Comparison of trends in predicted (VEPM) and real-world (RSD) emissions for the light duty fleet

2003 to 2011

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Report prepared for the NZ Transport Agency

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An important note for the reader

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Executive summary

Vehicle engine control and emissions reduction technologies are continually improving and, as a result, new vehicles tend to discharge less air pollution per kilometre travelled than older vehicles. In theory, as new vehicles replace old in the New Zealand fleet and as fuel quality improves, the amount of pollutants discharged on a *per vehicle* basis should (on average) be reducing.

The Vehicle Emission Prediction Model (VEPM) has been developed by Auckland Council and the NZ Transport Agency to quantify vehicle emissions and predict how these are likely to change over time. The model quantifies the effect that new technology and improved fuel should theoretically be having on emissions from New Zealand's vehicle fleet. VEPM is a critical tool used in Assessments of Environmental Effects for roading projects. The model is also used in regional and national emissions inventories to determine whether 'business-as-usual' policies and trends will be sufficient to ensure that National Environmental Standards for air quality and other guidelines will be met.

VEPM is based on results from international and New Zealand emission tests, in which selected vehicles are run through a simulated drive cycle on a chassis dynamometer. These tests are relatively time consuming and expensive. This means that emissions models are necessarily based on a relatively limited number of test results, which are extrapolated to the whole fleet.

The aim of this project was to undertake a preliminary comparison of the trends in predicted emissions from VEPM with those in "real-world" emissions measured using a remote sensing device (RSD) deployed in several campaigns in Auckland since 2003. Remote sensing samples the actual exhaust emissions of a large number of vehicles in an on-road situation but because it samples the exhaust at only one point in the drive cycle it cannot replace dynamometer drive cycle testing. However, remote sensing data can be used to check and validate findings derived from a smaller number of drive cycle tests.

This project utilised remote sensing measurements from campaigns undertaken in 2003, 2005, 2009 and 2011. The trends in measured carbon monoxide, nitric oxide (NO), hydrocarbons and uvSmoke (as an indicator of particulate matter) emissions were compared with the trends in predicted carbon monoxide, nitrogen oxides (NO_x), hydrocarbons and particulate matter less than 10 micrometres in diameter (PM_{10}) emission factors. Detailed fleet profiles were developed for each of the four years using the vehicle data in the remote sensing database. This ensured that the predicted emission factors from VEPM were based on the same fleet profile as the actual RSD measurements.

In addition to the trends analysis, the effect of local variations in fleet profile was tested by comparing the VEPM emissions factors for the RSD fleet profiles with those for the default national fleet profile. This comparison was undertaken for the entire Auckland RSD fleet profile (based on all monitored sites) as well as an individual (Rodney) RSD fleet profile.

Key conclusions and recommendations

Based on the preliminary analysis, there is very good agreement between trends in predicted (VEPM) average emission factors and those in measured (RSD) average emissions for overall light duty fleet between 2003 and 2011. This means users can be confident that VEPM does a good job of predicting overall fleet emission trends.

However, when the results are broken down by vehicle type, the agreement is less conclusive especially in the following cases:

- The trend in measured NO emissions (increasing) is contrary to the trend in predicted NO_x emission factors (reducing) from diesel vehicles.
- The measured reduction in uvSmoke emissions is less than the predicted reduction in PM_{10} emissions factors, especially for diesel vehicles.

The results suggest that the actual rate of reduction in NO_x and PM_{10} emissions from diesel vehicles is likely to be less than the theoretical rate of reduction predicted by VEPM.

Diesel vehicles contribute disproportionately to PM_{10} and NO_x emissions from the transport sector and therefore the emissions management policies currently in place may not be as effective as we thought. The 2011 RSD report (Kuschel *et al.* 2012a) found that the step change reductions expected, based on the differences between the limits for emissions standards (ie going from Euro 4 to Euro 5), were not evident in the roadside data, particularly for diesel vehicles. This finding is consistent with overseas studies, in particular one released recently (Carslaw & Rhys-Tyler 2013) which found that only petrol-fuelled vehicles have shown an appreciable reduction in total NO_x emissions over the past 15 to 20 years. Emissions of NO_x from diesel vehicles, including those with after-treatment systems designed to reduce emissions of NO_x, have not reduced over the same period of time.

Abstract

Vehicle emission reduction technologies are continually improving. In theory, as new vehicles replace old ones in the fleet and as fuel quality improves, the amount of pollutants discharged on a per vehicle basis should (on average) be reducing. Vehicle emissions models are used to estimate the effect of new technology and improved fuel on emissions over time. These models are used to evaluate emission reduction policies, as well as for assessing the air quality effects of transport projects. There is some uncertainty in model predictions because they are based on a relatively small number of vehicle emission test results. The aim of this project was to validate the trends predicted by the NZ Transport Agency Vehicle Emission Prediction Model by comparison with real-world emission trends observed in Auckland remote sensing campaigns.

This project used remote sensing results from 2003, 2005, 2009 and 2011. The measured trends in carbon monoxide, nitric oxide (NO), hydrocarbons and uvSmoke (as an indicator of particulate matter) were compared with predicted trends in carbon monoxide, nitrogen oxides (NO_x), hydrocarbons and particulate matter less than 10 micrometres in diameter (PM_{10}). To ensure that the predicted emissions were comparable with the remote sensing results, a detailed fleet profile was developed from the remote sensing vehicle database.

The results confirmed that fleet average emission trends predicted by the Vehicle Emission Prediction Model are comparable with measured trends in average vehicle emissions for the light duty fleet. However, when looking at more detailed sections of the fleet the agreement is less conclusive – particularly for PM and NO_x emissions from light duty diesel vehicles.

1 Introduction

1.1 Background

Many locations in New Zealand experience poor air quality, primarily due to home heating during winter but also with a contribution from motor vehicles. Vehicle emissions contribute between 11% and 81% of winter weekday emissions in metropolitan Christchurch (Smithson 2008) and between 27% and 82% in the Auckland region (Metcalfe *et al.* 2006), depending on the contaminant. In addition, unlike home heating, motor vehicles are a year-round source. Air pollution from vehicles alone is estimated to result in 256 premature deaths, more than 140 hospitalisations and 352,000 restricted activity days[1] in New Zealand each year (Kuschel *et al.* 2012b).

In 2005, the Ministry for the Environment introduced National Environmental Standards (AQNES) for air quality (MfE 2004). The AQNES have targets which must be met by 2016 and regional councils have been developing management strategies based on predictions of future likely emissions to achieve compliance in their airsheds, largely focusing on emissions from industry and home heating. At the same time, the Ministry of Transport (MoT) and the Ministry of Business Innovation and Employment (MBIE) (formerly the Ministry of Economic Development - MED) working in concert have significantly tightened controls on vehicle emissions and vehicle fuels through a variety of policy initiatives. Major progress has been made in fuels and technology, with sulphur levels in diesel now at Euro 5[2] (MED 2008) and new vehicles being required to meet a strict schedule of improving emissions standards (MoT 2007).

In theory, as new vehicles replace old in the New Zealand fleet and as fuel quality improves, the amount of pollutants discharged on a *per vehicle* basis should (on average) be reducing. The Vehicle Emission Prediction Model (VEPM) has been developed by the Auckland Council (formerly Auckland Regional Council), and the NZ Transport Agency (referred to hereafter as the Transport Agency) to quantify vehicle emissions and predict how these are likely to change over time. The model estimates the effect that new technology and improved fuel is actually having on emissions from New Zealand's vehicle fleet.

VEPM is a critical tool used in assessments of environmental effects for roading projects. The model is also used in regional and national emissions inventories to determine whether 'business-as-usual' policies and trends will be sufficient to ensure the AQNES and other ambient air quality guidelines will be met.

VEPM is based on results from international and New Zealand emission tests, in which selected vehicles are run through a simulated drive cycle on a chassis dynamometer. The exhaust emissions are collected and analysed to provide representative emissions for that vehicle type and drive cycle. These tests are relatively time consuming and expensive. This means that emissions models are necessarily based on a relatively limited number of test results, which are extrapolated to the whole fleet.

In contrast, remote sensing can sample the actual exhaust emissions of a large number of real-world vehicles in an on-road situation. Because remote sensing samples the exhaust at only one point in the drive cycle, it cannot replace dynamometer drive cycle testing. However, it does provide a complimentary

[1] A restricted activity day is one where a person is unable to undertake their normal daily activities, such as going to school/work or enjoying their recreation, because they are affected by air pollution.

[2] Sulphur in diesel must not be more than 10ppm by mass or less to allow vehicles to comply with Euro 5 emission standards. This has been a requirement for all diesel sold in New Zealand since 1 January 2009. However, historically, sulphur levels in diesel were much higher and were above 500ppm prior to August 2004.

data stream that can be used to check and validate findings derived from a smaller number of drive cycle tests.

1.2 Objectives and scope of the research

The primary objective of this project was to address the question:

> *Are the trends observed in on-road vehicle emissions monitoring programmes between 2003 and 2011 comparable with trends in light duty vehicle emission factors predicted by VEPM?*

This project also addressed the question:

> *Do local variations in the on-road fleet profile significantly affect light duty fleet weighted emission factors?*

It is important to note that the trend comparison is between measured on-road concentrations of pollutants (% or ppm) and predicted tailpipe emission factors (g/km). This means that the comparison is relative and not absolute. However, the comparison of the relative trends is robust and informative.

It is also important to note that this project was based only on light duty vehicles measured in Auckland and did not consider emissions from heavy duty vehicles, which are a major source of particulate matter measuring less than 10 micrometres in diameter (PM_{10}) and nitrogen oxides (NO_x) pollution from the transport sector.

1.3 Report structure

This report is structured as follows:

- Chapter 2 briefly describes the “real-world emissions” database compiled from remote sensing device (RSD) measurements.
- Chapter 3 reviews the development of the Vehicle Emission Prediction Model (VEPM).
- Chapter 4 describes the method for comparison of trends between real-world (RSD) and modelled (VEPM) emissions.
- Chapter 5 presents the results.
- Chapter 6 summarises the overall conclusions and recommendations.

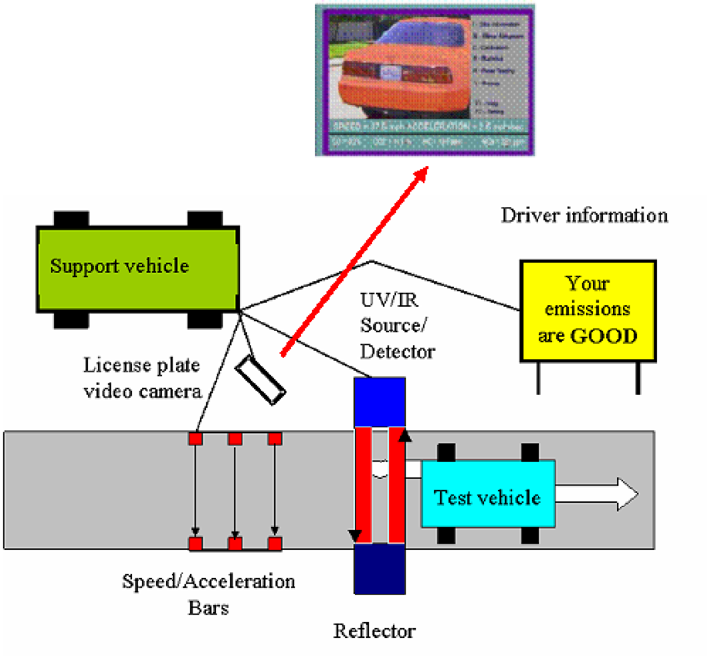
2 Real-world (RSD) emissions data

This chapter briefly outlines the development of a real-world emissions database collated from various campaigns utilising remote sensing devices (RSD) between 2003 and 2011. Further detail is provided in the RSD reports (Fisher *et al.* 2003, Bluett *et al.* 2010, Bluett *et al.* 2011, Kuschel *et al.* 2012a). The text and figures from this chapter are taken from the 2011 RSD report (Kuschel *et al.* 2012a).

2.1 Remote sensing equipment

The instruments used to collect the data used in this study were the RSD 3000 (2003 campaign) and RSD 4000EN models (2005, 2009 and 2011 campaign). A schematic diagram of the remote sensor monitoring equipment is shown in figure 2.1.

Figure 2.1 Schematic diagram showing the remote sensing system in operation



2.1.1 Measurement of gaseous pollutants

The RSD instrument includes an infrared (IR) component for detecting carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbons (HC), together with an ultraviolet (UV) spectrometer for measuring nitric oxide (NO).

The oxides of nitrogen (NO_x) emissions from motor vehicles principally consist of nitric oxide (NO) and nitrogen dioxide (NO_2). NO is the dominant species and is generally accepted to be a high proportion of the total NO_x that leaves the vehicle's tailpipe. Once in the atmosphere, NO oxidises to NO_2. For adverse human health effects of NO_X, NO_2 is the species of primary concern.

The RSD equipment is capable of measuring only NO. **It is important to note that VEPM predicts NO_x emissions from vehicles so the comparison of trends discussed in section 5 is indicative only.**

2.1.2 Measurement of particulate pollutants

Standard methods of measuring particulate air pollution are typically gravimetric – weighing a filter which has had a known volume of ambient air drawn through it. It is more difficult to accurately measure particulate using open path monitoring, such as that used in the RSD.

The RSD uses a dimensionless uvSmoke index as a proxy for particulate emissions. The uvSmoke data cannot be assumed to be equivalent to the results that would be obtained from gravimetric analysis carried out on a dynamometer – although they should be a good approximation.

2.1.3 Vehicle information

The RSD system includes a camera to record images of the licence plate of each vehicle measured. The camera takes an electronic image of the licence plate (figure 2.2) which is integrated into the RSD's monitoring database. The licence plate number is then used to interrogate the Transport Agency's Motor Vehicle Register[3] to obtain details for each vehicle, eg make, model, year of manufacture etc.

Figure 2.2 Example of a licence plate image recorded by the RSD system

2.2 RSD monitoring sites

Remote sensing has been used in four separate campaigns in Auckland between 2003 and 2011 to collect vehicle emission data for the light fleet. Each campaign involved multiple agencies, including the Auckland Regional Council (ARC) from 2003 to 2009, the newly-formed Auckland Council (AC) in 2011, and the NZ Transport Agency, Ministry for Transport (MoT), and National Institute of Water and Atmospheric Research (NIWA).

[3] Information from the Motor Vehicle Register (MVR) was provided both directly by the MoT and via Motochek. Motochek is an internet-based interface that enables registered users to access information from the NZ LANDATA (motor vehicle registration and relicensing and road user charges) database to obtain vehicle and owner details – see www.nzta.govt.nz/motochek/index.html for more information.

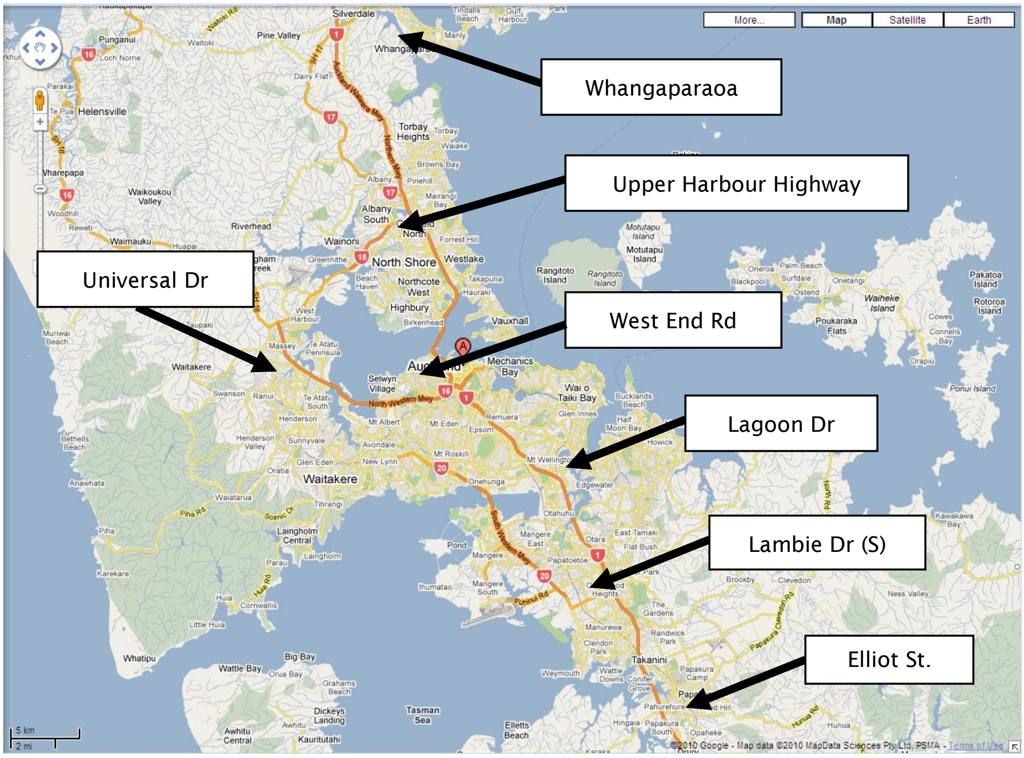
The database contains a complete record of all RSD measurements made in Auckland between 2003 and 2011 (approximately valid 146,000 records). Table 2.1 shows only the monitoring sites that were common to at least three campaigns, and presents the valid readings (and the number of individual vehicles) recorded for each of those sites. Figure 2.3 shows the locations of these sites.

Table 2.1 Comparison of common monitoring sites across the 2003, 2005, 2009 and 2011 campaigns

Site no	Site name	Site code	2011	2009	2005	2003
1	Lagoon Dr	AUC2	4,045	4,437	7,785	3,884
2	Lambie Dr (S)	MAN2	930	1,339	4,295	2,379
3	Universal Dr	WAI5	2,052	5,385	2,545	n/a
4	West End Rd	AUC8	1,133	1,066	2,555	n/a
5	Whangaparaoa Rd	ROD3	9,213	3,826	3,850	n/a
6	Elliot St (W)	PAP1	1,349	1,342	1,367	1,447
7	Upper Harbour Highway (W)	NOR5	5,660	5,558	2,992	1,937
Total valid readings			**24,382**	**22,953**	**25,389**	**9,647**
Total individual vehicles*			20,895	21,383	23,310	9,338

* Note some vehicles went through the remote sensor more than once – in one case 67 times – and therefore the number of individual vehicles captured is lower than the number of valid readings.

Figure 2.3 Map of Auckland indicating locations of all monitoring sites used in the 2009 RSD campaign



2.3 Structure and content of the database

The RSD and the Transport Agency's Motor Vehicle Register (MVR) datasets for all four campaigns were consolidated into a Microsoft Access™ database (Bluett *et al.* 2013). The database is structured around two principal tables:

- Emissions, and
- Vehicles.

The Emissions table contains all (valid and non-valid) road-side records obtained from the RSD equipment, including those from the subsequently-discarded 2003 and 2005 sites, and the 2005 heavy duty diesel (HDD) campaign (210,384 records). Key fields in this table include site name, date and time of measurements, pollutant concentrations, and licence plate (see table 2.2).

Table 2.2 Representative data fields contained in the Emissions table

Data field	Description of data
Monitoring site name	
Date and time of measurement	
Speed of vehicle	km/hr
Acceleration of vehicle	m/s^2
Speed/acceleration valid flag	Indicates if speed and acceleration measurements are valid
Pollutant concentrations	CO (%), HC (ppm), NO (ppm), uvSmoke
Pollutant measurement valid flag	Indicates if pollutant measurement is valid
Licence plate image number	Link to image of vehicle's licence plate
Licence plate number	Transcribed from Licence plate image

The Vehicles table holds all available information obtained from MVR for each licence plate associated with a valid emission measurement (146,550 records). Key fields in this table include licence plate, make/model, year of manufacture, and fuel type (see table 2.3).

The database can be interrogated using standard Microsoft Access queries, or by statistical software packages such as R or Matlab. Extracting subsets of data relevant to a particular study is generally straightforward, but care is necessary when linking the Vehicles and Emissions tables via the vehicle licence plate field. Individual vehicles are frequently encountered more than once (eg by passing through one or more sites several times during the same day) and can easily generate spurious duplicate records if queries are incorrectly formulated.

Table 2.3 Representative data fields contained in the Vehicles table

Data field	Description of data
Licence plate	
Make	Company which manufactured the vehicle
Model	
Year of manufacture	
Body style	Saloon, hatchback, station wagon, utility, light van, flat deck truck, heavy bus/service coach etc.
Engine capacity	cc
Vehicle type	Passenger car/van, goods van/truck/utility, motorcycle, bus, trailer/caravan, tractor etc.
Purpose of vehicle use	Private passenger, taxi, commercial passenger transport, licensed goods, other (standard) goods, ambulance, fire brigade, diplomatic etc.
Fuel type	Petrol, diesel, LPG, CNG, other
Country of origin	Country where vehicle was manufactured
WOF expires	Warrant of fitness expiry date
Country of first registration	Country where vehicle was first registered (if imported to NZ second hand)
Gross vehicle mass	kg
Tare weight	kg
Odometer reading	km or miles
Plate type	Standard, trade, personalised, investment, diplomatic or crown
Ownership	Private (male or female), company, fleet or lease
Subject to RUC	Subject to road user charges

3 The vehicle emission prediction model (VEPM)

This chapter briefly outlines the development of the Vehicle Emission Prediction Model (VEPM). Further detail is provided in the VEPM user guide (NZTA 2013) and associated technical reports which can be accessed from the Transport Agency's transport and air quality website at ***air.nzta.govt.nz***.

3.1 Brief history

The Vehicle Emission Prediction Model is an Microsoft Excel™ spreadsheet which is publicly available upon request from the VEPM helpdesk - e-mail: vepm@auckland.ac.nz

The Vehicle Emission Prediction Model (VEPM) was originally developed for the Auckland Regional Council in 2008 (EFRU 2008). The model was developed to:

- predict emissions for vehicles in the New Zealand fleet under typical road, traffic and operating conditions; and
- be suitable for air quality assessment projects on a regional and national basis.

Since its release in 2008, VEPM has been successfully used in Auckland and around New Zealand to estimate vehicle emissions in air quality assessments of road projects. Several updates have been made to the original 2008 (VEPM 3.0[4]) version to reflect the changing emissions profile of the New Zealand fleet as shown below. These have been jointly funded by the NZ Transport Agency and the Auckland Regional Council (now Auckland Council).

- 2008 VEPM 3.0 (EFRU 2008) based on emissions measurements in the United Kingdom National Atmospheric Emissions Inventory (UK NAEI) database from the 1990s and early 2000s. To estimate emissions from the Japanese vehicle fleet, a detailed comparison of Japanese and European emission factors was undertaken.
- 2011 VEPM 5.0 (EFRU 2011a) based on updated emissions measurements from the UK NAEI database (2009) and the European COPERT 4, version 8, 2011 database. VEPM 5.0 includes emissions from hybrid vehicles, the effects of gradient, particulate matter measuring less than 2.5 micrometres in diameter ($PM_{2.5}$) as output and updated (2010) fleet profile data for New Zealand vehicles. Extensive work was undertaken to calibrate VEPM 5.0 against all available emissions data from New Zealand.
- 2012 VEPM 5.1 (EFRU 2012) incorporates emission factors for light duty vehicles at different road gradients from the World Road Association (PIARC).

Additional supporting technical information can be found in EFRU 2010a, 2010b, 2011b and 2011c.

[4] Note VEPM 3.0 was the first version released publically. The earlier versions were developmental versions used for beta testing or one-off applications.

3.2 Features of the model

3.2.1 Average speed

VEPM is an average speed model which predicts emission factors for the New Zealand fleet under typical road, traffic and operating conditions. Average speed models are based on the fact that the average emissions factor for a pollutant and vehicle type/technology varies as a function of the average speed during a trip. A low average speed is typical of driving in congested traffic and a high average speed is typical of free flowing traffic.

The emissions factors used for average speed models are based on the results of thousands of empirical tests. These tests use drive cycles representing real life driving conditions rather than the cycles used for regulatory compliance. The cycles have a wide range of different operating conditions, ie acceleration rates, maximum speeds, periods of idle etc, and hence a similarly wide range of average speeds.

The model allows the user to define average speeds for light and heavy duty vehicles. Average speeds must be between 10km/h and 99km/h.

3.2.2 Emissions and pollutants

VEPM provides exhaust emission factors for CO, HC, NO_x, CO_2 and particulates ($PM_{2.5}$). Non-exhaust particulate emission factors for brake and tyre wear are also able to be output in a variety of size fractions ranging from particulate matter measuring less than 0.1 micrometres in size ($PM_{0.1}$) to total suspended particulates (TSP). VEPM does not currently estimate evaporative or crank case emissions.

3.2.3 Vehicle categories

VEPM calculates total emission factors for a range of vehicle categories, which include:

Cars

- Petrol cars (<1.4L, 1.4L to 2.0L and >2.0L)
- Diesel cars (≤2.0L and >2.0L)
- Hybrid cars
- Plug in hybrid cars
- Electric cars

Light commercial vehicles (LCVs)

- Petrol LCVs (≤3.5t)
- Diesel LCVs (≤3.5t)

Buses

- All buses are assumed to be diesel fuelled with equivalent emissions to HCVs

Heavy commercial vehicles (HCVs)

- Diesel HCVs broken down by various gross vehicle weight categories ranging from >3.5t to >30t

These categories are further broken down by country of origin and year of manufacture.

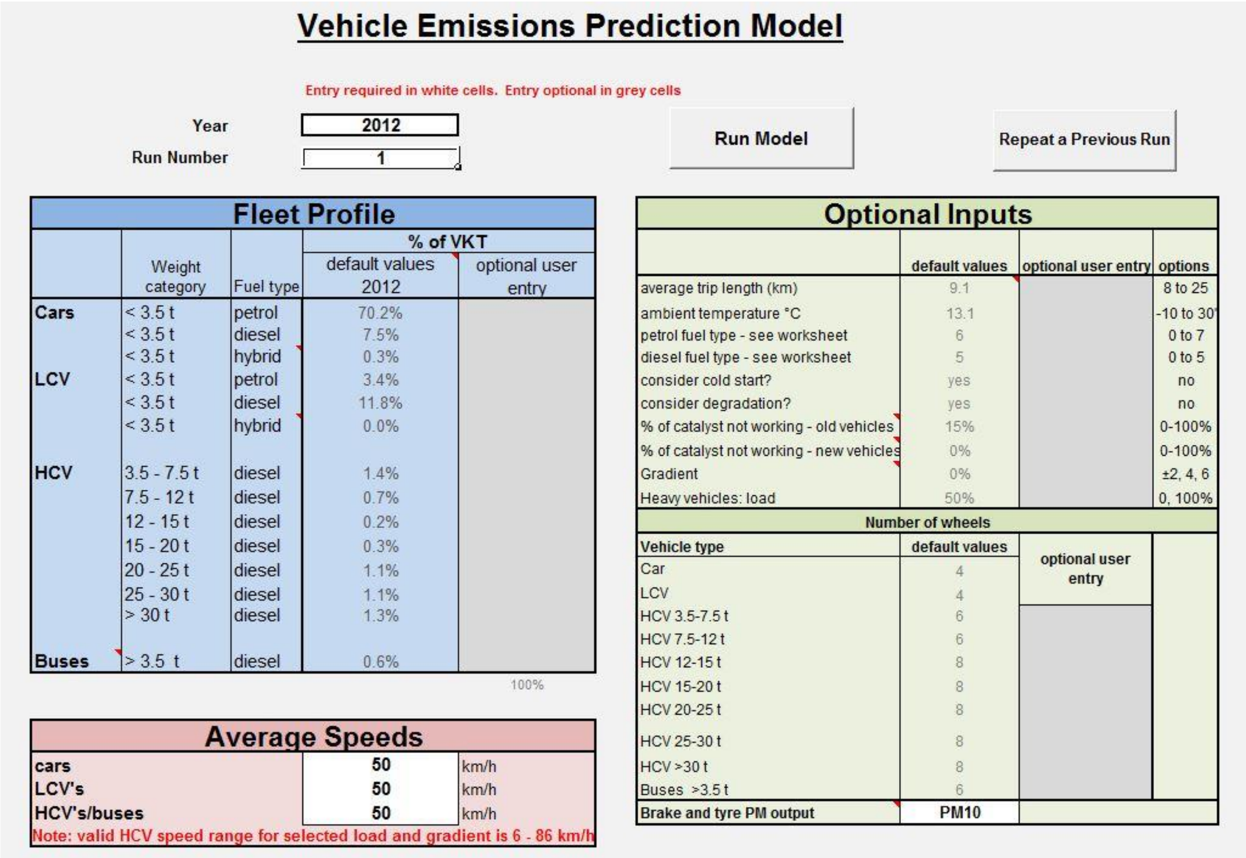
3.3 Calculation of fleet weighted emission factors

VEPM calculates fleet weighted emission factors based on a combination of default and/or user-selected input data.

3.3.1 Input required

Figure 3.1 shows the input worksheet for users.

Figure 3.1 Input sheet for VEPM



Vehicle Emissions Prediction Model

Entry required in white cells. Entry optional in grey cells

Year: 2012

Run Number: 1

Run Model

Repeat a Previous Run

Fleet Profile

	Weight category	Fuel type	% of VKT default values 2012	optional user entry
Cars	< 3.5 t	petrol	70.2%	
	< 3.5 t	diesel	7.5%	
	< 3.5 t	hybrid	0.3%	
LCV	< 3.5 t	petrol	3.4%	
	< 3.5 t	diesel	11.8%	
	< 3.5 t	hybrid	0.0%	
HCV	3.5 - 7.5 t	diesel	1.4%	
	7.5 - 12 t	diesel	0.7%	
	12 - 15 t	diesel	0.2%	
	15 - 20 t	diesel	0.3%	
	20 - 25 t	diesel	1.1%	
	25 - 30 t	diesel	1.1%	
	> 30 t	diesel	1.3%	
Buses	> 3.5 t	diesel	0.6%	
				100%

Average Speeds

cars	50	km/h
LCV's	50	km/h
HCV's/buses	50	km/h

Note: valid HCV speed range for selected load and gradient is 6 - 86 km/h

Optional Inputs

	default values	optional user entry	options
average trip length (km)	9.1		8 to 25
ambient temperature °C	13.1		-10 to 30
petrol fuel type - see worksheet	6		0 to 7
diesel fuel type - see worksheet	5		0 to 5
consider cold start?	yes		no
consider degradation?	yes		no
% of catalyst not working - old vehicles	15%		0-100%
% of catalyst not working - new vehicles	0%		0-100%
Gradient	0%		±2, 4, 6
Heavy vehicles: load	50%		0, 100%

Number of wheels

Vehicle type	default values	optional user entry
Car	4	
LCV	4	
HCV 3.5-7.5 t	6	
HCV 7.5-12 t	6	
HCV 12-15 t	8	
HCV 15-20 t	8	
HCV 20-25 t	8	
HCV 25-30 t	8	
HCV >30 t	8	
Buses >3.5 t	6	
Brake and tyre PM output	PM10	

Users typically select the year and the average speed for cars, LCVs and HCVs/buses.

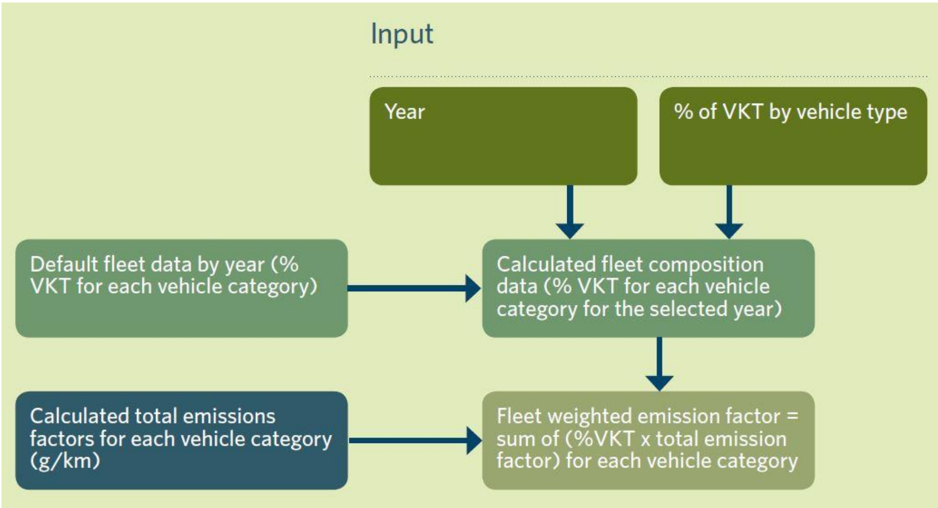
VEPM includes default fleet profiles for all years between 2001 and 2040. The data are based on the percentage of vehicle kilometres travelled (VKT) for each category for the national fleet and come from actual data and projections provided by Ministry of Transport from the Vehicle Fleet Emissions Model (VFEM). Users can run VEPM with these values or modify them according in the optional entry box.

VEPM also allows users to specify trip length, ambient temperature, fuel specifications, cold start, degradation, catalyst failure, gradient and loading. The number of wheels per category and the PM output for brake and tyre wear can also be specified.

3.3.2 Output

The fleet weighted average emission factor per kilometre is calculated as the sum of the percentage of VKT for each vehicle category x total emission factor for each vehicle category based on the user input selections as summarised in figure 3.2.

Figure 3.2 Calculation of fleet weighted emission factors in VEPM



The primary outputs of VEPM are fleet weighted emission factors. These are summarised in an output summary as shown in figure 3.3. Individual emission factors by vehicle category are also available.

Figure 3.3 Output summary from default VEPM fleets for years 2001 to 2040

Output Summary

Runs					fleet composition: Light Duty Vehicles <3.5t					
Run number	year	Speed Car	speed LCV	Speed HCV	% car petrol	% car diesel	% car hybrid	% LCV petrol	%LCV diesel	%LCV hybrid
1	2001	50	50	50	72.9%	7.0%	0.0%	5.9%	7.8%	0.0%
2	2010	50	50	50	70.4%	7.7%	0.2%	3.6%	11.0%	0.0%
3	2020	50	50	50	63.6%	11.0%	2.1%	2.2%	14.0%	0.6%
4	2030	50	50	50	46.0%	21.4%	8.5%	1.3%	13.1%	2.5%
5	2040	50	50	50	29.7%	24.5%	21.8%	0.7%	9.8%	5.8%
6										
7										
8										
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10										
11										
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17										
18										
19										
20										

Run number	fleet composition: Diesel HCV >3.5t							
	% buses	% HCV 3.5-7.5 t	% HCV 7.5-12t	% HCV 12-15t	% HCV 15-20t	% HCV 20-25t	% HCV 25-30t	% HCV >30t
1	0.5%	1.5%	0.7%	0.3%	0.3%	1.3%	1.0%	0.7%
2	0.7%	1.5%	0.8%	0.2%	0.3%	1.2%	1.1%	1.3%
3	0.6%	1.4%	0.7%	0.2%	0.3%	1.1%	1.1%	1.3%
4	0.6%	1.7%	0.7%	0.2%	0.3%	1.0%	1.2%	1.6%
5	0.6%	1.8%	0.7%	0.2%	0.3%	0.8%	1.1%	2.0%
6								
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19								
20								

Run number	fleet weighted emissions factors						
	CO g/km	CO2 g/km	VOC g/km	NOx g/km	$PM_{2.5}$ exhaust g/km	PM brake&tyre g/km	FC l/100km
1	8.81	236.35	0.61	1.18	0.0611	0.0099	10.36
2	4.82	237.81	0.28	0.73	0.0363	0.0099	10.15
3	2.04	211.24	0.14	0.43	0.0169	0.0099	8.82
4	0.96	181.84	0.08	0.32	0.0099	0.0099	7.40
5	0.60	150.33	0.06	0.28	0.0080	0.0100	6.01
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							

4 Method for trends comparison

The method for comparing trends in RSD emissions with trends in VEPM emission factors is described in this chapter.

The RSD emissions measurements are not directly comparable with VEPM emission factors. The RSD measures concentration, whereas VEPM predicts emissions in grams per kilometre. However, all other things being equal, the comparison of the rate of changes in concentration and emissions is robust and informative.

Remote sensing campaigns have been undertaken in Auckland in 2003, 2005, 2009 and 2011. To make the VEPM results and the RSD measurements as comparable as possible, a detailed VEPM compatible fleet profile was developed for the fleets actually monitored by the RSD in 2003, 2005, 2009 and 2011.

4.1 VEPM fleet categories

VEPM predicts emission factors for vehicles that are built to either Japanese or European emission standards (based on country of origin or first registration). VEPM also includes emission factors for vehicles manufactured in New Zealand (<2% of the fleet).

The vehicle fleet is further broken down in VEPM by:

- Vehicle type (car[5], other light duty[6] or heavy duty[7])
- Fuel type (petrol, diesel or petrol hybrid)
- Year of manufacture band (eg 1994-1997)
- Engine capacity (eg <1.4l)

An emission standard (eg Euro 2 or J05) is assigned within VEPM based on these variables.

4.2 Method for calculation of VEPM emission factors

The 2003, 2005, 2009 and 2011 RSD vehicle datasets were used to create light duty fleet profiles, which were input to VEPM to estimate fleet weighted emission factors for the monitored fleets. The assumptions and method used to create the detailed fleet profile are described in the following sections. The detailed 2011 RSD light duty fleet profile is shown as an example in appendix A. To estimate emission factors for the measured RSD fleet profile, the %VKT for each vehicle class was copied and pasted into the VEPM worksheets "Japan Front" and "EU & NZ Front". This overwrote the default fleet data that are normally used to calculate emissions in VEPM.

[5] Cars are defined as vehicles with a vehicle type field (VTYP) of 7 (Passenger Car/Van) in the Motor Vehicle Register.

[6] Other light duty vehicles are defined as vehicles with a vehicle type field (VTYP) of 8 (Goods Van/Truck/Utility), 9 (Bus) or 10 (Motor Home).

[7] Heavy duty vehicles are defined as vehicles with a gross vehicle mass of greater than 3.5 tonnes.

4.3 RSD fleet data used in the analysis

To simplify the analysis, vehicles from any country of first registration other than New Zealand or Japan were not included in the dataset[8].

The RSD datasets include vehicles that were measured more than once. The fleet profile developed for VEPM was based on the full datasets (eg if the vehicle was measured twice, it appeared twice in the dataset).

Table 4.1 shows the number of remote sensing measurements included in this analysis broken down by monitoring campaign year, vehicle type and country of first registration.

Table 4.1 The 2003 to 2011 monitored fleets included in the VEPM comparison

Year	Petrol car	Diesel car	Petrol other light duty	Diesel other light duty	Total	New Zealand*	Japan*
2003	7763	592	533	614	9502	52%	48%
2005	19932	1769	1279	1947	24927	48%	52%
2009	17888	1492	994	2075	22449	50%	50%
2011	18932	1685	1014	2242	23873	51%	49%

*Note that this is country of first registration

4.4 Method and assumptions to create the VEPM compatible fleet

The on-road fleet profile for input into VEPM was developed using RSD vehicle information from the RSD database. The database includes detailed vehicle information from the Transport Agency's Motor Vehicle Register (MVR). Table 4.2 summarises the data from the RSD database that were used to bin the RSD vehicles into VEPM compatible vehicle classes. The MVR data types do not exactly match the information that is used to describe the fleet composition within VEPM. Therefore a number of assumptions (detailed in sections 4.4.1 to 4.4.4) were made to bin each vehicle monitored in the RSD campaigns into VEPM compatible classes.

8 Vehicles from other countries of first registration account for approximately 2% of the fleet. These are primarily from Singapore, the UK and the US.

Table 4.2 Information used to classify the RSD fleet for VEPM

VEPM classification	RSD fleet data used
Japanese or European	Country of first registration – see section 4.4.1 for detail
NZ manufactured	Country of origin = NZ – see section 4.4.2 for detail
Car or other light duty vehicle	Vehicle type – see section 4.4.3 for detail.
Fuel	Fuel type
Year of manufacture	Year of manufacture
Engine capacity	Engine capacity

4.4.1 Japanese or European

The RSD vehicle database includes country of first registration. Compared with other countries, New Zealand has an unusual vehicle fleet in that it is split almost evenly between imported new and imported used vehicles. Vehicles are typically manufactured to meet the emissions control specifications in the country where they are intended to be registered for the first time and these specifications differ depending on the country.

As seen in table 4.1, the monitored fleets were also more or less evenly divided between New Zealand new and used vehicles imported from overseas (primarily from Japan). To assign vehicles from the RSD database to European or Japanese emission standards for VEPM it was assumed that:

- all vehicles first registered in Japan (used imports) were built to Japanese emission standards[9]; and
- all vehicles first registered in New Zealand (except for NZ assembled vehicles until the early 1990s) were built to European emission standards; and
- vehicles first registered in countries other than NZ or Japan (approximately 2% of the fleet) were not included in the comparison to simplify the analysis.

4.4.2 New Zealand manufactured vehicles

It was established in an earlier study that New Zealand petrol powered cars can be adequately represented by two technology classes (Campbell *et al.* 2005) - T1 and T4. T1 refers to cars without any active emission control systems whilst a T4 car would have an electronically controlled fuel injection system with feedback and equipped with an exhaust after treatment device (eg a 3 way catalyst). VEPM assumes a fraction of T1 to T4 by year of manufacture for New Zealand - manufactured vehicles from pre-1987 to just after 2003 (EFRU 2008). There are no New Zealand manufactured diesel vehicles in VEPM.

[9] It should be noted that a small number of used vehicles are imported from Japan each year that were built to Euro standards (eg the BMW 3 series are very popular used vehicle imports) and around 1000 New Zealand new vehicles are registered each year built to Japanese domestic standards. Both of these are small, however, versus the bulk of registrations and are therefore unlikely to distort the findings.

4.4.3 Car or light duty vehicle

The car or other light duty vehicle classification was based on the vehicle type field (VTYP) provided in the MVR. Cars were defined as those vehicles having VTYP = 7 (Passenger Car/Van). Other light duty vehicles were defined as those vehicles having VTYP = 8 (Goods Van/Truck/Utility), 9 (Bus) or 10 (Motor Caravan).

4.4.4 Vehicle emission standards

The Motor Vehicle Register includes a field for the emission standard associated with an individual vehicle. However, this information could **not** be used as it has only been collected since 2003 (when emission standards became a requirement for vehicles entering New Zealand). Instead, the fleet was broken down by country of origin and then by year of manufacture (as discussed in section 4.4.1 and 4.4.2). The emission standards were then assigned to each vehicle category within VEPM. This is consistent with the way that the default fleet is broken down in VEPM.

5 Results

This chapter discusses the comparison of trends in VEPM emissions factors and real-world vehicle emissions for the light duty fleet. The effect of local variations in fleet composition is also discussed.

5.1 Trends in light duty fleet emissions

The aim of this part of the project was to address the question:

> *Are the trends observed in on-road vehicle emissions monitoring programmes between 2003 and 2011 comparable with trends in the light duty vehicle emission factors from VEPM?*

In this section, trends in RSD measurements are compared with trends in emission factors predicted by VEPM assuming the same monitored fleets. Comparisons are provided for:

- Measured concentrations of CO compared with predicted CO emission factors.
- Measured concentrations of HC compared with predicted HC emission factors.
- Measured concentration of NO compared with NO_x emission factors. **This is indicative only. The trends in NO and NO_x may not be comparable because the ratio of NO to NO_2 in vehicle exhaust varies with fuel type and engine technology.**
- The RSD uvSmoke data compared with PM_{10} emission factors. **This is indicative only. uvSmoke cannot be assumed to be equivalent to PM_{10} although it should be a good approximation.**

Figures 5.1 to 5.4 and table 5.1 compare the measured concentrations of CO, HC, NO and uvSmoke for the overall light duty fleet with the fleet weighted CO, HC, NO_x and PM_{10} emission factors predicted by VEPM, respectively. Table 5.1 includes a further breakdown of the results for petrol cars, diesel cars, other petrol light duty and other diesel light duty vehicles.

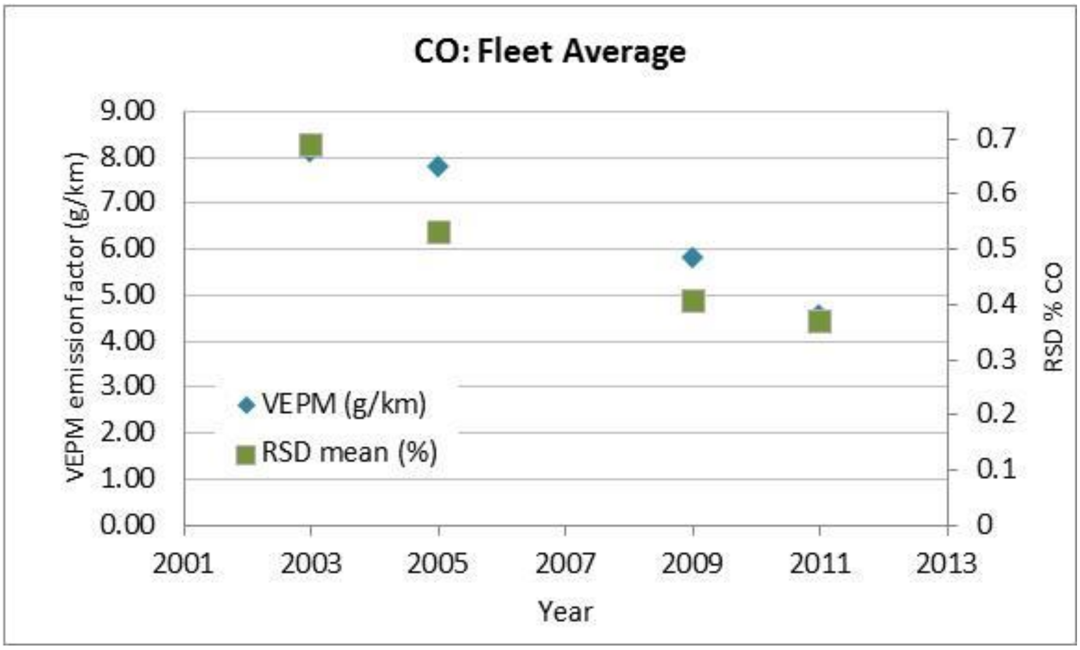
Vehicle emission data tend to be highly skewed, with a high number of low values offset by a smaller number of high values ("gross emitters"). The mean RSD values reflect the **actual** measured average per vehicle emissions. VEPM emission factors are intended to represent **predicted** average emissions from the fleet, including the impact of gross emitters. Therefore, the trends in VEPM emission factors should be comparable with the trends in mean emissions from the RSD fleet.

The graphs and table show generally good agreement between trends predicted by VEPM and measured trends in average vehicle emissions for the overall light duty fleet. There is excellent agreement for fleet average HC and NO emissions but less so for CO and for PM (but the latter is measured by the RSD using uvSmoke as a proxy indication of particulate matter). Both the RSD and VEPM show a downward trend in emissions over the years 2003 to 2011.

This good level of agreement is generally retained for the more detailed fleet breakdowns, with two exceptions noted for diesel vehicles:

- The trend in measured NO emissions (increasing) is contrary to the trend in predicted NO_x emission factors (reducing).
- The measured reduction in uvSmoke emissions is less than the predicted reduction in PM_{10} emissions factors.

Figure 5.1 Fleet average CO emission trends



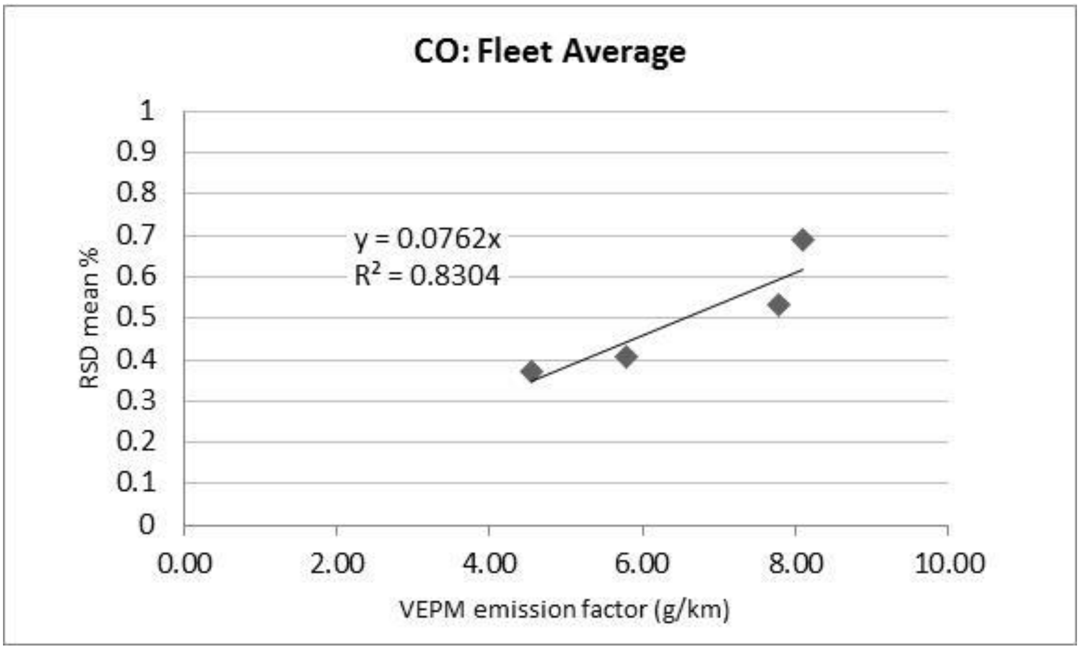
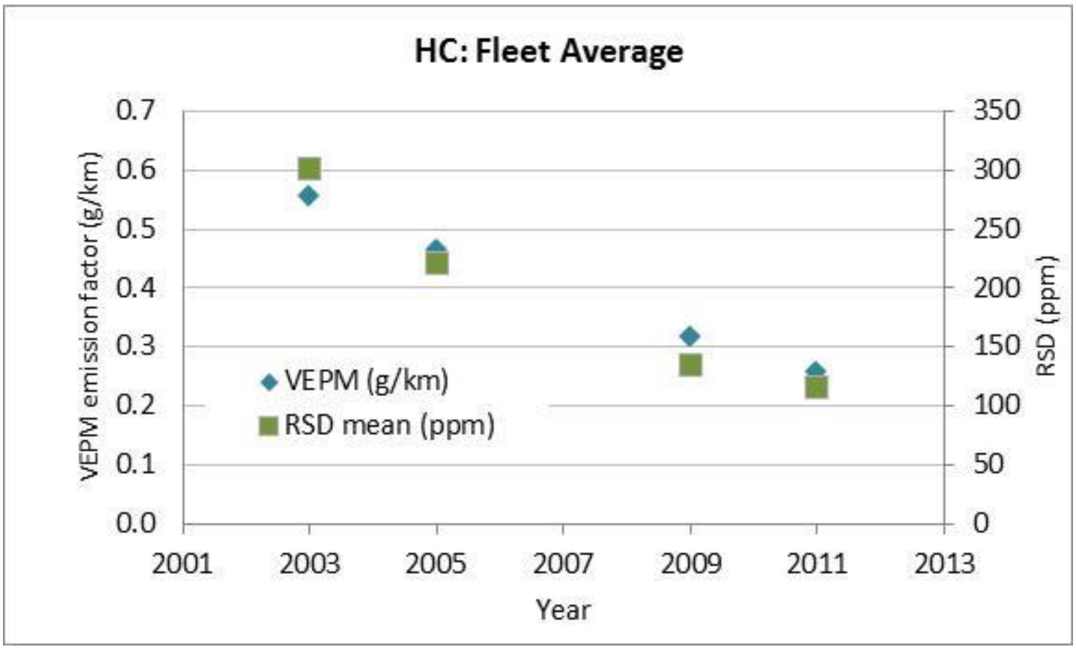


Figure 5.2 Fleet average HC emission trends



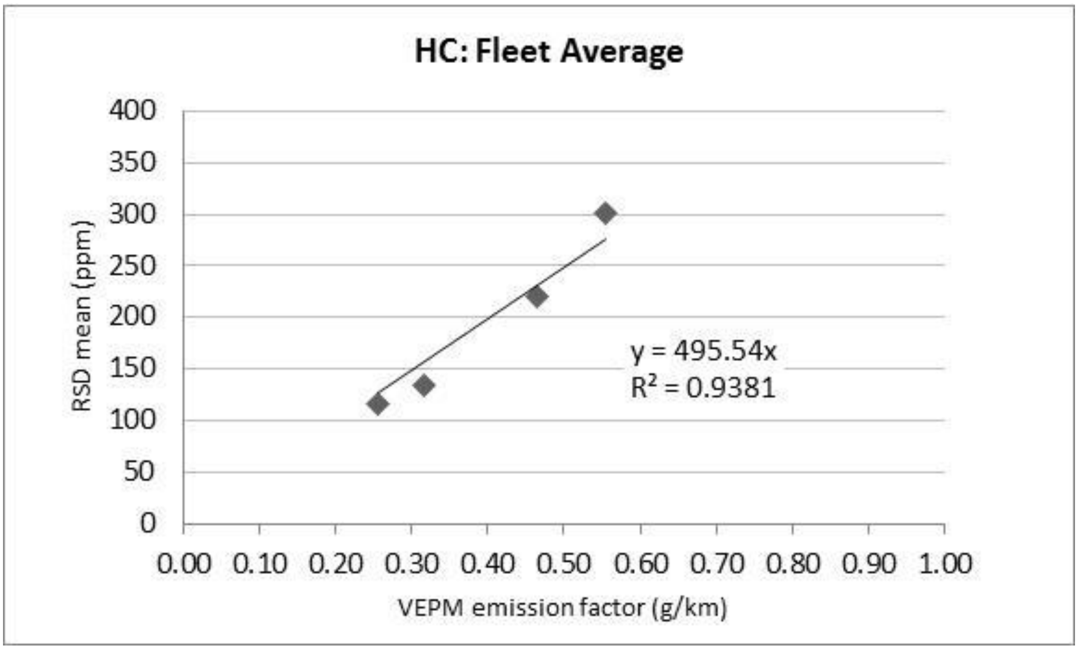
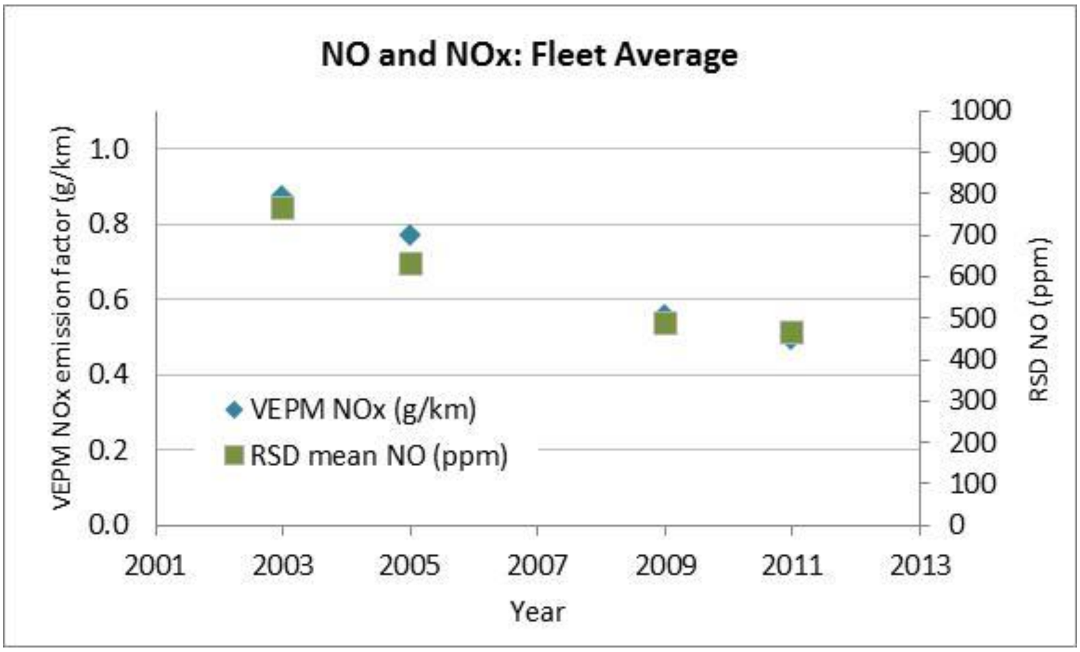


Figure 5.3 **Fleet average NO and NO_x emission trends**



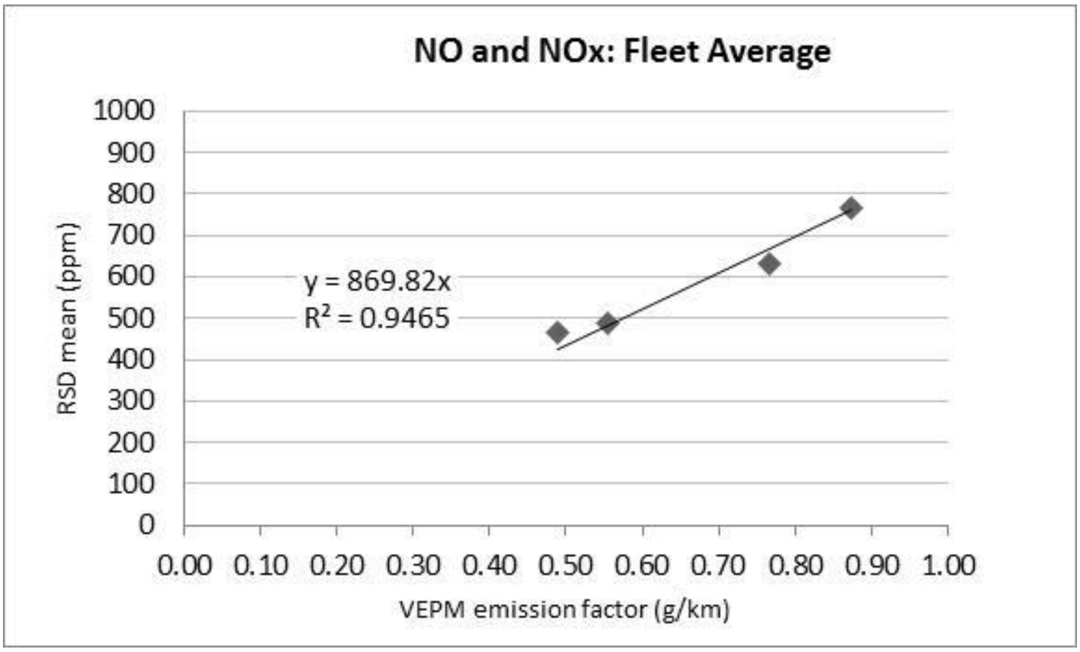


Figure 5.4 **Fleet average uvSmoke and PM_{10} emission trends**

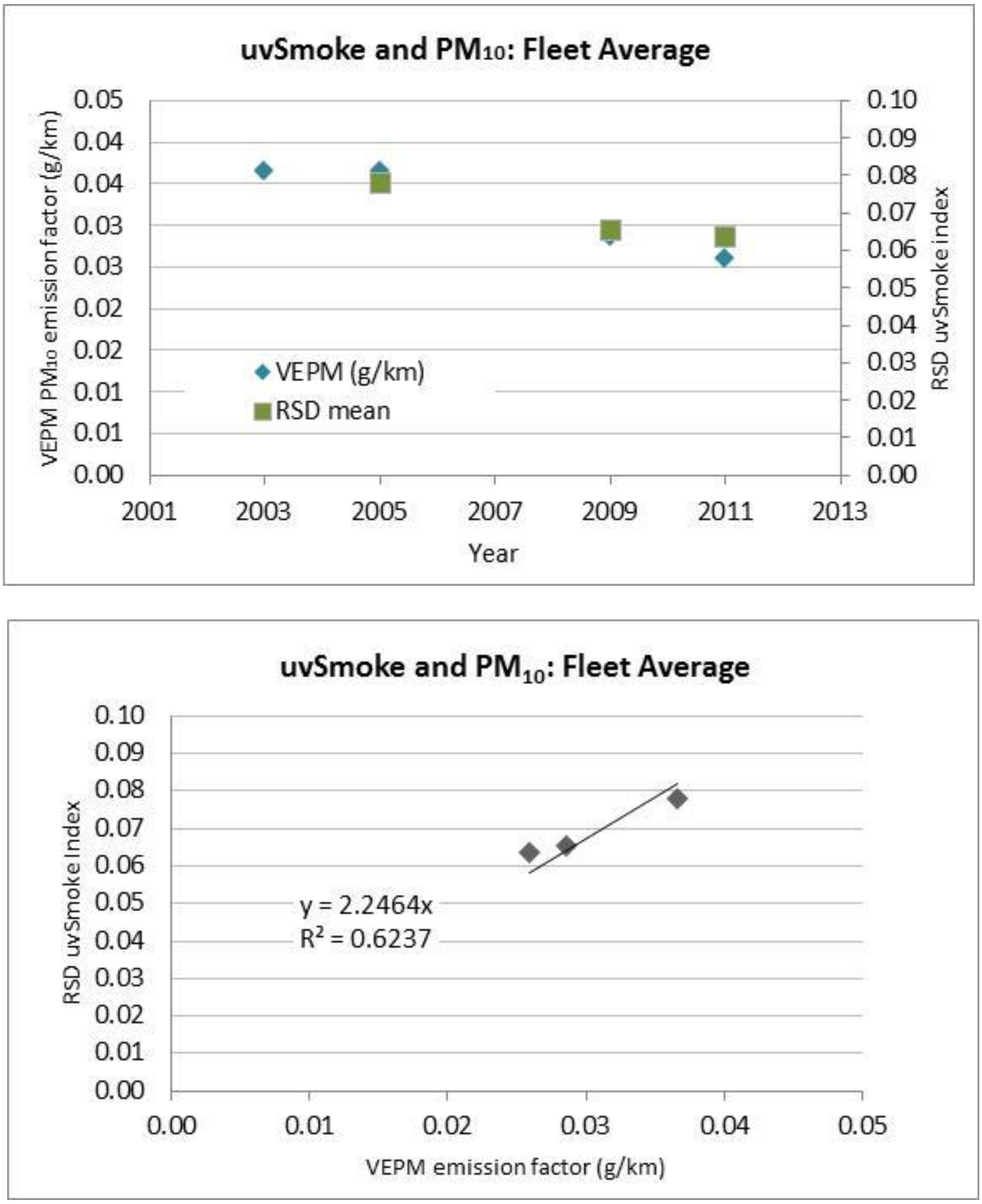


Table 5.1 Comparison of the mean emissions of the 2003 to 2011 monitored fleets overall and VEPM fleet weighted average emission factors

Year	CO		HC		NO	NOx	uvSmoke index	PM_{10}
	RSD	VEPM	RSD	VEPM	RSD	VEPM	RSD	VEPM
	Mean (%)	(g/km)	Mean (ppm)	(g/km)	Mean (ppm)	(g/km)	Mean	(g/km)
Overall monitored fleet								
2003	0.69	8.10	300	0.55	764	0.87	n/a*	0.04
2005	0.53	7.78	220	0.46	631	0.77	0.08	0.04
2009	0.41	5.79	135	0.32	489	0.55	0.07	0.03
2011	0.37	4.56	116	0.26	467	0.49	0.06	0.03
Change**	**46%**	**44%**	**61%**	**54%**	**39%**	**44%**	**18%**	**29%**
Petrol cars								
2003	0.75	8.80	317	0.55	783	0.80	n/a*	0.01
2005	0.60	8.71	230	0.48	628	0.69	0.06	0.00
2009	0.46	6.54	140	0.33	475	0.47	0.05	0.00
2011	0.42	5.11	118	0.27	436	0.41	0.04	0.00
Change**	**44%**	**42%**	**63%**	**51%**	**44%**	**49%**	**26%**	**15%**
Diesel cars								
2003	0.10	0.60	131	0.11	399	0.86	n/a*	0.30
2005	0.04	0.54	107	0.10	409	0.85	0.19	0.26
2009	0.02	0.42	95	0.09	438	0.75	0.17	0.20
2011	0.02	0.38	86	0.08	490	0.71	0.15	0.17
Change**	**80%**	**37%**	**34%**	**30%**	**-23%**	**18%**	**22%**	**35%**
Petrol light commercial vehicles								
2003	1.15	14.50	439	1.70	1211	1.24	n/a*	0.005
2005	0.94	13.86	388	1.37	1169	0.96	0.11	0.004
2009	0.79	11.27	216	0.87	877	0.62	0.09	0.003
2011	0.76	10.11	192	0.74	864	0.57	0.09	0.003
Change**	**33%**	**30%**	**56%**	**56%**	**29%**	**54%**	**19%**	**33%**
Diesel light commercial vehicles								
2003	0.10	0.94	127	0.10	507	1.45	n/a*	0.21
2005	0.03	0.78	110	0.08	466	1.35	0.15	0.17
2009	0.02	0.58	80	0.07	541	1.07	0.14	0.13
2011	0.03	0.51	88	0.06	783	0.99	0.16	0.11
Change**	**75%**	**46%**	**31%**	**38%**	**-54%**	**32%**	**-4%**	**37%**

* Note the RSD equipment used in 2003 measured opacity and not uvSmoke and therefore no results are available.

**This is the percentage decrease in 2011 compared with 2003, except for uvSmoke and PM_{10} which are compared with 2005.

These findings are consistent with the findings of the 2011 RSD study (Kuschel *et al.* 2012a) which concluded that:

- For diesel vehicles, the remote sensing results suggest a slight improvement in CO and uvSmoke as emissions standards improve. However, the step change reductions expected as a result of the differences between the emissions standards are not manifesting in the roadside data.
- Average NO emissions dropped between 2003 and 2005 but then plateaued in the 2009 and 2011 campaigns. This is of particular concern because ambient levels of NO_2 also seem to be stable or on the rise.

Although uvSmoke measurements are not directly comparable with $PM_{10,}$ the trends should be similar.

The picture is less clear for comparison of trends in NO and NO_x because NO_x is the sum of NO and NO_2. However, it is generally accepted that a high proportion of the total NO_x that leaves the vehicle's tailpipe is NO. This means that if there was a downward trend in NO_x, a similar downward trend would also be expected for NO. However, plateauing in NO has also been identified in overseas studies, in particular one released recently (Carslaw & Rhys-Tyler 2013) which found that only petrol-fuelled vehicles have shown an appreciable reduction in total NO_x emissions over the past 15 to 20 years. Emissions of NO_x from diesel vehicles, including those with after-treatment systems designed to reduce emissions of NO_x, have not reduced over the same period of time.

Overall, the results suggest that the actual rate of reduction in NO_x and PM_{10} emissions from diesel vehicles is likely to be less than the theoretical rate of reduction predicted by VEPM. This result could have significant policy implications because diesel vehicles contribute significantly to PM_{10} and NO_x emissions from the transport sector.

5.2 Effect of fleet profile on emission factors

VEPM is based on fleet information from the Ministry of Transport's vehicle fleet emissions model. This is a national model based on national fleet statistics. The aim of this part of the project was to address the question:

> *Do local variations in the on-road fleet profile significantly affect light duty fleet weighted emission factors?*

This was achieved by comparing emission factors for the VEPM default national fleet with those based on the RSD fleet as measured in the Auckland Council 2011 RSD programme (Kuschel *et al.* 2012a). The comparison was undertaken for the entire Auckland fleet as well as the fleet measured at the Rodney monitoring site. The Rodney monitoring site was selected as an example for this comparison because it has the largest sample size of the individual sites.

Detailed fleet profiles are shown in appendix A for the entire RSD fleet as measured in Auckland 2011, as well as the fleet measured at the Rodney RSD site in 2011. The default VEPM light duty fleet[10] for 2011 is also shown. The overall proportion of each vehicle type for these fleets is shown below in table 5.2.

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[10] To derive a default light duty fleet in VEPM, the % of VKT was changed in the optional user entry of the VEPM input sheet. The % of heavy duty vehicles (HCVs) was set at zero and other vehicle classes were prorated upwards to make a total of 100%.

Table 5.2 Overall light duty fleet profile for VEPM default and RSD measured fleets

	Fuel type	Overall light duty fleet profile		
		VEPM default	Auckland RSD fleet	Rodney RSD fleet
Cars	petrol	75.3%	78.6%	78.4%
	diesel	8.1%	7.0%	8.2%
	hybrid	0.3%	0.0%	0.0%
Light Commercial Vehicles	petrol	3.9%	5.1%	3.7%
	diesel	12.3%	9.3%	9.7%
	hybrid	0.0%	0.0%	0.0%

Table 5.2 shows that the overall fleet breakdowns in the Auckland and Rodney measured RSD light duty fleets are similar to the VEPM default fleet. The only significant difference is a higher proportion of diesel light commercial vehicles in the national fleet. However, there are significant differences in the detailed aspects of the RSD fleets and the VEPM default fleet. In particular, the VEPM default fleet has a higher proportion of Japanese vehicles compared to the RSD fleet. This is primarily because VEPM assumes that vehicles from Japan were manufactured to Japanese emission standards. Whereas the RSD detailed fleet assumes that vehicles first registered in New Zealand (except for NZ manufactured vehicles) were built to European emission standards, regardless of where they were manufactured. It is more realistic to assign the emission standard based on country of first registration because vehicles should be manufactured to the emission standard of the country where they are sold. This assumption has a significant effect on the detailed fleet profile but not necessarily on the emission factors.

VEPM emission factors for the default VEPM fleet are compared with emission factors for the RSD fleet profiles in table 5.3. The comparison is shown for the entire fleet as measured in the Auckland Council 2011 RSD programme (Kuschel *et al.* 2012a), as well as the fleet measured at the Rodney RSD site.

Table 5.3 Light duty fleet emission factors for the VEPM default and the RSD measured light duty fleets

Unit	Species	2011 light duty fleet average emission factors				
		VEPM default light duty fleet	Auckland RSD fleet	Difference vs. VEPM default	Rodney RSD fleet	Difference vs. VEPM default
g/km	**CO**	5.0	4.6	-10%	4.6	-8%
g/km	**CO_2**	208.1	205.8	-1%	204.3	-2%
g/km	**VOC**	0.3	0.3	-1%	0.3	-2%
g/km	**NO_x**	0.5	0.5	-4%	0.5	1%
g/km	**$PM_{2.5}$ exhaust**	0.03	0.03	-7%	0.03	7%
l/100km	**FC**	9.1	9.0	-1%	8.9	-2%

The comparison shows that emission factors are similar for the default fleet and the detailed Auckland RSD fleets, which demonstrates that VEPM emission factors are not especially sensitive to local variations in the light duty fleet composition.

It is generally accepted practice to define the local fleet profile in VEPM based on local variations in the proportion of heavy and light duty vehicles only. More detailed fleet data are rarely available. The results of this preliminary investigation suggest that this approach is appropriate. However, it is good practice to use site specific information if and when it is available. It is also worth noting that this study is based on results from one Auckland site only, so it would be valuable to look at the fleet effect on emissions for different sites[11] and different regions. The Auckland fleet is notably younger than fleets in the rest of the country. In other locations, especially provincial centres, fleets have a higher proportion of older light duty diesel vehicles.

This result also demonstrates that VEPM emission factors are not particularly sensitive to assumptions about whether vehicles are manufactured to Japanese or European standards.

[11] Further research is currently being undertaken by Auckland Council to investigate site to site variations.

6 Conclusions and recommendations

The section reviews the objective and aims of the project and reflects upon the achievement of these. An overview of the key findings is presented. The potential science and policy implications of the findings are discussed and recommendations are made.

6.1 Project objectives

The primary objective of this project was to address the question:

> *Are the trends observed in on-road vehicle emissions monitoring programmes between 2003 and 2011 comparable with trends in the light duty vehicle emission factors from VEPM?*

This project also addressed the question:

> *Do local variations in the on-road fleet profile significantly affect light duty fleet weighted emission factors?*

6.2 Key findings

The comparison shows good agreement between fleet average trends predicted by VEPM and measured trends in average vehicle emissions for the overall light duty fleet. This effectively validates the predicted rate of change in emissions provided by VEPM for the on-road fleet.

This good level of agreement is generally retained for the more detailed fleet breakdowns, with the following two exceptions:

- The trend in measured NO emissions (increasing) is contrary to the trend in predicted NO_x emission factors (reducing) from diesel vehicles.
- The measured reduction in uvSmoke emissions is less than the predicted reduction in PM_{10} emissions factors, especially for diesel vehicles.

The VEPM emission factors are not especially sensitive to local variations in the light duty fleet composition, at least for Auckland. The results of this preliminary investigation suggest that it is appropriate for users to define the local fleet composition based on the local split between heavy and light duty vehicles only. However, it would be valuable to investigate whether this holds true at other sites and in other regions.

6.3 Potential scientific and policy implications

When considering potential implications, it is important to note that this study was based only on vehicles measured in Auckland and did not consider emissions from heavy duty vehicles, which are a significant source of particulate and NO_x pollution from the road transport sector. In addition, the results have only undergone basic statistical analysis. Further work would be needed to establish whether the findings are statistically significant.

The overall conclusion from the project is that downward fleet average emission trends estimated by VEPM are consistent with trends in measured average vehicle emissions over the years 2003 to 2011. This is an excellent result, which should provide policy makers with increased confidence in emission predictions from VEPM. However, there are two key issues which will need to be considered and monitored.

Firstly, VEPM predicts a steady decrease in NO_x emissions from diesel vehicles in the measured RSD fleets. This is not reflected in the measured NO trends. The 2011 RSD report concluded that:

> *Emissions improvements appear to have plateaued. This is of significant concern (especially with regards to NO emissions from diesel vehicles) with many urban environments including Auckland showing steady or even rising levels of ambient NO_2 which has been linked to increased health effects in children living near busy roadways (Gauderman et al. 2005) and the increasing direct emissions from modern vehicles (Gense et al. 2006).*

This finding is consistent with overseas studies, in particular one released recently (Carslaw & Rhys-Tyler 2013) which found that only petrol-fuelled vehicles have shown an appreciable reduction in total NO_x emissions over the past 15 to 20 years. Emissions of NO_x from diesel vehicles, including those with after-treatment systems designed to reduce emissions of NO_x, have not reduced over the same period of time.

VEPM does not predict direct NO_2 emissions either separately or as a proportion of NO_x emissions. Quantifying the theoretical direct NO_2 emissions would be a valuable first step in furthering understanding of the NO_2 trends.

Secondly, VEPM predicts a steady decrease in PM_{10} emissions from diesel vehicles in the measured RSD fleets. As in the case of NO_x, the extent of the VEPM reduction is not reflected in the actual uvSmoke measurements. Although plateauing of NO_x emissions from diesel vehicles has been recognised worldwide, there is no international literature suggesting a similar phenomenon for PM_{10}. Given New Zealand has limited inspection and maintenance legislation for emissions – a visible (only) smoke test as part of WoF inspection - poor maintenance practices may be at least responsible for the lack of expected improvement in PM_{10} emissions.

Further work is required to better understand why expected reductions in PM_{10} and NO_x from diesel vehicles are not being seen in the roadside data. In the meantime, policy makers need to be aware that predicted reductions in NO_x and PM_{10} from diesel vehicles may not be realistic.

Conclusions and recommendations

- Emission trends predicted by VEPM are similar to real-world trends measured by remote sensing for the overall light duty fleet 2003 to 2011. This is the first real-world confirmation that VEPM modelled trends are realistic. The robustness of the findings could be improved by undertaking more detailed statistical analysis to test the significance of the results.
- Actual measured reductions in NO and uvSmoke from diesel vehicles are less than the theoretical or expected emission reductions in NO_2 and PM_{10} for the measured fleet. As discussed in the 2011 RSD report, (Kuschel *et al*. 2012a) these issues require further investigation.
- Quantification of the theoretical proportion of direct NO_2 emissions in NO_x emissions in VEPM would be a valuable first step in better understanding the NO_2 trends.
- There are insufficient RSD data to undertake a similar comparison of trends for the heavy duty fleet. Heavy duty vehicles contribute disproportionately more to emissions. The heavy duty emission factors in VEPM have not been calibrated or compared with any New Zealand specific

emission test data. This is a significant gap in our current knowledge of vehicle emissions in New Zealand and should be addressed in a targeted campaign as a priority.

- The results suggest that average emission factors are not especially sensitive to localised variations in the fleet. However, it is recommended that the effect of fleet composition should be investigated for locations outside Auckland. This study has demonstrated that VEPM and RSD results are comparable on a relative basis, so the site to site variability could be investigated either through remote sensing results from other regions, or through modelling of detailed fleet data from other regions.
- VEPM currently assumes that vehicles manufactured in Japan are manufactured to Japanese standards and vehicles manufactured in Europe are manufactured to European standards. It would be more correct to assign the emission standard based on country of first registration because vehicles should be manufactured to the emission standard of the country where they are sold. However, this is unlikely to significantly change emission factor estimates from VEPM.

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Glossary

AQNES	National Environmental Standards for Air Quality
ARC	Auckland Regional Council
CAR	Vehicles with a vehicle type field (VTYP) of 7 (Passenger Car/Van) in the Motor Vehicle Register
CO	Carbon monoxide, a type of air pollutant
CO_2	Carbon dioxide, a type of greenhouse gas
Gross emitter	Vehicle whose emissions fall in the top 10% of the readings for the fleet it is part of
HC	Hydrocarbons, a type of air pollutant
Heavy duty vehicles	Vehicles with a gross vehicle mass of greater than 3.5 tonnes
IM240	The IM240 test is a chassis dynamometer schedule used for emissions testing of in-use light duty vehicles in inspection & maintenance programs.
IR	Infrared light, includes wavelengths in the range 750nm and 100μm
MED	NZ Ministry of Economic Development
MfE	NZ Ministry for the Environment
MoT	NZ Ministry of Transport
Motochek	An internet based interface that enables registered users to access information from the NZ LANDATA (Motor Vehicle Registration and Relicensing and Road User Charges) database to obtain vehicle and owner details
NO	Nitric oxide, a precursor to the formation of NO_2
NO_2	Nitrogen dioxide, a type of air pollutant
NZTA	New Zealand Transport Agency
Opacity	A measure of the ability of a plume to absorb and scatter light, sometimes referred to as smokiness and used as a proxy for PM emissions
Other light duty vehicles	Vehicles with a vehicle type field (VTYP) of 8 (Goods Van/Truck/Utility), 9 (Bus) or 10 (Motor Home).
PM	Particulate matter
PM_{10}	Fine particles less than 10 microns in diameter, a type of air pollutant
ppm	Parts per million. Note this can be expressed by mass eg mg/kg or by volume eg ml/m^3
RSD	Remote sensing device
UV	Ultraviolet light, includes wavelengths in the range 10nm to 400nm
uvSmoke	A measure of the opacity but in the UV spectrum, sometimes used as a proxy for PM emissions

Appendix A: Detailed fleet profiles

Japanese						
		default VEPM fleet	Measured RSD fleet, 2011			
			Rodney site		all of Auckland	
1.0 Cars		%VKT	RSD vehicle count	% VKT	RSD vehicle count	% VKT
1.1 Petrol						
Title	**Model yr**					
Pre 1973, < 1.4 l	**50 - 74**	0.00%	**0**	0.00%	**0**	0.00%
Pre 1973, 1.4 - 2.0 l	**50 - 74**	0.00%	**1**	0.01%	**1**	0.00%
Pre 1973, > 2.0 l	**50 - 74**	0.00%	**0**	0.00%	**0**	0.00%
J75, J76 < 1.4 l	**75 - 77**	0.00%	**0**	0.00%	**0**	0.00%
J75, J76 1.4 - 2.0 l	**75 - 77**	0.00%	**1**	0.01%	**1**	0.00%
J75, J76 > 2.0 l	**75 - 77**	0.00%	**0**	0.00%	**0**	0.00%
J78 < 1.4 l	**78 - 85**	0.02%	**1**	0.01%	**2**	0.01%
J78 1.4 - 2.0 l	**78 - 85**	0.06%	**5**	0.06%	**11**	0.05%
J78 > 2.0 l	**78 - 85**	0.02%	**0**	0.00%	**0**	0.00%
J78, J88 < 1.4 l	**86 - 99**	2.32%	**163**	1.81%	**440**	1.83%
J78, J88 1.4 - 2.0 l	**86 - 99**	20.36%	**1713**	18.97%	**4479**	18.59%
J78, J88 > 2.0 l	**86 - 99**	7.93%	**570**	6.31%	**1483**	6.16%
J00 < 1.4 l	**00 - 04**	0.87%	**186**	2.06%	**444**	1.84%
J00 1.4 - 2.0 l	**00 - 04**	5.94%	**661**	7.32%	**1688**	7.01%
J00 > 2.0 l	**00 - 04**	4.91%	**333**	3.69%	**989**	4.11%
J05 < 1.4 l	**> 05'**	0.58%	**44**	0.49%	**104**	0.43%
J05 1.4 - 2.0 l	**> 05'**	4.01%	**103**	1.14%	**240**	1.00%
J05 > 2.0 l	**> 05'**	4.72%	**36**	0.40%	**108**	0.45%
Total		**51.73%**		**42.27%**		**41.47%**
1.2 Diesel						
Pre 1986 < 2.0 l	**50 - 85**	0.00%	**0**	0.00%	**0**	0.00%
Pre 1986 > 2.0 l	**50 - 85**	0.01%	**0**	0.00%	**1**	0.00%
J86 < 2.0 l	**86 - 91**	0.08%	**6**	0.07%	**11**	0.05%
J86 > 2.0 l	**86 - 91**	0.45%	**34**	0.38%	**82**	0.34%
J92, J94 < 2.0 l	**92 - 97**	0.24%	**20**	0.22%	**54**	0.22%
J92, J94 > 2.0 l	**92 - 97**	2.99%	**328**	3.63%	**706**	2.93%
J98 < 2.0 l	**98 - 01**	0.05%	**0**	0.00%	**1**	0.00%
J98 > 2.0 l	**98 - 01**	0.67%	**72**	0.80%	**116**	0.48%
J02 < 2.0 l	**02 - 04**	0.06%	**0**	0.00%	**0**	0.00%
J02 > 2.0 l	**02 - 04**	0.40%	**0**	0.00%	**0**	0.00%
J05 < 2.0 l	**> 05'**	0.41%	**0**	0.00%	**0**	0.00%
J05 > 2.0 l	**> 05'**	0.80%	**2**	0.02%	**3**	0.01%
Total		**6.16%**		**5.12%**		**4.04%**
2.0 Light Duty Vehicles (< 3.5 tonnes)						
2.1 Petrol						
J73, J75, J79	**50 - 79**	0.00%	**0**	0.00%	**2**	0.01%
J79, J81	**80 - 87**	0.08%	**1**	0.01%	**103**	0.43%
J88	**88 - 00**	1.48%	**35**	0.39%	**77**	0.32%
J01	**01 - 04**	0.55%	**22**	0.24%	**34**	0.14%
J05	**> '05**	0.50%	**11**	0.12%	**216**	0.90%
Total		**2.62%**		**0.76%**		**1.79%**
2.2 Diesel						
Pre 1974, J74	**50 - 76**	0.00%	**0**	0.00%	**0**	0.00%
J77, J79	**77 - 81**	0.00%	**0**	0.00%	**0**	0.00%
J82, J83, J87	**82 - 87**	0.07%	**1**	0.01%	**4**	0.02%
J88	**88 - 92**	0.54%	**21**	0.23%	**58**	0.24%
J93	**93 - 96**	1.04%	**60**	0.66%	**146**	0.61%
J97, J03	**97 - 04**	3.62%	**84**	0.93%	**265**	1.10%
J05	**> 05'**	4.23%	**9**	0.10%	**42**	0.17%
Total		**9.49%**		**1.94%**		**2.14%**
Grand Total		**70.00%**		**50.09%**		**49.44%**

European and New Zealand							
			default VEPM	Measured RSD fleet, 2011			
				Rodney site		all of Auckland	
1.0 Cars			%VKT	RSD vehicle count	%VKT	RSD vehicle count	%VKT
1.1 Petrol							
Pre - ECE	< 1.4 l	< '71	0.01%	0	0.00%	0	0.00%
	1.4 - 2.0 l	< '71	0.01%	0	0.00%	0	0.00%
	> 2.0 l	< '71	0.07%	1	0.01%	4	0.02%
ECE 15.00	< 1.4 l	72 - 77	0.00%	0	0.00%	2	0.01%
	1.4 - 2.0 l	72 - 77	0.00%	1	0.01%	2	0.01%
	> 2.0 l	72 - 77	0.01%	0	0.00%	1	0.00%
ECE 15.01	< 1.4 l	72 - 77	0.00%		0.00%		0.00%
	1.4 - 2.0 l	72 - 77	0.00%		0.00%		0.00%
	> 2.0 l	72 - 77	0.00%		0.00%		0.00%
ECE 15.02	< 1.4 l	78 - 80	0.00%	1	0.01%	4	0.02%
	1.4 - 2.0 l	78 - 80	0.00%	0	0.00%	0	0.00%
	> 2.0 l	78 - 80	0.01%	0	0.00%	0	0.00%
ECE 15.03	< 1.4 l	81 - 85	0.00%	5	0.06%	11	0.05%
	1.4 - 2.0 l	81 - 85	0.01%	3	0.03%	7	0.03%
	> 2.0 l	81 - 85	0.01%	0	0.00%	2	0.01%
ECE 15.04	< 1.4 l	85 - 92	0.06%	42	0.47%	79	0.33%
	1.4 - 2.0 l	85 - 92	0.22%	80	0.89%	173	0.72%
	> 2.0 l	85 - 92	0.06%	33	0.37%	76	0.32%
Euro 1	< 1.4 l	92 - 96	0.37%	41	0.45%	84	0.35%
	1.4 - 2.0 l	92 - 96	2.78%	211	2.34%	502	2.08%
	> 2.0 l	92 - 96	1.94%	163	1.81%	407	1.69%
Euro 2	< 1.4 l	97 - 00	0.26%	29	0.32%	58	0.24%
	1.4 - 2.0 l	97 - 00	2.03%	241	2.67%	603	2.50%
	> 2.0 l	97 - 00	1.68%	231	2.56%	590	2.45%
Euro 3	< 1.4 l	01 - 04	0.27%	57	0.63%	132	0.55%
	1.4 - 2.0 l	01 - 04	1.98%	269	2.98%	784	3.25%
	> 2.0 l	01 - 04	2.54%	396	4.39%	1191	4.94%
Euro 4	< 1.4 l	05 - 09	0.20%	100	1.11%	232	0.96%
	1.4 - 2.0 l	05 - 09	1.59%	476	5.27%	1286	5.34%
	> 2.0 l	05 - 09	2.01%	565	6.26%	1860	7.72%
Euro 5	< 1.4 l	10 - 14	0.34%	33	0.37%	84	0.35%
	1.4 - 2.0 l	10 - 14	1.84%	122	1.35%	327	1.36%
	> 2.0 l	10 - 14	2.26%	139	1.54%	422	1.75%
Euro 6	< 1.4 l	> 2015	0.00%	0	0.00%	0	0.00%
	1.4 - 2.0 l	> 2015	0.00%	0	0.00%	0	0.00%
	> 2.0 l	> 2015	0.00%	0	0.00%	0	0.00%
NZ new	< 1.4 l	<= 87'	0.31%	0	0.00%	0	0.00%
NZ new	1.4 - 2.0 l	<= 87'	0.22%	0	0.00%	0	0.00%
NZ new	> 2.0 l	<= 87'	0.33%	1	0.01%	1	0.00%
NZ new	< 1.4 l	88 - 92	0.01%	0	0.00%	0	0.00%
NZ new	1.4 - 2.0 l	88 - 92	0.03%	1	0.01%	3	0.01%
NZ new	> 2.0 l	88 - 92	0.01%	1	0.01%	1	0.00%
NZ new	< 1.4 l	93 - 97	0.01%	0	0.00%	0	0.00%
NZ new	1.4 - 2.0 l	93 - 97	0.04%	4	0.04%	7	0.03%
NZ new	> 2.0 l	93 - 97	0.02%	2	0.02%	3	0.01%
NZ new	< 1.4 l	98 - 02	0.00%	0	0.00%	0	0.00%
NZ new	1.4 - 2.0 l	98 - 02	0.01%	0	0.00%	2	0.01%
NZ new	> 2.0 l	98 - 02	0.01%	2	0.02%	2	0.01%
NZ new	< 1.4 l	>= 03'	0.00%	0	0.00%	0	0.00%
NZ new	1.4 - 2.0 l	>= 03'	0.00%	0	0.00%	0	0.00%
NZ new	> 2.0 l	>= 03'	0.01%	0	0.00%	0	0.00%
Total			**23.57%**		**36.00%**		**37.12%**

European and New Zealand								
			default VEPM	Measured RSD fleet, 2011				
				Rodney site		all of Auckland		
1.2 Diesel								
Pre-Euro	< 2.0 l	< '92	0.00%	0	0.00%	0	0.00%
	> 2.0 l	< '92	0.01%	0	0.00%	0	0.00%
Euro 1	< 2.0 l	92 - 96	0.03%	7	0.08%	8	0.03%
	> 2.0 l	92 - 96	0.12%	6	0.07%	11	0.05%
Euro 2	< 2.0 l	97 - 00	0.02%	5	0.06%	9	0.04%
	> 2.0 l	97 - 00	0.14%	12	0.13%	34	0.14%
Euro 3	< 2.0 l	01 - 04	0.04%	5	0.06%	14	0.06%
	> 2.0 l	01 - 04	0.18%	43	0.48%	90	0.37%
Euro 4	< 2.0 l	05 - 09	0.43%	83	0.92%	188	0.78%
	> 2.0 l	05 - 09	0.59%	49	0.54%	179	0.74%
Euro 5	< 2.0 l	10 - 14	0.14%	36	0.40%	111	0.46%
	> 2.0 l	10 - 14	0.22%	28	0.31%	67	0.28%
Euro 6	< 2.0 l	> 2015	0.00%	0	0.00%	0	0.00%
	> 2.0 l	> 2015	0.00%	0	0.00%	0	0.00%
Total			**1.94%**		**3.03%**		**2.95%**
1.3 Hybrid and Electric							
Hybrid		All Years	0.28%	0	0.00%	1	0.00%
Plug-in hybrid		All Years	0.00%	0	0.00%	0	0.00%
Electric		All Years	0.01%	0	0.00%	0	0.00%
Total			**0.29%**				
2.0 Light Duty Vehicles (< 3.5 tonnes)							
2.1 Petrol							
Pre-Euro		< '94	0.23%	55	0.61%	165	0.68%
Euro 1		94 - 97	0.22%	28	0.31%	84	0.35%
Euro 2		98 - 00	0.22%	31	0.34%	85	0.35%
Euro 3		01 - 06	0.32%	99	1.10%	287	1.19%
Euro 4		07 - 10	0.22%	44	0.49%	156	0.65%
Euro 5		11 - 15	0.06%	10	0.11%	21	0.09%
Euro 6		> 2015	0.00%	0	0.00%	0	0.00%
Total			**1.28%**		**2.96%**		**3.31%**
2.2 Diesel							
Pre-Euro		< '94	0.04%	21	0.23%	29	0.12%
Euro 1		94 - 97	0.06%	51	0.56%	112	0.46%
Euro 2		98 - 00	0.25%	61	0.68%	160	0.66%
Euro 3		01 - 06	0.48%	279	3.09%	720	2.99%
Euro 4		07 - 10	1.46%	274	3.03%	661	2.74%
Euro 5		11 - 15	0.53%	18	0.20%	45	0.19%
Euro 6		> 2015	0.00%	0	0.00%	0	0.00%
Total			**2.81%**		**7.80%**		**7.17%**
Grand Total			**29.89%**		**49.78%**		**50.55%**