The development, use and value of a long-term on-road vehicle emission database in New Zealand

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**ABSTRACT**

Vehicle emission standards and management options are continually improving but, with ambient levels of some vehicle-related pollutants remaining stable or increasing in many urban environments, concern is growing that theoretical emissions reductions are not translating into real-world emissions reductions. Remote sensing technology is a useful and cost effective method of collecting large amounts of real-world vehicle emission data. Monitoring campaigns in Auckland, New Zealand, in 2003, 2005, 2009 and 2011, have yielded a database with real-world emissions records for approximately 146,000 vehicles. In this paper we describe the development of the database, and the important features which make it a valuable research and regulatory tool for managing vehicle emissions in New Zealand. We then provide key examples of how the database has been applied to date, including analyses of fleet and emissions trends from 2003 to 2011; comparisons between emissions measured by remote sensing and those predicted using the Vehicle Emissions Prediction Model; and how emission factors derived from the database compare with those used in the Auckland air emissions inventory. We conclude by discussing other potential applications for the database, and plans for its ongoing development and maintenance.

Keywords: Remote sensing, vehicle exhaust emissions, emissions trends, emissions factors, New Zealand

**INTRODUCTION**

Vehicle engine control and emission 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 older ones in the fleet and as fuel quality improves, mean pollutant discharge per vehicle should be reducing. In New Zealand, mandatory emission standards were first introduced in 2003 and linked to a series of major improvements in vehicle fuel quality. The legislation was staged and has required progressively more stringent standards over time. However, it is unknown how much influence (if any) these improvements are actually having on real-world emissions. This information is critical as it determines whether "business-as-usual" policies and trends will likely be sufficient to ensure that environmental standards will be met. Gaining an understanding of how real-world vehicle fleet emissions are changing with time could flag that additional vehicle emission reduction strategies and policies are required.

Internationally, concern is building that the laboratory drive cycle tests used to test and provide type approval for cars in Europe do not accurately reflect on-road emissions (Weiss et al. 2012). The UK and Japan are already calling for the development and adoption of more realistic drive cycles to better reflect real-world driving conditions, particularly with regards to nitrogen oxides (NOx) emissions from diesel vehicles (DEFRA 2011; JAMA 2011).

Road-side vehicle emission monitoring using remote sensing device (RSD) technology is recognised internationally as a useful and cost effective method of collecting large amounts of real-world vehicle emission data. Monitoring programmes have been undertaken in Europe, UK, USA, China, Australia and New Zealand. Remote sensing is employed by a number of environmental authorities in the USA to enforce and assess the effectiveness of vehicle inspection and maintenance programmes (e.g., Bishop and Stedman 2005). The California Air Resource Board (CARB) has evaluated remote sensing for improving California's smog check programme (CARB 2008). RSD data have been used to assist in evaluation of Denver's vehicle emissions inventory (Pokharel et al. 2002).

RSD monitoring has numerous benefits compared with a dynamometer testing programme which tests a 'tame fleet' in a simulated drive cycle. Sampling takes less than one second per vehicle, allowing up to 2000 vehicles to be monitored each hour, compared with approximately 30 minutes to complete a single Inspection/Maintenance-240-seconds (IM240) tailpipe setup and test. The RSD monitor is also unobtrusive because there is no physical connection to the vehicle and no specific behaviour is required of the driver.

There are, of course, limitations with RSD monitoring as follows:

- Vehicle emissions are measured at a single point (generally under slight acceleration) as opposed to integrating the emissions for a series of driving events (which also include decelerations and steady state behaviour), and therefore may not represent average emissions over a full drive cycle.
- The monitoring sites used are single lane on- or off-ramps, arterial roads, or one way streets. Measured emissions therefore reflect driving conditions that predominate on these roadways, and may not necessarily represent emissions generated for other roadways (e.g., busy intersections, or suburban roads where vehicles operating under cold start conditions may be more common).
- Particulate emissions measurement using open path technology is still evolving, and is unlikely to be as accurate as measurements by a dynamometer set up.
- With the RSD, it is not possible to get under the bonnet of the vehicles to inspect the on-board diagnostic systems and identify any possible causes of high emissions.

The RSD measures emissions just above road level, so emissions from vehicles that discharge exhaust vertically (e.g., some heavy duty trucks) cannot be measured. Light duty vehicles that discharge exhaust gases sideways can be measured by the RSD. However, the capture rate of valid measurements for these vehicles may be a little lower than for vehicles that discharge backwards.

Consequently, data provided by an RSD programme will not be identical to those obtained from dynamometer drive cycle testing. However, they may be more reflective of actual on-road emissions, especially with regards to trends over time. Remote sensing has been used in four separate campaigns in Auckland between 2003 and 2011 to collect vehicle emission data. This paper:

- Describes the development of the real-world vehicle emission database and the important features which make it a valuable research and regulatory tool for managing vehicle emissions in New Zealand;
- Illustrates the usefulness of the database using key examples of how the database has been applied to date; and
- Discusses other potential applications for the database and plans for its on-going development and maintenance.
DEVELOPMENT OF THE DATABASE

This section outlines how and when the measurements were made, how the data were analysed, and what the resultant database covers.

On-road measurements

The RSD system was originally developed by Donald Stedman and his team at the Fuel Efficiency Automobile Test Data Centre (FEAT), University of Denver, Colorado, USA and is described in detail in Williams et al. (2003). Two (slightly) different models of RSD equipment were used for the Auckland campaigns: the RSD 3000 in 2003 and the RSD 4000EN for the three subsequent campaigns.

The system consisted of an infrared (IR) detector for measuring carbon monoxide (CO), carbon dioxide (CO2) and hydrocarbons (HC), together with an ultraviolet (UV) spectrometer for measuring nitric oxide (NO) and uvSmoke (for the RSD 4000EN).

The source/detector module (SDM) was positioned on one side of the road, with a corner cube reflector on the opposite side. Beams of IR and UV light were passed across the roadway into the corner cube reflector and returned to the detection unit. The light beams were then focused onto a beam splitter, which separated the IR and UV components which were then sent to the respective detectors.

The path length and density of the observed plume vary considerably between vehicles and depend on (among other things) the height of the vehicle’s exhaust pipe, wind, and turbulence behind the vehicle. For these reasons, the remote sensor can only directly measure ratios of CO, HC or NO to CO₂. These ratios are constant for a given exhaust plume, and on their own are useful parameters for describing the combustion products discharged from the vehicle.

Both RSDs used in the Auckland campaigns reported the %CO, ppm HC and ppm NO in the exhaust gas, corrected for water vapour and excess oxygen not used in combustion. In the 2003 campaign, particulate emissions were measured via an opacity measurement. From 2005 onward, particulate emissions were measured by a UV detector to provide a parameter denoted uvSmoke. A detailed technical description of the way the RSD 4000EN measures particulate pollutants can be found in Stedman and Bishop (2002).

The RSD 4000EN also included speed and acceleration bars which provided information about the driving conditions of the vehicles at the time of the measurements. The bars were set up as close as practical (~2 m) to the SDM to minimise any changes in speed and acceleration prior to a vehicle’s emissions being measured. These data were also used to derive a vehicle performance measure, vehicle specific power (VSP). VSP is a measure of the load on a vehicle as it drives along and is defined as the power per unit mass to overcome road grade, rolling resistance, aerodynamic resistance, and internal friction.

Vehicle information

The RSD system included video equipment to record freeze-frame images of the licence plate of each vehicle measured. The camera images were integrated into the RSD’s monitoring data file. Following each day’s monitoring, licence plate images for vehicles with valid emission measurements were viewed and transcribed into a text file. This list was then submitted to the New Zealand Transport Agency (NZTA)’s vehicle register (Motochek) to obtain supporting information for each vehicle.

The main vehicle parameters recorded in the database were year of manufacture, fuel type, engine capacity, vehicle type, country of first registration, gross vehicle mass and odometer reading. The full list of variables available for each vehicle from Motochek can be found at http://www.nzta.govt.nz/motochek/help.html.

Monitoring campaigns

Campaigns to measure vehicle emission using remote sensing were undertaken in Auckland in 2003, 2005, 2009 and 2011. Each campaign involved multiple agencies, including the Auckland Regional Council (ARC) from 2003 to 2009, the newly-formed Auckland Council (AC) in 2011, and NZTA, Ministry for Transport (MoT), and National Institute of Water and Atmospheric Research (NIWA).

The database contains a complete record of all RSD measurements made in Auckland between 2003 and 2011 (approximately valid 146,000 records). Table 1 shows only the monitoring sites that were common to the most recent three or all four campaigns, and presents the valid readings (and the number of individual vehicles) recorded for each of those sites. Figure 1 shows the locations of these sites.

Additional sites beyond those detailed in Table 1 were monitored in 2003 and 2005. These sites could not be monitored in subsequent campaigns as they had been either upgraded to more than one lane, installed with ramp metering signals which interrupted the traffic flow, or no longer existed. Details of all sites and the total number of vehicles monitored in 2003 and 2005 are provided in Fisher et al. (2003) and Bluet et al. (2010) respectively.

### Table 1. Monitoring sites common to the most recent three or all four (2003, 2005, 2009 and 2011) campaigns.

<table>
<thead>
<tr>
<th>Site No</th>
<th>Site Name</th>
<th>2011</th>
<th>2009</th>
<th>2005</th>
<th>2003</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Lagoon Dr</td>
<td>4,045</td>
<td>4,437</td>
<td>7,785</td>
<td>3,884</td>
</tr>
<tr>
<td>2</td>
<td>Lambie Dr</td>
<td>930</td>
<td>1,339</td>
<td>4,295</td>
<td>2,379</td>
</tr>
<tr>
<td>3</td>
<td>Universal Dr</td>
<td>2,052</td>
<td>5,385</td>
<td>2,545</td>
<td>n/a</td>
</tr>
<tr>
<td>4</td>
<td>West End Rd</td>
<td>1,133</td>
<td>1,066</td>
<td>2,555</td>
<td>n/a</td>
</tr>
<tr>
<td>5</td>
<td>Whangaparaoa Rd</td>
<td>9,213</td>
<td>3,826</td>
<td>3,850</td>
<td>n/a</td>
</tr>
<tr>
<td>6</td>
<td>Elliot St</td>
<td>1,349</td>
<td>1,342</td>
<td>1,367</td>
<td>1,447</td>
</tr>
<tr>
<td>7</td>
<td>Upper Harbour Highway</td>
<td>5,660</td>
<td>5,558</td>
<td>2,992</td>
<td>1,937</td>
</tr>
<tr>
<td>Total valid readings</td>
<td>24,382</td>
<td>22,953</td>
<td>25,389</td>
<td>9,647</td>
<td></td>
</tr>
<tr>
<td>Total individual vehicles*</td>
<td>20,895</td>
<td>21,383</td>
<td>23,310</td>
<td>9,338</td>
<td></td>
</tr>
</tbody>
</table>

* 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 1. Map of Auckland showing the RSD monitoring sites common to the most recent three or all four (2003, 2005, 2009 and 2011) campaigns.
In addition to the four Auckland light duty campaigns, a campaign was run in 2005 targeting heavy duty diesel (HDD) vehicles (>13,500 kg). The HDD campaign measured emissions for approximately 400 buses and 1,300 trucks and is discussed in Bluett et al. (2010a). The HDD and bus measurements are included in the database. Remote sensing was also undertaken in Wellington during 2006, and the data will be incorporated into the Auckland database. As data for future campaigns in Wellington and other cities are added, the database will increasingly become of national significance. This will provide an opportunity to study national real-world vehicle emissions, not just for Auckland.

Data quality assurance
Quality assurance calibrations and audits were performed in the field to ensure the quality of the data collected met specified standards. These calibrations and audits were performed according to the equipment manufacturer’s specifications and these are described in Kuschel et al. (2012). The equipment manufacturer also specifies criteria which must be met before any measurement can be deemed valid.

Engine load is a function of vehicle speed and acceleration, the slope of the site, vehicle mass, aerodynamic drag, rolling resistance and transmission losses. Under moderate to heavy acceleration, vehicle engines will enter enrichment modes that can increase emissions many times. These readings may bias the average results, and the vehicles may be incorrectly classified as high emitters. Heavy braking can also distort results. Therefore, it was useful to have a vehicle performance measure to screen out measurements of vehicles operating outside of normal steady state conditions. The emissions data from a vehicle were only considered valid if the corresponding VSP values fell between zero and 40 kW tonne⁻¹. Other criteria used to assess the validity of data are described by Stedman and Bishop (2003).

Statistical tools/techniques for data analysis
Emissions data from vehicles are not normally-distributed. They are highly skewed with many low values and relatively few high values. The non-normal distribution of the vehicle emission datasets collected can be accounted for by using appropriate statistical methods. The Kruskal-Wallis (K-W) test of significant differences was used to analyse the emissions measurements. The K-W test is a non-parametric one-way analysis of variance which handles the skewed nature of the data and provides statistically defensible conclusions.

Like all scientific instruments, the RSD has some uncertainty or error associated with its measurements. When measuring pollutants from newer (typically lower emitting) vehicles, concentrations are frequently close to or at zero. The method employed by the RSD to calculate pollutant concentrations means concentrations close to zero may be recorded as negative. While in reality there is no such thing as a negative concentration, negative values produced by the RSD remain valid (provided the quality assurance criteria are met) as they reflect measurement uncertainty and provide a useful indicator of instrument noise. When analysing the RSD data, we retained all valid negative data when calculating means and medians etc. However, for ease of display and interpretation, the box plots which show the emissions measurements show only the positive data.

Structure and content of the database
The RSD and Motochek data sets for all four campaigns were consolidated into a Microsoft Access™ database, with a total file size of 570MB. 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 HDD campaign (210,384 records). Key fields in this table include site name, date and time measurements are included in the database.
of measurements, pollutant concentrations, and licence plate (Table 2). The Vehicles table holds all available information obtained from Motechek 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 (Table 3).

Additional database tables hold lookup or reference data, structured so as to provide a natural repository for metadata relating to each annual campaign, sites within each campaign, and RSD emission log files associated with each site. These tables allow new data (e.g., from new RSD on-road measurements) to be stored in a systematic and controlled manner. They include:

- A master table with one entry for each annual campaign - including basic metadata (e.g., year, project code, notes and comments), and a hyperlink to the appropriate report;
- A table with one entry for each monitoring site - including name, site code, type, slope, and (potentially) GPS map coordinates;
- A table with one entry for each RSD emission log file - including site code, date, log file name, and any relevant comments;
- Lookup tables (mostly imported from Motechek) for selected fields in the Motechek database (e.g., vehicle type, fuel type, country codes).

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 (e.g., by passing through one or more sites for several times during the same day) and can easily generate spurious duplicate records if queries are incorrectly formulated.

Data ownership and availability

The ownership of the data within the on-road vehicle emission database rests with the organisations which funded each of the specific monitoring campaigns - 2003 (ARC and NIWA), 2005 (ARC), 2009 (NZTA, ARC and NIWA) and 2011 (AC). The database was developed and is hosted by NIWA. Discussion is underway between NIWA and database stakeholders for the on-going management and maintenance of this resource as well as access to and use of the database by interested third parties.

APPLICATIONS OF THE ON-ROAD VEHICLE EMISSION DATABASE

The 2003-2011 data have been widely used to characterise the type of vehicles that constitute Auckland’s real-world vehicle fleet, and to quantify their emissions. This section illustrates the utility of the database by showcasing some of the applications to date.

<table>
<thead>
<tr>
<th>Year</th>
<th>No of vehicles</th>
<th>% of total fleet</th>
<th>Mean Age (yrs)</th>
<th>No of vehicles</th>
<th>% of total fleet</th>
<th>Mean Age (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>8,169</td>
<td>87.5%</td>
<td>9.1</td>
<td>1,164</td>
<td>12.5%</td>
<td>8.7</td>
</tr>
<tr>
<td>2005</td>
<td>19,876</td>
<td>85.3%</td>
<td>9.5</td>
<td>3,419</td>
<td>14.7%</td>
<td>9.2</td>
</tr>
<tr>
<td>2009</td>
<td>18,044</td>
<td>84.5%</td>
<td>10.0</td>
<td>3,317</td>
<td>15.5%</td>
<td>9.0</td>
</tr>
<tr>
<td>2011</td>
<td>17,646</td>
<td>84.5%</td>
<td>10.7</td>
<td>3,239</td>
<td>15.5%</td>
<td>9.3</td>
</tr>
</tbody>
</table>

Trends in the light duty vehicle age and fuel type – 2003 to 2011

Vehicle age and fuel type influence emissions. The level of emissions control technology installed tends to be correlated with year of manufacture, although this correlation is less pronounced in New Zealand where emissions control standards have been in place only since 2003. In addition, as a vehicle ages, emissions performance tends to degrade as parts or systems wear. Fuel type is another important emissions determinant, as vehicles using different fuel types emit pollutants in different proportions.

The database was used by the Auckland Council to investigate trends in age and fuel type of Auckland vehicles between 2003 and 2011. Table 4 compares the proportion and mean ages of petrol and diesel light duty vehicles in the monitored fleet from 2003 to 2011.

The proportion of petrol vehicles decreased slightly from 2003 to 2009 but did not appear to change from 2009 and 2011. This is consistent with trends seen in the New Zealand light fleet overall which show 85.4% petrol vehicles in 2005 and minimal change between 2009 and 2010 with the proportion holding steady at 84.7% of the total (MoT 2011). The proportion of diesel vehicles increased from 12.5% in 2003 to 15.5% in 2009 and 2011.

Petrol vehicles tended to be older than diesel vehicles over all four campaigns and the petrol vehicle fleet appears to aging more quickly than the diesel vehicle fleet (Table 4). Mean age of the petrol fleet increased by 1.6 years (from 9.1 to 10.7 years) from 2003 to 2011, compared to only 0.7 years (from 8.7 to 9.3 years) for the diesel fleet over the same period.

An aging vehicle fleet indicates that vehicles with older (or no) emission control technology are being retained within the fleet for longer periods. The implication of this aging trend is that potential emission reductions provided by new vehicle emission control technology are being slowed or even stalled.

Trends in light duty vehicle average emissions – 2003 to 2011

The database has also been used by the Auckland Council to investigate trends in Auckland light duty vehicle emissions from 2003 to 2011. Figure 2 uses box and whisker plots to compare emissions of CO, HC, NO and uvSmoke from light duty petrol and diesel vehicles from 2003 to 2011. The upper and lower limits of the central box show the upper and lower quartiles. Thus, the box contains the central 50 per cent of the raw data. The whiskers represent the 5th and 95th percentile values. More extreme data values, possibly extending well beyond the maximum axis value, are suppressed. Red circles show the mean, whilst the median is represented by the line across the waist on each box. The width of the box represents the relative number of measurements for each year.

Mean emissions of CO, HC and NO decreased significantly from 2003 to 2011. uvSmoke emissions were not measured in 2003 but the trend from 2005 to 2011 shows a reduction similar to that for the other three pollutants (Figure 3). However, the rate of improvement for all pollutants has slowed since 2009, even allowing for the four year gap between the 2005 and 2009 campaigns. Relative to 2003, an average vehicle in the overall light fleet in 2011 now emits:

- 54 per cent of the CO
- 39 per cent of the HC
- 61 per cent of the NO

Relative to 2005, an average vehicle in the overall light fleet in 2011 emitted:

- 81 per cent of the uvSmoke

Median emissions of CO, HC and NO have all shown a downward trend since 2003. As seen with the mean values, the rate of improvement in median values of CO and HC has slowed in the last campaign. However, the rate of reduction in median NO value continues to improve. Median uvSmoke reduced between 2005 and 2009 but increased marginally in 2011.

Trends in petrol fleet emissions are similar to those seen in the overall fleet, while trends in the diesel fleet over time are quite different to those seen in the overall fleet. Mean emissions of CO, HC and uvSmoke decreased from the diesel fleet between 2003 and 2009, whilst mean NO emissions held more or less steady. In 2011, mean emissions of CO, HC and uvSmoke held steady but there was an increase in NO. The increasing NO emissions from the diesel fleet suggest that, despite increasingly tighter emissions requirements for vehicles entering the fleet, current standards are not delivering the expected improvements in actual emissions. This situation has human health impact implications and suggests that future emissions requirements
should be based on standards set for, and more representative of, real-world driving conditions.

Comparison of modelled and real-world vehicle fleet emissions

The Vehicle Emission Prediction Model (VEPM) (Jones et al. 2011) has been developed by the Auckland Council and NZTA to quantify vehicle emissions, and predict how these are likely to change over time. 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 VEPM is necessarily based on a relatively limited number of test results, which have been extrapolated to represent the whole fleet. If VEPM is to provide useful and realistic information, emissions estimates should be checked against real-world data. One way of doing this is to compare modelled and RSD measured vehicle emissions.

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

The database was used by NZTA to compare the trends over 2003 and 2011 in real-world emissions and VEPM predicted emission factors for Auckland’s light duty vehicle fleet. Figure 3 compares measured CO concentrations from the on-road light duty fleet with the fleet weighted CO emission factors predicted by VEPM (default settings) for the years of the four monitoring campaigns. Agreement between fleet average trends predicted by VEPM and measured trends in average vehicle emissions is good. Both sources show average emissions reducing from 2003 to 2011, with relative reductions of 46% and 44% for the RSD and VEPM results, respectively.

Trend analyses for HC, NO and PM were also undertaken by NZTA. The level of agreement between the two data sources is generally retained but with the following two exceptions:

- The trend in measured NO emissions (increasing) is contrary to the trend in predicted NOx emission factors (reducing) from diesel vehicles.
- The measured reduction in \(uvSmoke\) emissions is less than the predicted reduction in PM10 emissions factors, especially for diesel vehicles.

These two results highlight potential areas for investigation which could lead to an improvement in VEPM’s ability to predict future vehicle emission scenarios.

Validation of emission factors

Following the NZTA work that compared trends over time for RSD and VEPM predicted emission factors, Auckland Council commissioned a study which converted the on-road measurements into VEPM comparable g km\(^{-1}\) emission factors. The aim of this work was to help validate VEPM predictions. The method used was developed by FEAT at the University of Denver to convert the 2005 Auckland RSD data into emission factors measured in grams of pollutant per litre of fuel burned (g L\(^{-1}\)). The FEAT conversion is based on the stoichiometry of fuel combustion, described in detail by Pokharel et al. (2002), and has been used more recently by Guo et al. (2007), Smit and Bluett (2011) and Rhys-Tyler and Bell (2012).

The emission factors used in the Auckland Air Emissions Inventory 2006 (AC 2011) are expressed in g km\(^{-1}\). The on-road emission factors are expressed in g L\(^{-1}\). To compare on-road emission factors with those used in the Auckland inventory the real-world emission factors (in g L\(^{-1}\)) were converted to g km\(^{-1}\) by employing a fuel efficiency factor (in L 100km\(^{-1}\)). The fuel efficiency factor (in L 100km\(^{-1}\)) needed to make either of these conversions was taken from the VEPM model, as used for the Auckland 2006 inventory.

The RSD measures NO but the Auckland inventory provides estimates of NOx (NO + NO\(_2\) emissions. To compare on-road emission factors with those used in the Auckland inventory the real-world emission factors (in g L\(^{-1}\)) were converted to g km\(^{-1}\) by employing a fuel efficiency factor (in L 100km\(^{-1}\)). The fuel efficiency factor (in L 100km\(^{-1}\)) needed to make either of these conversions was taken from the VEPM model, as used for the Auckland 2006 inventory.
Typical NO/NO₂ ratios are different for petrol vehicles (10%) versus diesel vehicles (20%). There is significant debate about NO/NO₂ ratios in vehicle exhaust. However, the assumptions made for this comparison are considered to provide a sensible first order estimate which enables the comparison between RSD and VEPM NOx emission factors to be made.

Figure 4 compares the fleet average on-road emission factors from the 2005 RSD campaign with VEPM emission factors used for Auckland 2006 emission inventory (AC 2011). These results have not been published elsewhere. The measured fleet composition was used for calculating the on-road emission factor, and the national average fleet composition for the VEPM emission factor. The difference in the fleet compositions was not considered a significant contributor to the difference of the calculated emission factors.

Figure 4 shows:
- Very good agreement between the RSD and VEPM emission factors for HC and NOx;
- On-road emission factors of CO tend to be lower than VEPM emission factors; and
- On-road emissions factors of particulate emissions may contribute to the low particulate emissions factors.

A number of low CO concentration measurements which were recorded as negative values may result in under-estimation of the emissions factors. The uncertainty of using uVSmoke as an indicator of particulate emissions may contribute to the low particulate emissions factors. Despite the encouraging results, the comparison suggests a need to improve our understanding of the relationship between modelled and real-world vehicle fleet emissions.

### THE FUTURE OF THE DATABASE

This section discusses other potential applications for the database and outlines plans for its on-going development and maintenance.

#### Links to policy effectiveness

Since 2003, five reports have been published that chart the development of the emissions database, and present the findings from each RSD monitoring campaign. The first campaign established the viability of roadside vehicle emission monitoring in New Zealand and provided benchmark data for future campaigns (Fisher et al. 2003). The primary 2005 campaign was a flagship initiative of the formal Auckland Regional Council’s public education campaign “The Big Clean Up” (Bluett et al. 2010). A major feature of this campaign was the use of a “smart sign” providing instant feedback to drivers on their emissions. Drivers of gross emitting vehicles were sent follow-up letters advising them of their emission test results together with a discount voucher for a vehicle tune. The secondary 2005 campaign monitored emissions from heavy duty diesel (HDD) vehicles at truck and bus depots and characterised and quantified their emissions (Bluett et al. 2010a).

The primary objective of both the 2009 (Bluett et al. 2011) and 2011 (Kuschel et al. 2012) campaigns was to track trends in the profile of emissions from Auckland’s light duty vehicle fleet. In addition to these five reports, numerous journal and conference papers based on the database have also been published (e.g., Xie et al. 2005; Bluett 2007; Kuschel and Bluett 2007; Kuschel et al. 2011).

Beyond meeting the key aims and objectives of these five campaigns, the database has been used to investigate complementary scientific and emission control policy issues. These issues include, but are not limited to, assessing the effectiveness of emissions legislation and evaluating the potential benefits of implementing future emissions control strategies, including:
- Identifying and profiling gross emitting vehicles (Bluett et al. 2010);
- Investigating whether social deprivation has an influence on vehicle emissions (Bluett et al. 2010);
- Quantifying the influence of improving emission control technology (Kuschel et al. 2010);
- Exploring the influence of vehicle mileage on emissions (Kuschel et al. 2012); and

This work is in the process of moving from individual research campaigns to an on-going monitoring programme in order to adopt the results as a formal indicator of vehicle emissions policy effectiveness. The monitoring campaign should be continued and expanded to centres other than Auckland, and the RSD monitoring could and should be integrated with other environmental and transport monitoring initiatives.

#### Future development and maintenance

Looking back over the ten years that RSD monitoring has been undertaken in New Zealand, the development of the database has hinged on significant multi-organisational collaboration between (mainly) the Auckland Council, NZTA, MoT and NIWA. Each organisation has invested in, and benefited from, the development and use of this extensive database. The database now contains 210,000 records and provides a very valuable research and regulatory tool. The effort and investment to date has created a nationally significant database and New Zealand is one of only a few countries that have a comprehensive longitudinal record of vehicle emissions. For this reason, the New Zealand database also has international significance.

Each campaign is logistically challenging and resource intensive (NZ$100k-200k).
The recommendations made within the NZTA 2011 (Bluett et al. 2011) and Auckland Council 2012 (Kuschel et al. 2012) reports are that roadside remote sensing be undertaken every two years. The next monitoring campaign is still to be confirmed.

**CONCLUSION**

Remote sensing technology is a useful and cost-effective method of collecting large amounts of real-world vehicle emission data. The four light duty monitoring campaigns in Auckland in 2003, 2005, 2009 and 2011 have generated an extensive database which provides a very valuable research and regulatory tool. The database has been widely used to characterise the type of vehicles that constitute Auckland’s real-world vehicle fleet, and quantify their emissions. Comparison of modelled and real-world emissions has also been undertaken. Changes in real-world vehicle fleet emissions reflect the effectiveness of vehicle emission reduction strategies and policies, and can flag that additional regulations may be required.

This paper has described the development of New Zealand’s real-world vehicle emission database, illustrated the value it has provided to roadway regulators and operators and highlighted a number of the limitations and benefits of this type of vehicle data.

It is suggested that stakeholders reflect upon the importance of this database and evaluate the potential value added by an on-going and long-term real-world vehicle emission monitoring programme.

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