of the urban area. Note that the emissions are represented as an average over a single CAU, and modelled features on smaller spatial scales within the Carterton CAU may be unreliable. A more robust assessment would incorporate a more detailed spatial breakdown of input emissions. It should also be noted that the model results shown in Figure 10 do not include emissions from the Waingawa industrial area. Contributions from the industrial area to PM_{10} in Carterton are examined below.

[7] With emissions reduction measures planned or already put in place by the industries since their consent applications, the impacts of industry may currently be lower than depicted by the modelling in this report. However, for new industry, comments on the possibility of its production of PM_{10} levels above 2.5 µg/m^3 still hold, as the trigger level for emissions offsets only depend on the new emitter, and not the baseline PM_{10} from other sources.

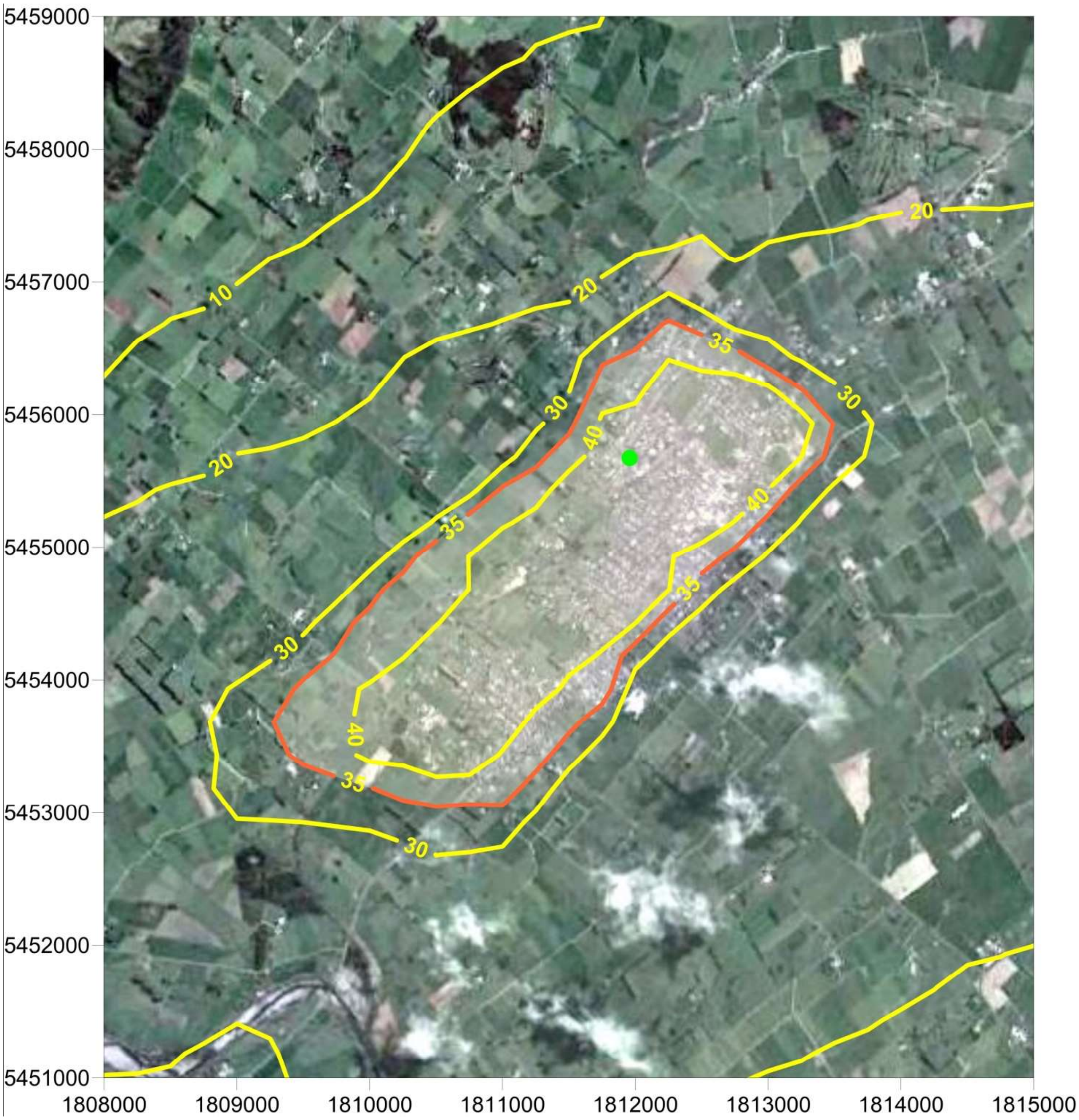


Figure 10: Modelled worst-case 2nd-highest 24-hour PM_{10} concentration around Carterton.

The impacts of sources outside Carterton on ambient PM_{10} within Carterton may be inferred by modelling the sources separately, and potential worst-case impacts on Carterton are shown in Table 5. (To determine the contribution from the Waingawa industrial area, the CALPUFF modelling was carried out for a set of discrete receptors in Carterton. These results were not combined with the domestic heating results presented in Figure 10). It can be seen that there is some influence of Masterton's urban emissions on Carterton, potentially up to 15 µg/m^3 PM_{10} on the 24-hour average. Concentrations of PM_{10} from Masterton can reach 20 µg/m^3 in the vicinity of Carterton, but these occur to the northeast of the urban area (not shown here).

Table 5: Worst-case modelled 24-hour PM_{10} impacts on Carterton from each source region.

Source	Impact on Carterton
Masterton domestic heating	10 µg/m^3 to 15 µg/m^3
Waingawa industrial area	1 µg/m^3 to 1.5 µg/m^3

4.3 Evidence for Inter-Annual Trends in PM_{10} Emissions

At the commencement of this project, it was proposed that an inter-annual trend in emissions could be inferred from the year by year model performance. For instance, if the model went from general under-prediction of ambient PM_{10} in earlier years to general over-prediction of ambient PM_{10} in later years, then this would infer – as the same model emissions were assumed each year – that the true emissions had actually decreased. In theory, the model should account for the year-to-year meteorological variability and this effect on PM_{10} concentrations could be separated from an underlying trend in actual emissions. GWRC is interested in whether a trend in emissions can be discerned.

The average of the highest ten modelled and observed daily PM_{10} concentrations at Wairarapa College for each year from 2009 to 2013 are compared in Figure 11. The match between modelled and observed values is similar for the final three years, indicating no systematic trend in actual emissions over this time; the modelled and observed peak PM_{10} values rising and falling together due to the varying meteorology through each winter season. There is less certainty over the previous years, as the model over-estimated PM_{10} in 2009 and under-estimated PM_{10} in 2010. If these model errors are due to a change in emissions, then a rise in emissions is inferred between 2009 and 2010, and a fall between 2010 and 2011.

Thus there is no conclusive evidence from the modelling of a trend in domestic heating emissions in Masterton. It is likely that there has not been a significant change in emissions over recent years.

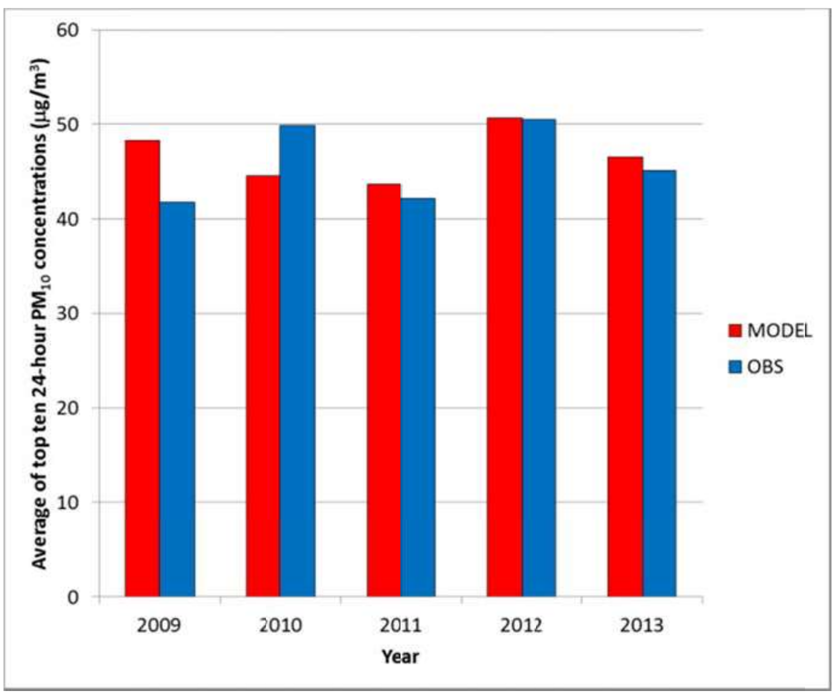


Figure 11: Average of the top ten 24-hour PM_{10} concentrations at Wairarapa College, Masterton, for each modelled year.

4.4 PM_{10} Concentrations under Typical Emissions

Peak modelled PM_{10} concentrations shown for Masterton and Carterton in Figure 9 and Figure 10, respectively, are based on worst-case emissions information as provided in the 2013 inventory. If it is assumed that a large contribution to the observed PM_{10} arises from overnight smouldering, it is of interest to estimate the ambient PM_{10} in the absence of this component. Such a situation is represented by the typical emissions scenario in the 2013 inventory, and the airshed model has been run based on these emissions data. The peak PM_{10} under typical emissions is shown for Masterton and Carterton combined in Figure 12.

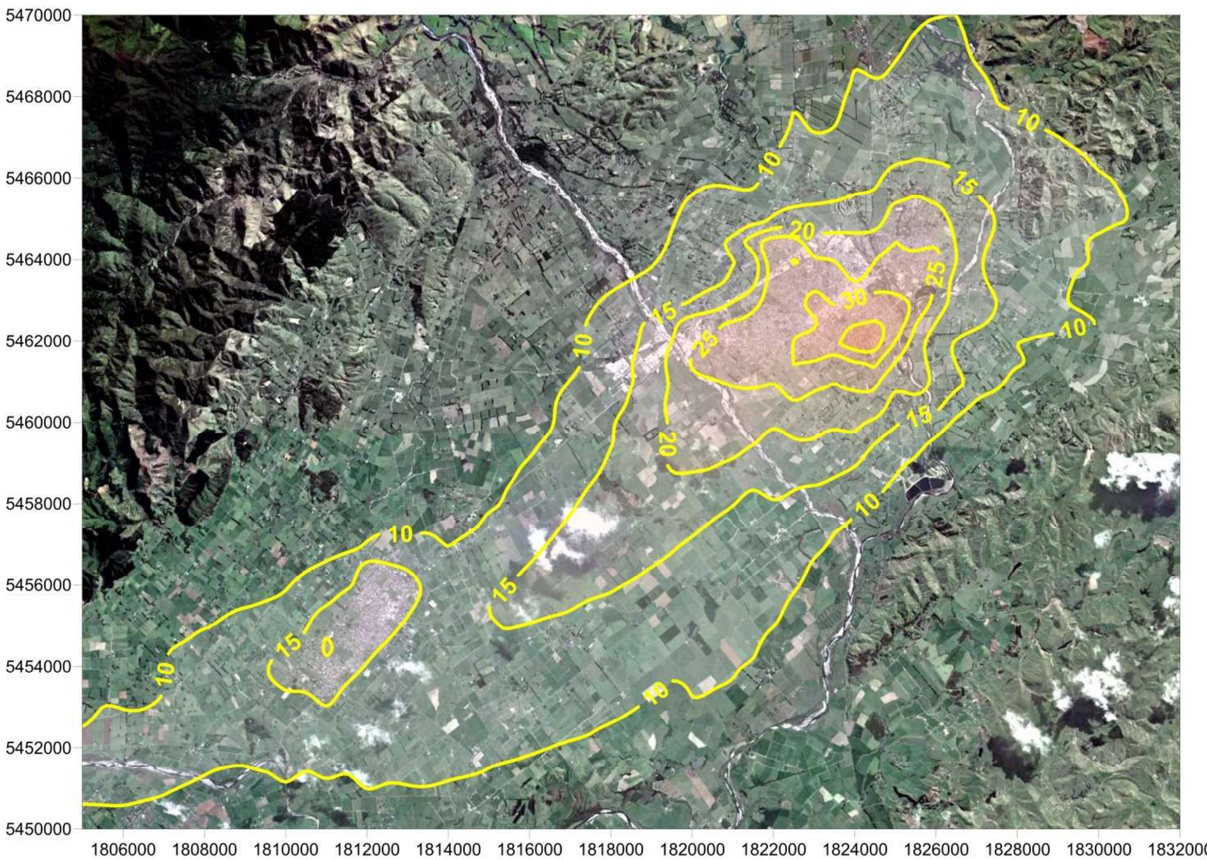


Figure 12: Modelled peak 24-hour PM_{10} concentrations around Masterton and Carterton under typical emissions.

If should be noted that model runs using typical emissions were carried out as part of the testing and evaluation described in Appendix C. This means that the results presented in Figure 12 are calculated on the 500 m dispersion grid, and do not include the contribution from industry. They do include 5 µg/m^3 from vehicles and natural sources. The peak PM_{10} GLC in Masterton is 37 µg/m^3 and in Carterton it is 21 µg/m^3. If a contribution from industry (as indicated in the tables above) were included, the model still indicates that Masterton and Carterton would both be compliant with the NES for PM_{10} under the typical emissions scenario. Masterton is known to be non-compliant currently, and the model results indicate that it could be compliant if emissions were reduced to the typical levels provided in the inventory, that is, if overnight smouldering emissions (which are not in the inventory) were to cease.

4.5 Compliance with the Guideline for $PM_{2.5}$

The World Health Organization (WHO) has updated its recommended air quality guidelines (Krzyzanowski & Cohen 2008; WHO 2006), which now include a guideline concentration for 24-hour-average $PM_{2.5}$ of 25 µg/m^3. This guideline is referred to in the good-practice guide for assessing discharges from industry to air (MfE 2008). As there is the potential for future standards to be based on $PM_{2.5}$, rather than PM_{10}, GWRC is interested in likely $PM_{2.5}$ concentrations in the Wairarapa Valley, whether $PM_{2.5}$ guidelines would be exceeded, and the extent of airsheds were they to be based on $PM_{2.5}$ exceedences.

The Masterton emissions inventory for 2013 does not contain information on $PM_{2.5}$. However, if the fraction of emitted PM_{10} that is actually $PM_{2.5}$ is known for the modelled sources, emissions could be derived and airshed and point-source $PM_{2.5}$ modelling could be carried out. In the case of domestic heating and motor vehicle exhausts, most of the emitted PM_{10} is in the $PM_{2.5}$ fraction, and an indication of $PM_{2.5}$ levels can be obtained by inspection of PM_{10} model results. In the Wellington region, GWRC indicates that on high-pollution days, $PM_{2.5}$ reaches 25 µg/m^3 when PM_{10} is around 35 µg/m^3. If this ratio of $PM_{2.5}$ to PM_{10} holds for Masterton and Carterton, this means that an airshed boundary based on the WHO guideline for 24-hour $PM_{2.5}$ (of 25 µg/m^3) would be in the same place as the 35 µg/m^3 contour of PM_{10}.

The 35 µg/m^3 PM_{10} contours around Masterton and Carterton are marked in orange on Figure 9 and Figure 10, respectively, as an approximate to the airshed boundary if it were defined by the $PM_{2.5}$ guideline. In this case, the $PM_{2.5}$-defined airshed covers a larger area around Masterton than if it were defined by the NES for PM_{10}, and includes some of the Waingawa industrial area. Also, an airshed boundary beyond the urban limits arises for Carterton if based on the $PM_{2.5}$ guideline.

Note that the estimated $PM_{2.5}$ airshed boundaries may be slightly conservative as they are based on the 2nd highest 24-hour concentration from each modelled year. The guideline for $PM_{2.5}$ allows 3 exceedences of 25 µg/m^3 and therefore should be based on the 4th-highest concentration. The airshed boundary may enclose a smaller area than shown by the 35 µg/m^3 contour.

4.6 Annual-average PM_{10} and $PM_{2.5}$

The ambient air quality guideline (AAQG) for annual-average PM_{10} is 20 µg/m^3 (MfE 2002). As the airshed model was run for four months each year, the annual-average PM_{10} has been calculated as one-third of the four-month average for each model year (this assumes that no wood burning occurs in the non-winter months). The maximum annual-average PM_{10} over 5 years from all sources is estimated in Table 6, Table 7 and Table 8.

Table 6: Annual-average PM_{10} in Masterton.

Source	Concentration	Comment
Domestic heating	8 µg/m^3	Modelled peak in Masterton
Motor vehicles and natural sources	Between 4 µg/m^3 and 6 µg/m^3	From source-apportionment
Industry	0.5 µg/m^3	SW urban limit of Masterton
All sources	Approximately 13 µg/m^3	Sum of each contribution

Table 7: Annual-average PM_{10} in the Waingawa industrial area.

Source	Concentration	Comment
Domestic heating	Between 1 µg/m^3 and 2 µg/m^3	From airshed modelling
Motor vehicles and natural sources	Between 4 µg/m^3 and 6 µg/m^3	From source-apportionment
Industry	4 µg/m^3	Off-site maximum (receptor 1)
All sources	Approximately 10 µg/m^3	Sum of each contribution

Table 8: Annual-average PM_{10} in Carterton.

Source	Concentration	Comment
Domestic heating	5 µg/m^3	Peak in Carterton from airshed modelling
Motor vehicles and natural sources	Between 4 µg/m^3 and 6 µg/m^3	From source-apportionment
Industry	0.2 µg/m^3	Receptor at Carterton pool
All sources	Approximately 10 µg/m^3	Sum of each contribution

The model results indicate that the AAQG for annual-average PM_{10} is not exceeded anywhere in the Wairarapa Valley. The local-maximum PM_{10} concentrations reach between 50 % and 65 % of the AAQG. Note that there is some uncertainty in these results. Domestic heating in non-winter months has not been modelled, which would underestimate the annual average. On the other hand, the worst-case emissions scenario assumes constant maximum PM_{10} emissions through the winter months, and this would over-estimate.

The WHO guideline for annual-average $PM_{2.5}$ is 10 µg/m^3 (WHO 2006). Indications from the model results for PM_{10} and known relationships between $PM_{2.5}$ and PM_{10} are that the annual-average $PM_{2.5}$ could reach its guideline concentration in Masterton, but is less likely in Carterton.

5.0 DISCUSSION

The main findings from the modelling carried out for the Wairarapa Airshed Project may be summarized as follows:

1) The area of Masterton that, according to the modelling, is in breach of the NES for PM_{10} (24-hour average) extends around 2 km outside the residential area to the southwest, southeast and northeast. The non-compliant area does not extend over the northwestern edge of the town, and does not cover the industrial area around the Waingawa River.

2) The Waingawa industrial area is not, according to the modelling, in breach of the NES for PM_{10} (24-hour average).

3) The modelling indicates that currently consented discharges may contribute between 4 µg/m^3 and 7 µg/m^3 to PM_{10} concentration at the southwestern edge of Masterton. New industrial discharges at similar levels to current emissions could also contribute a few µg/m^3 to PM_{10} in Masterton, and therefore may invoke the emissions-offset regulation in the NES.

4) There appears to be a significant baseline of PM_{10} in the Waingawa industrial area due to domestic heating emissions in Masterton, and a low level of PM_{10} in the Waingawa industrial area due to domestic heating emissions in Carterton.

5) There is no strong evidence as yet to suggest that Carterton is in breach of the NES for PM_{10} (24-hour average), but it appears to come close. There is a small component of PM_{10} in Carterton due to domestic heating emissions in Masterton. The component of industrial impacts in Carterton from sources in the Wairarapa is almost negligible.

6) There is a small component of PM_{10} in Masterton due to domestic heating emissions in Carterton.

7) Greytown and Martinborough are unlikely to be in breach of the NES for PM_{10} (24-hour average).

8) Featherston is probably not in breach of the NES for PM_{10} (24-hour average).

Other findings not related to the chief aims of the project are worthy of note, as follows:

1) No evidence has been found in the modelling carried out in this study for a consistent inter-annual trend in PM_{10} emissions in the Wairarapa Valley due to changes in home heating methods (or increases or decreases in numbers or types of appliance).

2) The spatial extent of the Masterton airshed could be substantially increased if it were based on non-compliance with the WHO (2006) guideline for 24-hour $PM_{2.5}$. Carterton would be in breach of the $PM_{2.5}$ guideline and an airshed boundary could be defined (there is no boundary defined by PM_{10} breaches).

3) The Wairarapa Valley is compliant with the MfE AAQG for annual-average PM_{10}. It is possible that Carterton and (more likely) Masterton are not compliant with the WHO guideline for annual-average $PM_{2.5.}$

All of these statements arise from a substantial computational modelling exercise. Therefore they are indications, or estimates, rather than definitive statements of fact. However, the models have been evaluated with respect to measurements of meteorological and air quality parameters, to ensure that the results are credible and as realistic as practical.

Following on from the above findings, the comprehensive set of model runs carried out in the course of this work may be used as a basis for further air quality investigations, through further examination of model results. For instance, the model may be used to provide spatially-detailed baseline PM_{10} information to assess cumulative effects of new sources, or for examining the effects of some emissions-change scenarios (for which a re-scaling of outputs is not sufficient). It may be readily adapted to simulate future PM_{10} levels based on projected emissions. In addition, the five-year TAPM and CALMET meteorological data sets covering Masterton and Carterton may be used as a basis for dispersion-modelling assessments of air quality effects carried out for industrial resource consent applications.

There are yet further uses to which the airshed modelling could be put, but some of these may be hindered by uncertainties resulting from inadequacies in currently-available information. Golder would recommend that GWRC considers the following to aid further investigations of air quality in the Wairarapa Valley.

1) Research on smouldering emission factors for overnight use of wood burners (noting that information on the number households burning wood overnight is known from the inventory survey).

2) Improved spatial detail in PM_{10} emissions from Carterton to provide a firmer assessment of the town's compliance with the NES.

3) Compilation of an emissions inventory for $PM_{2.5}$, in anticipation of regulations based on this parameter and the need to assess levels of $PM_{2.5}$ and define airsheds accordingly.

4) Increased detail in the quantification of natural sources such as sea spray, soil dust, and dust from exposed bed of the Waingawa River.

5) Monitoring of PM_{10} beyond the edge of the Masterton urban area to capture natural PM_{10} (when upwind of the town), enable evaluation of model results at locations where no emissions occur and evaluation of the model-estimated airshed boundary.

6.0 CONCLUSION

The Wairarapa Airshed Study has used advanced modelling techniques to assess PM_{10} concentrations around Masterton and Carterton, and define airshed boundaries where appropriate. The modelled airshed boundaries are the result of a scientific investigation of meteorology and dispersion of pollutants from the main sources in the region and indicate the areas likely to be non-compliant with the NES for PM_{10}. The results of this study will be used by GWRC and airshed boundaries provided here will be refined through further consultation and alignment with property boundaries, before final establishment of new airsheds by notice in the *New Zealand Gazette.*

7.0 LIMITATIONS

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

8.0 ACKNOWLEDGEMENTS

This work was carried out under a contract between GWRC and Golder. Golder thanks Tamsin Mitchell of GWRC for supply of monitoring data from GWRC’s sites in Masterton and Carterton, and for ongoing guidance through the course of the project. The new emissions inventory was compiled by Emission Impossible Limited and detailed emissions data were supplied to Golder through GWRC. Meteorological data from Masterton Airport were supplied by MetService. Meteorological data from Martinborough were obtained from the National Climate Database (CliFlo). Copies of industrial assessments were supplied by GWRC and the Masterton District Council. Synoptic meteorological data to drive TAPM were supplied by CSIRO.

9.0 REFERENCES

Further references are listed in each Appendix to this report.

Ancelet T, Davy PK, Mitchell T, Trompetter WJ, Markwitz A & Weatherburn DC 2012. Identification of particulate matter sources on an hourly time-scale in a wood burning community. Environmental science & technology. 46 (9): 4767–74. Accessed <http://www.ncbi.nlm.nih.gov/pubmed/22468798>

Golder 2012. Towards improving the prediction of extreme pollution concentrations - accounting for uncertainties and randomness. Report prepared by Golder Associates (NZ) Limited for NIWA. 27 September 2012. p. 30.

Golder 2013a. Defining airshed boundaries in the Wairarapa Valley - Recommendations for further investigation. Report no. 1278104006_002_R_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. February 2013. p. 41.

Golder 2013b. Greytown, Martinborough and Featherton Box Model for PM10. Report prepared for Greater Wellington Regional Council by Golder Associates (NZ) Limited. 16 May 2013. p. 13.

Golder 2013c. TAPM Meteorological Modelling for Masterton and Carterton. Report prepared for Greater Wellington Regional Council by Golder Associates (NZ) Limited. 16 July 2013. p. 21.

Golder 2013d. Wairarapa Air Quality Modelling - Determination of airshed boundaries in the Wairarapa Valley. Proposal no. 1378104103_001_P_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. April 2013. p. 24.

Krzyzanowski M & Cohen A 2008. Update of WHO air quality guidelines. Air Quality, Atmosphere & Health. 1 (1): 7–13.

MfE 2002. Ambient air quality guidelines. Air Quality Report No. 32, May 2002.

MfE 2008. Good practice guide for assessing discharges to air from industry. Ministry for the Environment Report ME880. June 2008.

MfE 2011. 2011 Users' Guide to the revised National Environmental Standards for Air Quality. Quality. Ministry for the Environment Report ME1068. p. 144.

Sridhar S & Wickham L 2013. Masterton & Carterton Domestic Fire Emissions Inventory 2013. Report prepared by Emission Impossible Ltd for Greater Wellington Regional Council, 30 August 2013. p. 60.

WHO 2006. Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide - Global update 2005. Report WHO/SDE/PHE/OEH/06.02. p. 22.

APPENDIX A

Greytown, Martinborough and Featherston Box Model for PM_{10}

1.0 INTRODUCTION

The Wairarapa Airshed Study is composed of a number of specific tasks, described in Golder's proposed Scope of Services (Golder 2013a), and listed in Table A1. This Appendix relates to Task 1.

Table A1: Wairarapa Airshed Study task list.

Task	Name	Location
1	Greytown, Martinborough and Featherston Box Model for PM_{10}	Appendix A
2	TAPM Meteorological Modelling for Masterton and Carterton	Appendix B
3	Urban Airshed Modelling of PM_{10} from Domestic Heating in Masterton and Carterton	Appendices C and D
4	CALMET Meteorological Modelling for Masterton and Carterton	Appendix E
5	Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area	Appendices F and G
6	Determination of Airshed Boundaries in the Wairarapa Valley	Main Report

A previous scoping report (Golder 2013b) found that the towns of Featherston, Greytown and Martinborough are likely to be compliant with the National Environmental Standards for Air Quality (NES). This was based on an examination of PM_{10} emission rates from wood and coal burning for domestic heating in each town using the Emissions and Socio-Economic Spatial Model (ESESM)[1]. It was recommended that compliance for the smaller towns be examined through a simple box-model assessment of likely ambient PM_{10} levels. The outcomes of that task are described in the following sections.

2.0 METHOD

The box model is a spreadsheet-based tool, which treats the atmosphere as a well-mixed layer above an urban area. It estimates the volume-averaged 1-hour average PM_{10} concentration, which increases due to emissions into the box from domestic heating sources and decreases due to transport out of the box by the wind. The concentration also changes as the depth of the well-mixed layer above the urban area changes. Once validated through comparison with ambient PM_{10} observations, the model may be used to estimate PM_{10} levels under chosen emissions-change scenarios. This has been done for Christchurch (Foster et al. 1997; Foster 1998; Gimson 1999).

The following equation encapsulates the box model:

$$\frac{dX}{dt} = -\frac{1}{h}\frac{dh}{dt}(X-B) + \frac{100Q}{h} - \left(\frac{3.6U}{l} + \frac{36v}{h}\right)(X-B)$$

The symbols in the equation represent the following:

- X is the volume-averaged hourly PM_{10} concentration (in µg/m^3).
- B is the background PM_{10} concentration (in µg/m^3).
- Q is the PM_{10} emission rate (in g/ha/hr).

[1] http://wrenz.niwa.co.nz/webmodel/emissions%20

- *U* is the hourly wind speed (in m/s).
- *v* is the dry deposition velocity (in m/s).
- *l* is a horizontal length scale for the urban area (in km).
- *h* is the hourly mixing height (in metres).

The terms containing *U* and *v* are negative as they both remove ambient PM_{10} from the box volume. Constants appear in the equation due to the different units in use. The equation can be easily solved hour by hour in a spreadsheet (supplied). Terms containing the rate of change of mixing height appear, because the PM_{10} dilutes as the box volume deepens.

The box model requires as inputs the hourly PM_{10} emission rate, surface wind speed, mixing height and a horizontal length scale. The horizontal length scale is defined as the length of the urban area in the direction of the wind. As the wind direction changes and the towns in the Wairarapa Valley do not have the same lengths and widths, this length has been taken as the geometric mean of the length and width of each urban area. That is, the town is assumed to be square. The emission rate is the total over all source locations, that is, the whole urban area. The model has been run for domestic heating sources only, with the 24-hour emission total taken from the ESESM for each small town in the Wairarapa Valley. Other sources are assumed to have a small contribution in comparison. The hour-by-hour emissions are given the same percentages of the daily total as determined in the 2009 Christchurch inventory for weekdays in the urban area (CRC 2011).

The box model was run for the winter period of 2010, during which ambient monitoring took place in Carterton (Mitchell 2012). The model used the measured surface wind speed from the ambient monitoring programme. No mixing height data or adequate surrogate parameters were available; therefore the mixing height had to be calculated using available data. It was assumed that the same hour-by-hour pattern of mixing height was appropriate for days of worst-case observed PM_{10}. This hour-by-hour pattern was found by minimizing the hourly model error for the top ten worst PM_{10} days. Thus the box model was calibrated using Carterton data, and then applied to Greytown, Featherston and Martinborough using their respective ESESM emission rates and length scales.

The following assumptions were made in the box modelling:

i) Pollution is well-mixed so that the modelled volume average PM_{10} concentration is representative of the measured GLC at a centrally-placed monitoring site.

ii) The calculated mixing height is representative of all worst-case days in Carterton.

iii) The wind speed and mixing height of Carterton are appropriate to use when modelling the other towns.

iv) The ESESM domestic heating emissions estimates are conservative. This is true in comparison with the Masterton 2008 inventory (Wilton & Baynes 2008), whose total emissions – from all sources – are less than the ESESM estimate for domestic heating only.

v) Contributions to the ambient PM_{10} from other anthropogenic sources small in comparison with domestic heating and are assumed to be negligible.

vi) The hour-by-hour contributions of PM_{10} emissions to the daily-total emission are in proportion to the those determined for the Christchurch urban area in the emissions inventory for 2009 (CRC 2011).

vii) There is a natural component of PM_{10} of concentration 5 $\mu g/m^3$.

viii) Dry deposition occurs with a deposition velocity of 0.1 cm/s.

The box model parameters for each town are shown in Table A2. The hour-by-hour fraction of the daily PM_{10} emitted is shown in Figure A1.

Table A2: Box model parameters.

Town	Length$ (km)	Width$ (km)	Length scale (km)	PM_{10} emission rate# (g/ha/day)
Carterton	3.9	1.6	2.5	459
Featherston	1.7	1.5	1.6	427
Greytown	2.5	1.5	1.9	279
Martinborough	2.5	1.9	2.2	178

$ Extent of urban area estimated from Google Earth.
# Total of wood and coal burning from the ESESM.

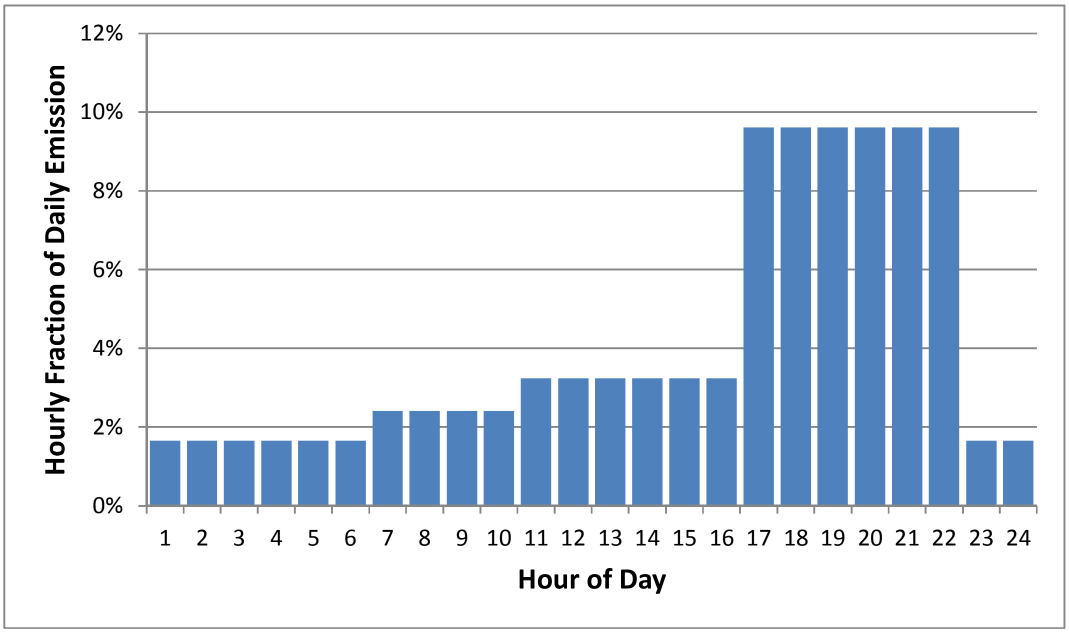


Figure A1: Hourly fraction of daily PM_{10} emission rate for domestic heating. Taken from CRC (2011).

3.0 RESULTS

The highest ten observed 24-hour PM_{10} GLCs in Carterton during winter 2010 ranged from 35 µg/m^3 to 53 µg/m^3. The second highest was 46 µg/m^3. Solving for the mixing height by minimizing the hourly model error led to the hourly pattern of mixing height shown in Figure A2, which ranges between 14 m and 1700 m. Note that the mixing heights are parameters derived mathematically. They appear to be quite realistic, being very low at night and high during the day.

With the calculated mixing heights, the maximum modelled 24-hour PM_{10} for Carterton is 47 µg/m^3. Comparing the modelled and monitored data, suggests that the highest-modelled PM_{10} can thus be taken as an estimator of the 2nd-highest-observed PM_{10} in winter 2010.

The box model has been re-run for the other towns with the wind speed and estimated mixing height from Carterton, but using the specific parameters for each shown in Table A2. The modelled highest PM_{10} concentrations for each town are shown in Table A3.

Table A3: Modelled 2nd-highest 24-hour PM_{10} GLCs in Wairarapa towns for winter 2010.

Town	Box-model maximum
Carterton	47 µg/m^3
Featherston	38 µg/m^3
Greytown	29 µg/m^3
Martinborough	22 µg/m^3

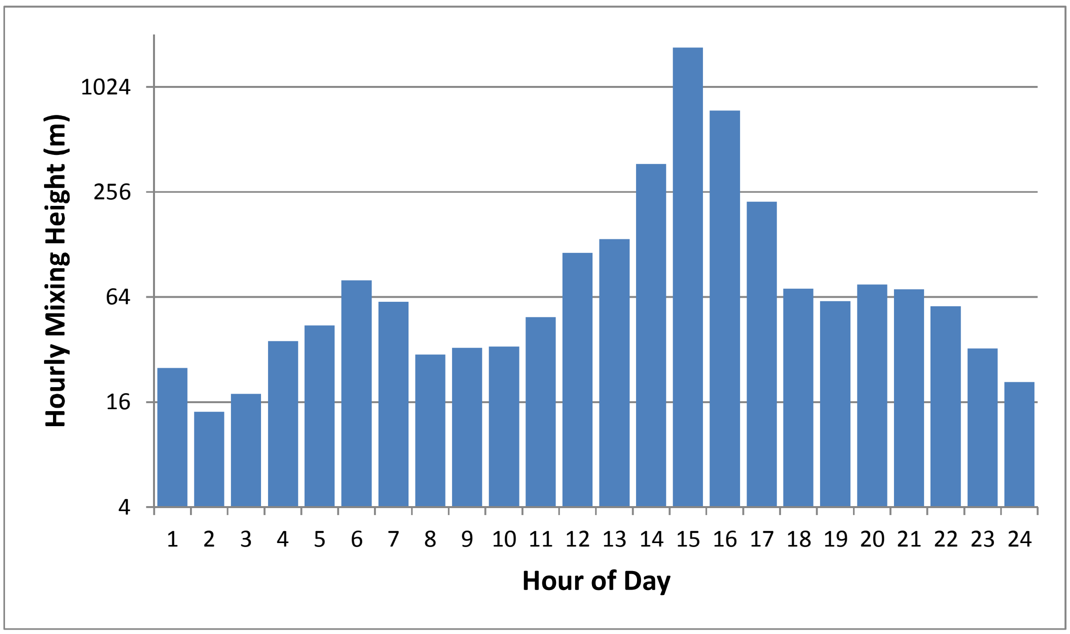


Figure A2: Calculated mixing height. Note the logarithmic vertical scale chosen to accentuate night-time values.

The estimated 2nd-highest 24-hour PM_{10} GLCs for the three towns Featherston, Greytown and Martinborough (the box-model maximum GLCs) indicate that these towns are compliant with the NES for PM_{10} by a reasonable margin. The question remains as to what the GLC may be in years other than 2010. The concentrations contained in Table A4 represent an increase of the 2010 results by 36% to account for inter-annual variability. The variability factor was taken from the 2nd-highest observed concentrations each year in Masterton from 2005 to 2011[2]. The highest of these is 36% higher than the lowest. Greytown and Martinborough are still estimated to be compliant with the NES, with the box-model maximum PM_{10} for Featherston reaching 52 µg/m^3. However, it is considered that the margin of 36% is very conservative, as 2010 was actually the worst year in Masterton. The likelihood of a breach of the NES for PM_{10} in Featherston is still small.

[2] http://www.mfe.govt.nz/environmental-reporting/air/air-quality/pm10/nes/wellington/

Table A4: Estimated 2nd-highest 24-hour PM_{10} GLCs in Wairarapa towns for all winters.

Town	Box-model maximum + 36%
Carterton	64 µg/m^3
Featherston	52 µg/m^3
Greytown	40 µg/m^3
Martinborough	30 µg/m^3

4.0 DISCUSSION

Care should be taken when using the box model. Although it is a simple representation of a boundary layer, realistic parameters are required for input, or the output concentrations would be too conservative. In the absence of meteorological data, it would be easy to assume a small mixing height and small wind speed and arrive at extremely large concentrations. Although there were no mixing height data available for Carterton, the box model was calibrated by finding a generic 24-hour pattern which enabled the best fit of model results to ambient PM_{10} measurements under worst-case conditions. Therefore for Carterton, the box model has no predictive ability, but in combination with data on emissions and meteorological parameters it enables the mixing height data to be estimated and the resulting model has been applied to the other towns in the Wairarapa Valley. The assumptions made in the application to other towns have been listed above.

As the box model assumes well-mixed pollutants within the layer (that is, concentrations do not vary with location or height), it cannot be used to model spatial patterns or the extent of air quality impacts – air pollution which has left the box is no longer considered by the model. It should not be used for geographically complex locations or where there are significant impacts from outside the area (for instance, a close neighbouring town). Neither of these limitations applies to the small, isolated towns considered in this Appendix.

However, given conservative assumptions in the configuration of the model, especially the high PM_{10} domestic emission rate, it can be concluded with some certainty that, if modelled concentrations are low enough, an urban area is very likely to be compliant with the NES for 24-hour ambient PM_{10}. This is the conclusion reached for Featherston, Greytown and Martinborough.

5.0 CONCLUSION

The box model is a simple tool for estimating pollution levels that can give reasonable results when used carefully. Given the assumptions listed and following the modelling procedure outlined above, the model strongly indicates that the Featherston, Greytown and Martinborough airsheds are compliant with the NES for 24-hour PM_{10}, although Featherston may reach ‘alert’ status. Based on this finding it is suggested that there is no immediate need for more detailed modelling or ambient monitoring in these towns.

6.0 ELECTRONIC FILES

The following electronic files will be supplied to GWRC:

- Carterton Box Model.xlsx
- Featherston Box Model.xlsx
- Greytown Box Model.xlsx
- Martinborough Box Model.xlsx

7.0 REFERENCES

CRC 2011. Inventory of emissions to air in Christchurch, 2009. Environment Canterbury Regional Council Report R11/17. p. 157.

Foster E 1998. Reductions in suspended particulate concentrations in Christchurch: a technical background paper. Canterbury Regional Council, Christchurch, ISBN 1-86937-334-0, Published by Canterbury Regional Council. p. 51.

Foster E, Ayrey RB, Gimson NR & Fisher GW 1997. Evaluating the emissions reductions needed to achieve desirable ambient particulate levels in Christchurch's air. National Institute of Water and Atmospheric Research Ltd, Canterbury Regional Council Technical Publication No. U97/67.

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

Golder 2013a. Wairarapa Air Quality Modelling - Determination of airshed boundaries in the Wairarapa Valley. Proposal no. 1378104103_001_P_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. April 2013. p. 24.

Golder 2013b. Defining airshed boundaries in the Wairarapa Valley - Recommendations for further investigation. Report no. 1278104006_002_R_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. February 2013. p. 41.

Mitchell T 2012. Annual air quality monitoring report for the Wellington region, 2010. Greater Wellington Regional Council, Publication No. GW/EMI-G-12/15, Wellington. p. 29.

Wilton E & Baynes M 2008. Air Emission Inventory - Masterton, July 2008. Prepared for the Greater Wellington Regional Council. p. 37.

APPENDIX B

TAPM Meteorological Modelling for Masterton and Carterton

1.0 INTRODUCTION

1.1 The Wairarapa Airshed Study

The Wairarapa Airshed Study is composed of a number of specific tasks, described in Golder's proposed Scope of Services (Golder 2013a), and listed in Table B1. This Appendix relates to Task 2, TAPM meteorological modelling for Masterton and Carterton.

Table B1: Wairarapa Airshed Study task list.

Task	Name	Location
1	Greytown, Martinborough and Featherston Box Model for PM_{10}	Appendix A
2	TAPM Meteorological Modelling for Masterton and Carterton	Appendix B
3	Urban Airshed Modelling of PM_{10} from Domestic Heating in Masterton and Carterton	Appendices C and D
4	CALMET Meteorological Modelling for Masterton and Carterton	Appendix E
5	Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area	Appendices F and G
6	Determination of Airshed Boundaries in the Wairarapa Valley	Main Report

1.2 TAPM Meteorological Modelling for Masterton and Carterton

1.2.1 Background to the project and relationship to other tasks

Long-term ambient air quality monitoring in recent years has shown that the urban area of Masterton is not in compliance with the National Environmental Standards for Air Quality (the NES; see MfE 2011a, 2011b) PM_{10} concentrations have been found to exceed the 24-hour concentration limit of 50 µg/m^3. Short-term campaigns in Carterton using NES-compliant monitoring techniques have shown concentrations close to the NES criterion, indicating that Carterton may also be non-compliant. Information on air quality in Masterton and Carterton was reviewed in a scoping report (Golder 2013b), which recommended further monitoring in Carterton, the development of an up-to-date inventory of domestic-heating emissions from the two towns, and airshed modelling to determine the likely spatial extent of non-compliant areas. An NES-compliant PM_{10} monitoring site was set up in Carterton by GWRC in April 2013, and an inventory of PM_{10} emissions from domestic heating is in preparation, based on a telephone survey carried out in June 2013. Urban airshed modelling of PM_{10} dispersion from domestic heating will be carried out under Task 3 of this project, using The Air Pollution Model (TAPM). The meteorological component of the urban airshed modelling, also modelled using TAPM under Task 2, is described in this Appendix. Meteorological modelling using CALMET under Task 4 will also be based on the TAPM modelling described here.

1.2.2 Structure of this Appendix

This Appendix describes the configuration of the meteorological component of TAPM for part of the Wairarapa Valley containing Masterton and Carterton (Section 2.0), and evaluates the model's performance using common statistical measures of performance (Section 3.0). Section 4.0 contains an examination of the effects of wind-data assimilation into the model runs, followed by some concluding remarks (Section 5.0). A glossary of terms, list of electronic files provided and a list of cited references are contained in Sections 6.0, 7.0 and 8.0, respectively.

2.0 METHOD – CONFIGURATION OF THE METEOROLOGICAL MODEL

Airshed modelling of Masterton was carried out as part of a public-funded research program (Xie et al. 2006; Gimson et al. 2005a; Gimson et al. 2005b), and subsequently under a contract to GWRC on Straight-line Paths and emissions reductions by Gimson (2006). In these studies TAPM was used, with a fine grid covering Masterton and Carterton. The model was run in the previous studies for a single winter season (2004) to compare the modelled PM_{10} concentration with observations at Wairarapa College. However, the modelling described here has been carried out for a full five-year period from 2008 to 2013. This was done for two reasons; (i) a more recent period would allow a more direct comparison with later PM_{10} measurements taken using the latest monitoring equipment, and (ii) a five-year period was chosen to incorporate more meteorological variability and allow a more straightforward determination of airshed compliance with the NES (whereby an airshed is considered to be un-polluted if the criterion concentration is exceeded no more than once per year for five years). In this project, the TAPM runs were set up according to the parameters listed in Table B2. The model domain was centred on the latitude/longitude coordinates (40° 59.5' S, 175° 35.5' E) in the World Geodetic System (1984), with the central point midway between Masterton and Carterton. TAPM works on a rectangular coordinate system of the user's choosing. In this case New Zealand Transverse Mercator (NZTM) coordinates were chosen so that sources, receptors, terrain and land cover would be located correctly relative to each other.

Table B2: TAPM configuration parameters.

Parameter	Value
Start and end dates	1 September 2008 to 31 August 2013
Grid centre (Latitude/Longitude, WGS84)	40° 59.5' S 175° 35.5' E
Grid centre (NZTM)	(1818001, 5458933) (m)
No. of grids; no. of grid cells in horizontal	4; 40 x 40
Horizontal grid-cell spacing (one value per grid)	27 km, 9 km, 3 km, 1 km
Grid size east to west (equals distance north to south)	1080 km, 360 km, 120 km, 40 km
No. of levels in the vertical; level heights	25; heights 10 m, 25 m, 50 m, 100 m, 150 m, 200 m, 250 m, 300 m, 400 m, 500 m, 600 m, 750 m, 1000 m, 1250 m, 1500 m, 1750 m, 2000 m, 2500 m, 3000 m, 3500 m, 4000 m, 5000 m, 6000 m, 7000 m, 8000 m

TAPM employs a one-way grid nesting. Each grid has the same centre and the same number of grid cells, so that the higher resolution grids cover successively smaller areas. The vertical levels 'telescope' up from the surface, with lower levels closer together and the distance between levels increasing with height. Four grids were used in this work, shown in Figure B1. Grid 4 has the finest horizontal resolution (1 km grid cell size).

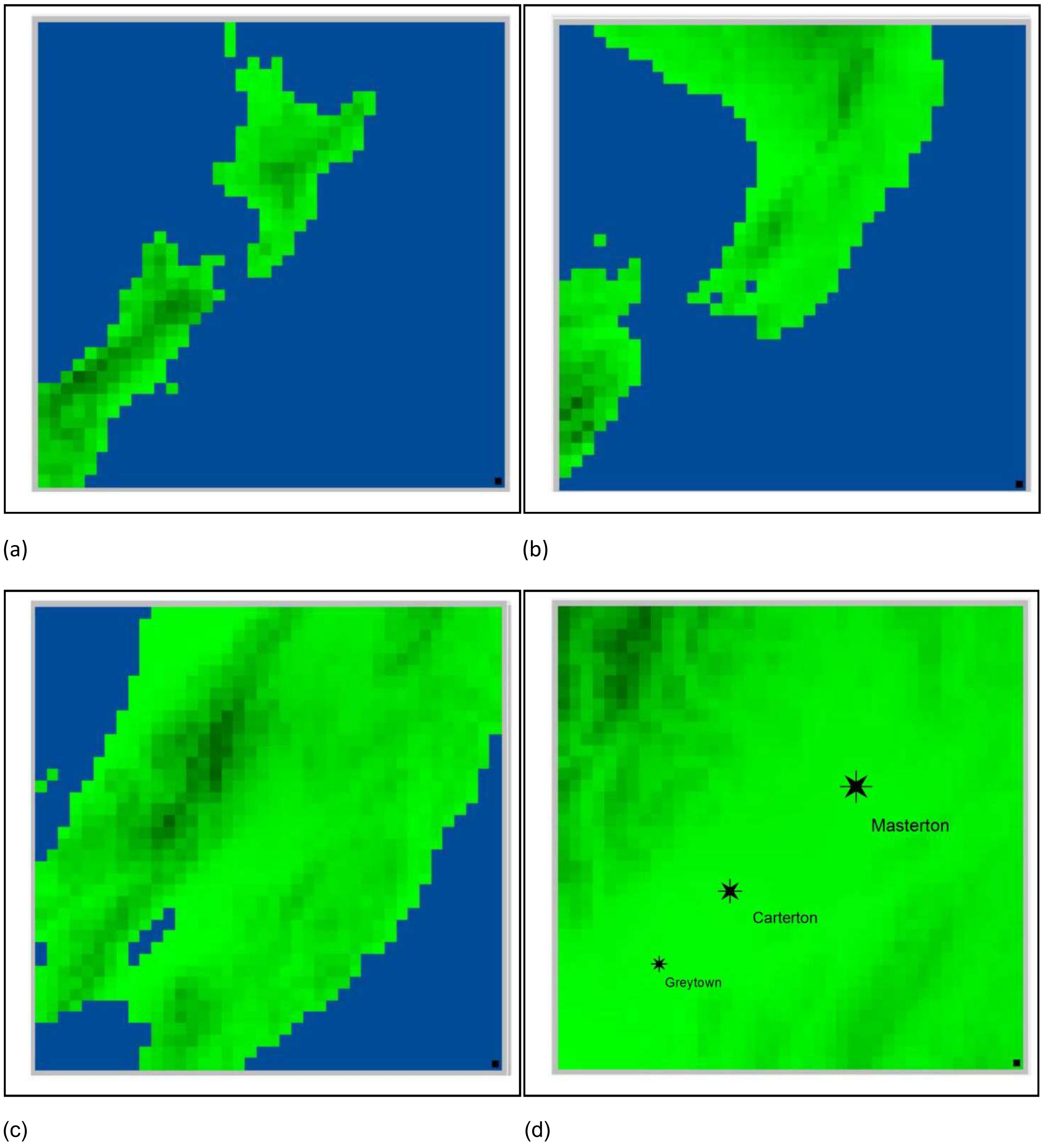


Figure B1: TAPM grid extents. Sea is coloured dark blue; land is coloured green, with darker pixels representing grid cells of higher terrain. (a) 27 km grid cell size; (b) 9 km grid size; (c) 3 km grid size; (d) 1 km grid size.

TAPM is driven at its outer boundaries by synoptic meteorology, which is generated by Australian forecast models and supplied by TAPM's developer, CSIRO. Data for a five-year period between 2008 and 2013 are used to drive the model runs described in this Appendix. Local mesoscale meteorological features, such as land/sea breezes and slope flows, are produced internally by the model, according to its mathematical formulation of atmospheric processes.

TAPM can assimilate observations of wind speed and direction, and uses a scheme commonly known as 'nudging', in which the modelled wind components are weakly forced towards their observed values near to climate-site locations. Wind data assimilation may improve the model results, particularly in the simulation of cold, calm wintertime conditions. Nudging is one of a number of data-assimilation techniques; more sophisticated techniques are generally used in weather-forecasting models. TAPM has been run both with and without nudging here, and a comparison of the two sets of results has been carried out. In the runs with nudging, wind observations at the three sites listed in Table B3 were incorporated into the model. The two Masterton sites are on all four grids; Martinborough is on the three outer grids. Surface meteorological data were incorporated into the lowest two model levels (10 m and 25 m above ground level), over a radius of influence around each site of 7 km (covering the likely extent of pollution impacts from sources in Masterton).

TAPM configuration parameters not specifically mentioned in this Appendix – such as sea-surface temperature and soil temperature and moisture content – should be assumed to take their default values (see Hurley 2008), or else they relate to a particular feature of the model which is not used in this study.

To keep output file sizes manageable, the five-year modelling period was broken down into short TAPM runs, each four months long. Airshed modelling of PM_{10} dispersion from domestic heating sources requires the modelled meteorology for the months May to August only. However, modelling of dispersion from industrial sources requires year-round meteorological data, as their impacts are not confined to the winter season.

Table B3: List of meteorological stations whose wind data are assimilated into the TAPM runs.

Site name	Observer	Easting (NZTM, m)	Northing (NZTM, m)
Martinborough EWS	NIWA	1800229	5430479
Masterton Airport AWS	MetService	1822052	5460551
Wairarapa College, Masterton	GWRC	1822746	5463166

The TAPM meteorological modelling was carried out under the following assumptions:

i) TAPM is capable of modelling the meteorology of the Wairarapa sufficiently well to meet the objectives of the project, including the surface wind, temperature and boundary-layer structure (this is evaluated in the next section).

ii) TAPM also provides a reasonable simulation of meteorological conditions aloft, in and above the boundary layer.

iii) Model performance does not need to be evaluated for all five years. It should be similar from year to year.

iv) Model performance will be sufficiently good without assimilating wind data from meteorological sites.

v) Wind fields may be improved at the locations of meteorological sites when their data is assimilated into the model runs (but effects on other meteorological parameters and on the meteorology at other locations may be detrimental).

vi) The finest model grid (40 km by 40 km at 1 km resolution) is sufficiently large, and detailed, to capture the meteorology and pollution dispersion impacts in and around Masterton and Carterton.

TAPM outputs hourly, three-dimensional fields of meteorological parameters such as wind, temperature, pressure and humidity. It also outputs hourly, two-dimensional fields such as rainfall, surface fluxes of momentum and heat, and dispersion-relevant boundary-layer parameters such as mixing height, friction velocity, and Monin-Obukhov length. The results section of this Appendix focuses on an evaluation of model performance by comparison with observations from surface sites, and by inspection of spatial patterns of wind. As there are no local upper-air data it is not possible to evaluate the model's performance for conditions aloft, and it is assumed (as stated above) that the model gives a reasonable representation of those conditions.

3.0 RESULTS – MODEL-PERFORMANCE STATISTICS

Time series of TAPM meteorological outputs have been compared with observations at monitoring sites for two of the five years, using commonly used statistical measures to assess model performance. Model performance measures are described by Willmott (1981; 1982) and in Section 6.0. Their formulas are given by Golder (2007). The TAPM outputs have been compared with GWRC's meteorological data from Wairarapa College in Masterton, the NIWA-run weather station at Martinborough, and the station at Masterton Airport, run by MetService. These stations are those used in the nudging process.

Three measures of model performance have been used here, as follows:

Index of Agreement (IOA) between observed and modelled parameters: this varies between 0 for no agreement and 1 for perfect agreement.

Model skill score known as Skill_R: this is the root-mean-square (RMS) of the model error, divided by the standard deviation of the observed parameter, and quantifies the model error as a fraction of the observed variability. It is greater than zero, and should be as small as possible.

Model skill score known as Skill_V: this is the ratio of the standard deviations of the modelled and observed parameters. It should be as close as possible to 1, meaning that the variability in the model parameter is similar in size to the observed variability.

Table B4 shows the IOA for the wind speed (labelled WS), the components U and V of the wind vector (the westerly and southerly wind-velocity components, respectively), and temperature and relative humidity (labelled T and RH). For each of the three sites, results from 2011 without nudging, and results from 2009 with and without nudging are shown[1]. Hence a comparison between neighbouring lines can show differences in performance from year to year, and the effect of incorporating wind data into the model runs.

Table B4: IOA between TAPM outputs and meteorological observations. Parameters are wind speed (WS), wind components (U and V), temperature (T) and relative humidity (RH).

Site	Year	Wind data assimilation	WS	U	V	T	RH
Wairarapa College	2011	No	0.77	0.78	0.85	0.95	0.83
	2009	No	0.81	0.78	0.87	0.96	0.86
		Yes	0.96	0.95	0.98	0.95	0.85
Masterton Aero AWS	2011	No	0.76	0.77	0.82	0.94	0.85
	2009	No	0.74	0.77	0.83	0.93	0.87
		Yes	0.94	0.96	0.97	0.91	0.83
Martinborough EWS	2011	No	0.79	0.85	0.83	0.93	0.81
	2009	No	0.78	0.86	0.83	0.93	0.85
		Yes	0.93	0.96	0.95	0.92	0.81

[1] At the time of writing, TAPM has not been run for 2011 with nudging, as it may not be necessary (see later in this Appendix).

The results in Table B4 may be summarized as follows:

- The IOA is at least 0.74 for all parameters, indicating generally good model performance. It is at least 0.91 for temperature.
- The IOA changes little between model years, indicating that model performance does not change between years (and would be as good for the other periods modelled).
- Model performance for the wind components is significantly improved by nudging. This is to be expected, as the modelled winds are nudged closer to the observations. The IOA for wind components in 2009 with data assimilation is at least 0.93 for each site.
- Model performance for temperature and relative humidity is not changed greatly by nudging; temperature and moisture data are not assimilated. There may be a slight indirect effect on temperature and relative humidity by the change in wind components.

Results for Skill_R are presented in Table B5. Values are below 0.52 for temperature, which indicates good performance. Skill_R for wind components without nudging are somewhat higher (but still less than 1). There is little difference between modelled years 2009 and 2011, and with nudging included in the 2009 model run, Skill_R decreases to 0.46 or less.

Table B5: Skill score Skill_R for the TAPM meteorological runs.

Site	Year	Wind data assimilation	WS	U	V	T	RH
Wairarapa College	2011	No	0.97	1.00	0.77	0.40	0.77
	2009	No	0.83	0.95	0.69	0.36	0.67
		Yes	0.40	0.42	0.29	0.39	0.69
Masterton Aero AWS	2011	No	0.87	0.85	0.73	0.43	0.73
	2009	No	0.86	0.80	0.67	0.45	0.65
		Yes	0.45	0.37	0.30	0.52	0.77
Martinborough EWS	2011	No	0.77	0.70	0.76	0.47	0.81
	2009	No	0.77	0.65	0.73	0.46	0.70
		Yes	0.46	0.37	0.42	0.48	0.79

Results for Skill_V are presented in Table B6. On the whole, modelled variability is less than observed, so that Skill_V is less than 1. However, it is still reasonably close.

In summary, consideration of the model statistics at the meteorological monitoring sites demonstrates that TAPM's meteorological component performs well on whole, both with and without use of the nudging technique. The statistics presented here may infer that the use of nudging is preferable. However, before drawing any conclusion on this aspect, further examination of model results is required. This is described in the next section.

Table B6: Skill score Skill_V for the TAPM meteorological runs.

Site	Year	Wind data assimilation	WS	U	V	T	RH
Wairarapa College	2011	No	1.11	1.23	1.03	0.85	0.99
	2009	No	0.99	1.11	0.96	0.82	0.89
		Yes	1.00	1.00	0.96	0.82	0.90
Masterton Aero AWS	2011	No	0.83	0.85	0.77	0.78	0.92
	2009	No	0.70	0.75	0.71	0.74	0.85
		Yes	0.77	0.78	0.80	0.76	0.89
Martinborough EWS	2011	No	0.77	0.88	0.93	0.76	0.95
	2009	No	0.71	0.84	0.83	0.75	0.88
		Yes	0.79	0.86	0.85	0.76	0.91

4.0 FURTHER EXAMINATION OF THE EFFECTS OF NUDGING

4.1 Introduction

This section considers the hour-by-hour details of the meteorological model results, along with spatial variability of wind patterns. Specifically, it examines the effects of nudging on these aspects, which are additional to the model-performance measures considered in Section 3.0, and attempts to determine with more certainty whether or not the nudging process should be used. The aim is to find the most realistic choice for the meteorological model, also bearing in mind its requirement as an input to the dispersion modelling of PM_{10} from low-level sources on cold, calm winter nights. The following questions are discussed in the next sections.

1) How well does the model simulate overnight-minimum temperature and wind speed?

2) How are the overnight-minimum temperature and wind speed, along with the frequency of occurrence of low wind speeds and low mixing heights, affected by nudging using wind data?

3) How does the model perform at a distance from the meteorological sites? How are spatial patterns of meteorological fields affected by the inclusion of data at the monitoring site locations?

4.2 Time-Series Statistics

4.2.1 Night-time wind speed and temperature at the Wairarapa College site

TAPM outputs for 2009 have been examined at the Wairarapa College monitoring site. A time series comparison (not shown here), indicates that the winter night-time minimum wind speed is not always captured by the model. For instance, the modelled minimum wind speed may be around 2 m/s when the observed wind speed is less than 1 m/s. This aspect is much improved by nudging. Table B7 shows that the RMS error in wind speed[2] at 4 am is halved when nudging is used. This occurs through winter (months May, June, July and August), and over the whole year. Table B7 also shows that the surface temperature at the same time of the night is much less affected by wind-data assimilation, although the errors appear to increase slightly when nudging is used. The model temperature does not reach the cold extremes observed, and can be up to 5 °C warmer on some nights.

[2] The daily difference between the observed and modelled wind speed is squared, the squared values are averaged over the 365 days of 2009, and the square root is taken. This gives the RMS error in wind speed. A similar calculation is done for temperature.

Table B7: Summary of the effect of nudging on the modelled wind speed and temperature at 4:00 (2009 model results at Wairarapa College).

Run Description	Wind speed RMS error (all of 2009)	Wind speed RMS error (winter 2009)	Temperature RMS error (all of 2009)	Temperature RMS error (winter 2009)
No wind-data assimilation	0.8 m/s	0.9 m/s	2.3 °C	2.6 °C
Wind-data assimilation included	0.4 m/s	0.4 m/s	2.6 °C	2.8 °C

4.2.2 Hourly wind speeds and mixing heights

The range of modelled and observed wind speed at all hours during 2009 at Wairarapa College is shown as a histogram in Figure B2. Without nudging (blue columns), there are fewer hours of low wind speed than observed (green columns). Including nudging (red columns) produces a closer distribution of wind speeds to those observed, by reducing the frequency of wind speeds between 1 m/s and 2 m/s, and increasing the frequency of wind speeds below 1 m/s. This is reflected in the improvement in the IOA for the hourly wind speed, and the reduction of errors in the 4 am wind speed due to the inclusion of nudging, and potentially leads to higher modelled peak ground-level concentrations of pollutants released at night-time.

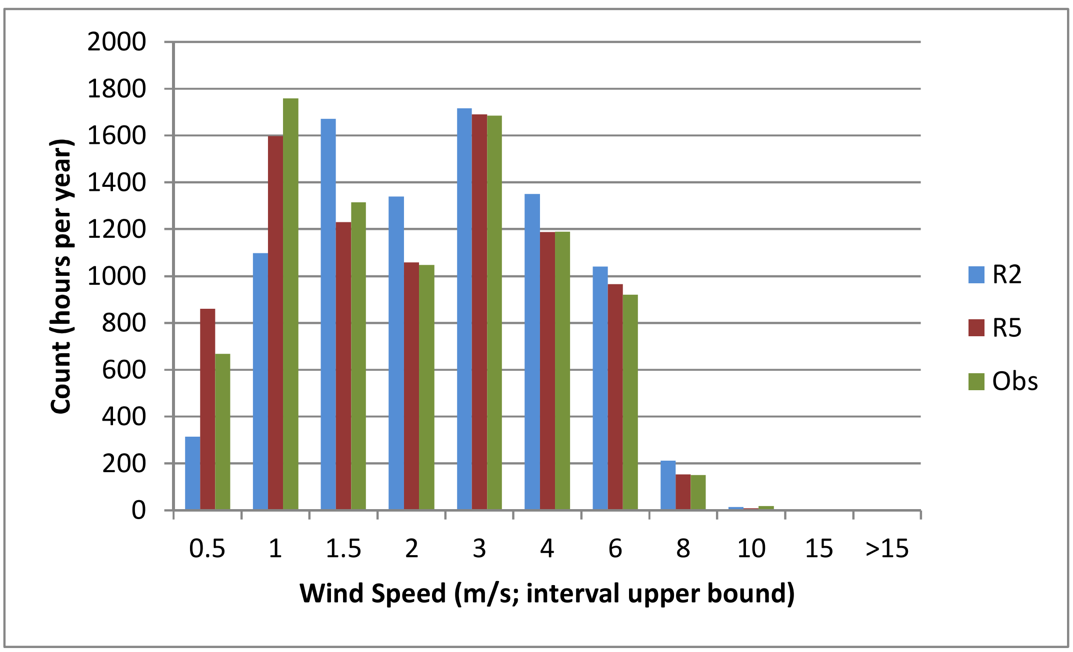


Figure B2: Frequency histogram of modelled and observed wind speed. Run R2 does not include nudging; Run R5 includes nudging.

The range of modelled mixing height at all hours during 2009 at Wairarapa College is shown as a histogram in Figure B3. Intuitively, lower night-time wind speeds should be associated with a cooler, more stable nocturnal boundary layer and a higher frequency of low mixing heights. However, the incorporation of nudging leads to lower night-time wind speeds, but a *lower* frequency of mixing heights 50 m or less. This is counterintuitive, and may potentially lead to lower modelled peak ground-level concentrations of pollutants released at night-time.

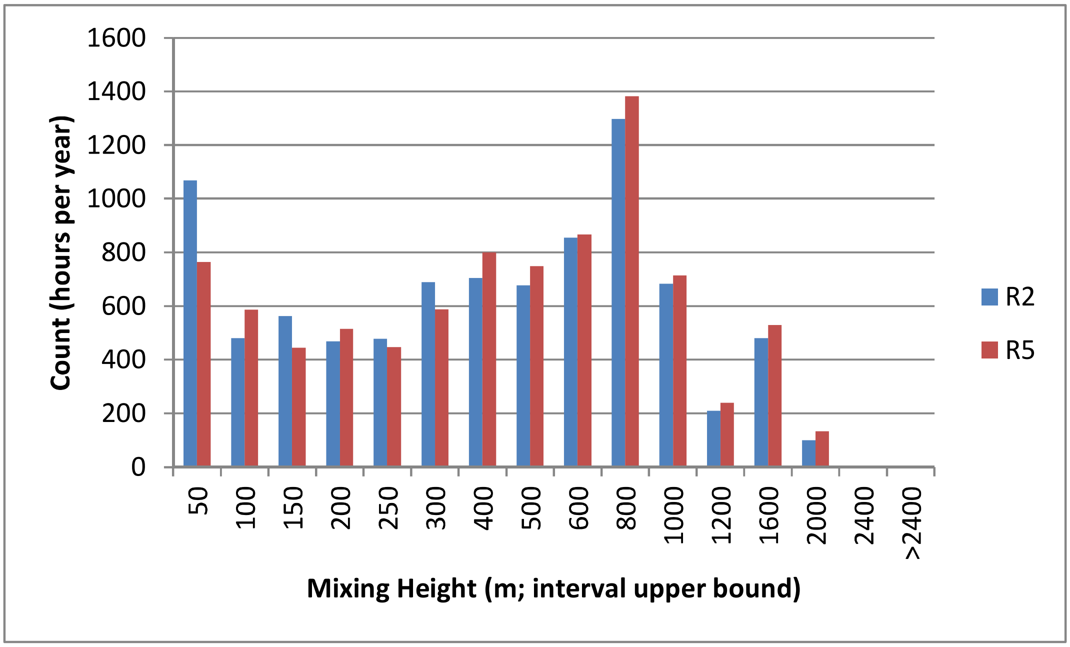


Figure B3: Frequency histogram of modelled mixing height. Run R2 does not include nudging; Run R5 includes nudging.

4.2.3 Airflow through the mixed layer

A useful indicator of the potential for pollution dispersion through the surface mixed layer is the product of wind speed and mixing height. This quantifies airflow through the mixed layer, and is an indicator of the rate at which air pollutants emitted into the layer will be diluted. Under Task 1, a box model was used to estimate PM_{10} concentrations in the mixed layer over the small towns in the Wairarapa Valley. Although this model is not as appropriate for use in Masterton, a steady-state approximation to the box model yields the following schematic relationship between PM_{10} concentration and airflow:

$$X = \frac{Ql}{A}.$$

$A = Wh$ is the airflow parameter (in m^2/s). The other symbols in the equations represent the following:

- X is the PM_{10} concentration (in $\mu g/m^3$) arising from local PM_{10} emissions.
- Q is the PM_{10} emission rate (in $kg/m^2/s$).
- W is the wind speed (in m/s).
- h is the mixing height (in metres).
- l is a horizontal length scale for the source, in the direction of the wind (in metres).

The above equations show how the parameters are related, with the airflow parameter *A* appearing in the denominator as a dilution factor for the pollutant concentration. A frequency histogram of this quantity is shown in Figure B4 for model runs with and without nudging. It is notable that despite the wind speed and mixing heights being affected by the nudging process, the frequency distribution of the airflow factor appears to be unchanged. This indicates that the nudging may not greatly affect modelled levels of PM_{10}, although this has yet to be confirmed by dispersion modelling.

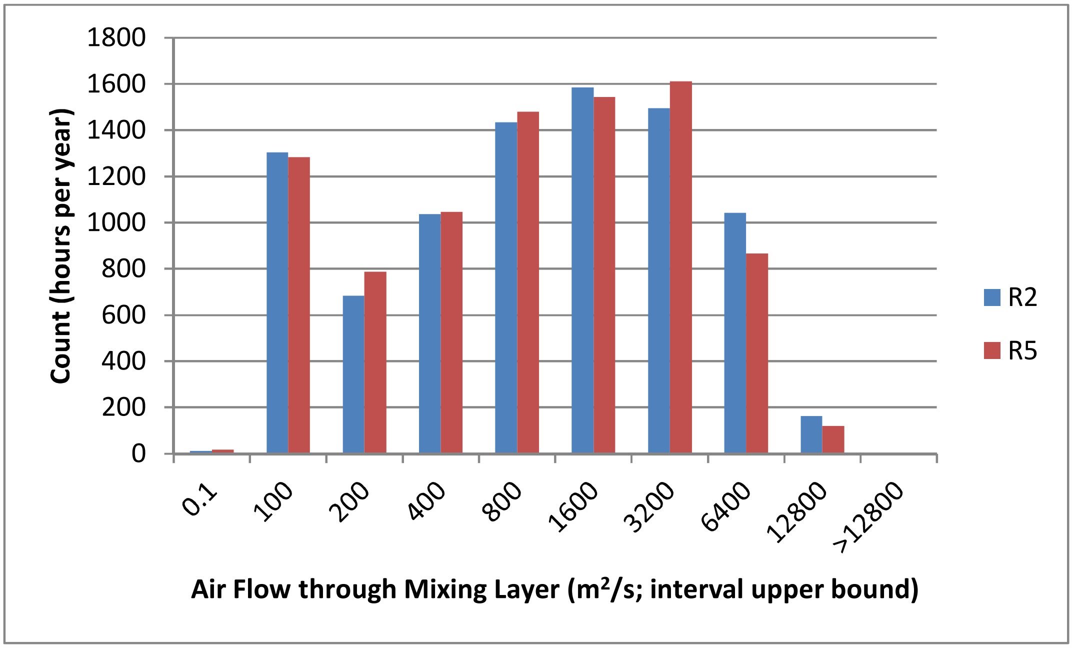
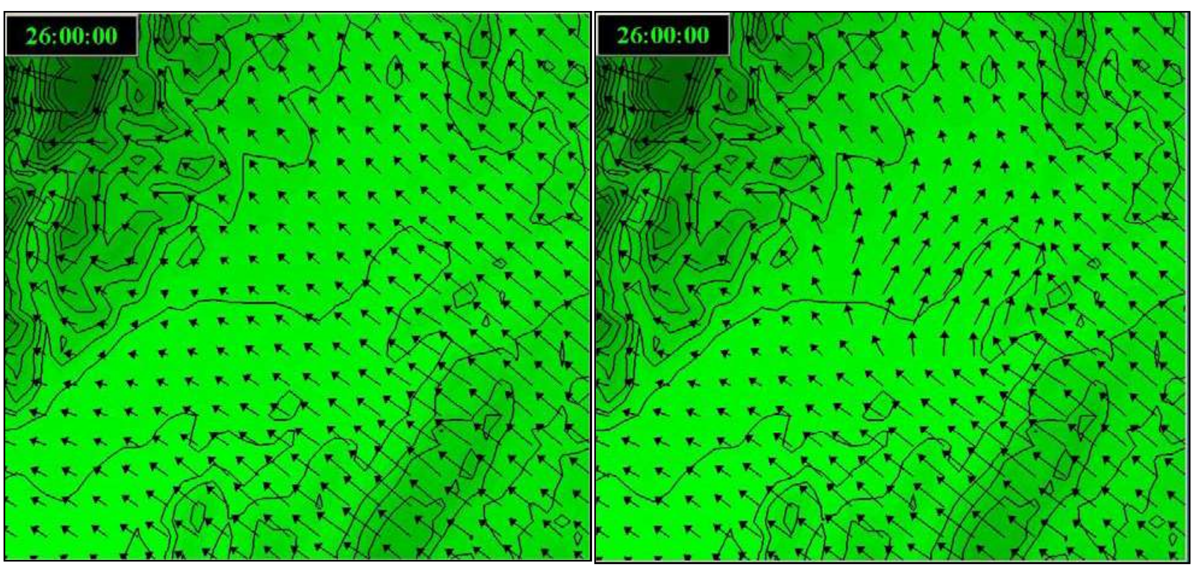


Figure B4: Frequency histogram of the airflow parameter A = Wh (in m^2/s). Run R2 is without wind-data assimilation; Run R5 includes wind-data assimilation.

4.3 Spatial Wind-Field Patterns

Examples of instantaneous wind fields from TAPM runs with and without nudging are shown in Figure B5.



(a) (b)

Figure B5: Surface winds from TAPM at midnight on 26 May 2009. (a) without wind-data assimilation; (b) with wind-data assimilation.

The left panel shows the wind as modelled by TAPM on grid 4, which has a reasonably uniform southeasterly flow across the valley, with some diversion of the wind as it flows uphill on the northwest slopes. With nudging (right panel), the wind in the centre of the domain is from the southwest, due to the assimilation of observations at Wairarapa College and Masterton Airport. At this hour, the observed wind was southwesterly, and the 7 km radius of influence of the observations produces a roughly circular region of southwesterly wind having that radius. Outside this area, the wind rather abruptly changes to southeasterly, as the observations have no impact outside the radius of influence; it appears that the model's internal dynamics do not act to smooth the transition in the wind direction. In spite of the apparent improvement brought about by the nudging process (in terms of the model's wind statistics at the sites discussed in Section 3.0), unrealistic spatial wind field patterns can arise.

4.4 Summary of Results

This section has examined more closely the impacts of the nudging process on the meteorological model results, by addressing some specific questions. The questions are repeated here, with summary answers inserted.

1) How well does the model simulate overnight-minimum temperature and wind speed? *Minimum wind speed and temperature are simulated reasonably well, although the model can miss extremes of cold temperature and low wind speed.*

2) How are the overnight-minimum temperature and wind speed, along with the frequency of occurrence of low wind speeds and low mixing heights, affected by nudging using wind data? *Nudging improves the minimum wind speed, but leaves the temperature unchanged. Low wind speeds become more frequent, but the lowest mixing heights are less frequent. The frequency distribution of the airflow factor, defined as the product of wind speed and mixing height, is not substantially changed by the nudging process.*

3) How does the model perform at a distance from the meteorological sites? How are spatial patterns of meteorological fields affected by the inclusion of data at the monitoring site locations? *The nudging process occurs over a user-defined radius of influence. Within this radius, the wind field matches the site measurements; outside the radius of influence, the model produces the wind field which would occur in the absence of nudging. If the modelled and observed winds are different – as they may be hour by hour – a near-discontinuity in the wind occurs at the edge of the site influence, leaving an unrealistic 'bull's-eye' in the wind field.*

4.5 Discussion on the Effects of Nudging

TAPM has been configured to provide meteorological fields to be used for modelling dispersion from domestic-heating emissions in Masterton and Carterton and from industrial emissions in the Waingawa area southwest of Masterton. Good-quality meteorological fields are important to providing a realistic representation of the dispersion of pollutants, and TAPM has been shown to work reasonably well with respect to commonly-used statistical measures of model performance. However, TAPM predictions can sometimes miss extremes of calm and cold conditions (and this is not necessarily a feature only of TAPM). The model has very few parameters which can be changed to improve performance, but the use of wind-data assimilation using the nudging technique is an alternative which has been examined here.

The nudging process involves the blending of observations into the model hour by hour. However, TAPM is not intended to exactly reproduce meteorological conditions hour by hour, but to produce physically-realistic results which are, on the whole, statistically correct. For example, a timing error of an hour or two in the passage of a weather system, or some other change in conditions would not be considered a failing of the model. However, during those two hours the model can differ significantly from observations, potentially over a large area. The same is true for the local terrain-driven wind flow, which may also be subject to timing errors. In both cases, nudging the model towards the surface wind would bring the modelled wind speed and direction closer to observations, but this may not be consistent with two- and three-dimensional aspects of the flow and its thermodynamic relationship to pressure and temperature.

Applying the nudging process over a radius of influence of 7 km around the monitoring sites, as done in this work, can lead to roughly circular regions where the modelled wind matches the observations, outside of which the model fields abruptly change to what would be simulated in the absence of nudging. This was demonstrated in the previous section.

When wind data are available, it is recommended by some model developers that they should be assimilated into the model run. The examinations carried out above have shown that model results are not better in every respect when nudging is used. It is beyond the scope of this work to determine why this is the case, except to say that the mathematical equations solved by the model are intended to represent the balance between physical properties such as wind velocity, temperature, pressure and moisture of the air and ground surface. The more subtle effects of wind-observation nudging on meteorological parameters *other than the wind* may be due to this balance being disturbed through the forcing of some parameters but not others.

To alleviate the potential for resulting discontinuities in the resulting wind fields, it is also recommended by some modellers that a small radius of influence is used. This would merely move the discontinuities closer to the monitoring sites. A value of 7 km was chosen in this work so that the likely range of dispersion of PM_{10} from sources in Masterton does not extend over the limit of influence of the meteorological data and into a region of unrealistic wind fields.

The advantages and disadvantages of wind-data assimilation (through nudging) may be summarized as follows:

Advantages of nudging: better model performance for wind at monitoring sites; improvement in overnight minimum wind speeds.

Disadvantages of nudging: unrealistic discontinuities in spatial patterns of wind (horizontally and vertically); possible disturbance of thermodynamic balance in the model.

Neutral features: model performance for temperature and relative humidity not changed; range of airflow rates in the mixing layer unchanged.

In short, use of the nudging technique has as many disadvantages as advantages. However, it may be argued that the discontinuities in the modelled wind patterns are actually serious deficiencies, and that the nudging technique should not be used. Alternatively, if the technique *is* used, the radius of influence should be large enough so that the model does not disperse air pollutants beyond the discontinuity.

5.0 CONCLUSION

The Appendix presents the outcomes of Task 2 of the Wairarapa Airshed Study – TAPM Meteorological Modelling for Masterton and Carterton.

TAPM meteorological model runs have been carried out, with reasonable model performance being achieved. Consequences of the key configuration choice – the use, or not, of wind-data assimilation through nudging – have been examined. At this stage it is considered likely that meteorological model runs without data assimilation will be most suitable as a basis for further meteorological modelling using CALMET (Task 4), and the dispersion modelling using TAPM and CALPUFF under Tasks 3 and 5 of this project. The main reason for this to avoid the discontinuities in wind fields which arise when nudging is used. However, some test runs of the airshed model under Task 3 will be carried out using the results of both types of meteorological model run before a final decision is made.

6.0 GLOSSARY OF MODEL PERFORMANCE MEASURES

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

Index of Agreement (IOA):

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

Root-mean-square error (RMSE):

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

Model skill scores (Skill_E, Skill_R and Skill_V):

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

Skill_E = RMSEs/Std_O	the systematic error as a fraction of the observed variability,
Skill_R = RMSE/Std_O	the total model error as a fraction of the observed variability,
Skill_V = Std_P/Std_O	the model variability as a fraction of the observed variability.

Skill_E and Skill_R should be less than 1 (and Skill_E should be much less than Skill_R), meaning the errors in the model are less than the variability in the observations. Skill_V should be close to 1, meaning the model reproduces the observed variability.

Results for the variants of RMSE and Skill_E have not been presented for the current model runs.

7.0 ELECTRONIC FILES

Electronic files sufficient to re-create the five-year meteorological model runs will be supplied to GWRC. These will be the TAPM input files containing model parameters, terrain files and processed wind observation files. The file types are *.def, *.inp, *.bat, *.top and *.obs.

TAPM itself and the associated raw data sets for synoptic meteorological inputs will not be supplied to GWRC, as these have been purchased by Golder under a single-user licence. However, other licenced users of TAPM would be able to recreate identical model runs using the electronic files supplied.

8.0 REFERENCES

Gimson N 2006. Masterton Straight-Line Path development. NIWA, NIWA Client Report WLG2006-49, prepared for Greater Wellington Regional Council. p. 19.

Gimson N, Xie S, Revell M & Zawar-Reza P 2005. Predicting compliance with National Air Quality Standards using an Urban Airshed Model. Meteorological Society of New Zealand 26th Annual Conference. Wellington, New Zealand, 23-25 November.

Gimson N, Zawar-Reza P, Xie S & Revell M 2005. Straight-Line Paths and Urban Airshed Modelling. (End-user report, may be downloaded from http://www.niwascience.co.nz/ncces/air_quality).

Golder 2007. Dispersion Modelling in New Zealand. Part 1 - Assessment of Meteorological Models. End-user report under FRST programme Protecting NZ's Clean Air.

Golder 2013a. Wairarapa Air Quality Modelling - Determination of airshed boundaries in the Wairarapa Valley. Proposal no. 1378104103_001_P_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. April 2013. p. 24.

Golder 2013b. Defining airshed boundaries in the Wairarapa Valley - Recommendations for further investigation. Report no. 1278104006_002_R_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. February 2013. p. 41.

Hurley P 2008. TAPM V4. User Manual. CSIRO Marine and Atmospheric Research Internal Report No. 5. October 2008. p. 36.

MfE 2011a. 2011 Users' Guide to the revised National Environmental Standards for Air Quality. Quality. Ministry for the Environment Report ME1068. p. 144.

MfE 2011b. Resource Management (National Environmental Standards for Air Quality) Regulations 2004. September 2004, Ministry for the Environment, Wellington, New Zealand. Accessed <http://www.mfe.govt.nz/laws/standards/air-quality/review/index.html>

Willmott CJ 1981. On the validation of models. Physical Geography. 2184–194.

Willmott CJ 1982. Some comments on the evaluation of model performance. Bulletin of the American Meteorological Society. 631309–1313.

Xie S, Gimson N & Clarkson T 2006. Modelling wintertime PM10 dispersion in Masterton, New Zealand: a tool for implementing national standards. Air Pollution XIV - WIT Transactions on Ecology and the Environment, Vol 86. WIT Press, New Forest, UK. pp. 65–74.

APPENDIX C

Urban Airshed Modelling of PM_{10} from Domestic Heating in Masterton and Carterton

1.0 INTRODUCTION

The Wairarapa Airshed Study is composed of a number of specific tasks, described in Golder's proposed Scope of Services (Golder 2013), and listed in Table C1. This Appendix relates to Task 3, urban airshed modelling of PM_{10} from domestic heating in Masterton and Carterton. The TAPM meteorological pre-processing (Task 2) required to underpin Task 3 is described in Appendix B. Configuration parameters for the airshed modelling are listed in Appendix D.

Table C1: Wairarapa Airshed Study task list.

Task	Name	Location
1	Greytown, Martinborough and Featherston Box Model for PM_{10}	Appendix A
2	TAPM Meteorological Modelling for Masterton and Carterton	Appendix B
3	Urban Airshed Modelling of PM_{10} from Domestic Heating in Masterton and Carterton	Appendices C and D
4	CALMET Meteorological Modelling for Masterton and Carterton	Appendix E
5	Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area	Appendices F and G
6	Determination of Airshed Boundaries in the Wairarapa Valley	Main Report

The purpose of the airshed modelling is to provide modelled PM_{10} concentrations from domestic heating emissions over a five-year period, for combination with PM_{10} concentrations due to industrial emissions. This Appendix describes the configuration of TAPM for this purpose, the results of testing and evaluation of the airshed model, and modelled PM_{10} concentrations themselves. It examines the sensitivity of the airshed model results to (i) the assimilation of wind data into the meteorological model and (ii) the chosen emissions scenario.

The rest of this Appendix is structured as follows. Section 2.0 describes the airshed model configuration, including emissions and other data incorporated into the study, and outlines the case studies carried out. Section 3.0 describes the model results and evaluation, shows examples of calculated airshed boundaries, and discusses several aspects of emissions and air quality in Masterton and Carterton. Issues for discussion are addressed as they arise in Section 3.0, instead of in a separate section. Section 4.0 brings together a summary of the main findings of this Appendix, and Section 5.0 provides some concluding remarks. Section 6.0 provides a list of references.

2.0 AIRSHED MODELLING OF DOMESTIC HEATING SOURCES OF PM_{10} IN MASTERTON AND CARTERTON

2.1 The Air Pollution Model (TAPM)

TAPM was developed by CSIRO in the late 1990s as a tool to carry out air quality assessments (Hurley 1999; Hurley et al. 2005b). It includes a prognostic meteorological model and several modules to simulate dispersion of air contaminants. It was developed to model dispersion from industrial point sources, and also as an urban airshed model (Hurley et al. 2003; Luhar & Hurley 2003). It has been evaluated by comparison with several standard test data sets, and its results compare favourably with other commonly used dispersion models such as AUSPLUME and CALPUFF (Hurley & Luhar 2005; Hurley et al. 2005a; Hurley 2006). The work presented here uses Version 4 (Hurley 2008; Hurley et al. 2008).

TAPM has been used for air quality studies in several cities in NZ. These include Auckland (Gimson 2005a; Golder 2011), Christchurch (Zawar-Reza et al. 2005), Alexandra (Tate et al. 2011), towns in the Hawke's

Bay region (Golder 2009; Gimson 2006; Wilton et al. 2009; Golder 2012) and Masterton (Gimson 2006; Xie et al. 2006).

TAPM has been found to perform well in cities whose emissions are dominated by domestic heating, and provides practical results for use by air quality managers. The domestic heating emissions are distributed as area sources over the model's grid – this has been found to be an adequate representation of a collection of discrete sources of PM_{10}.

As mentioned in Appendix B and in the Scoping Report, previous airshed modelling studies of Masterton and Carterton modelled a single winter season (2004) to compare the modelled PM_{10} concentration with observations at Wairarapa College. However, the modelling described here has been carried out for five consecutive winters between 2009 and 2013 inclusive. This was done for two reasons; (i) a more recent period would allow a more direct comparison with later PM_{10} measurements made using the most recently installed monitoring equipment, and (ii) a five-year period was chosen to incorporate more meteorological variability and allow a more comprehensive determination of airshed compliance with the NES (whereby an airshed is considered to be un-polluted if the criterion concentration is exceeded no more than once per year for five years). In addition, measurements have been made at Chanel College (Masterton) and in Carterton, so that the model may also be evaluated with respect to the data from these two newer monitoring sites.

2.2 Assumptions

The urban airshed modelling was carried out under the following assumptions:

i) TAPM is an appropriate model to use for the dispersion of PM_{10} from domestic fires in an urban airshed.

ii) Representing the sources of PM_{10}, which are the chimneys of individual dwellings, as CAU-average emissions is appropriate and adequate.

iii) Standard emissions inventory techniques (involving surveys of household heating methods and the use of emissions factors for fuel burnt) provide the necessary emission inputs to the airshed model.

iv) Impacts from other sources, such as motor vehicles, sea spray and windblown crustal matter can be incorporated into the airshed model results as a post-processing step using source-apportionment observations, as these components are relatively small.

v) The emitted PM_{10} may be treated as an inert tracer. There are no depletion mechanisms such as chemical reactions, settling or deposition. This may lead to slightly conservative results.

vi) A five-year modelling period is adequate to capture inter-annual variation in the local meteorology; this is in line with international practice.

vii) CAU-based emissions are resolved adequately on a 250 m regular grid of points. It is noted that model testing and evaluation is carried out on a pollution-dispersion grid at 500 m resolution, so that the spatial pattern of emissions is somewhat smoothed. There is no requirement in TAPM for the emissions and dispersion grids to match. This should not be detrimental to the model evaluation presented in this Appendix.

viii) Running the airshed model on a 250 m grid of points (matching the emissions grid) is adequate to determine the airshed boundary. The final runs (shown in the main report) have been carried out at this resolution.

2.3 Meteorological Inputs

The meteorological modelling, also using TAPM, is described fully in Appendix B. A five-year period was run on a series of grids of increasing resolution, with the finest at 1 km in the horizontal covering Masterton, Carterton, Greytown and the surrounding hills (see Appendix B, Figure B1(d)). The airshed modelling uses the modelled meteorology of the finest grid.

Two meteorological scenarios were considered – one in which monitored surface wind data were assimilated in the TAPM runs (labelled M1), and one which did not include wind-data assimilation (labelled M2).

2.4 PM_{10} Emissions from Domestic Heating

In addition to the meteorology, the other key inputs to the airshed model are the emissions. In 2013, GWRC commissioned Emission Impossible Limited (EIL) to develop an inventory of PM_{10} domestic fire emissions from Masterton and Carterton. The inventory was designed to provide input data to the airshed modelling for the purpose of re-defining airshed boundaries in the Wairarapa Boundary (Sridhar & Wickham 2013). The inventory was based on surveys of home heating methods in Masterton during winter 2013 and provides emission factors according to type and age of burner. The inventory of total emissions was based on a survey of 550 households in Masterton and extrapolated to provide emissions for Carterton. In addition, data on population distribution was used to provide a breakdown of emissions into the nine census area units (CAUs) of Masterton (including Waingawa, which is outside the urban area). The TAPM emissions grid at 250 m was considered sufficiently detailed to resolve the individual CAUs, and for the purpose of converting inventory data to model inputs, a mapping between model grid points and CAU was provided to Golder by GWRC. Further to the spatial breakdown of emissions, EIL provided a temporal breakdown of typical emissions with the following variation:

1) By hour of day – evening and morning heating, with some burners running continuously.

2) By day of week – longer heating periods at weekends.

3) By month of year – variation during winter months, with more burners in operation in June and July than May and August.

In addition a 'worst-case' emissions scenario was provided in which all wood burners are in use 24 hours of the day. In modelling this case the emissions have been assumed constant for all winter months.

Note that the airshed modelling has been carried out for the months May to August (inclusive) of the five-year period. Some use of wood burners occurs in the neighbouring months, but the focus of this work is on the worst-case conditions which are appropriate to consider when defining the airshed boundary. A summary of emissions information, as supplied by EIL, is given in Table C2. The density of emissions (in $kg/day/km^2$) depends on the area of the CAU, and the number and type of domestic wood burners within that CAU; the CAUs with the highest density of emissions are Masterton West, Masterton East, and Ngaumutawa. The PM_{10} emission density is shown on the TAPM emissions grid in Figure C1, with these high-emission suburbs coloured orange and red.

2.5 Emissions Scenarios

The airshed modelling considers three emissions scenarios, which are summarized in Table C3. Under the typical emissions scenario, the main weekday emissions cease at 9 pm and weekend emissions cease at 10 pm; a proportion of burners are taken to operate continuously. However, ambient air quality monitoring shows that elevated ambient concentrations of PM_{10} persist through the night in most towns, including Masterton. This may be due to meteorological conditions, or to emissions from wood burners which are left to smoulder overnight. The purpose of scenario E3 was to carry out a 'back-calculation' to estimate the magnitude of smouldering emissions which, in combination with the scenario E1 early-evening emissions, would give modelled ambient PM_{10} consistent with overnight observations. Note that this approach assumes in advance that the model is performing well; therefore the results should be treated with care, and ideally evaluated against data obtained independently (for example, known smouldering emission factors).

Table C2: PM_{10} emission totals from the 2013 inventory.

CAU name	Daily average (kg/day)	Weekday (kg/day)	Weekend (kg/day)	Worst case (kg/day)
Masterton Central	24	21	28	54
Masterton West	98	88	118	222
Masterton East	115	102	137	259
Solway North	80	71	96	181
Solway South	99	88	118	224
Ngaumutawa	51	45	61	115
Masterton Railway	10	9	11	22
Lansdowne	136	121	163	307
Waingawa	8	7	10	18
Masterton (Total)	***620***	***553***	***741***	***1402***
Carterton	146	130	174	329

Table C3: Modelled emissions scenarios.

Label	Name	Description
E1	Typical	Weekday and Weekend emissions as shown in Table C2. Weekdays 78% of burners running 7:00-10:00 and 17:00-21:00; 22 % running for 24 hours. Weekends 69% of burners running 8:00-12:00 and 16:00-22:00; 31 % running for 24 hours. Step changes in emissions assume all burners are lit and shut down at the same time, rather than a gradual change through the day.
E2	Worst case	Worst case emissions as shown in Table C2. Emissions constant for 24 hours.
E3	Smouldering	Unit emissions for Masterton and Carterton. Emissions for six hours overnight, starting when the emissions of scenario E1 finish. Magnitude of smouldering emissions determined as a post-processing step, in combination with modelled outputs from option E1.

As mentioned above, the emissions were input to TAPM on a grid of cells with horizontal dimension 250 m.

2.6 Other Sources of PM_{10}

Observations of PM_{10} from winter 2010 at Wairarapa College and Chanel College in Masterton, apportioned according to source, were supplied to Golder by GNS to provide estimates of levels of PM_{10} from sources other than domestic fires (see Ancelet et al. 2012). Sources identified in the PM_{10} measurements were biomass burning (that is, wood and coal in domestic fires), motor vehicles, marine aerosol and crustal matter. Over the observation period, the mean PM_{10} concentrations from vehicles, marine aerosol and crustal matter combined were approximately 4 µg/m^3 at Wairarapa College and 6 µg/m^3 at Chanel College. These values, based on measurements, were added to the modelled concentrations from domestic heating at those sites.

No industrial sources were identified in the source-apportioned data. The source-apportionment technique could identify PM_{10} from individual industries if they were close and upwind of the monitoring sites with sufficient frequency, and had a sufficiently distinct elemental 'fingerprint'. In other words, air quality impacts due to industry may occur at the monitoring sites but are not seen by the source-apportionment techniques with any statistical significance. Evaluation of the airshed modelling in this Appendix, accounts for modelled domestic heating and observed vehicle, sea spray and crustal components, but not industry.

2.7 Other TAPM Configuration Aspects

The pollution-dispersion grid was nested within the meteorological grid. Two configurations have been used. These were (i) dispersion on a 500 m grid covering the whole of the meteorological grid (option G1, and area 40 km by 40 km), and (ii) dispersion on a 250 m grid covering a sub-area containing Masterton and Carterton (option G2, 28 km by 28 km). These areas are shown in Figure C1 and Figure C2. Under both options, emissions were input on the 250 m grid. It was initially planned to run the airshed model on grids around Masterton and Carterton separately. However, tests indicate some transport of pollution from Masterton to Carterton, demonstrating that the two urban areas should be modelled together. In addition, tests also indicated recirculation of pollutants as the wind changes direction during the evening. To capture these processes in the model, the domain had to incorporate a sufficient portion of the hills surrounding the urban areas.

For the modelling described here, PM_{10} was assumed to be an inert, conserved tracer. This means no changes occur to PM_{10} concentrations due to chemical transformations, nor removal and deposition on the surface. In TAPM, four inert tracers can be modelled simultaneously. They might be, for instance, (i) PM_{10} from Masterton under typical emissions, (ii) PM_{10} from Carterton under typical emissions, (iii) PM_{10} from Masterton under worst-case emissions and (iv) PM_{10} from Carterton under worst-case emissions. It is convenient to separate these components as the contributions to the total modelled PM_{10} from different locations can then be determined.

Tables of configuration parameters used by TAPM for this study are given in Appendix D. For completeness, these include the meteorological model configuration from Appendix B and the emissions scenarios described above.

TAPM can be set up to solve for the meteorology and dispersion of pollutants together, with the pollution

2.8 PM_{10} monitoring

Monitoring sites have been established by GWRC at Wairarapa College, Masterton and Chanel College, Masterton, and at Carterton pool. For a description of the sites, see GWRC's monitoring reports (for example, Mitchell 2010; Mitchell 2012a, 2012b; Mitchell 2012). Observations of hourly PM_{10} concentrations were supplied to Golder by GWRC for the periods shown in Table C4, and these have been used for model-evaluation purposes at the three sites. Evaluation has been carried out, as described below, for selected years, as the sites have not been operating continuously.

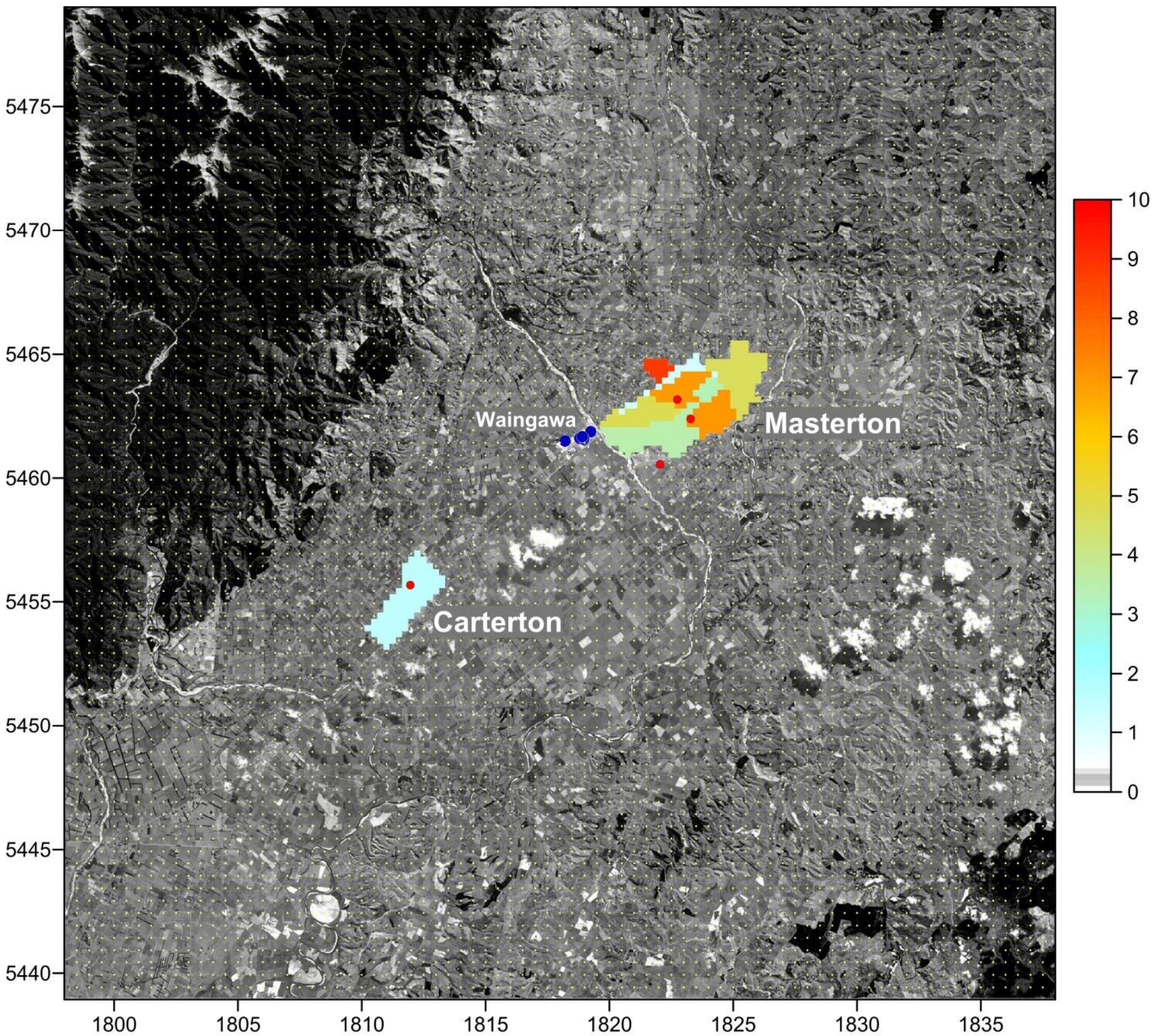


Figure C1: Pollution grid option G1, with small dots showing grid-point locations at 500 m spacing. PM_{10} worst-case emissions from domestic fires shown in kg/day/cell on a grid of 250 m x 250 m cells. Red dots show monitoring sites; blue dots show industrial sources.

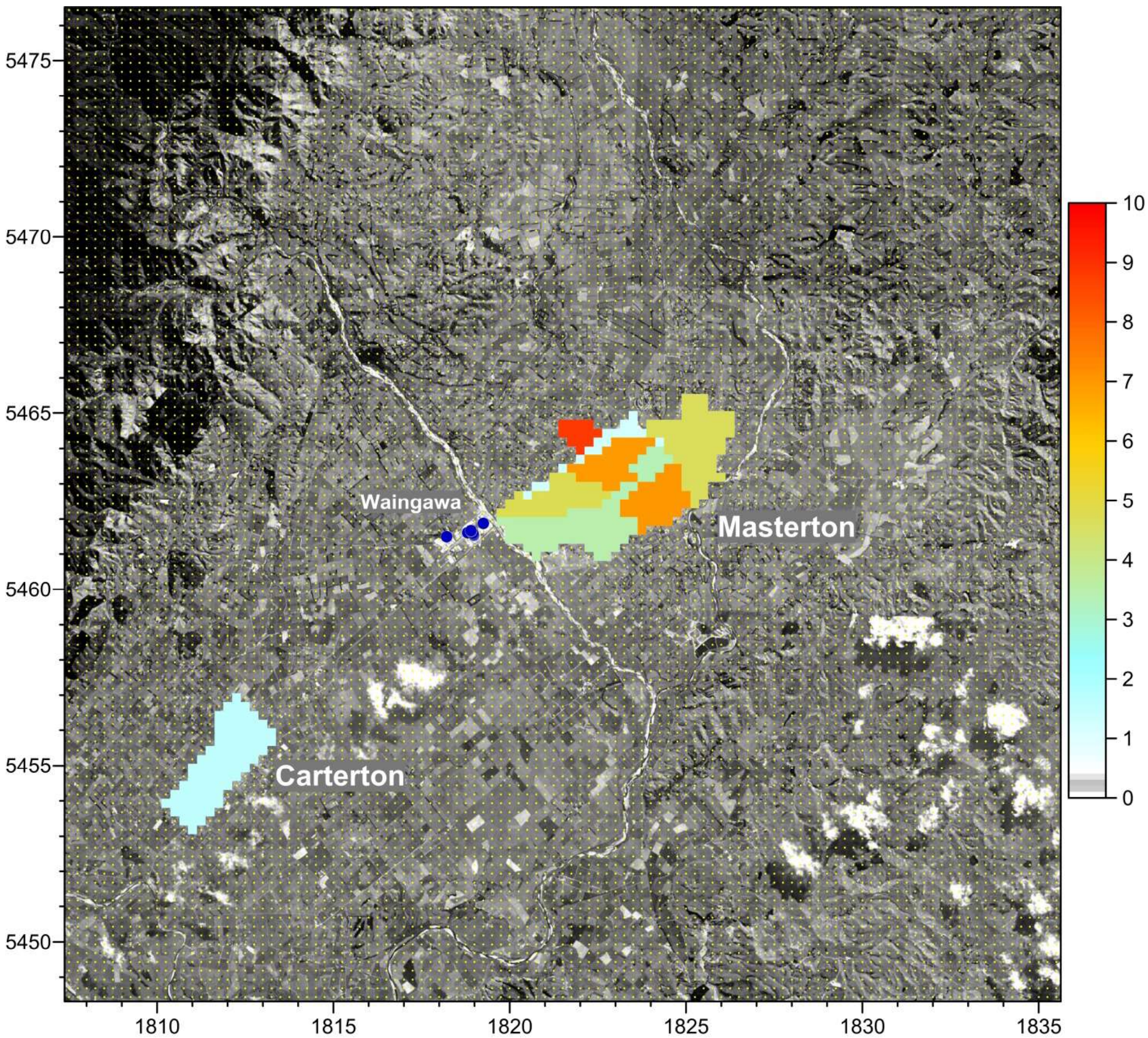


Figure C2: Pollution grid option G2, with small dots showing grid-point locations at 250 m spacing. PM_{10} worst-case emissions from domestic fires shown in kg/day/cell on the same grid of 250 m x 250 m cells.

Table C4: PM_{10} monitoring data used for model evaluation.

Location	Data Availability
Wairarapa College, Masterton	Winter 2009 to winter 2013
Chanel College, Masterton	Winter 2012 to winter 2013
Carterton pool	Winter 2010 and winter 2013

2.9 Model Configuration Options

The above sections mention options available for use in different parts of the airshed modelling exercise. These are a choice of meteorological model set-up (M1 or M2), emissions scenarios (E1, E2, or E3) or pollution grid resolution (G1 or G2). TAPM has been run for several combinations of these options, to serve specific purposes, as outlined in Table C5. The model performance evaluation stage allows decisions to be made on the optimal meteorology and emissions options. It will be shown that the best options are to base the airshed modelling on a meteorological model which has not incorporated wind observations (option M2), and on worst-case PM_{10} emissions from domestic heating in Masterton and Carterton (option E2).

Table C5: TAPM airshed modelling case studies.

Item	Purpose	Options	Description
1	Model performance evaluation	M1/2, E1/2, G1	Evaluate model performance; evaluate options for wind data assimilation and emissions scenarios; carry out on the 500 m pollution grid
2	Refinement of airshed boundaries	M2, E2, G2	Determine extent of NES exceedences on the 250 m pollution grid.

Case studies on the 250 m pollution grid, which would produce more detailed spatial patterns of PM_{10} and a refined airshed boundary (item 2 of Table C5) are presented in the main report. The case studies presented in the main report include dispersion from industrial sites.

Section 3.0 describes the model performance evaluation (item 1 of Table C5).

3.0 RESULTS AND DISCUSSION

3.1 Model Performance Evaluation

3.1.1 Introduction

This section presents an examination of the performance of TAPM for dispersion of PM_{10} from domestic heating sources, by comparison of model results with measurements of PM_{10} at monitoring sites run by GWRC, namely, Wairarapa College, Chanel College and Carterton pool. The section addresses item 1 of Table C5, with the aim of determining the optimal combination of meteorological and emissions scenarios to meet the project objectives (that is, M1 *versus* M2, and E1 *versus* E2).

3.1.2 Model performance at Wairarapa College

Wairarapa College is in Masterton. In Figure C1, its location is marked by the northernmost red dot in the urban area. It is in the Masterton West CAU, which has a relatively high density of PM_{10} emissions according to the 2013 inventory. According to observations of daily PM_{10}, several exceedences of the NES were observed during winter 2012, and one exceedence was observed in 2011. Considering 2011 and 2012 as years of ‘good’ and ‘bad’ air quality, respectively, TAPM results have been compared in this section with observations for these two years.

A basic comparison between model results and observations can be done through use of the ‘quantile-quantile’ (QQ) plots, in which modelled and observed concentrations are ordered before being presented in a scatter plot. This is a commonly used tool in evaluation of air quality models, and can be used to gauge whether the model is generally over- or under-predicting concentrations, and whether the model can simulate the peak observed concentrations. Figure C3 and Figure C4 show QQ plots of modelled PM_{10} against observed PM_{10} at Wairarapa College for the winters of 2011 and 2012 combined. The model results have the baseline concentration of 4 $\mu g/m^3$ added. Figure C3 shows the results using wind data assimilation in the TAPM meteorological model (option M1); Figure C4 shows the results with no wind data assimilation in the TAPM meteorological model (option M2).

The two figures have a similar character, so that these results alone cannot be used to make a decision on whether option M1 or M2 provides better results. However, the meteorological results examined in Appendix B indicate that option M2 (no data assimilation) should be taken (see Sections 4.5 and 5.0 of Appendix B), and the relevant QQ plot to consider when evaluating model performance for the airshed modelling is Figure C4.

The notable feature of Figure C4 is the contrast between results using the typical and worst-case emissions scenarios (options E1 and E2 respectively). Modelled PM_{10} concentrations due to typical emissions underestimate the observed PM_{10} concentrations, by a factor of two. Note that the modelled temporal profile for domestic heating ceases emissions late in the winter evening (10 pm). However, ambient levels of PM_{10} are observed to persist after midnight. The post-midnight observed high concentrations are thought to be due either to persistence of emissions or non-dispersion of PM_{10} after emissions have ceased. The model does not produce PM_{10} emissions after midnight, so it is either failing to retain pollutants over the urban area in calm, stable conditions, or the inventory is neglecting a component of the emissions. We postulate that as the meteorological model is performing reasonably (see Appendix B), the latter is true, and there is a proportion of households in Masterton whose wood burners are allowed to smoulder overnight.

Modelled levels of PM_{10} are closer to reality under the worst-case emissions scenario (option E2). This is because the worst-case scenario assumes wood burners are in operation constantly, and higher modelled PM_{10} levels arise from post-midnight burning. Due to this improved model performance the worst-case emissions scenario (option E2) is considered more appropriate for the further analysis, modelling and decision-making required in this project.

More formal model performance statistics at the Wairarapa College site are presented in Table C6. For definitions of the index of agreement (IOA), and the model-skill scores (E, R and V), see the glossary (Section 6.0) in Appendix B. The table presents results for 2011 and 2012 separately, for combinations of options M1, M2, E1 and E2.

The IOA ranges from zero for no agreement to 1 for complete agreement; a value of 0.5 would be considered poor performance, with values 0.7-0.8 considered good. It can be seen that the IOA shows poor performance for option E1, but good performance for E2. There is very little change between M1 and M2.

Regarding the skill scores, Skill V is ideally 1, and Skill E and Skill R are ideally small (less than 1). Option E2 gives better values of Skill V and Skill R than option E1 (although Skill R values are not good in either case). However, option E1 gives better values of Skill E than E2.

The 2nd-highest modelled concentration compares better with the 2nd-highest observed concentration for E2 than for E1, with less of a difference between M1 and M2. Note that the 2nd-highest concentrations are chosen in preference to the maximum, as the NES are based on the 2nd-highest 24-hour concentration each year.

On balance, option E2 (using worst-case emissions) has better model performance statistics and is therefore considered the more appropriate option to use.

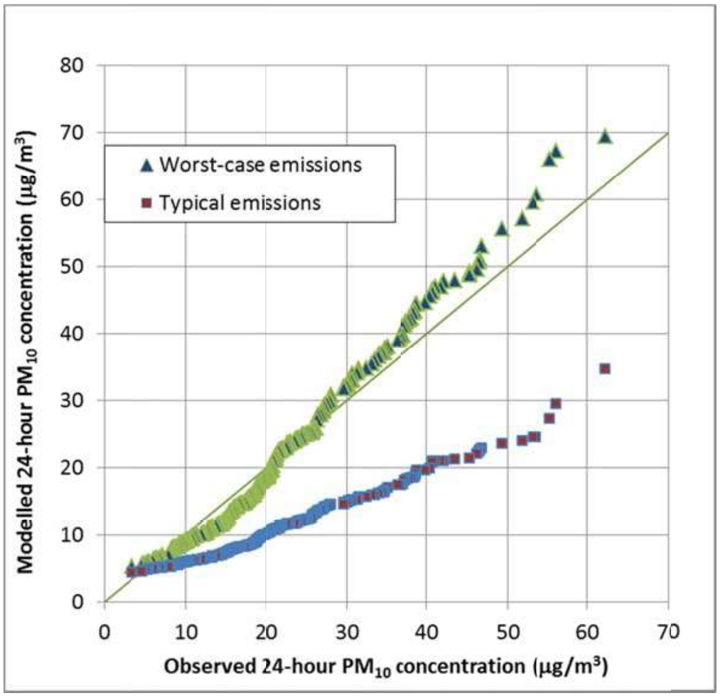


Figure C3: Quantile-quantile plot of modelled against observed 24-hour PM_{10} at Wairarapa College (modelled winters 2011 and 2012 combined). Wind observations assimilated in TAPM (option M1).

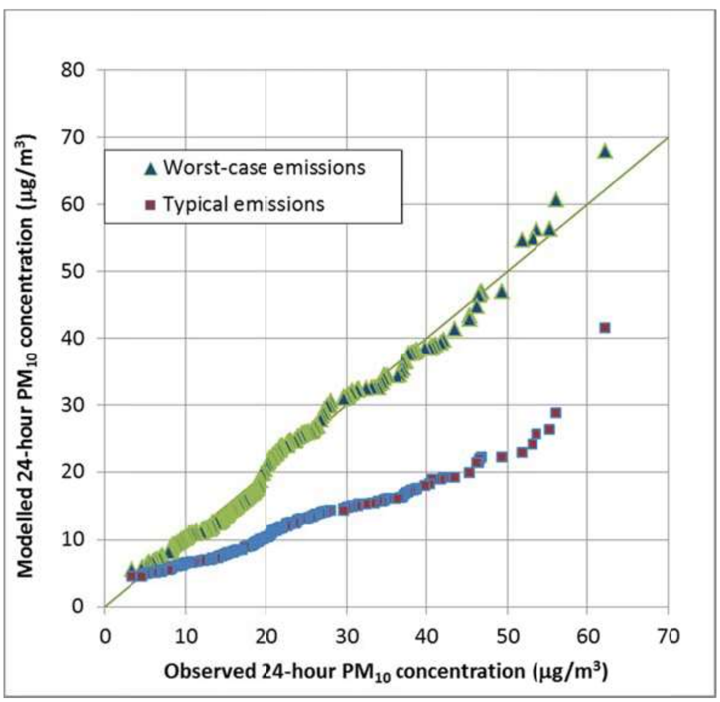


Figure C4: Quantile-quantile plot of modelled against observed 24-hour PM_{10} at Wairarapa College (modelled winters 2011 and 2012 combined). Wind observations not assimilated in TAPM (option M2).

Table C6: Model performance statistics at Wairarapa College. Values coloured green are considered good; values coloured red are considered poor.

Year	Wind obs. nudging	Emissions option	IOA	Skill E	Skill R	Skill V	Obs. 2nd highest	Model 2nd highest
2011	On (option M1)	Typical (option E1)	0.5	0.4	1.4	0.5	46	23
2011	Off (option M2)	Typical (option E1)	0.5	0.4	1.4	0.4	46	22
2012	On (option M1)	Typical (option E1)	0.5	0.4	1.5	0.5	55	29
2012	Off (option M2)	Typical (option E1)	0.5	0.4	1.6	0.4	55	26
2011	On (option M1)	Worst-case (option E2)	0.8	0.9	1.0	1.2	46	51
2011	Off (option M2)	Worst-case (option E2)	0.8	0.9	1.0	1.1	46	55
2012	On (option M1)	Worst-case (option E2)	0.7	1.0	1.1	1.2	55	67
2012	Off (option M2)	Worst-case (option E2)	0.7	0.8	1.1	1.0	55	61

3.1.3 Model performance at Chanel College

Chanel College is also in Masterton. In Figure C1, its location is shown in the urban area by the red dot southeast of Wairarapa College. It is in the Masterton East CAU, which has a relatively high density of PM_{10} emissions according to the 2013 inventory. TAPM results have been compared with observations for 2012, as the site was not commissioned in 2011. In 2012, there were several exceedences of the NES for PM_{10}, and in general, concentrations are more elevated at Chanel College than at Wairarapa College.

Modelled and observed PM_{10} at Chanel College are shown as QQ plots in Figure C5 for the winter of 2012. The model results have the baseline concentration of 6 $\mu g/m^3$ added. The figure shows results with no wind data assimilation in the TAPM meteorological model (option M2). Figure C5 shows a contrast between results using the typical and worst-case emissions scenarios (options E1 and E2 respectively). As at Wairarapa College, option E2 leads to more realistic estimates of 24-hour PM_{10} levels, and produces realistic 2^{nd}-highest PM_{10} levels. However, there is some under-prediction of mid-level concentrations (between 20 $\mu g/m^3$ and 60 $\mu g/m^3$),

Table C7 presents model-performance statistics for 2012 only. Comments on the IOA and skill scores made with regard to results at Wairarapa College also apply here, confirming that the most appropriate model configuration options to take are M2 and E2.

Table C7: Model performance statistics at Chanel College.

Year	Wind obs. nudging	Emissions option	IOA	Skill E	Skill R	Skill V	Obs. 2nd highest	Model 2nd highest
2012	On (option M1)	Typical (option E1)	0.5	0.3	1.6	0.4	78	34
2012	Off (option M2)	Typical (option E1)	0.5	0.3	1.6	0.4	78	34
2012	On (option M1)	Worst-case (option E2)	0.7	0.9	1.2	1.0	78	78
2012	Off (option M2)	Worst-case (option E2)	0.7	0.8	1.1	0.9	78	82

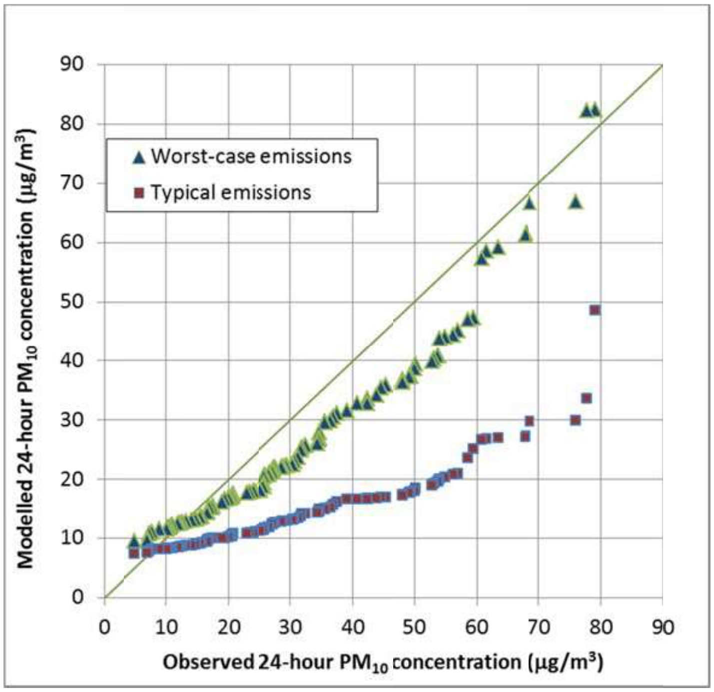


Figure C5: Quantile-quantile plot of modelled against observed 24-hour PM_{10} at Chanel College (modelled winter 2012). Wind observations not assimilated in TAPM (option M2).

3.1.4 Model performance at Carterton pool

Monitoring at Carterton pool was carried out by GWRC during the winters of 2010 and 2013. The site location is marked in Figure C1 in the Carterton urban area, which consists of a single CAU. Figure C6 and Figure C7 show QQ plots of modelled PM_{10} against observed PM_{10} for the winters of 2010 and 2013 separately for worst-case emissions. The model results for domestic heating have a baseline concentration of 5 µg/m^3 added, this being the minimum-observed concentration. The results presented use options M2 and E2. These options lead to under-prediction of observed PM_{10} levels at Carterton pool, by a factor of approximately 1.4 for 2010 and 1.2 for 2013. To demonstrate this, the QQ plots in Figure C6 and Figure C7 also show curves with modelled results scaled up by these factors.

It is unclear why the model should under-predict PM_{10} in Carterton. From discussions with GWRC, possible reasons are as follows:

i) Carterton may have a higher proportion of wood burners than Masterton, despite the same proportion of wood burners to property numbers being used for both towns in the 2013 inventory. The inventory survey was of households in Masterton, and the proportions assumed the same in Carterton;

ii) The number of occupied dwellings in the Carterton CAU increased by 16 %, compared to an increase of 5 % in the eight central CAUs of Masterton (2013 census results)[1]. This may have a bearing on the relative number of wood burners between the two towns, even assuming the same proportion of wood burners to property numbers.

This presents some uncertainty when examining results further and attempting to define an airshed boundary around Carterton, not only because the model generally under-predicts, but because the extent of under-prediction appears to change between years. This matter is returned to in Section 3.2.

[1] http://www.stats.govt.nz/Census/2013-census/data-tables/population-dwelling-tables/wellington.aspx

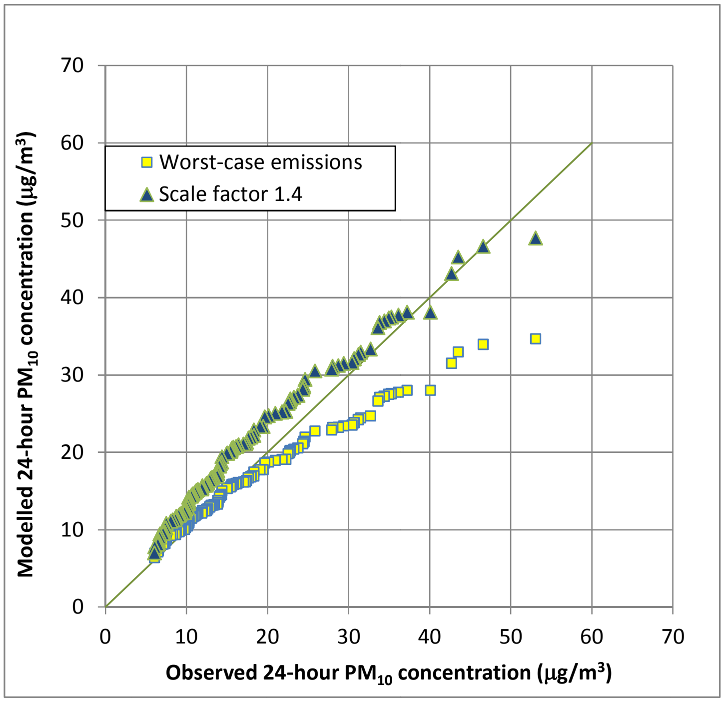


Figure C6: Quantile-quantile plot of modelled against observed 24-hour PM_{10} at Carterton pool (modelled winter 2010). Wind observations not assimilated in TAPM (option M2). Results using worst-case emissions (option E2).

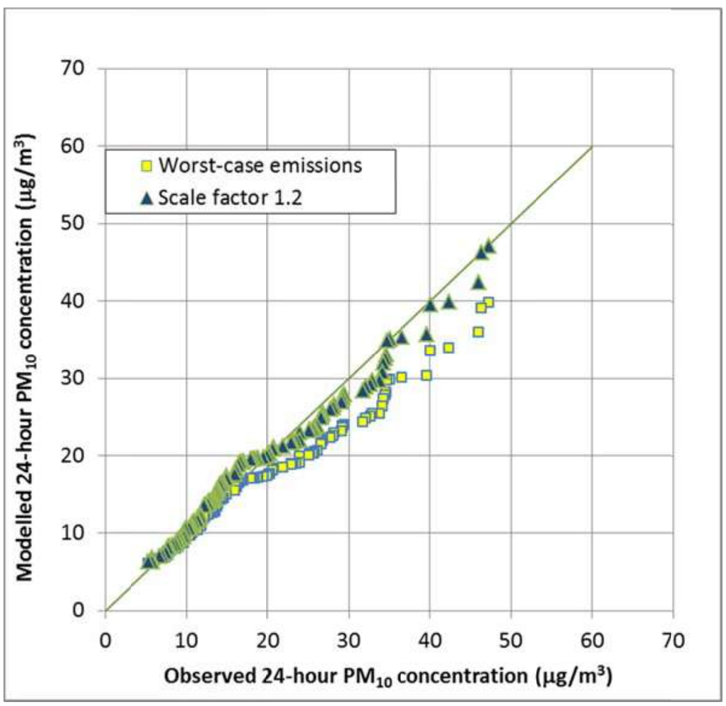


Figure C7: Quantile-quantile plot of modelled against observed 24-hour PM_{10} at Carterton pool (modelled winter 2013). Wind observations not assimilated in TAPM (option M2). Results using worst-case emissions (option E2).

The IOA between modelled and observed PM_{10} at Carterton pool is 0.6 for both 2010 and 2013. These values are less than those for the Masterton sites. The model does not perform as well for Carterton, presumably due to the general under-estimation of concentrations. This means that care should be taken when using model results to define an airshed boundary around this town (see Section 3.2.3).

3.2 Modelled Airshed Boundaries

3.2.1 Introduction

Having determined the optimal model configuration, including emissions scenarios, use of meteorological data, and other model parameter choices, and produced a reasonable comparison with observed air quality, it is now possible to examine modelled spatial patterns of PM_{10}, in particular the boundaries of non-compliant regions. Note that the dispersion model is incomplete at this stage, because it does not include dispersion from industrial sources. Also, the final airshed boundaries will be presented using model results on a 250 m horizontal grid; results discussed in this Appendix are on a 500 m grid.

Nevertheless, it is appropriate to describe the method here used to define airshed boundaries, which can be referred to from the main report. A preliminary example of airshed boundary definitions is provided here; the main report itself contains only the final airshed boundaries.

An airshed may be regarded as compliant with the NES if there is never more than one exceedence of the 24-hour NES for PM_{10}. That is, the 24-hour PM_{10} may exceed 50 µg/m^3 only once per year. The polluted area, which defines the airshed for the purposes of this project, is the area where the concentration could exceed 50 µg/m^3 twice or more. Thus the boundary of the non-compliant area in a particular year is the 50 µg/m^3 contour line of 2nd-highest PM_{10}. The airshed is then defined as the area enclosed by all possible contour lines – which would lie in different locations year to year due to the meteorology varying.

For consistency in the model, the definition is also be based on the 2nd-highest 24-hour PM_{10} in a modelled year. Also, a five-year period has been modelled, to capture the range of expected meteorology, and it is assumed that this includes conditions which would be expected in any year.

Therefore the modelled airshed boundary may be determined as follows:

i) Calculate the spatial distribution of the 2nd-highest PM_{10} concentration for each of the five modelled years over the model grid area;

ii) At each model grid point, find the largest of the five calculated 2nd-highest PM_{10} concentrations in step (i);

iii) Produce a spatial plot of the largest concentrations calculated in step (ii). The plot shows the largest likely 2nd-highest PM_{10} concentration in any year, and the 50 µg/m^3 contour of this quantity then defines the modelled airshed boundary.

3.2.2 Airshed Boundary for Masterton

Figure C8 illustrates the airshed boundary for Masterton calculated following this method. Note that this shows results for PM_{10} from domestic heating only, and does not include emissions from industry or other sources. The final boundary is defined by the outer extent of the 50 µg/m^3 contours of the 2nd highest 24-hour PM_{10} concentration for each year. The outer boundary is coloured white, with the individual years shown in other colours. It can be seen that the western and northeastern extents of the airshed are defined by worst-case air quality in 2013. The eastern extent matches the 2012 boundary. Note that airshed extends out of the urban area to the east and south, and does not lie over the urban area in the north and west. This is a meteorological effect, due to a down-valley drift of air from the north during winter nights, and is consistent with Chanel College having higher concentrations than Wairarapa College.

All points along the airshed boundary as defined above should be touched by a boundary defined for one or more of the individual years, as the maximum concentration over five years is equal to one of the individual maximum concentrations.

Airshed boundaries appear in Figure C8 for years in which exceedences were not observed to occur at Wairarapa College, namely, 2009 and 2011. In 2011, the second-highest modelled PM_{10} concentration at Wairarapa College was greater than 50 µg/m^3, whereas the observed second-highest was less, at 46 µg/m^3. The third-highest modelled concentration at Wairarapa College was 45 µg/m^3. If the third-highest is a better estimator of the true peak, then at Chanel College this would be 53 µg/m^3. Despite the conservative nature of the model results in 2011, they indicate that although the NES was not breached at the Wairarapa College site, it may have been breached at Chanel College. This is indicated by the shape of the green boundary for 2011 in Figure C8, whose northern part is indented southwards. The variability in model performance from year to year (which includes under-prediction of peak PM_{10} levels in 2010) shows the importance of carrying out multi-year model simulations and validating the model. For the purpose of airshed boundary determination, the worst-case air quality conditions need to be found, and shown to be realistically-modelled.

Figure C8: Masterton airshed boundary. 50 µg/m^3 contours of 2nd-highest 24-hour PM_{10} due to domestic heating for each modelled winter (2009 orange; 2010 blue; 2011 green; 2012 yellow; 2013 purple; maximum over five years white outline with yellow shading).

3.2.3 Airshed Boundary for Carterton

Following the same method to define an airshed boundary for Carterton, there are no modelled 24-hour average PM_{10} concentrations above 50 µg/m^3. Neither are there observations from Carterton pool above this level. Applying a conservative emissions scaling factor of 1.4 leads to small areas of non-compliance in the northeast and southwest of the town, but not at the monitoring site. As the monitoring does not demonstrate non-compliance, and there is very little indication from the modelling that there is non-compliance in other areas of Carterton or in years where no monitoring took place, the Carterton urban area has not been shown to be a polluted airshed. Therefore an airshed boundary cannot be determined according to the definition used in this work. This conclusion is unchanged when the 250 m pollution grid is used (as discussed in the main report).

4.0 SUMMARY OF FINDINGS

The findings of the airshed modelling carried out in and presented in this Appendix may be summarized in the following:

1) The 'worst-case' emissions scenario from the inventory leads to the best simulation of observed PM_{10} levels, as it includes overnight emissions. (The 'typical' inventory emissions scenario leads to under-prediction of PM_{10} after midnight and 24-hour-average PM_{10} levels around half of those observed).

2) Assimilation of wind data into the meteorological model does not substantially change the dispersion model results, but can lead to unrealistic meteorological results (as discussed in Appendix B). Therefore it is not used in the final runs.

3) Model performance can vary depending on meteorological year. Results were found to be conservative for 2009 and 2011, with under estimates of observed higher PM_{10} concentrations in 2010. The use of a multi-year run period is needed to ensure the worse-case year is modelled reasonably, which incorporates a comparison with monitored PM_{10} levels.

4) The model captures the difference in air quality at the two monitoring sites in Masterton, due to a wind drift across the town, predominantly from north to south.

5) There is significant under-prediction of air quality impacts in Carterton. However, even accounting for this, the model does not indicate non-compliance of Carterton with the NES. This is consistent with observations made so far at Carterton pool.

6) Masterton's boundary of non-compliance of with the NES does not coincide with the limits of the urban area. It extends to the southwest, south, southeast and east, but neither north nor due west.

5.0 CONCLUSION

This Appendix reports on Task 3 of the Wairarapa Airshed Study, urban airshed modelling of the dispersion of air emissions from domestic fires in Masterton and Carterton. Examination and evaluation of model results has been based on a horizontal grid of spacing 500 m, along with discussion of some issues of interest related to Masterton's air quality. The final determination of airshed boundaries is based on airshed modelling on a 250 m grid, combined with the results from industrial point-source modelling under Tasks 4 and 5 (see Appendices E, F and G), and is reported in the main body of the report.

6.0 REFERENCES

Ancelet T, Davy PK, Mitchell T, Trompetter WJ, Markwitz A & Weatherburn DC 2012. Identification of particulate matter sources on an hourly time-scale in a wood burning community. Environmental science & technology. 46 (9): 4767–74. Accessed <http://www.ncbi.nlm.nih.gov/pubmed/22468798>

Gimson N 2006. Masterton Straight-Line Path development. NIWA, NIWA Client Report WLG2006-49, prepared for Greater Wellington Regional Council. p. 19.

Gimson NR 2006. Airshed Modelling of PM10 levels in the Hawke's Bay region. NIWA Client Report WLG2006-48 prepared for the Hawke's Bay Regional Council, September 2006.

Gimson NR 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.

Golder 2012. Airshed Modelling of Exposure to Particulates in the Hawke's Bay Region. Report prepared by Golder Associates (NZ) Limited for the Hawke's Bay Regional Council, June 2012.

Golder 2009. Contributions to PM10 levels in Napier and Hastings from surrounding urban and rural areas - airshed modelling re-analysis. Report prepared by Golder Associated (NZ) Limited for the Hawke's Bay Regional Council, April 2009.

Golder 2011. Population exposure to particulates in Auckland - urban airshed modelling. Report prepared by Golder Associated (NZ) Limited for the Auckland Council, March 2011.

Golder 2013. Wairarapa Air Quality Modelling - Determination of airshed boundaries in the Wairarapa Valley. Proposal no. 1378104103_001_P_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. April 2013. p. 24.

Hurley P 2006. An evaluation and inter-comparison of AUSPLUME, AERMOD and TAPM for seven field datasets of point source dispersion. Clean Air and Environmental Quality. 40 (1): 45–50.

Hurley P 2008. TAPM V4. Part 1: Technical description. CSIRO Marine and Atmospheric Research Paper No. 25, October 2008. p. 59 pages.

Hurley P 1999. The Air Pollution Model (TAPM) Version 1: Technical description and examples. CSIRO, Melbourne.

Hurley P, Edwards M & Luhar A 2008. TAPM V4. Part 2: Summary of some verification studies. CSIRO Marine and Atmospheric Research Paper No. 26, October 2008. p. 31 pages.

Hurley P, Hill J & Blockley A 2005. An evaluation and inter-comparison AUSPLUME, CALPUFF and TAPM - Part 2: Anglesea and Kwinana annual datasets. Clean Air and Environmental Quality. 39 (1): 46–51.

Hurley P & Luhar AK 2005. An evaluation and inter-comparison AUSPLUME, CALPUFF and TAPM - Part 1: the Kincaid and Indianapolis field datasets. Clean Air and Environmental Quality. 39 (1): 39–45.

Hurley P, Manins PJ, Lee S, Boyle R, Ng YL & Dewundege P 2003. Year-long high-resolution, urban airshed modelling: verification of TAPM predictions of smog and particles in Melbourne, Australia. Atmospheric Environment. 37 (14): 1899–1910.

Hurley P, Physick W & Luhar A 2005. TAPM - A practical approach to prognostic meteorological and air pollution modelling. Environmental Modelling & Software. 20737–752.

Luhar AK & Hurley PJ 2003. Evaluation of TAPM, a prognostic meteorological and air pollution model, using urban and rural point-source data. Atmospheric Environment. 37 (20): 2795–2810.

Mitchell T 2010. Annual air quality monitoring report for the Wellington region, 2009. Greater Wellington Regional Council, Publication No. GW/EMI-G-10/160, Wellington. p. 34.

Mitchell T 2012a. Annual air quality monitoring report for the Wellington region, 2010. Greater Wellington Regional Council, Publication No. GW/EMI-G-12/15, Wellington. p. 29.

Mitchell T 2012b. Annual air quality monitoring report for the Wellington region, 2011. Greater Wellington Regional Counci, Publication No. GW/EMI-G-12/151, Wellington. p. 31.

Mitchell T 2012. Masterton particulate monitoring methods and inter-site comparison, winter 2012. Greater Wellington Regional Council Publication. p. 30.

Sridhar S & Wickham L 2013. Masterton & Carterton Domestic Fire Emissions Inventory 2013. Report prepared by Emission Impossible Ltd for Greater Wellington Regional Council, 30 August 2013. p. 60.

Tate A, Cullen N & Spronken-Smith R 2011. Wintertime PM10 measurements and modelling in Alexandra, Central Otago, New Zealand: Understanding the bi-modal peak in evening air pollution. Air Quality and Climate Change. 45 (3): 19–25.

Wilton E, Smith J, Gimson N & Phillips J 2009. Source Apportionment and Modelling of PM10 in Hastings, New Zealand. Air Quality and Climate Change. 43 (2): 31–39.

Xie S, Gimson N & Clarkson T 2006. Modelling wintertime PM10 dispersion in Masterton, New Zealand: a tool for implementing national standards. Air Pollution XIV - WIT Transactions on Ecology and the Environment, Vol 86. WIT Press, New Forest, UK. pp. 65–74.

Zawar-Reza P, Kingham S & Pearce J 2005. Evaluation of a year-long dispersion modelling of PM10 using the mesoscale model TAPM for Christchurch, New Zealand. Science of the Total Environment. 349 (1-3): 249–259.

APPENDIX D

TAPM Dispersion Model Configuration

TAPM version 4.0 was run for the winter months – May, June, July and August – of five years, from 2009 to 2013 inclusive. A list of configuration parameters used in the TAPM runs is given in the following tables. The small number of tables reflects the small number of parameters which need to be chosen by the TAPM user. Other parameters are left at default values, following the developers' recommendations.

Table D1: TAPM meteorological model parameters (based on Table B2 of Appendix B).

Parameter	Value
Start and end dates	1 September 2008 to 31 August 2013
Airshed model run dates	Monthly runs: May, June, July, August; 2009, 2010, 2011, 2012, 2013
Grid centre (Latitude/Longitude, WGS84)	40° 59.5' S 175° 35.5' E
Grid centre (NZTM)	(1818001, 5458933) (m)
No. of grids; no. of grid cells in horizontal	4; 40 x 40
Horizontal grid-cell spacing (one value per grid)	27 km, 9 km, 3 km, 1 km
Grid size east to west (equals distance north to south)	1080 km, 360 km, 120 km, 40 km
No. of levels in the vertical; level heights	25; heights 10 m, 25 m, 50 m, 100 m, 150 m, 200 m, 250 m, 300 m, 400 m, 500 m, 600 m, 750 m, 1000 m, 1250 m, 1500 m, 1750 m, 2000 m, 2500 m, 3000 m, 3500 m, 4000 m, 5000 m, 6000 m, 7000 m, 8000 m
Wind data assimilation	Yes (option M1); No (option M2) – both options have been run

Table D2: Pollution-dispersion grids. Parentheses contain the eastward, then northward, components of the parameter.

Parameter	Value(s) (option G1)	Value(s) (option G2)
Number of grid cells	(79, 79)	(113, 113)
Grid resolution	500 m	250 m
SW cell-centre coordinates (m, NZTM)	(1798501, 5439433)	(1807501, 5448433)
NE cell-centre coordinates (m, NZTM)	(1837501, 5478433)	(1835501, 5476433)
Range on meteorological grid	(1, 1) to (40, 40) (the whole grid)	(10, 10) to (38, 38) (a sub-area)

Table D3: Modelled emissions scenarios.

Label	Name	Description
E1	Typical	Weekday and Weekend emissions as shown in Appendix C, Table C2. Weekdays 78% of burners running 7:00-10:00 and 17:00-21:00; 22 % running for 24 hours. Weekends 69% of burners running 8:00-12:00 and 16:00-22:00; 31 % running for 24 hours. Step changes in emissions assuming all burners are lit and shut down at the same time, rather than a gradual change through the day.
E2	Worst case	Worst case emissions as shown in Appendix C, Table C2. Emissions constant for 24 hours.
E3	Smouldering	Unit emissions for Masterton and Carterton. Emissions for six hours overnight, starting when the emissions of scenario E1 finish. Magnitude to be determined as a post-processing step.

APPENDIX E

CALMET Meteorological Modelling

1.0 INTRODUCTION

The modelling of exposure to airborne pollutants requires a detailed meteorological data set that accounts for spatial variation in wind speed, direction and other atmospheric parameters on an hourly basis and as a function of height above ground level. Hourly, three-dimensional meteorological data sets, when used as inputs to sophisticated dispersion models, allow higher-quality, scientifically defensible predictions of air pollution dispersion.

For the Wairarapa Airshed Study, the most appropriate models have been chosen for the dispersion of PM_{10} from domestic heating emissions in Masterton and Carterton, and from industrial emissions in the Waingawa area. These are the airshed model component of The Air Pollution Model (TAPM) for domestic heating and CALPUFF for industry, and each dispersion model has a meteorological counterpart. These are the meteorological component of TAPM, and the CALMET pre-processor, respectively. For background information on TAPM, see Hurley, Physick & Luhar (2005), Hurley (2000) and Hurley et al. (2003). For information on CALMET, see Scire et al. (1999) and TRC (2011).

One of the challenges of this work is to ensure that the two meteorological models provide bases for dispersion modelling that are consistent with each other, to provide compatible dispersion model results for different source types, and enable cumulative effects of the different sources to be combined hour by hour if required. This is accomplished by basing CALMET's meteorology on TAPM's, with minimal change to the wind fields. Also – for consistency – observed meteorological data were not assimilated into either of the meteorological models.

The TAPM meteorological modelling was carried out under Task 2 of the Wairarapa Airshed Study. Results have been presented as a self-contained report, and included in this work as Appendix B. TAPM was used to simulate weather patterns and their modification by the coasts and terrain of New Zealand, from synoptic scales (~1000 km) down to the mesoscale (~1 km). Dispersion modelling of domestic heating emissions using the airshed model component of TAPM is described in Appendices C and D.

TAPM provides inputs to CALMET, which down-scales the meteorological information further, to provide slightly more detailed terrain- and land-use-driven three-dimensional wind patterns in the Wairarapa Valley. This information is used to drive CALPUFF, which simulates dispersion from industrial sources in the Waingawa area (described in Appendix F).

The procedure for creating meteorological data sets is outlined as follows:

1) Create 5-year-long three-dimensional meteorological data sets for the Wairarapa Valley at 1 km horizontal resolution using TAPM (see Appendix B).

2) Convert TAPM results into a suitable format for input to CALMET, using the CALTAPM routine (see Section 2.1.2).

3) Create two-dimensional gridded data sets of terrain and land-use at 500 m resolution for use by CALMET (see Section 2.1.3).

4) Configure CALMET subject to the following requirements:

    a. TAPM outputs are incorporated into CALMET at the 'initial-guess' stage, to allow an increase in resolution and accompanying terrain-flow adjustments by CALMET (see Section 2.1.4).

    b. CALMET is run in 'no-observations' mode, in which no climate-station data are incorporated (see Section 2.1.4).

    c. Testing is carried out for selection of the terrain-adjustment parameter *terrad*. Note that when running CALMET in no-observations mode, *terrad* is the only run-specific parameter which needs to be selected, and does not have a default value (see Section 2.1.6).

d. The 5-year run period coincides with the TAPM run, and CALMET at 500 m resolution covers the same area as TAPM at 1 km resolution. Model parameters are listed in Section 2.1.7.

5) Run CALMET, configured as above.

In the remainder of this Appendix, Section 2.0 describes in more detail the process outlined above. Section 3.0 provides a list of references.

2.0 CONFIGURATION AND TESTING OF CALMET

2.1.1 Introduction

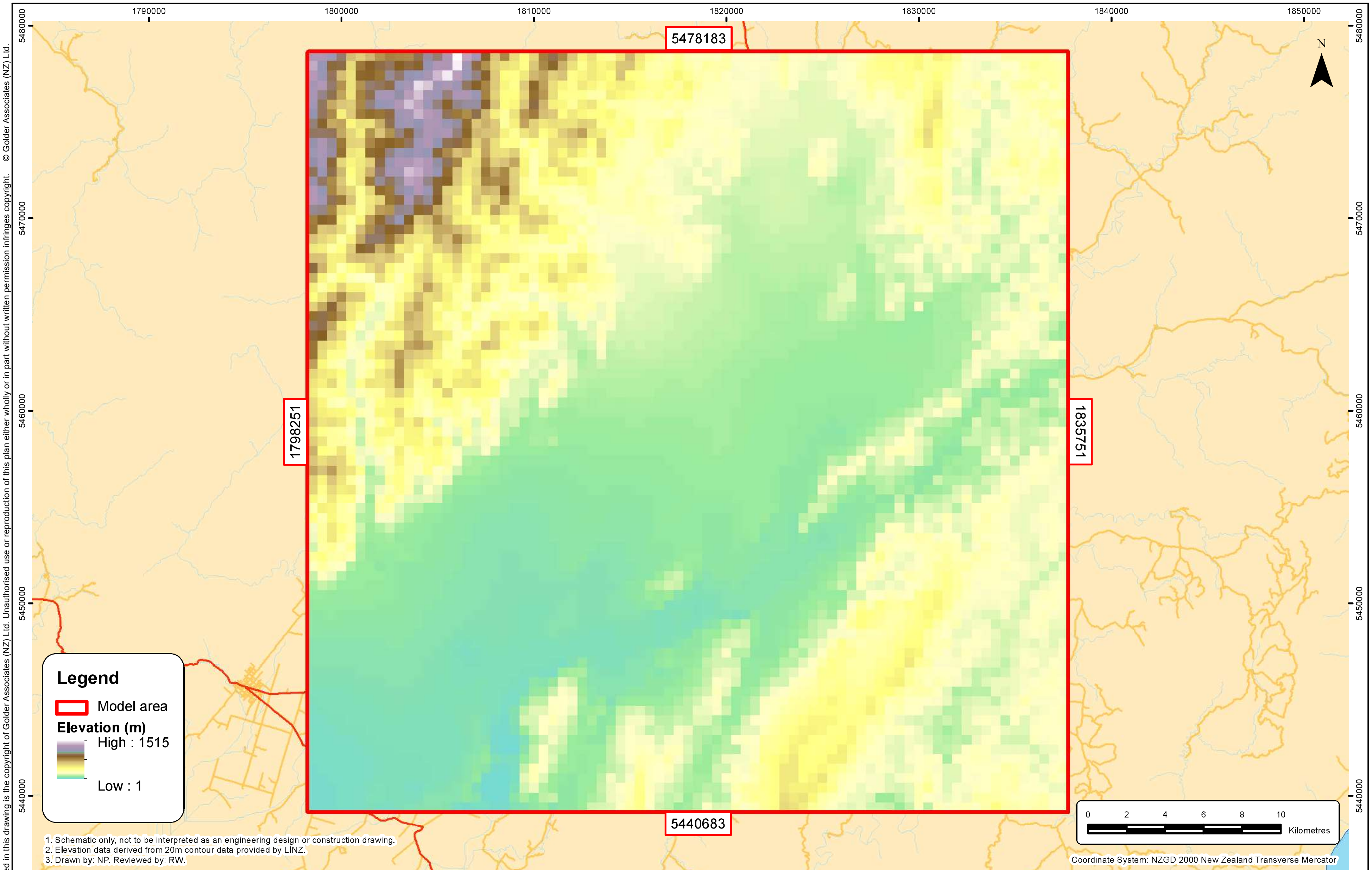
CALMET version 6.334 has been used to provide hourly, three-dimensional meteorological fields for input to the CALPUFF dispersion model. The 5-year CALMET run period coincides with the TAPM run, and the CALMET model at 500 m resolution covers the same area as TAPM at 1 km resolution. The spatial resolution of CALMET is higher than that of TAPM, with the TAPM fields interpolated onto the CALMET grid at the initial-guess stage of each hour of the run. The wind fields were then adjusted according to the higher-resolution terrain and land use to produce final CALMET fields for each hour. No meteorological observations were input to CALMET. However, meteorological data from sites near Masterton were used in the evaluation of TAPM to ensure its results are realistic. The TAPM results propagate into CALMET and, in much of the Valley, are unchanged by CALMET.

2.1.2 Creation of three-dimensional prognostic-model input files for CALMET

The CALMET meteorological model allows for the assimilation of outputs from a variety of prognostic weather prediction models. In this work, modelled hourly, three-dimensional fields of wind, temperature, and relative humidity from TAPM were used in the CALMET run. TAPM solves the equations of atmospheric motion mathematically to give physically-realistic meteorological fields. Numerical outputs from TAPM were converted to CALMET-ready inputs using the CALTAPM utility. CALTAPM converts TAPM's output into the more general '3d.dat' input files for CALMET, as can be done with outputs from several other weather-prediction models. This process provided data for the period 1 September 2008 to 1 September 2013 based on the finest TAPM grid (horizontal resolution 1 km x 1 km).

2.1.3 Geographical data

CALMET has been run at a horizontal grid resolution of 500 m over area of the finest TAPM grid. This higher resolution enables additional terrain-driven wind flows, such as slope and valley flows, to be simulated in CALMET. It requires terrain and land-use data to be provided for the new resolution of CALMET. The terrain and land-use were generated in-house, based on Land Information New Zealand (LINZ) data sets. The area covered is 37.5 km from east to west and 37.5 km from north to south, with the southwest corner of the domain at coordinates (1798.251, 5440.683) (km, NZTM). The terrain data used by CALMET is shown in Figure E1, and land-cover classifications are shown in Figure E2.



1. Schematic only, not to be interpreted as an engineering design or construction drawing.
2. Elevation data derived from 20m contour data provided by LINZ.
3. Drawn by: NP. Reviewed by: RW.

Golder Associates

TITLE CALMET TERRAIN ELEVATION

MARCH 2014

PROJECT 1378104103

E1

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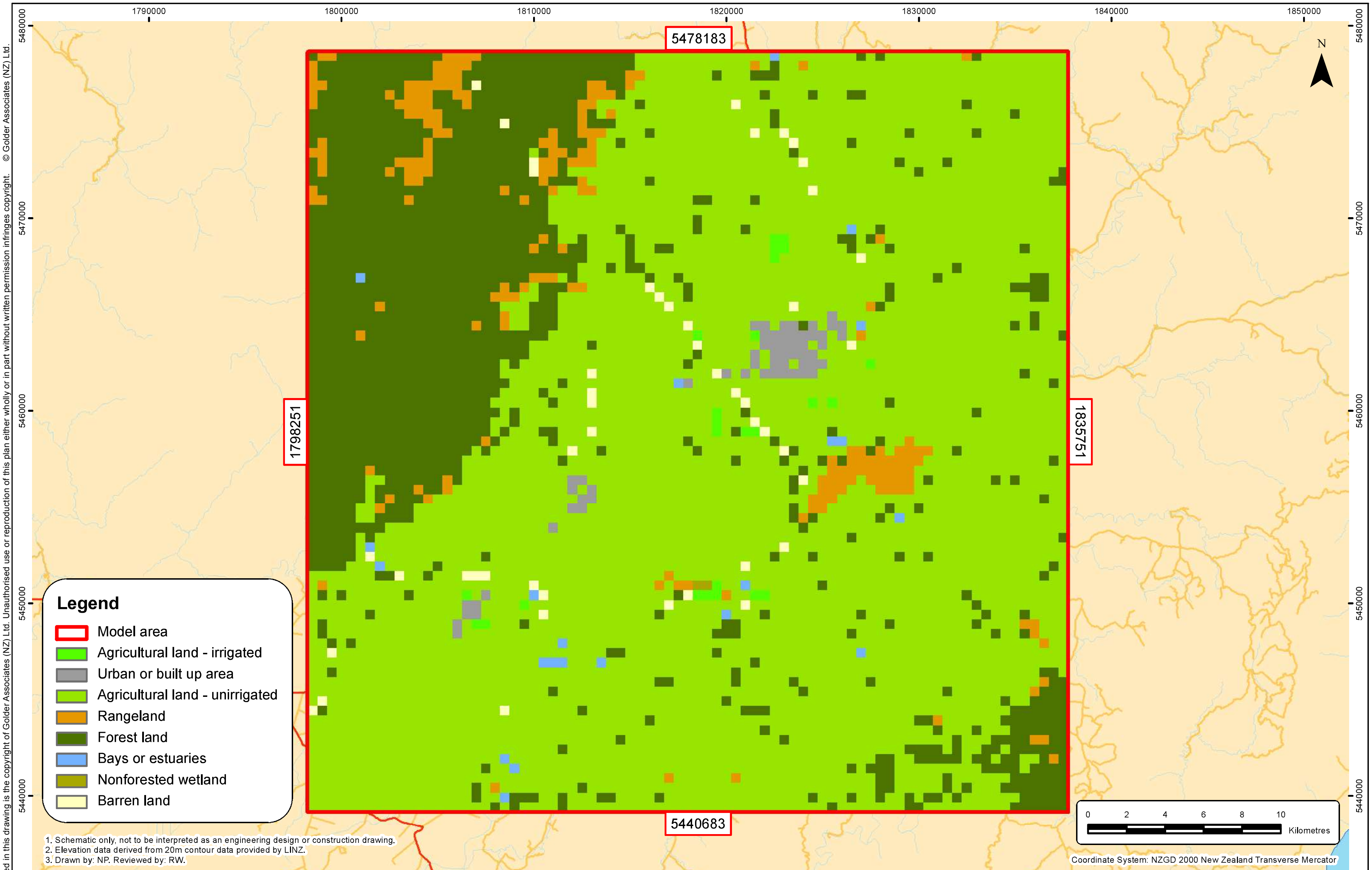

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3. Drawn by: NP. Reviewed by: RW.

Golder Associates

TITLE CALMET LAND COVER

MARCH 2014

PROJECT 1378104103

E2

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2.1.4 Incorporation of TAPM data as the 'initial guess' in CALMET

There are three main stages in the production of each hourly CALMET meteorological field. These are (i) the 'initial guess' of the three-dimensional field, based on extrapolated surface and upper-air data, or on prognostic-model outputs, (ii) the Step 1 field, in which terrain-adjustment processes such as slope flows and blocking are incorporated, and (iii) the Step 2 field, where meteorological observations are incorporated into the model solution at locations around the monitoring sites. Prognostic model outputs can be incorporated into CALMET at any of the three stages. However, it is recommended by CALMET's developers that the prognostic model data is only incorporated at the initial-guess stage. This is the only option which permits a further increase in resolution and to account for better resolved terrain flows in CALMET.

2.1.5 'No-observations' mode

CALMET has three options for the blending of prognostic model outputs with surface and upper-air meteorological data. These are (i) a fully observational mode where CALMET's meteorology is determined by interpolated surface and upper-air measurements (ii) a 'no-observations' mode where CALMET's meteorology is determined by prognostic-model information, and (iii) a hybrid mode where observations are used at the surface and prognostic-model information for the atmosphere above.

Despite there being surface-based, but no upper-air observations available in the Wairarapa, the no-observations mode is used here, and CALMET's meteorology is based entirely on TAPM's. TAPM can also assimilate wind data hour by hour. Testing was carried out with TAPM to determine whether the wind data *should* be assimilated, and it was concluded that the solution was, on the whole, better without wind data assimilation (Appendix B for details). Although data assimilation can improve the modelling of low wind speeds on winter nights, discontinuities in wind fields can occur, leading to unrealistic spatial patterns (resembling bulls-eyes).

For consistency with TAPM, and to avoid bulls-eye-like wind patterns in its own outputs, CALMET has been run in no-observations mode, and the resulting meteorology from CALMET is based on that of TAPM (with some terrain adjustments to the flow due to increased terrain resolution).

2.1.6 Terrain influence on wind flows

When running CALMET in no-observations mode, most input parameters are able to take default values. The exception is the terrain radius of influence *terrad*. CALMET generates slope and valley flows which are dependent on neighbouring terrain peaks – their height and slope. The parameter *terrad* defines the distance over which local terrain peaks have an influence on the flow. Or, from the perspective of each model grid point, the maximum terrain height within a radius *terrad* is used to determine the slope flow at that grid point. If *terrad* increases, a wider area is searched for the peak, and larger modelled impacts on the flow can occur. It is recommended by the developers of CALMET that for valleys in complex terrain, *terrad* is at least half the distance between neighbouring peaks, so that the influence on the flow of the slope down from (or up to) those peaks can be modelled. However, it is noted that this rule should not apply to wide valleys (such as the Wairarapa Valley), as the resulting flow would be unrealistic and the larger-scale flow should be captured in the prognostic model, TAPM.

The parameter *terrad* should be large enough to produce realistic impacts of complex, detailed terrain (which a prognostic model may miss), but small enough so as not to produce unrealistic flow distortions when the terrain is relatively flat. Anticipating that in the hills alongside the Wairarapa Valley, *terrad* should have a value of a small number of kilometres, several values of *terrad* have been tested for short run periods. These were 2 km, 5 km, 10 km and 20 km. Terrain-driven flows are most easily identified during night-time stable conditions, when the flow in the absence of terrain would be calm. Thus it is appropriate to examine CALMET results from such times. Figure E3 and Figure E4 show CALMET wind fields from two night-time hours in the winter of 2012. Each panel shows results using a different terrain radius of influence. Panels (c) and (d) of each figure show flow effects extending into the valley, even where the terrain is relatively flat, indicating that a value of 10 km is too large. On the other hand, panel (a) shows drainage flows in the hills to the northwest of the valley when *terrad* is 2 km (which are unchanged at higher *terrad* values). Therefore, a value of 2 km is sufficient to model enhanced effects in the complex terrain (which would not be seen by TAPM at its coarser resolution).

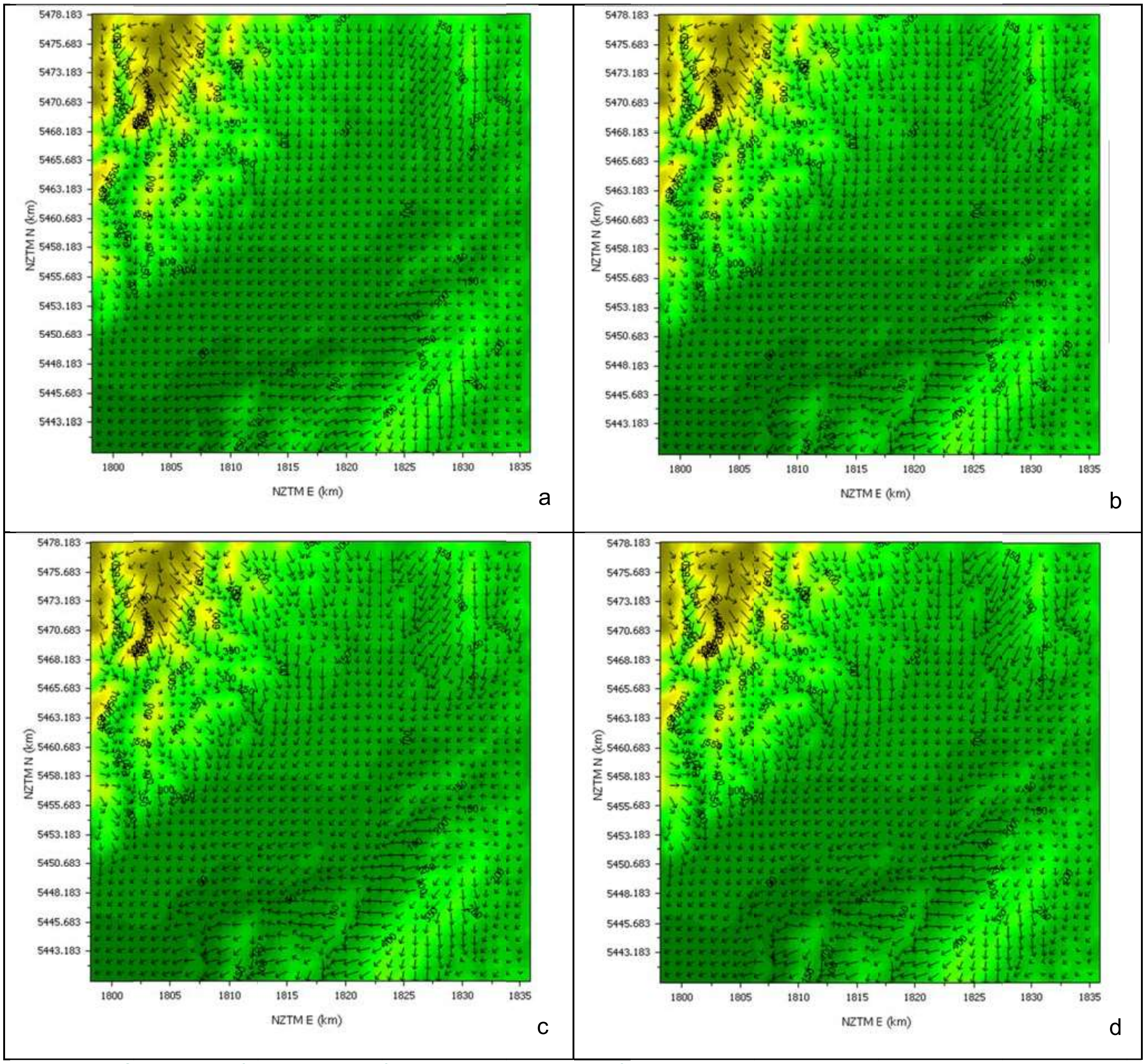

Figure E3: CALMET surface-level wind for 0700 on 28 July 2012 for TERRAD a) 2 km, b) 5 km c) 10 km d) 20 km. Shading indicates terrain height.

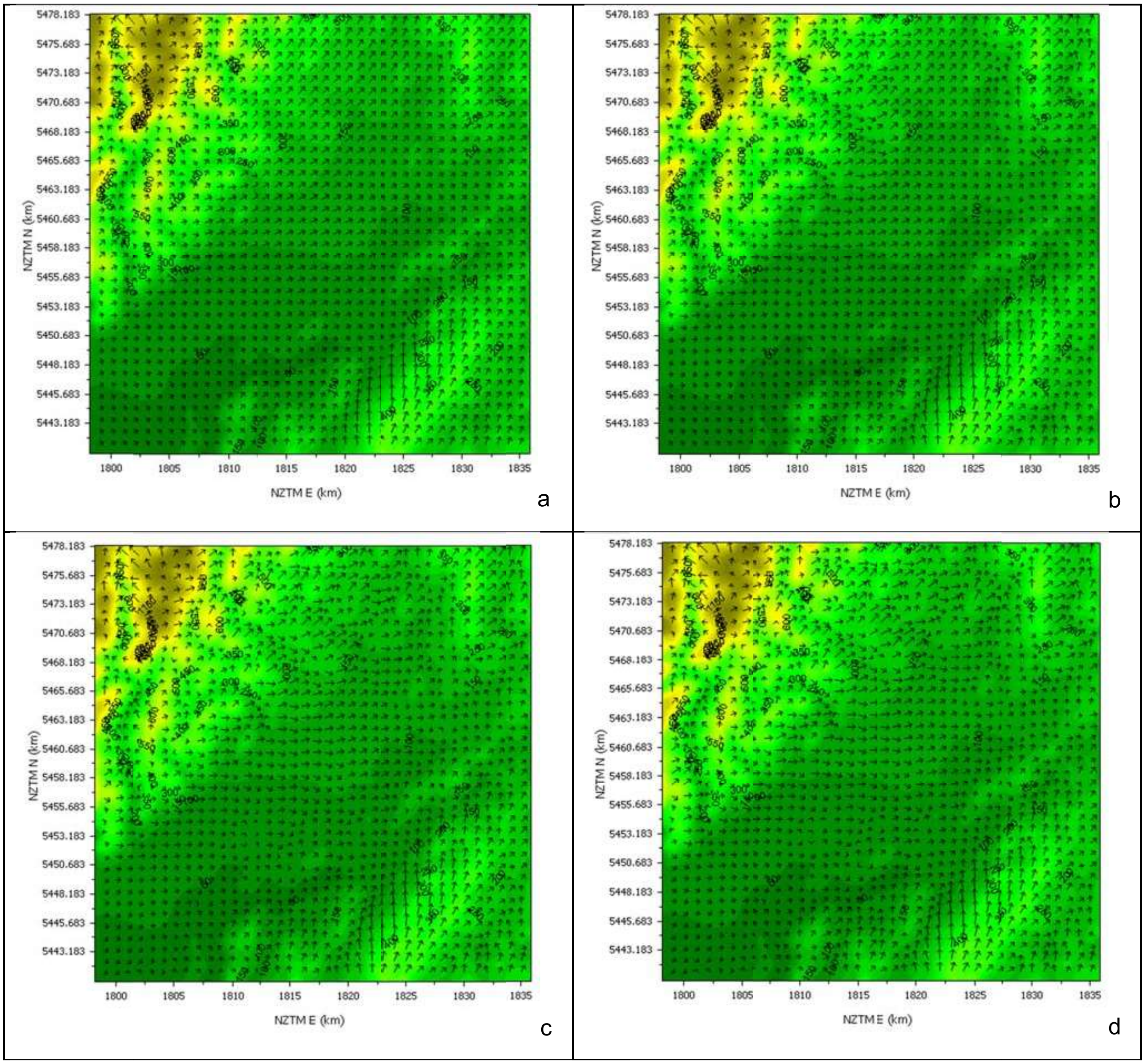

Figure E4: CALMET surface-level wind for 0000 on 22 August 2012 for TERRAD a) 2 km, b) 5 km c) 10 km d) 20 km.

2.1.7 Other CALMET parameters

The following tables provide details of user-specified parameters used for generating the three-dimensional meteorological datasets with CALMET. Parameters not mentioned take default values, or they relate to a particular feature of the model that is not used.

Table E1: Run Control.

Parameter	Value
Starting date/time	1 September 2008 00:00:00
Finish date/time	1 September 2013 00:00:00
Time zone	UTC+1200
Time step	3600 s
Number of runs	30 – two months each

Table E2: Map projection.

Parameter	Value
Map projection	Tangential Transverse Mercator (TTM)
Datum region	WGS-84
Projection origin	41 S, 175.6 E
False origin (*NZTM coordinates*)	(1818.000, 5459.000) km

Table E3: Grid control.

Parameter	Value
SW corner of grid cell (1,1)	(1798.251, 5440.683) km (NZTM)
Grid dimensions	75 x 75 grid cells at spacing 0.5 km
Vertical grid, number of layers	12
Cell-face heights for vertical grid (m)	0, 20, 45, 80, 130, 195, 275, 385, 540, 740, 1000, 1700, 3000

Table E4: Prognostic model options.

Parameter	Value
Use of TAPM for surface or upper-air information	NOOBS = 2; No surface of upper air observation. Use TAPM for surface and upper-air
Use of TAPM for wind information	IPROG = 14; use TAPM as initial-guess wind field
Use of TAPM for temperature information	ITPROG = 2; No surface of upper air observation. Use TAPM for surface and upper-air.
Use of TAPM for relative humidity information	IRHPROG = 1; use prognostic RH
Use of TAPM for cloud information	ICLOUD = 4; Gridded cloud cover from prognostic relative humidity at all levels.
Use of TAPM for precipitation information	NPSTA = 0; precipitation included in the surface file

Table E5: Wind field options.

Parameter	Value
Radius of influence of terrain features	TERRAD = 2 km

3.0 REFERENCES

Hurley P 2000. Verification of TAPM meteorological predictions in the Melbourne region for a winter and summer month. Australian Meteorological Magazine. 49 (2): 97–107.

Hurley P, Manins PJ, Lee S, Boyle R, Ng YL, Dewundege P 2003. Year-long high-resolution, urban airshed modelling: verification of TAPM predictions of smog and particles in Melbourne, Australia. Atmospheric Environment. 37 (14): 1899–1910.

Hurley P, Physick W, Luhar A 2005. TAPM - A practical approach to prognostic meteorological and air pollution modelling. Environmental Modelling & Software. 20737–752.

Scire J, Robe F, Fernau M, Yamartino R 1999. A User's Guide for the CALMET Meteorological Model (Version 5.0). Earth Tech, Concord, Massachusetts.

TRC 2011. CALPUFF Modeling System - Version 6 User Instructions. Report prepared by Atmospheric Studies Group, TRC Companies, Inc., April 2011. 873pp.

APPENDIX F

Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area

1.0 INTRODUCTION

1.1 The Wairarapa Airshed Study

The Wairarapa Airshed Study is composed of a number of specific tasks, described in Golder's proposed Scope of Services (Golder 2013d), and listed in Table F1. This Appendix relates to Task 5, dispersion modelling of PM_{10} from discharges in the Waingawa industrial area. The meteorological pre-processing (under Task 4) is described in Appendix E, and configuration parameters for the dispersion modelling are listed in Appendix G.

The main purpose of this component of the study is to provide modelled industrial PM_{10} concentrations for combination with modelled PM_{10} from urban emissions. Discharges from currently operating industries, current emissions from the urban area, and natural emissions are as a whole part of the air quality baseline and are considered cumulatively in the main report. However, to examine the impact of each source-type on air quality in the Wairarapa Valley – part of the study objectives – air quality impacts due to industry in the Waingawa industrial area alone have been considered. This has been done to assess whether breaches of the NES for PM_{10} could occur due to industry only, and to examine the contribution from industry to air quality impacts in the Masterton and Carterton urban areas. It is not the purpose of this work to re-litigate assessments which have already been carried out and which have resulted in the granting of resource consents. PM_{10} concentrations from industry modelled here may not match those modelled for their consent applications and the reasons are discussed in Section 4.0.

Table F1: Wairarapa Airshed Study task list.

Number	Name	Location
1	Greytown, Martinborough and Featherston Box Model for PM_{10}	Appendix A
2	TAPM Meteorological Modelling for Masterton and Carterton	Appendix B
3	Urban Airshed Modelling of PM_{10} from Domestic Heating in Masterton and Carterton	Appendices C and D
4	CALMET Meteorological Modelling for Masterton and Carterton	Appendix E
5	Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area	Appendices F and G
6	Determination of Airshed Boundaries in the Wairarapa Valley	Main Report

1.2 Dispersion Modelling of PM_{10} from Discharges in the Waingawa Industrial Area

Several industries are located in an area to the southwest of the Masterton urban area, close to the Waingawa River. Four resource consents have been granted by GWRC, which permit discharges of contaminants to air. The locations of the industries are shown in Figure F1. The edge of the residential area can be seen in the northeast of the figure; the Juken New Zealand Limited (JNL) and Kiwi Lumber (KL) sites are about 1.5 km and 3 km, respectively, from the nearest houses. As part of the consenting process, dispersion modelling of discharges from JNL, Oldfield Asphalts Limited (Oldfields) and KL was carried out. No modelling was carried out for the fourth industry, Allied Concrete as part of its resource consent application. As mentioned above, the Wairarapa Airshed Study aims to provide advice on airshed boundaries, which are defined as modelled areas of non-compliance with the National Environmental Standards (NES) for air quality. To provide a consistent approach within the study, and to enable examination of the air quality impacts of industry in isolation from and in combination with impacts of other sources in the urban area, the discharge of PM_{10} from industrial sources in the Waingawa industrial area have been re-modelled. The same PM_{10} emission rate and building information has been used here as in the original industrial assessments; the difference is in the meteorological data sets, length of modelling period and the dispersion model used.

The rest of this Appendix is structured as follows. Section 2.0 describes the configuration of CALPUFF for modelling the industrial point sources, including emissions to air, building downwash effects and meteorology. Section 3.0 presents the resulting modelled PM_{10} concentrations from industry in the Waingawa area, including contour plots of peak PM_{10} over the area and an examination of concentrations at sensitive locations. Findings are summarized and discussed in Section 4.0 and concluding remarks are made in Section 5.0. Section 6.0 contains a list of references.

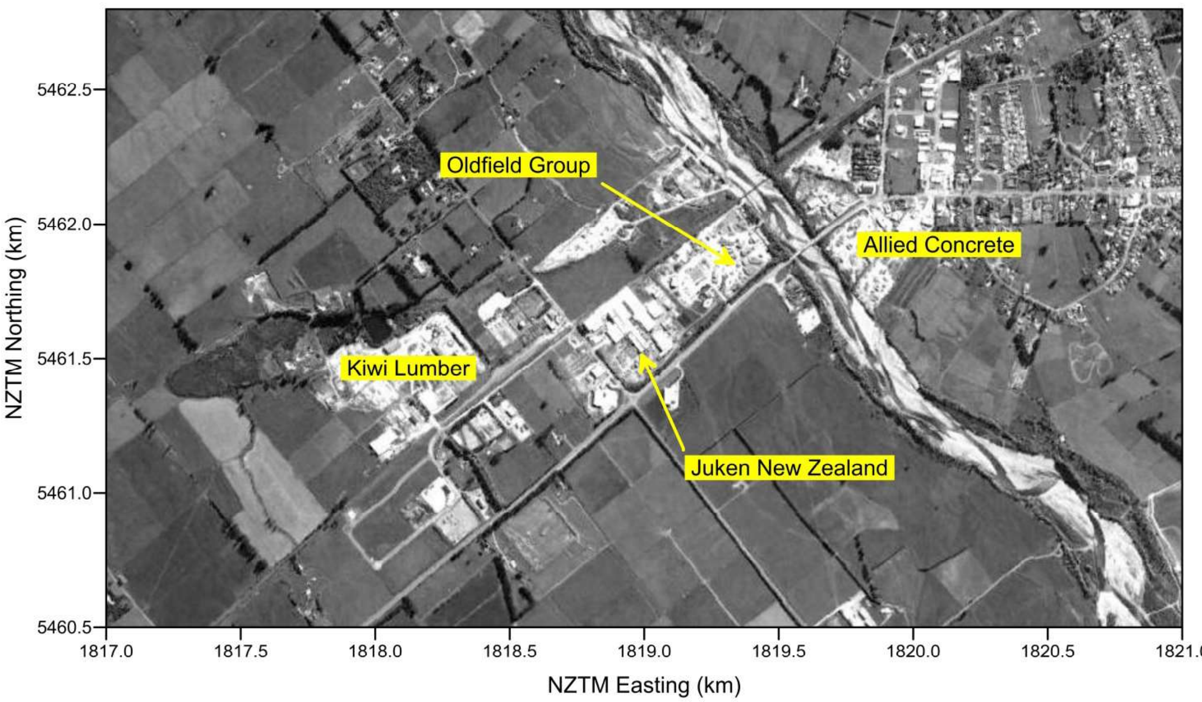

Figure F1: Industrial sites in Waingawa with air discharge permits.

2.0 CONFIGURATION OF CALPUFF FOR DISPERSION FROM SOURCES IN THE WAINGAWA INDUSTRIAL AREA

2.1 Sources of Information

Assessments of air quality impacts were provided to Golder by GWRC for the four industries in the Waingawa industrial area (SKM 2006, 2008; MWH 2010; RPC 2012). Stack parameters, locations, discharge rates and building information have been taken from those reports which included dispersion modelling and an assessment of air impacts from three of the sites (namely, JNL, KL and Oldfields). Information contained in the assessments supplied to Golder varied in detail and presentation format, requiring some pre-processing. In particular, building information provided for each site needed to be converted to an appropriate format for use with CALPUFF, as much of the modelling was originally done with AUSPLUME (EPA 2000). The stack and emission characteristics for each modelled site are given in Section 2.5 and their building parameters in Section 2.6.

2.2 The CALPUFF Dispersion Model

For this part of the study the three sites which were previously modelled have been modelled together here, using the CALPUFF dispersion model (Scire et al. 1999b; TRC 2011a) and its meteorological pre-processor, CALMET (Scire et al. 1999a). CALPUFF and CALMET were set up in accordance with current guidance on best modelling practice (MfE 2004, 2008; TRC 2011b).

General parameters pertaining to the configuration of CALPUFF are listed in Appendix G. Emissions and building parameters are discussed in the following sections.

2.3 Assumptions

The dispersion modelling of industrial sources was carried out under the following assumptions:

(i) The source and building configurations used in the original industrial assessments are still appropriate to use. Subsequent emissions-reduction measures (such as those recently being put in place by JNL) have not been accounted for. Hence model results for JNL are conservative, relative to likely future emissions. Fugitive emissions such as building leaks or windblown dust from product stock piles have not been modelled, as there is no quantitative information on these. It is assumed that such emissions do not have significant impacts.

(ii) The CALPUFF model is appropriate to use in all cases (even though AUSPLUME was originally used in some of the assessments).

(iii) The meteorological data set described in Appendix E is appropriate to use for the dispersion modelling described in this Appendix. This is based on the TAPM modelled meteorology described in Appendix B, re-formatted for CALMET.

(iv) Most sources are considered to be in operation constantly at maximum emission rate, as assumed in their original application (those whose emissions vary are detailed below). No particle settling, dry deposition, wet deposition or chemical transformations are modelled. These assumptions may lead to slightly conservative model predictions, but it is assumed that their effects are small during times of worst-case pollution.

2.4 Meteorology

Tasks 2 and 4 of the Wairarapa Airshed Study involved the production of a meteorological data set on which to base the dispersion modelling of emissions from domestic heating and from industry. For this, the meteorological component of TAPM was run to simulate the meteorology on a NZ-wide scale, telescoping down to higher-resolution detail over the Wairarapa Valley. This provided an hourly, three-dimensional data set, of five-year duration, with the finest grid at 1 km horizontal resolution over the valley (Task 2, Appendix B). The meteorology from TAPM was used directly in the airshed modelling of domestic heating sources. CALPUFF requires compatible meteorological data from CALMET. CALMET was therefore run to convert the outputs from TAPM into a CALPUFF-ready form, as Task 4 of the study. The CALMET modelling process and resulting meteorological outputs are described in Appendix E.

2.5 Stack Parameters and PM_{10} Emissions

Allied Concrete

Allied Concrete operates a concrete batching plant, producing between 8 and 14 truck-loads per day. Dust may be generated at the site during cement truck loading and cement silos filling. The dust control measures at the site include water sprays, minimal drop heights, and filters on the cement silo. MWH (2010) considered that these mitigation measures were sufficiently effective in reducing the discharges from the site. Therefore, dispersion modelling of discharges from this site was not undertaken, nor is any modelling of the site done in this Appendix.

Oldfield Asphalts Limited

Oldfields operates a 4.8 MW (gross heat output), 60 tonne per hour asphalt plant running on diesel oil, which discharges PM_{10} and other contaminants through a single stack. Dispersion modelling of discharges from this site was carried out by SKM (2006) with CALPUFF. All stack and discharge parameters, except for stack location and elevation, were taken directly from the SKM assessment. Stack co-ordinates were converted from NZMG to NZTM for consistency with the meteorological model, and stack base elevations were updated based on the terrain information used by the meteorological model. The discharge parameters, stack location and PM_{10} emission rate are given in Table F2. PM_{10} is discharged at a rate of 1.6 kilograms per hour (kg/h) (or 0.44 grams per second (g/s)).

The asphalt plant would usually operate for only a few hours per day, up to a maximum of 9 hours for a large contract. However, under a very large contract, the plant could operate for 24 hours per day. A 24-hour operational period would be exceptional and does not represent normal conditions for the site. Modelling was originally carried out for 9-hour and 24-hour operating periods. However, the modelling in this Appendix assumes the plant is in operation from 7 am to 4 pm each day.

Kiwi Lumber

KL operates an 8.6 MW (gross heat output) wood-fired boiler, which discharges PM_{10} and other contaminants through a single stack. This boiler can also operate partially on coal as a temporary supplementary fuel. Additional PM_{10} discharges on the site come from a dry shavings bag filter. This bag filter discharges particulates at a rate of 0.27 kg/h (0.075 g/s); a relatively small discharge, whose impacts are likely to be very localized. No further discharge parameters for the bag filter were given by RPC (2012), hence the bag filter stack is not included in the current modelling. The site also includes a number of kiln stacks, but these were assumed in the original assessment to not discharge PM_{10}.

All stack and discharge parameters, except the stack location and elevation, were taken from the RPC (2012) report. The stack co-ordinates were converted from NZMG to NZTM, and the base elevation of the stack was chosen to be consistent with the terrain information used by CALMET. The discharge parameters, stack location and PM_{10} emission rate are given in Table F2. The wood-fired boiler operates with supplementary coal discharges PM_{10} at a rate of 3.6 kg/h (1.0 g/s), and this is the only source modelled. The modelling in this in this Appendix assumes the plant is in operation 24 hours a day, seven days a week.

Juken New Zealand Limited

JNL operates a sawmill and laminated timber products plant. The plant includes nine sources of PM_{10}, comprising a 38 MW wood-fired boiler, three silo stacks, two laminated veneer lumber filters and three solid wood filters. There is also a 5 MW backup diesel-fired boiler on site for use when the wood-fired boiler is off line. The diesel-fired boiler is not included in the modelling as it operates around 15 days per year and is a minor source of PM_{10}.

All stack and discharge parameters, except the stack location and elevation, were taken from the assessment report (SKM 2008). Stack co-ordinates were converted from NZMG to NZTM to make the location consistent with the meteorological model. Similarly, the base elevation of the stack was updated based on the terrain information used by CALMET. The discharge parameters, stack location and PM_{10} emission rate are given in Table F2. The original modelling for this site was carried out for some of the sources using AUSPLUME, meaning that input data needed to be converted into a CALPUFF-ready format. The main source of PM_{10} from the JNL is the wood-fired boiler which discharges PM_{10} at a rate of 8.95 kg/h (2.49 g/s). All other PM_{10} sources on the site are considerably smaller and discharge at between 0.04 kg/h and 0.18 kg/h (0.01 g/s and 0.05 g/s).

Table F2: Stack locations, physical discharge parameters and PM_{10} emission rates as modelled.

Site	Stack name, model designation	NZTM east (km)	NZTM north (km)	Base elevation§ (m)	Stack height (m)	Efflux diameter (m)	Efflux velocity (m/s)	Efflux temperature (K)	PM_{10} emission rate (g/s)	Hours of operation
Oldfield Asphalts Ltd	Asphalt plant, OLDS1	1819.251	5461.878	120	7	0.6	15.5	343	0.444	7am – 4pm
Kiwi Lumber	Wood-fired boiler, KLStac	1818.211	5461.508	126	15.7	0.8	15.7	423	1.00‡	24 hours per day
Juken New Zealand Limited	38 MW wood-fired boiler, JNBoil†	1818.985	5461.549	123	30	1.5	13.5	464	2.49	24 hours per day
	Silo 1, JNSil1	1818.975	5461.567	123	17	2.4	0.5	293	0.011	24 hours per day
	Silo 2, JNSil2	1818.972	5461.567	123	17	2.4	0.5	293	0.011	24 hours per day
	Silo 3, JNSil3	1818.969	5461.567	123	17	2.4	0.5	293	0.011	24 hours per day
	Laminated veneer lumber filter 1, JNLVL1	1818.835	5461.631	123	4	1.0	14.0	293	0.049	24 hours per day
	Laminated veneer lumber filter 2, JNLVL2	1818.810	5461.614	123	3	0.7	16.0	293	0.029	24 hours per day
	Solid wood filter 1, JNSW1	1818.954	5461.606	123	4	1.1	11.0	293	0.046	7am – 5pm
	Solid wood filter 2, JNSW2	1818.910	5461.662	123	4	1.1	11.0	293	0.046	7am – 5pm
	Solid wood filter 3, JNSW3	1818.903	5461.671	123	3	0.7	16.0	293	0.028	7am – 5pm

Notes: † Modelled at 70 % MCR. ‡ Assumed that 75 % of the total particulate is emitted as PM_{10} (RPC 2012). § Elevation taken from CALMET model grid at 500 m resolution (see Appendix E).

2.6 Building Downwash Effects

Good practice guidance (for instance, MfE 2004) advises that enhanced ground-level pollution impacts occur in the lee of nearby buildings if they are greater than 40 % of the stack height, and the distance from stack to building is less than or equal to five times the building height or its projected width (whichever is the lesser). That is, building downwash is expected to occur if the building is high enough or close enough to the stack, and such effects should be modelled. This requires pre-processing of information on building heights and location using the Building Profile Input Program (BPIP) routine, which provides parameters for use by the Plume Rise Model Enhancements (PRIME) algorithm for estimating building downwash effects in CALPUFF.

The three industrial sites are sufficiently far apart, and the stacks and buildings are short enough, that discharges from each site are only affected by the buildings on that site. The building parameters output from BPIP used in the individual air quality assessments for each industry are therefore appropriate for use when the industries are being modelled together. The building information and BPIP outputs are summarized below.

Oldfield Asphalts Limited

Previous modelling for Oldfields was carried out using CALPUFF, and the BPIP outputs given by SKM (2006) are used directly here. The modelled building parameters are given in Appendix G.

Kiwi Lumber

RPC (2012) included the co-ordinates and heights of each of the buildings on the KL site. These co-ordinates were used to set up an input file to BPIP, which was processed to obtain the required building parameters for CALPUFF. Both the BPIP data and CALPUFF inputs are shown in Appendix G. Note that the building information is processed in NZMG co-ordinates, as in the KL assessment. This presents no problem provided the buildings are stacks are in the correct relative locations for the BPIP processing.

Juken New Zealand Limited

The original JNL modelling was carried out using both CALPUFF and AUSPLUME. All building parameter information is given by SKM (2008) in an AUSPLUME format. These outputs were converted to a CALPUFF format and are listed in Appendix G.

3.0 MODELLED PM_{10} FROM THE WAINGAWA INDUSTRIAL AREA

3.1 Peak Modelled 24-hour-average PM_{10} Concentrations

The maximum predicted 24-hour average PM_{10} ground level concentrations (GLCs) for each of the five years are presented in Figure F2 through to Figure F6. Each period runs from 1 September to the following 31 August inclusive. The complete modelling period covers 1 September 2008 to 31 August 2013 inclusive.

The overall pattern of the GLCs is similar in each of the five years, consisting of higher peak PM_{10} concentrations confined to the KL and JNL sites, but low concentrations away from the industrial area. The red contour line shows the boundary of exceedence of the 24-hour NES of 50 µg/m^3. Exceedences are indicated to occur on the KL and JNL sites, but not the Oldfields site. There is some variability in the extent of the 5 µg/m^3 contour, which can affect different parts of the Masterton urban area in different years.

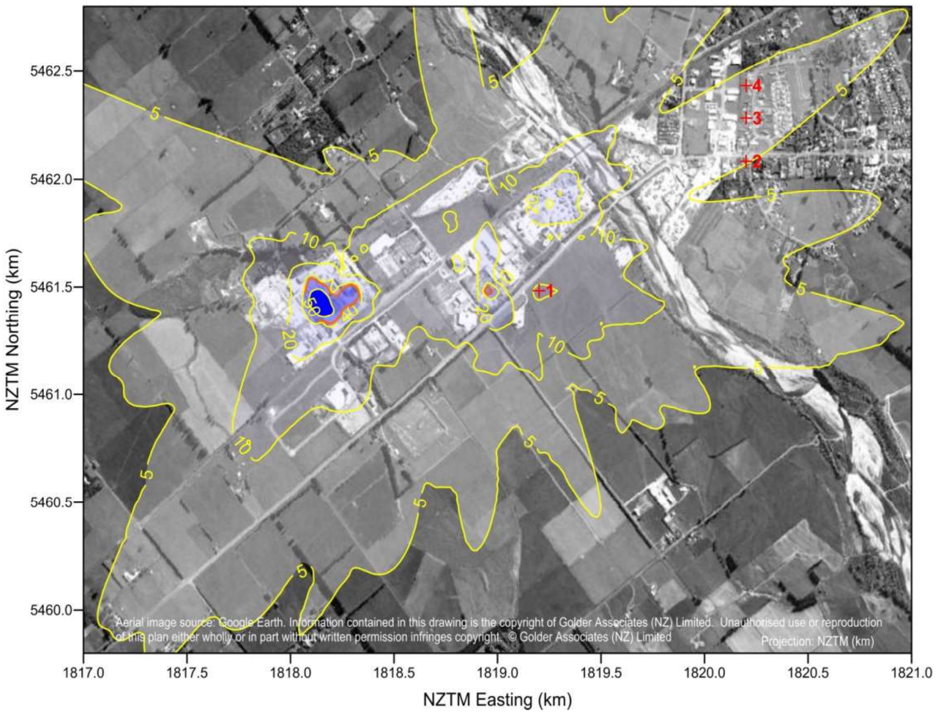

Figure F2: Maximum predicted (maximum modelled) 24-hour average PM_{10} GLCs for 1 September 2008 to 31 August 2009 inclusive. Four selected receptors identified for further discussion are marked with red crosses.

Figure F3: Maximum predicted (maximum modelled) 24-hour average PM_{10} GLCs for 1 September 2009 to 31 August 2010 inclusive.

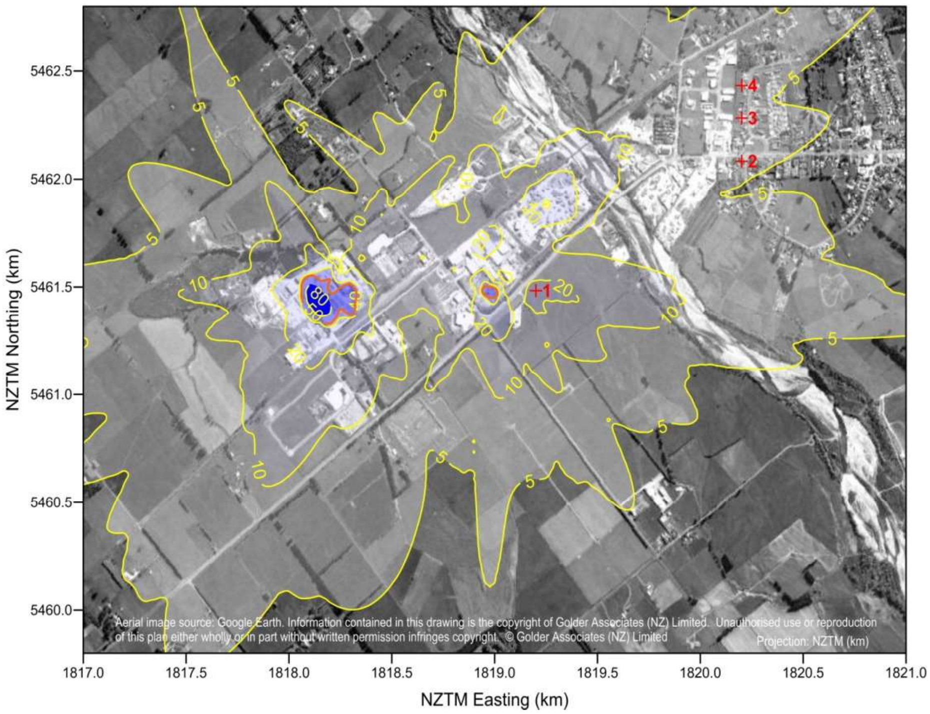

Figure F4: Maximum predicted (maximum modelled) 24-hour average PM_{10} GLCs for 1 September 2010 to 31 August 2011 inclusive.

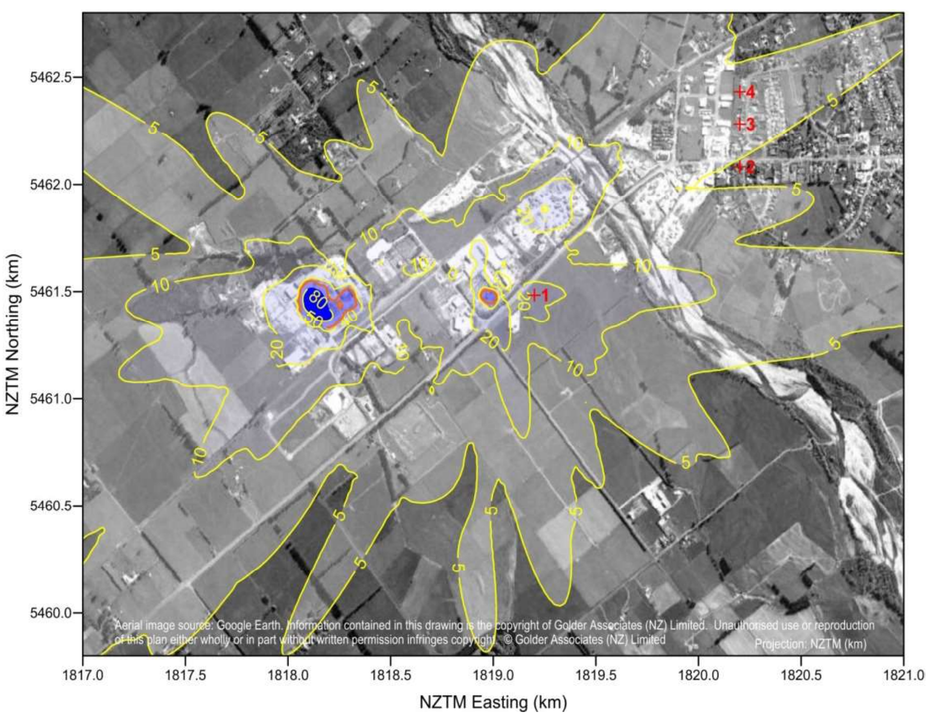

Figure F5: Maximum predicted (maximum modelled) 24-hour average PM_{10} GLCs for 1 September 2011 to 31 August 2012 inclusive.

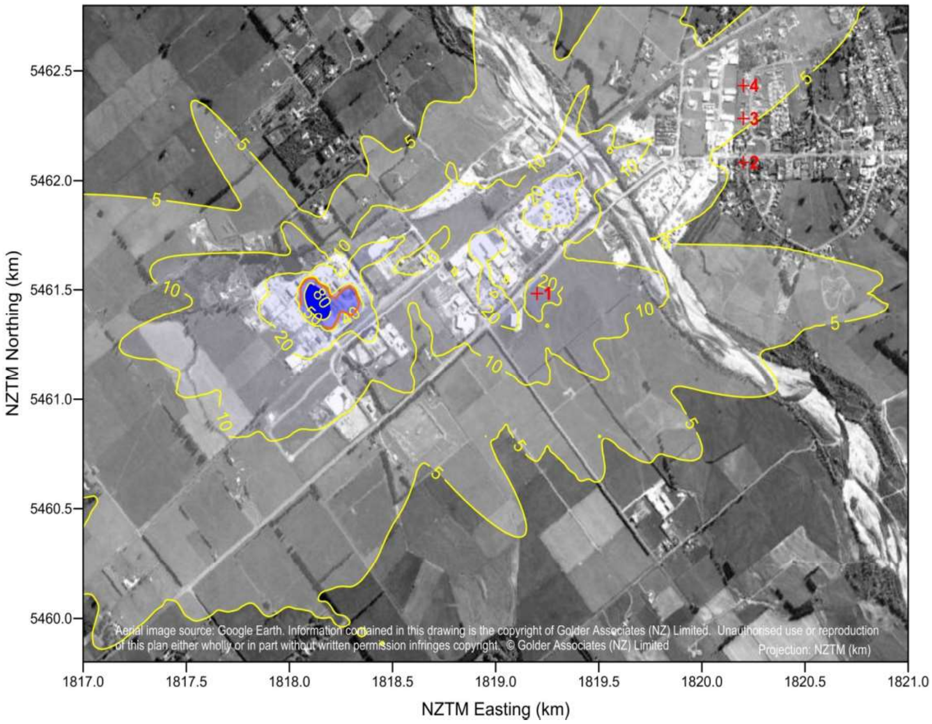

Figure F6: Maximum predicted (maximum modelled) 24-hour average PM_{10} GLCs for 1 September 2012 to 31 August 2013 inclusive.

3.2 Ground-level Concentrations at Sensitive Receptors

Four potentially sensitive locations have been identified and are marked on Figure F2 to Figure F6. They are defined as discrete model receptors and time series of daily PM_{10} at these receptors have been examined. Receptor 1 is location of the maximum off-site concentration in the industrial area. This is close to the southeast boundary of the JNL site. Receptors 2 to 4 are at the edge of the Masterton residential area, and are the locations of the highest PM_{10} impacts of the industrial discharges on Masterton during the modelled years. Receptors 2 and 4 are 350 m apart.

The maximum 24-hour-average PM_{10} GLCs at each of the receptors for each year (1 September to 31 August inclusive) are shown in Table F3. The variation between years is small. At receptor 1, the higher GLCs can occur at any time of the year. In comparison, the highest GLCs at receptors 2, 3 and 4 occur during the middle part of the year, from April to September.

Table F3: Maximum 24-hour average PM_{10} GLCs at each of the discrete receptors.

Year	Maximum 24-hour average PM_{10} GLC (µg/m³)			
	Receptor 1 – industrial	Receptor 2 – residential	Receptor 3 - residential	Receptor 4 - residential
2008-09	22.3	5.22	7.35	5.81
2009-10	21.8	7.22	4.95	4.33
2010-11	24.9	6.14	5.38	7.13
2011-12	23.9	4.02	7.04	6.21
2012-13	25.1	4.74	5.80	7.09

4.0 SUMMARY AND DISCUSSION

The model results shown in the previous sections show that the more major PM_{10} impacts from industry in the Waingawa area are confined within the boundaries of the industrial sites. Moreover, the pattern of pollution indicates that the ground-level impacts are due to building downwash (this assumption hasn't been tested here, but may be surmised from modelling carried out for the KL site by RPC (2012)). It does not appear that the NES for 24-hour PM_{10} would be exceeded off-site in the industrial area. However, the following should be noted:

(i) Industrial sources may contribute up to around 7 µg/m^3 of PM_{10} (24-hour average, see Table F3) over the nearest residential area in Masterton. The contribution is generally highest in winter, when PM_{10} levels in the residential areas would be elevated due to domestic heating emissions. Hence PM_{10} from both industrial and domestic-heating emissions could accumulate, depending on wind direction changes during the 24-hour period (for constant wind direction, they will not accumulate, as the receptors will be consistently upwind of some of the sources).

(ii) Impacts over the industrial area due to urban sources (vehicles, domestic heating) and natural sources (wind-blown dust, sea spray) have not been incorporated into the results presented in this Appendix, but airshed modelling of impacts from domestic heating emissions indicates that there may be an additional 20 µg/m^3 to 30 µg/m^3 of PM_{10} due to these sources occurring over the industrial area (see Appendices C and D).

The CALPUFF model results presented here appear in general to be more conservative than those in the assessments carried out for the industries at the time of their application for resource consent. Possible reasons for this are as follows:

(i) CALPUFF can be more conservative in the near-field, compared to AUSPLUME (the model used in most of the original assessments).

(ii) CALPUFF allows dispersion under calm conditions, which may lead to higher impacts from relatively low-level sources. (AUSPLUME cannot model such conditions and Gaussian plume models in general should not be run with wind speeds less than 1 m/s in the meteorological inputs).

(iii) The runs presented here are based on a five-year meteorological data set, to incorporate a more complete range of meteorological conditions. Peak concentrations from the full five-year period will logically be at least as high as those arising from a shorter modelling period.

5.0 CONCLUSION

The main purpose of this component of the Wairarapa Airshed Study is to provide modelled PM_{10} concentrations from the Waingawa industrial area, just southwest of Masterton. This has been successfully carried out using the CALPUFF model and presented in this Appendix. Further analysis of the CALPUFF modelling is not necessary here. Combination of these results with the TAPM modelling of PM_{10} from domestic heating, along with an examination of the contributions of the different source to air quality in neighbouring regions, is carried out in the main body of the report.

6.0 REFERENCES

EPA 2000. AUSPLUME Gaussian Plume Dispersion Model - Technical User Manual. Prepared by the Centre for Air Quality Studies, EPA, Victoria, Australia, November 2000. p. 107.

Golder 2013a. Defining airshed boundaries in the Wairarapa Valley - Recommendations for further investigation. Report no. 1278104006_002_R_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. February 2013. p. 41.

Golder 2013b. Greytown, Martinborough and Featherton Box Model for PM10. Report prepared for Greater Wellington Regional Council by Golder Associates (NZ) Limited. 16 May 2013. p. 13.

Golder 2013c. TAPM Meteorological Modelling for Masterton and Carterton. Report prepared for Greater Wellington Regional Council by Golder Associates (NZ) Limited. 16 July 2013. p. 21.

Golder 2013d. Wairarapa Air Quality Modelling - Determination of airshed boundaries in the Wairarapa Valley. Proposal no. 1378104103_001_P_Rev0 prepared by Golder Associates (NZ) Limited for Greater Wellington Regional Council. April 2013. p. 24.

MfE 2008. Good practice guide for assessing discharges to air from industry. Ministry for the Environment Report ME880. June 2008.

MfE 2004. Good practice guide for atmospheric dispersion modelling. Ministry for the Environment, Report ME522. Wellington, New Zealand. p. 142.

MWH 2010. Allied Concrete - Masterton concrete batching plant. Application for consent to discharge contaminants to air. Project number Z1906400. Report prepared for Allied Concrete by MWH, August 2010.

RPC 2012. Kiwi Lumber (Masterton) Limited - Application for air discharge consent to discharge contaminants to air from existing sawmill and related activities. Technical description and assessment of effects on the environment. Report prepared for Kiwi Lumber (Masterton) Limited by Ron Pilgrim Consulting, 29 March 2012. p. 112.

Scire J, Robe F, Fernau M & Yamartino R 1999a. A User's Guide for the CALMET Meteorological Model (Version 5.0). Earth Tech, Concord, Massachusetts.

Scire JS, Strimaitis DG & Yamartino RJ 1999b. A user's guide for the CALPUFF dispersion model (version 5.0). Earth Tech, Inc., Boston.

SKM 2008. Juken New Zealand Limited, Masterton - Application for Air Discharge Permit: Technical Report. p. 125.

SKM 2006. Oldfield Asphalts Limited: Application for an air discharge permit. Report prepared for Oldfield Asphalts Limited by Sinclair Knight Merz, 23 February 2006. p. 55.

TRC 2011a. CALPUFF Modeling System - Version 6 User Instructions. Report prepared by Atmospheric Studies Group, TRC Companies, Inc., April 2011. p. 873.

TRC 2011b. Generic Guidance and Optimum Model Settings for the CALPUFF Modeling System for Inclusion into the "Approved Methods for the Modeling and Assessments of Air Pollutants in NSW, Australia."Prepared for NSW Office of Environment and Heritage, Sydney, Australia, March 2011. p. 69.

APPENDIX G

CALPUFF Dispersion Model Configuration

1.0 INTRODUCTION

CALPUFF version 6.42 was run for a five-year period from 1 September 2008 to 1 September 2013, to include the winter of 2013. Most standard options were used, including the PRIME building-wake algorithm and the non-Gaussian formulation for dispersion under daytime convective conditions. Concentrations of PM_{10} were calculated on a grid with 50 m spacing, and at selected receptors to represent sensitive locations in southwest of the Masterton urban area adjacent to the industrial sources. The extent of the grid is shown with the modelling results in Appendix F.

Results presented in Appendix F for industrial emissions of PM_{10} relate to 12-month modelling periods (1 September to 1 September); the combination of industrial PM_{10} with PM_{10} from domestic heating is carried out for the winter months May to August each year.

The following sections list the parameters used in the CALPUFF runs, which appear in the CALPUFF input file.

2.0 CALPUFF PARAMETERS

A list of parameters used in the CALPUFF runs is given in the following tables. Parameters not mentioned below take their default values, or they relate to a particular feature of the model that is not used in this study.
A table of stack locations, with PM_{10} emission rates and other discharge parameters is given in Appendix F (Table F2). Building parameters have been taken from the air quality assessments for Juken New Zealand Limited, Kiwi Lumber and Oldfield Asphalts Limited.

Table G1: CALPUFF start and end times.

Parameter		Value	
Start date/time		00:00	1 September 2008
End date/time		00:00	1 September 2013
Base time zone	ABTZ	UTC+12 (NZST)	
Time step	NSECDT	3600 s	

Table G2: 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)

Dry deposition	MDRY	0 (No dry deposition)
Wet deposition	MWET	0 (No wet deposition)

Table G3: Technical options.

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

Table G4: Map projection.

Parameter	Value
Map projection	Tangential Transverse Mercator (TTM)
Datum region	WGS-84
Projection origin	41 S, 175.6 E
False origin (*NZTM coordinates*)	(1818.000, 5459.000) km

The TTM option is chosen, as it allows the specification of any rectangular co-ordinate system in the model. In this case, the NZTM system is used.

Table G5: Grid control (meteorological grid used by CALMET).

Parameter		Value
SW corner of grid cell (1,1)		(1798.251, 5440.683) km (NZTM)
Grid dimensions	NX x NY; DGRIDKM	75 x 75 grid cells at spacing 0.5 km
Vertical grid, number of layers NZ		12
Cell-face heights for vertical grid (m)		0, 20, 45, 80, 130, 195, 275, 385, 540, 740, 1000, 1700, 3000

Table G6: Grid control (subset of CALMET grid points used by CALPUFF).

Parameter	Value

Parameter		Value
CALPUFF computational grid range E-W		31 to 55 out of NX= 75
CALPUFF computational grid range S-N		30 to 55 out of NY= 75
Use of gridded receptors?		Yes
Receptor grid range E-W		31 to 55 out of NX= 75
Receptor grid range S-N		30 to 55 out of NY= 75
Receptor grid nesting	MESHDN	10 (receptor grid spacing 50 m)

APPENDIX H

Report Limitations

Report Limitations

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