Impacts of exposure to dust from unsealed roads

April 2017

(replacing the version released in August 2016)

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NZ Transport Agency research report 590
Contracted research organisation – Golder Associates (NZ) Limited

ISBN 978-0-478-44551-0 (electronic)
ISSN 1173-3764 (electronic)

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Jeff Bluett, Maria de Aguiar and Neil Gimson (2017) Impacts of exposure to dust from unsealed roads. *NZ Transport Agency research report 590.* 104pp.

Golder Associates (NZ) Limited was contracted by the NZ Transport Agency in 2015 to carry out this research.

Keywords: dust PM_{10}, dust suppression, health effects, unsealed roads

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Changes made to version of report published in August 2016

- Order of authors changed to more accurately reflect the relative effort contributed.
- Page 8, paragraph five of the Executive summary – edited to include the 10 year cost estimate.
- Page 8, paragraph six of the Executive summary - edited to update the BCR values as a result of corrected health cost calculations.
- Page 68, table 6.2; page 69, tables 6.3 and 64. Values in all three tables have been updated to reflect corrected health cost calculations.
- Page 69, paragraph 1 - updated BCR values transcribed from updated tables 6.3 and 6.4.
- Page 70, paragraph 1 - number of years a sealed road needs to be used to get a BCR of 1 updated as a result of the revised health costs.
- Page 77, paragraph 2 – information in parenthesis, approximate percentage of days monitored, deleted.
- Page 78, section 8.3 - updated BCR values transcribed from updated tables 6.3 and 6.4.
- Page 95, Appendix D2, Benefit assumptions - corrected health cost calculations incorporated.
- Page 97, Appendix D7, Health costs from dust - corrected health cost calculations incorporated.

In the original version of the report, Golder had incorrectly presented the health costs calculated for the Kiakohe CAU rather than the Ngapuhi-Kaikou CAU within which Mataraua Road is located. A review by Emission Impossible Ltd highlighted the issue and enabled Golder to amend the report. We acknowledge this error and appreciate the opportunity to correct it.

Incorporating the correct health cost calculations into the report has resulted in a slight change to the conclusions. The BCR values have changed (improved) as follows:

- treating the surface of the road with chemical suppressant - BCR has gone from 0.8 to 1.1.
- sealing the surface of the road (40 year use) - BCR has gone from 1.4 to 1.9.
- sealing the surface of the road (10 years use) - BCR has gone from 0.7 to 0.9.

Acknowledgements

A number of people made contributions that were instrumental in the successful completion of project. The project team would particularly like to acknowledge:

- Rob Hannaby (NZTA), Jon Cunliffe (Marlborough District Council), Alan Wallace (Auckland Transport), Frances Graham (Ministry for Health) Greg Haldane (NZTA) and Iain McGlinchy (Ministry of Transport) for their valuable guidance and suggestions as members of the project Steering Group.
- Far North District Council for hosting the dust monitoring programme, supply of traffic data, liaising with the residents of Mataraua Road and liaising with forestry transport companies.
- Transfield Services (Mike Grimshaw, Far North Branch) for supplying the vehicles and personnel needed to apply the dust suppressant and for supply and operation of a vehicle counter.
- Air Quality (Mark Bart and Paul Baynham) for input into the design of the monitoring programme, for commissioning and operation of the equipment and processing the monitoring data.
- Dust Control Solutions (Anthony Stewart) for advice on dust suppressant type and for supplying the dust suppressant.
- Kaingahoa Marae (Jane Whiu), Tasha Whiu, Doug Boyd, Colin Pinkney for hosting the monitoring equipment on their Mataraua Road properties.
- Northland Regional Council for assistance with clarifying the activity status of applying the dust suppressant.
- Professor Andrew Sturman (University of Canterbury) and Simon Harris (Land Water People Ltd) for their very helpful peer reviewer feedback.

Contents

Executive summary

The primary purpose of this research was to improve the understanding of the impacts dust emissions from unsealed roads have on people, and to identify environmentally sustainable and financially cost-effective mitigation measures likely to be effective at reducing those impacts.

The key research objectives of the project were to:

- characterise the dust from unsealed roads and quantify its impacts on people
- determine the effectiveness and cost of available dust mitigation measures
- estimate the costs of the health impacts of dust from unsealed roads and estimate the benefits of mitigating the dust
- propose a methodology to support decision making about mitigation options.

A two-month monitoring campaign was undertaken to characterise the road dust and quantify the potential impacts on people of dust from unsealed roads. The monitoring was undertaken during February, March and April 2015 on a section of Mataraua Road, 10km southwest of Kaikohe in the Far North District.

The meteorology of the monitoring site is an important factor to consider when interpreting the dust data. For this reason, wind speed, wind direction, temperature, relative humidity and rainfall were therefore monitored on-site for the duration of the field campaign.

The traffic monitoring showed distinct weekday and weekend diurnal patterns for light duty vehicles (LDVs) and heavy duty vehicles (HDVs), which included a relatively high proportion of HDVs during weekdays and a relatively low proportion of HDVs during the weekend. While the legal speed limit on the road was 100km/h the average speed of the vehicles passing through the monitoring site was approximately 50km/h.

To assess what fraction of the road dust has the potential to cause adverse effects on humans, data on the total suspended particulates (TSP) and PM_{10} concentrations was compared. PM_{10} was found to comprise approximately 30% of the TSP at locations where people are most likely to be exposed. PM_{10} concentrations measured adjacent to the untreated section of the road were found to exceed the National Environmental Standard (NES) value of 50µg/m^3 for 15 of the 52 days monitored (approximately 30% of days monitored) at locations were people are most likely to be exposed[1]. The monitoring results indicate that dust discharged from untreated unsealed roads has the potential to cause adverse effects on human health.

Measurements across the PM_{10} monitoring network show the effect of the untreated road PM_{10} dust plume extends further than 80m from the roadside, while the effect of the PM_{10} plume from the treated section of the road extends for less than 30m.

Dust deposition monitoring showed the deposited dust at the roadside on the untreated section of the road was higher by a factor of between 4 and 12 than the Ministry for the Environment trigger level of 4g/m^2/month (above background levels). Dust deposition monitoring showed the deposited dust on the treated section of the road was no greater than background levels.

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[1] Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

A comparison of the PM_{10} concentrations monitored at the untreated and treated sites show the application of the suppressant significantly reduced the impact of dust discharged from the road.

PM_{10} concentrations measured on the treated section of the road were found not to have exceeded the NES[1] at locations were people are most likely to be exposed. The monitoring results indicate that the potential for adverse impacts on human health due to the dust discharged from unsealed roads treated with dust suppressants is relatively low compared with the effects of untreated road surfaces.

A qualitative assessment of the PM_{10} data measured during the two-month monitoring programme suggests the effectiveness of the dust suppressant did not appreciably decrease over the duration of the monitoring programme.

The total cost of applying a chemical suppressant once per year to an unsealed road was estimated to be $15,000 per km of road.

The total annual cost of sealing and maintaining a road surface was estimated to be $21,000 per year per km of road, assuming a 40-year life and $38,000 per year per km of road, assuming a 10-year life. However, if it was assumed that the forestry resource and the logging truck movements persisted for a period of 10 years on that road the total annual cost increased to $31,000 per year per km of road.

A simplistic approach to estimating the benefit-to-cost ratio (BCR) of mitigating the dust from the section of unsealed road of Mataraua Road showed the cost of:

- treating the surface of the road with chemical suppressant is slightly less than the health benefits gained from the reduction in PM_{10} concentrations (BCR = 1.1)
- sealing the surface of the road is less than the health benefits gained from the reduction in PM_{10} concentrations if the road has a useful life of 40 years (BCR = 1.9).
- sealing the surface of the road is slightly higher than the health benefits gained from the reduction in PM_{10} concentrations if the road has a useful life of 10 years (BCR = 0.9).

Using the experience and data gained during the Mataraua Road dust monitoring and suppression trial a framework was developed to support the decision-making process of any territorial local authority considering whether to mitigate dust from unsealed roads. Three key questions are:

- Is there a need to mitigate road dust?
- What road dust mitigation options are suitable for the site?
- Which mitigation option provides the best benefit-to-cost outcome?

A framework and tools are provided to enable these questions to be answered. A first order assessment of whether there is a need to mitigate road dust for a particular section of road is made by calculating a site dust risk score. The site dust risk score categorises the site as low, medium or high risk. For high risk sites, assessment criteria are provided to define which (if any) dust mitigation measures are suitable for the specific site being considered. An introduction on how to use the information gained from the Mataraua Road monitoring programme to undertake a basic cost-benefit assessment of suitable dust mitigation measures is provided.

Abstract

The primary purpose of this research was to improve our understanding of the impacts that dust emissions from unsealed roads have on people and investigate dust mitigation measures. The project's key research objectives were:

1 Characterise the dust and quantify the impacts of dust from unsealed roads on people.

2 Determine the effectiveness and cost of dust mitigation measures.

3 Estimate the costs of the health impacts of dust and estimate the benefits of mitigating the dust.

4 Propose a methodology to support decision making about mitigation options.

A two month road dust monitoring campaign was undertaken on a section of Mataraua Road, 10km southwest of Kaikohe in the Far North District, during February, March and April 2015.

The monitoring results indicated that potential adverse human health impacts might occur due to the dust discharged from untreated unsealed roads. A comparison of the PM_{10} concentrations monitored at the untreated and treated sites showed that the application of a dust suppressant significantly reduced the impact of dust discharged from the road.

1 Introduction

1.1 Background

Unsealed roads give rise to dust emissions during dry weather conditions when vehicles are travelling along them. Dust is generated mainly by the action of vehicle wheels, which disturbs and entrains fine dust particles from the road surface. The vehicle wheels also act to grind down the road aggregate and create additional fine dust material.

A number of adverse effects can occur from dust arising from unsealed roads, including nuisance, health and ecological impacts. Nuisance dust particles typically comprise the larger size fraction of suspended particles and are referred to as total suspended particulate (TSP – aerodynamic diameter up to 100 microns). The finer size fraction of dust particles with an aerodynamic diameter of less than 10 microns (PM_{10}) are of concern regarding their potential health effects.

Northland Regional Council carried out monitoring in 2013 of PM_{10} within 50m of the roadside of four unsealed rural roads, which highlighted the potential health effects associated with exposure to dust from unsealed roads (NRC 2014). The monitoring indicated that the National Environmental Standard (NES) for PM_{10} was exceeded, and was related to dry weather conditions and peaks in traffic volume. The health effects of these particles for prolonged periods are predominantly respiratory and cardiovascular related, with symptoms including coughs, chronic bronchitis, exacerbation of asthma and post-neonatal respiratory mortality.

New Zealand’s roading network contains a significant proportion (approximately 40%) of unsealed roads. In districts that cover large areas and have relatively small populations the proportion of unsealed roads can be much higher. For example:

- Far North District Council: 2,542km of roads, 1,800km (71%) unsealed
- Wairoa District Council: 830km of roads, 550km (66%) unsealed
- Marlborough District Council: 1,527km of roads, 641km (42%) unsealed
- Hurunui District Council: 1,454km of roads, 853km (59%) unsealed

Many unsealed roads are in use to service sparsely populated rural areas. However, these rural areas are increasingly being divided into smaller ‘lifestyle blocks’, resulting in a greater number of people being exposed to dust associated with unsealed roads. Furthermore, houses associated with lifestyle blocks or new farm houses tend to be built relatively close to the road in order to minimise costs (of power and phone supply, for instance), unlike many of the original farm houses that were typically set well back from an unsealed road. Consequently, district health boards and local residences have expressed concern and asked for relief from high levels of dust exposure from unsealed roads.

Some districts have a high proportion of unsealed roads, which would incur a significant cost to seal in order to control dust impacts. This has been cited as being ‘an unrealistic prospect’ (Laird 2013) in many cases. Waste oil has been used in the past to suppress dust emissions from unsealed roads. However, the environmental and health risks associated with using waste oil for dust control are significant and the practice is not environmentally sustainable. Consequently, there is a need for effective dust mitigation measures that are environmentally sustainable and a cost-effective alternative to sealing roads.

There is a limited amount of published information that can be used to understand the impacts of dust from unsealed roads and to quantify the costs of the impacts on the community and the environment. This is in contrast to the construction, mining and quarrying industry sectors, where there is a large amount of information on dust control and impacts on air quality. However, the information relating to these sectors does not readily apply to controlling dust impacts from rural unsealed roads. Accordingly, there is a need to better understand the potential health and ecological effects of dust from unsealed roads, the measures that can be used to mitigate the impacts effectively, and the financial costs and benefits of these mitigation measures.

1.2 Legal framework for managing dust emissions in New Zealand

The Ministry for the Environment's (MfE 2015) draft *Good practice guide for assessing and managing dust* provides a useful commentary on the legal framework for managing the effects of dust emissions in New Zealand. MfE (2015) provides an overview of the roles and responsibilities of the central and local government bodies in managing the effects of dust in New Zealand (this framework is largely unchanged from that described in the original MfE (2001) Good practice guide). To put this road dust project into the context of the relevant environmental management, we quote from a MfE (2015) overview:

> *Primary responsibility for discharges to air, including discharges of odour and dust, lies with the source of the discharge (i.e. the discharger). This is true whether the source is a private motor vehicle, a domestic wood burner or a large factory.*
>
> *In addition to this, regional councils and territorial authorities have certain responsibilities for managing discharges to air, including those that may cause offensive or objectionable dust.*
>
> *Under the RMA, regional councils (and unitary authorities) have primary responsibility for regional management of discharges of contaminants into the air. In practical terms, this means regional councils are responsible for:*
>
> - *Considering the potential effects of dust discharges to air in planning and resource consent processes;*
> - *Monitoring compliance with resource consent conditions applied to dust*
> - *Responding to complaints about offensive or objectionable dust.*
>
> *As noted above, whilst regional councils are responsible for responding to dust complaints – primary responsibility for the dust emission still rests with the source of the dust (i.e. the discharger).*
>
> *Regional councils will often encourage or facilitate discussions between the discharger and affected communities. However, if there is no agreement and the issue cannot be resolved then regional councils should ensure that the effects are assessed using the methods discussed in section 4 and appropriate action is taken in accordance with the RMA.*
>
> *Territorial authorities have responsibilities for dust discharges under both the RMA and the Health Act 1956. Under the RMA they must consider the effect of land-use decisions on amenity and effects of the land transport system. They are also responsible for protecting public health and preventing nuisances under the Health Act. As such, territorial authorities employ environmental health officers to monitor and take enforcement action to abate conditions likely to be injurious to health or offensive, as well as to abate nuisances.*

As outlined above, Regional Councils consider national guidance and local circumstances to determine policy and shape plan provisions intended to manage dust emissions under the RMA. Over and above any

Regional Council requirements, Section 17 of the RMA states that "Every person has a duty to avoid, remedy, or mitigate any adverse effect on the environment arising from an activity carried on by or on behalf of the person……". This duty puts responsibility for managing dust emissions on the users of roading networks in New Zealand. However, as responsible neighbours and the managers of the road, road controlling authorities should endeavour to work with industry to help them manage dust emissions.

As the developer and operator of the roading networks within their respective districts, the relevant territorial local authority (TLA) has responsibility for managing the dust discharged from public unsealed roads.

1.3 Research purpose

The primary purpose of this research was to improve the understanding of the impacts dust emissions from unsealed roads have on people and to identify environmentally sustainable and financially cost-effective mitigation measures likely to be effective at reducing those impacts.

This information is intended for use by the New Zealand Transport Agency (the Transport Agency) and other agencies responsible for road transport in making decisions regarding measures that could be implemented for reducing exposure to dust from rural unsealed roads.

1.4 Research objectives

The key to the success of this project was to consolidate existing information and experience, and enhance this by carrying out new research. The project aimed to achieve the following research objectives:

1 Describe and quantify the impacts of dust exposure from unsealed roads by reviewing New Zealand and international literature.

2 Quantify the impacts of dust from unsealed roads on people, by undertaking research to characterise the dust and collecting new data.

3 Determine the effectiveness and cost of available dust mitigation measures. Consider other impacts of the mitigation measures.

4 Estimate the costs of the health impacts of dust from the unsealed road and the benefits of mitigating the dust.

5 Propose a methodology to support decision making about mitigation options.

1.5 Overview of method

There were five principal tasks which together formed the methodology for this project:

1 Review the literature

2 Design dust suppression and dust monitoring trial

3 Undertake dust suppression and dust monitoring trial

4 Develop a dust suppression and dust monitoring database

5 Analyse the database to determine exposure and effectiveness of dust suppressants.

1.6 Project outputs

The key outputs from the research were the following:

- A review of the state of knowledge internationally on dust impacts from unsealed roads and their mitigation.
- A methodology for quantifying the impacts of dust emissions on air quality, partitioning between unpaved road sources and rural background levels.
- A database containing the results from the dust monitoring programme.
- A report which presents:
  - a summary of the literature review.
  - a description of and results from the dust monitoring programme.
  - a comparison of dust concentrations from untreated and treated unpaved road surfaces.
  - estimates of health costs of dust from untreated unpaved road surfaces and estimates of the potential health benefits of treating unpaved road surfaces.
  - a methodology to support decision making around dust mitigation options.
- A presentation to a wide range of stakeholders and publication of the report in the Transport Agency research database.

In addition to the key project outputs, two complementary data streams were collected which are available for analysis:

- four filter samples of road dust suitable for speciation analysis
- video record of the vehicles passing through monitoring sites.

Issues specifically excluded from the project scope were:

- indoor air quality effects arising from dust exposure from unsealed roads
- effects on other users of unsealed roads such as cyclists, walkers or horse riders
- quantitative analyses of the effect of vehicle numbers and meteorology on PM_{10} concentrations
- a business case analysis (BCA) for the suppression of dust from unsealed roads as defined in the *Economic evaluation manual* (EEM) (NZ Transport Agency 2013).

1.7 Structure of the report

The report is structured as follows:

- Research objective 1:
  - Chapter 1 summarises the New Zealand and international literature used to describe and quantify the impacts of dust exposure from unsealed roads.
- Research objective 2
  - Chapter 3 describes the collection of data used to characterise the dust and quantify the impacts of dust from unsealed roads.
  - Chapter 4 characterises the dust and quantifies the impacts of dust from unsealed roads.

- Research objective 3:
  - Chapter 5 determines the effectiveness and the costs of the dust mitigation measure and discusses other issues to consider when selecting the most appropriate dust mitigation measure.
- Research objective 4:
  - Chapter 6 estimates the costs of the health impacts of dust from unsealed roads and the benefits of mitigating the dust.
- Research objective 5:
  - Chapter 7 details a methodology that can be used to support decision making about mitigation options.

1.8 Project limitation

The results presented in this report are specific to the sites at which the monitoring was undertaken. Road dust concentrations will vary from site to site and reflect the construction and geology of the roadway, the number, vehicle speed and types of vehicles using the road and the local meteorological conditions.

Therefore caution must be taken when generalising the results to other roads and areas. The transferability of the results to other roads and areas will be considered in the conclusions and recommendations of this report (see chapters 8 and 9).

2 Literature review

The information presented in this section addresses research objective number 1:

- Describe and quantify the impacts of dust exposure from unsealed roads by reviewing New Zealand and international literature.

2.1 Nature and composition of dust from unsealed roads

2.1.1 Nature of road dust

An overview of dust-generating processes, impacts, costs and controls of road dust is given in a report by Jones (2000). This report pertains to South Africa, which has a large amount of unpaved roads, and describes a process of suspension of dust, which begins with a loss of fine particles (which bind the coarser particles together), and is followed by suspension of coarser particles, leaving potholes and corrugations in the surface. The loss of fine particles results from around one-third of the dust being blown away by the wind, while most of the dust re-settles, to be re-entrained later.

2.1.2 Composition and size distribution

The World Health Organisation (WHO) assumes road dust is in the particulate material (PM) size range from 1µm to 100µm in diameter (WHO 2006). Williams et al (2008) measured vehicle-generated dust on an unpaved road, finding particles in the size range from 0.05µm to 159µm. Samples were composed largely of silt and clay, dominated by the elements carbon, aluminium and silicon. They noted a sensitivity of the $PM_{2.5}$ fraction to vehicle speed, but this was not the case for PM in the range 2.5µm to 10µm. The United States Environmental Protection Agency (USEPA) estimates that PM_{10} is approximately 30% of TSP and $PM_{2.5}$ is approximately 10% of PM_{10} in fugitive dusts arising from unsealed roads (USEPA 2006a).

Organiscak and Reed (2004) surveyed dust from mine haulage roads, finding 10% of PM up to 6µm in diameter, 15% of PM up to 10µm in diameter, and 60% of PM up to 25µm in diameter. The authors stated that the majority of the PM was 'non-respirable' (the particles being greater than 10µm in diameter).

Gunawardana et al (2012) characterised road dust from different land-use types in Australia, according to composition. They found the dust was composed of soil-derived minerals (60%, including quartz 40–50%), clays from surrounding soils (38%) and 2% plant matter. They found soil-derived minerals containing iron, aluminium and manganese, with other metals – zinc, copper, lead, nickel, chromium and cadmium – arising from brake and tyre wear.

2.1.3 Summary

Publications in the open literature on the nature, composition and size distribution of road dust are not in plentiful supply. While the work by Jones (2000), mentioned above on the nature of road dust, appears to be generic, work on the composition and size distribution of suspended dust particles is specific to the composition of the road surface, the nature of the surrounding off-road surfaces, and the type of vehicles using the road. A large range of particle sizes can be generated, while the particles can be dominated by crustal, soil and plant-matter components in addition to non-tailpipe emissions from vehicles.

2.2 Effects of unpaved road dust

2.2.1 Human health effects

The health effects, both short (acute) and long term (chronic), of $PM_{2.5}$ and PM_{10} are well documented, and occur at concentrations well below current guideline values (WHO 2006; WHO 2013). Evidence is increasing for the adverse effects on health of fine particles (<$PM_{2.5}$), with short-term effects of $PM_{2.5-10}$ being observed independently of the effects of $PM_{2.5}$. In addition, there is increasingly strong evidence linking long-term exposure to PM_{10} with health effects, especially for respiratory outcomes. Coarse and fine particles deposit at different locations in the respiratory tract, have different sources and composition, act through partly different biological mechanisms, and depending on the physiology and age of the person, result in different health outcomes. On the whole, health benefits may be gained from the reduction in long-term mean concentrations of $PM_{2,5}$ and PM_{10} to levels far below the current guidelines.

Particulate matter includes both solid and liquid phase material suspended in the atmosphere. As mentioned above, airborne dust from unsealed roads has a range of particle sizes from around 1μm to 100μm in diameter. However, in practice, particles with diameters greater than 20μm to 30μm do not last long in the atmosphere, as they tend to fall out rapidly and settle. The remaining PM_{10} and $PM_{2.5}$ are important from a health point of view because they are sufficiently small to penetrate the thoracic region of the lung (PM_{10}) and have a high probability of deposition in the smaller conducting airways and alveoli ($PM_{2.5}$).

A list of potential effects of dust is given by MfE (2015), which includes eye irritation, silicosis due to respirable quartz and health impacts of toxic metals. There is a lot of uncertainty around attribution of individual sources to health effects, although combustion source and road traffic have more certain causative outcomes (Adams et al 2015). It is difficult to pinpoint health effects due to unpaved road dust emissions, as emissions are intermittent, they are highly seasonal and a low number of people are exposed.

Moreover, WHO (2013) points out that it is difficult to quantify the effects of individual chemical components, such as black carbon, metals, secondary sulphates and nitrates and organic components. It also states that coarse particles may be as toxic as fine particles on short time scales, even though the biological mechanisms are different, and that long-term exposure effects can occur through the progression of underlying diseases, not just the exacerbation of short-term effects. WHO (2013) has little to say specifically about road dust as a source in itself. However, there is evidence of health risks due to toxic metals, which are contained in dust (from paved and unpaved roads) and desert dust, even though there are uncertainties over which components are the cause (crustal, anthropogenic or biological).

In light of these uncertainties, MfE (2015) recommends that all PM should be treated as if it has the same impact on public health, so that, for instance, the effect of the PM_{10} component of unpaved road dust is presumed to be the same as that of PM_{10} from other sources such as wood-burner smoke or diesel particulate material. This is not because the effects are actually equal, but because the sources cannot be distinguished in the epidemiological data. Consistent with the MfE (2015) recommendation, the health and air pollution in New Zealand (HAPINZ) study (Kuschel et al 2012) has produced a *Health effects model*, which allows estimation of public health outcomes and associated social costs due to exposure to PM_{10}. The model is applied in chapter 6 of this report to quantify the cost of health impacts of dust from unpaved roads.

2.2.2 Other effects

A number of other effects of suspended dust have been described by several authors (see McCrea 1984; Jones 2000; MfE 2001; MfE 2015). They are listed as follows:

Nuisance/amenity

- Visual soiling of clean surfaces (cars, window ledges, household washing) increasing the cost of cleaning
- Dust deposits on flowers, fruit and vegetables
- Indoor dust deposits, increasing the cost of cleaning
- Reduced enjoyment of the outdoor environment (camping, picnicking, barbecues)
- Reduction of property values
- Visibility degradation (and associated safety concerns).

Plants

- Reduced photosynthesis through reduced light penetration, reduced growth rates and plant health
- Increased incidence of pests and diseases (dust acts as a medium for their growth)
- Reduced pesticide effectiveness, through reduced contact
- Resulting downgrading and rejection of produce.

Agriculture/forestry

- Restriction of photosynthesis and transpiration
- Reduced agricultural and forestry yields
- Reduced contact (and effectiveness of pesticides and fungicides)
- Ovine pneumonia
- Dirty fleeces
- Reduced dairy yield due to decrease in palatability of grass
- Increased vehicle operating costs (dust filters, driving on exposed gravel)
- Reduced lambing rates.

Water (deposition of dust on the surface)

- Contamination of fish
- Algal blooms
- Contamination of roof-collected water supplies and unsafe drinking water.

There is a wide range of activities which may be sensitive to the effects of suspended dust; the impacts listed above are not merely *potential* effects – they have been documented in the literature. However, as for public-health effects, these effects may not be specifically attributable to suspended dust from unpaved roads, as the dust may be intermittent, infrequent, or may impact on only a small area in the vicinity of the roadside. The literature review revealed a general lack of guideline values to assess the effect of dust on the environmental issues listed above. MfE (2001) has a mitigation trigger level for the nuisance effects of deposited dust (albeit dated) of 4g/m^2/30 days. The monitoring carried out as part of this project includes the collection dust deposition data, which aims to assess the nuisance effects of dust from unsealed roads.

2.3 Quantification of effects of road dust

2.3.1 Introduction

This section briefly describes some monitoring campaigns focused on fugitive dust emissions from unpaved roads. These have aimed to estimate emission rates, in addition to measuring ambient dust concentrations, either at the roadside or alongside a moving vehicle. The current project is not aimed at calculating emission factors *per se* – but at investigating the effects on ambient concentrations from the use of dust suppression techniques. Accordingly, the following review sections provide some background about the factors on which dust from unpaved roads depends.

2.3.2 Factors determining dust emissions

Most calculated emissions from unpaved road dust are based on the USEPA AP-42 formulas (USEPA 2006b, section 13.2.2). For instance, the Australian National Pollutant Inventory uses these formulas (Environment Australia 1999). The original emission factors (USEPA 1996) included a dependence on vehicles speed – this was removed for a time, but later re-instated. The emission factors for unpaved roads distinguish between 'industrial' unpaved roads (for instance haulage roads for mining or logging) and 'public' roads (light-duty motor vehicles). Different road/vehicle combinations use different formulas. In addition, the original PM_{10} factors have been expanded to include $PM_{2.5}/PM_{10}$ fractions. Although there is much additional background information available, USEPA (2006a) contains the latest information on emission factors from PM_{10} and $PM_{2.5}$ on industrial and public unpaved roads.

For unpaved surfaces at industrial sites, the dust emissions depend on the following:

- vehicle weight
- vehicle speed
- surface silt content
- surface moisture.

Road dust also contains components due to the following:

- vehicles' exhaust emissions
- brake and tyre wear.

Emission factors have been developed by the USEPA to represent $PM_{2.5}$, PM_{10} and PM_{30} on industrial and public unpaved roads. In addition, corrections for natural precipitation and evaporation are included.

2.3.3 Measurement campaigns

Several field campaigns have been undertaken by various researchers to examine the dependencies of dust emissions and to verify the USEPA factors. They often find that the USEPA factors underestimate emission rates, and that emissions can depend on a number of factors in addition to the parameters mentioned in the previous section. Some examples of fieldwork are given in this section.

Kuhns et al (2003) describe the TRAKER on-board sampling system. This samples PM in front of and behind a vehicle's tyre, with the difference being used to infer the PM suspension from the roadway due to the vehicle's movement. The system was tested on 400km of unpaved road in open desert and compared with flux-tower measurements of PM. Emissions were found to be sensitive to vehicle speed (proportional to vehicle speed cubed), kilometres travelled and road use.

Gillies et al (2005) compared calculated dust emissions caused by different vehicle types as they passed by instrumented towers. A range of vehicles were tested, of different weights, sizes and number of wheels. The authors identified that dust emissions depended strongly on vehicle speed and weight, and exceeded USEPA estimates at higher speeds and weights.

Cox and Isley (2013), Cox (2014) and Cox and Laing (2014) carried out sampling of dust emissions along the haul roads around open-cut coal mines. Mobile sampling involved the intake of near-surface dust (from watered and uncontrolled road surfaces), next to the truck wheels. Particle sizes were separated on-board using a hydro-cyclone. Stationary monitoring was also carried out, capturing vertical profiles of dust at (typically) upwind and downwind locations to aid the calibration of the mobile monitors. Results were sensitive to the road surface silt content, surface moisture, and meteorological factors such as temperature, humidity and incoming solar radiation. The trials showed that dust emissions depend on a number of factors not included in the USEPA formulas, such as wind speed, vehicle speed, weight, number of wheels, particle size distribution of the surface material, 'restraint' (compaction, bonding, durability of surface), precipitation/evaporation and silt fraction. The potential for road dust emissions was found to increase if the temperature was greater than 25C, relative humidity less than 40% and solar radiation above 600W/m^2. Higher dust emissions were found for roads either under construction, recently graded, or with high traffic volumes. The use of water was found to reduce emissions by more than 80%. Several methods were used by the researchers to calculate dust emissions from the monitoring data. Emissions from unsealed roads were found to be a factor of 10 higher than those from sealed roads.

Jia et al (2013) measured dust emissions from unpaved roads using static dust monitors at two sites in Sweden. Vehicles were driven past the monitors at a range of fixed speeds. Emission factors were found to be sensitive to vehicle speed and surface moisture. They were compared with the USEPA formulas (which did not include vehicle speed dependence). This comparison identified that increased emissions occurred at higher vehicle speeds and surface silt content; the USEPA formulas underestimated the emission factors by about 50% for speeds above 25km/h and silt content above 2%.

Zhu et al (2014) carried out mobile monitoring of emissions using the TRAKER platform under different surface moisture levels, on industrial and public unpaved roads. Water was applied to the surface to produce a range of moisture levels. A sharp drop in emissions was found as the moisture content increased above 2%.

2.4 Control of dust from unsealed roads

The Australian Coal Association Research Programme's report *Generation, measurement and control of dust from unsealed haul roads* (PAE-Holmes 2013) provides a comprehensive description of the methods available to control dust from unsealed roads. The key relevant points from this report are summarised below.

There are three different approaches to controlling dust from unsealed roads:

1. Road construction and maintenance – geometry of roadway, materials chosen for strength and durability and adequate drainage
2. Surface mechanical stabilisation – mixing substrate materials to provide a hard wearing surface
3. Chemical suppressants – agglomerate the fine particles, bind the surface particles together or increase the density of the road surface material.

Chemical suppressants are the primary method by which dust control can be practically achieved when managing an already built unsealed road. The types of chemical dust suppressants available include:

- water
- water attracting chemicals (chlorides, salts and brine solutions)
- organic non-petroleum chemicals (lignin-sulphates, pine tar, vegetable oils and molasses)
- petroleum based binders including waste oils (bitumen emulsions and waste oils)
- electrochemical stabilisers (sulphonated petroleum, ionic stabilisers and bentonite)
- synthetic polymer emulsions (polyvinyl acrylics and acetates)
- microbiological binders (cryptogams and enzyme slurries).

Each of these suppressants has positive and negative performance indicators which determine the best type of suppressant for any specific situation. The objectives of the Transport Agency project and the design of the field campaign determined that the key selection criteria for the suppressant were:

- it must be commercially available
- it must not have any significant adverse environmental effects
- it must not be prohibitively expensive
- it must be easy to apply.

These selection criteria narrowed the choice of potential suppressants for this project to:

- water attracting chemicals (commonly magnesium chloride)
- organic non-petroleum chemicals (commonly lignin sulphates)
- synthetic polymer emulsions.

Table 2.1 details the method of action, method of application and advantages and disadvantaged of these three chemical suppressants. Table 2.2 shows the relative performance of the dust suppressant under different traffic volumes. The information provided in Tables 2.1 and 2.2 is a summary of the review provided in PAE-Holmes (2013).

Table 2.1 Comparison of chemical dust suppressant characteristics (after PAE- Holmes 2013)

Suppressant	Method of action	Advantages	Disadvantages
Magnesium chloride	Draws water into the surface of roadway.	Ability to absorb moisture from atmosphere. Good longevity (effective for 3–4 months). Low maintenance – does not require refreshing.	Does not work well in excessively wet or dry climates. Can cause roads to become slippery when wet and create a hazard for vehicles. Corrosive to metals.
Lignin sulphate	Physically bind and/or agglomerate surface particles together. Work best when incorporated into surface gravel.	Natural product. Considered relatively environmentally benign.	Not effective for long periods – requires refreshing.
Synthetic polymer emulsions	Bind surface particles together and form a semi rigid film on road surface.	Increases the load bearing strength of roadway surface. Considered non-toxic, non-corrosive and do not pollute ground water.	Only effective on lightly trafficked roads.

Table 2.2 Relative performance of the dust suppressant under different traffic volumes (after PAE- Holmes 2013)

Suppressant	**Traffic volumes (annual average daily traffic)**		
	Light (<100)	Medium (100 to 250)	High (>250)
Magnesium chloride	Good	Good	Fair
Lignin sulphate	Good	Good	Fair
Synthetic polymer emulsions	Good	Fair	Poor

3 Methodology

The information presented in this section addresses the first part of research objective number 2:

- Describe the collection of data used to characterise the dust and quantify the impacts of dust from unsealed roads

To achieve this objective a short-term road dust monitoring campaign and dust suppression trial was designed and undertaken during February, March and April 2015. The field work collected representative data to allow an assessment of dust levels against relevant health and nuisance effects guidelines and to provide an indicator of the effectiveness of a dust suppressant. Anecdotally, dust emissions peak in January. The logistics of dust suppressant supply and the lead time needed to find a suitable monitoring site and then prepare and install monitoring equipment determined a February start date for the dust monitoring programme.

3.1 Monitoring site selection

The selection of a suitable monitoring site was a complex decision, which was influenced by multiple variables. At a high level there were three primary criteria the monitoring site had to meet:

- Unsealed roads trafficked by reasonably high volumes of vehicles, including a significant number of heavy duty vehicles.
- A TLA that was prepared to act as a host by assisting with site selection, provision of traffic data, and providing support with the logistics of monitoring.
- A location within a region that allowed the application of dust suppressants on unsealed roads.

During the initial phases of site selection, three districts were identified as meeting the first two primary site criteria. These districts were:

- Far North District Council, Northland region
- Marlborough District Council
- Wairoa District Council, Hawke’s Bay region.

A review of the relevant regional resource management plan rules, to determine the activity status of the application of dust suppressants to unsealed roads, eliminated Marlborough District as a potential site. In the Marlborough District, the application of some types of dust suppressants considered for the trial would have required a resource consent, which would have incurred time delays and increased costs for the project. This left the Far North District and Wairoa District as potential sites. Of these two options, the Far North District became the preferred site as it is closer to Auckland, therefore minimising the travel time and other logistical costs for the company contracted to undertake the monitoring. A key benefit of increased accessibility was the reduction of risks from lost data caused by delayed repairs of faulty equipment.

Four locations within the Far North District were identified as sites that could provide the data required to meet the project’s objectives. These sites were:

- Ngapipito Road
- Pipiwai Road
- Mataraua Road
- Piccadilly Road.

These four sites were compared using the following six criteria:

1. Number and type of vehicles passing the site each day (a larger number vehicles including heavy duty vehicles should provide a stronger road dust signal).
2. Number of nearby dwellings (assessment of dust impacts in a location that has sensitive receptors).
3. Topography and meteorology (maximum frequency of cross-road winds).
4. Cell phone coverage (ability to telemeter the monitoring data from site).
5. Suitable locations to install equipment near to the roadside (requires permission from private land owners).
6. Mains power supply available for some monitoring equipment (solar-powered monitoring equipment more expensive to install and problematic to run).

A site selection decision matrix was developed and each of the four potential sites in the Far North District was assessed according to these six criteria. As a result, the preferred monitoring site was identified as Mataraua Road. The key factors determining this outcome were that Mataraua Road provided good cell phone coverage and Far North District Council staff were able to negotiate landowner permission to install equipment on four privately owned properties with a suitable power supply.

3.2 Monitoring site location

Figure 3.1 shows the approximate location of Mataraua Road in Northland. Figure 3.2 shows the location of Mataraua Road as being approximately 10km southwest of the township of Kaikohe.

Figure 3.1 Location of the Kaikohe monitoring site in Northland

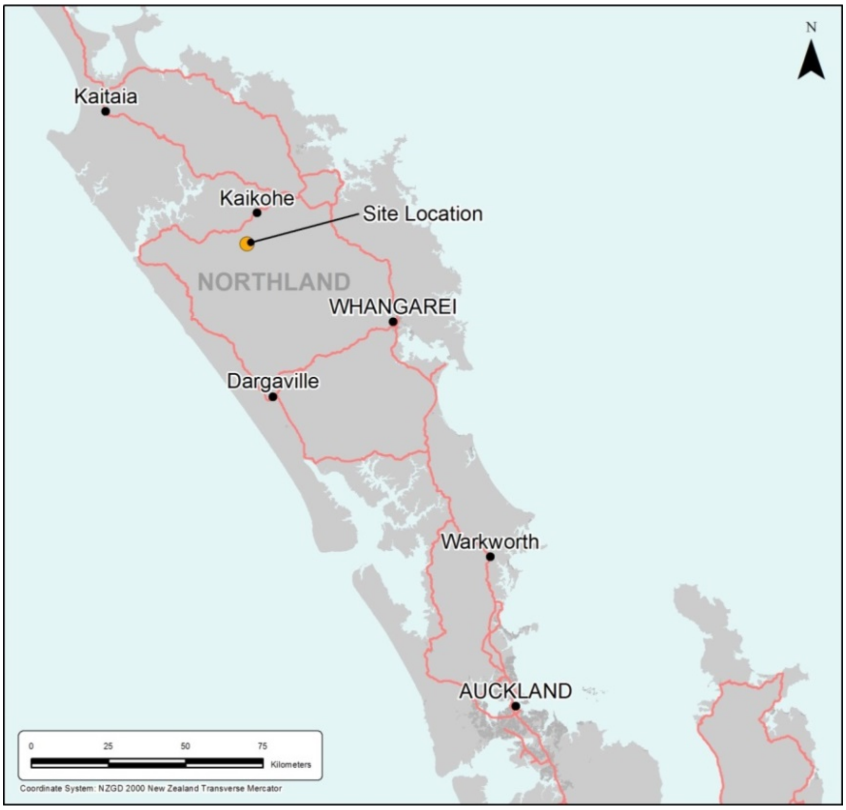
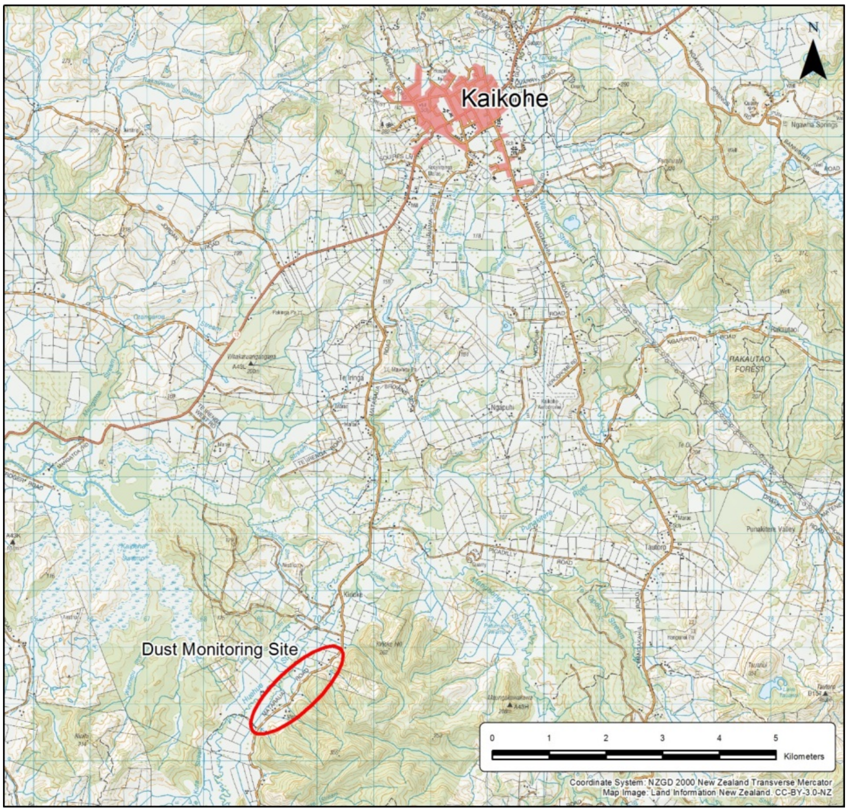


Figure 3.2 Location of the dust monitoring site (red oval) in relation to Kaikohe

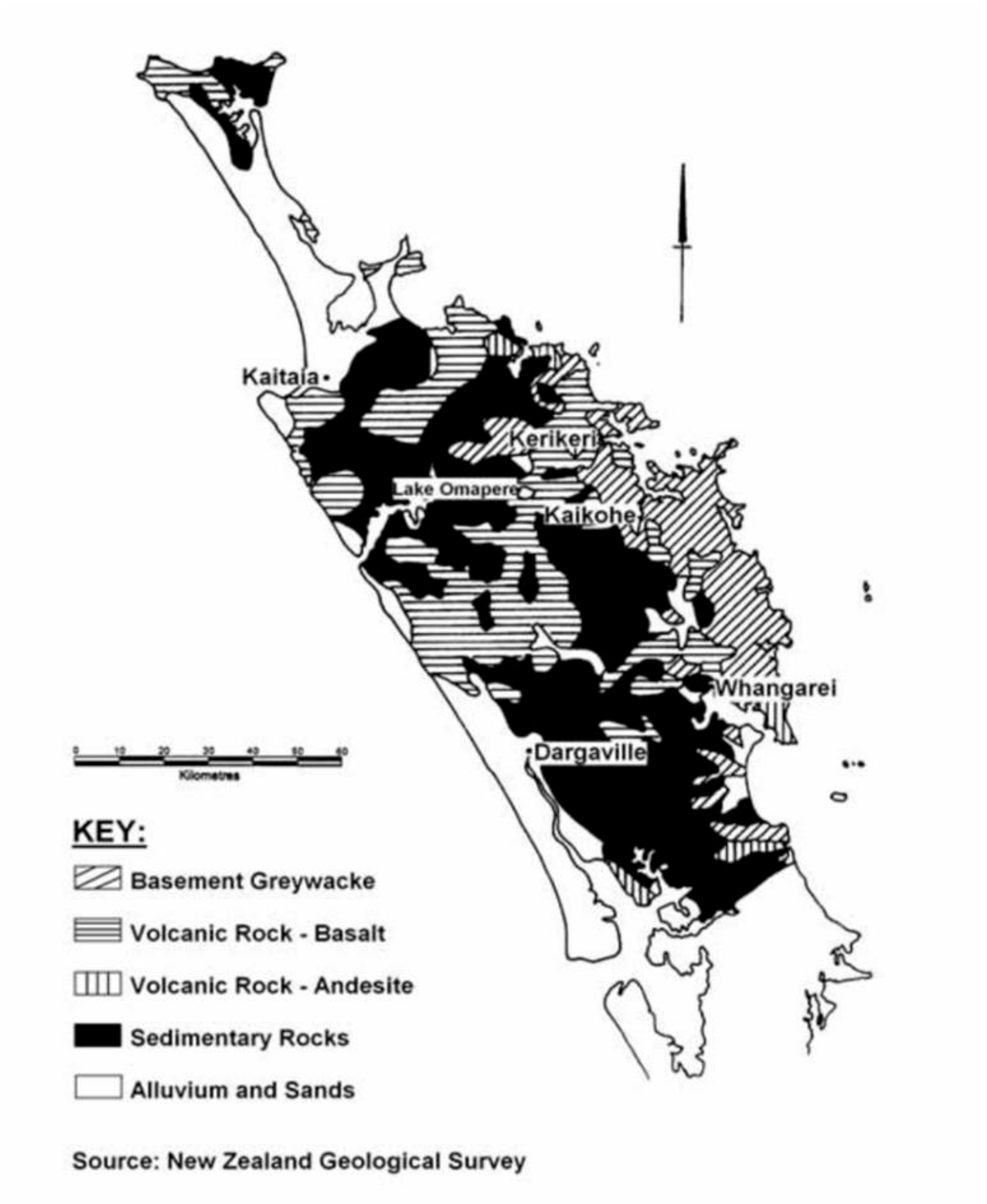


3.3 Monitoring site geology, roadway construction and traffic

To put the road dust results obtained at the Mataraua site in context with what might be found at other sites in Northland and around New Zealand, it is important to understand the geology of the area and the details of the roadway construction and the volume of traffic using the road.

Figure 3.3 shows the geology of Northland. As with most of New Zealand, the basement rocks of the Northland region are mainly composed of greywacke (indurated sandstone), argillite and chert (an opaque form of silica), together with volcanic rocks, such as basalt. The red dot on figure 3.3 indicates the approximate location of the monitoring site.

Figure 3.3 Geology of Northland



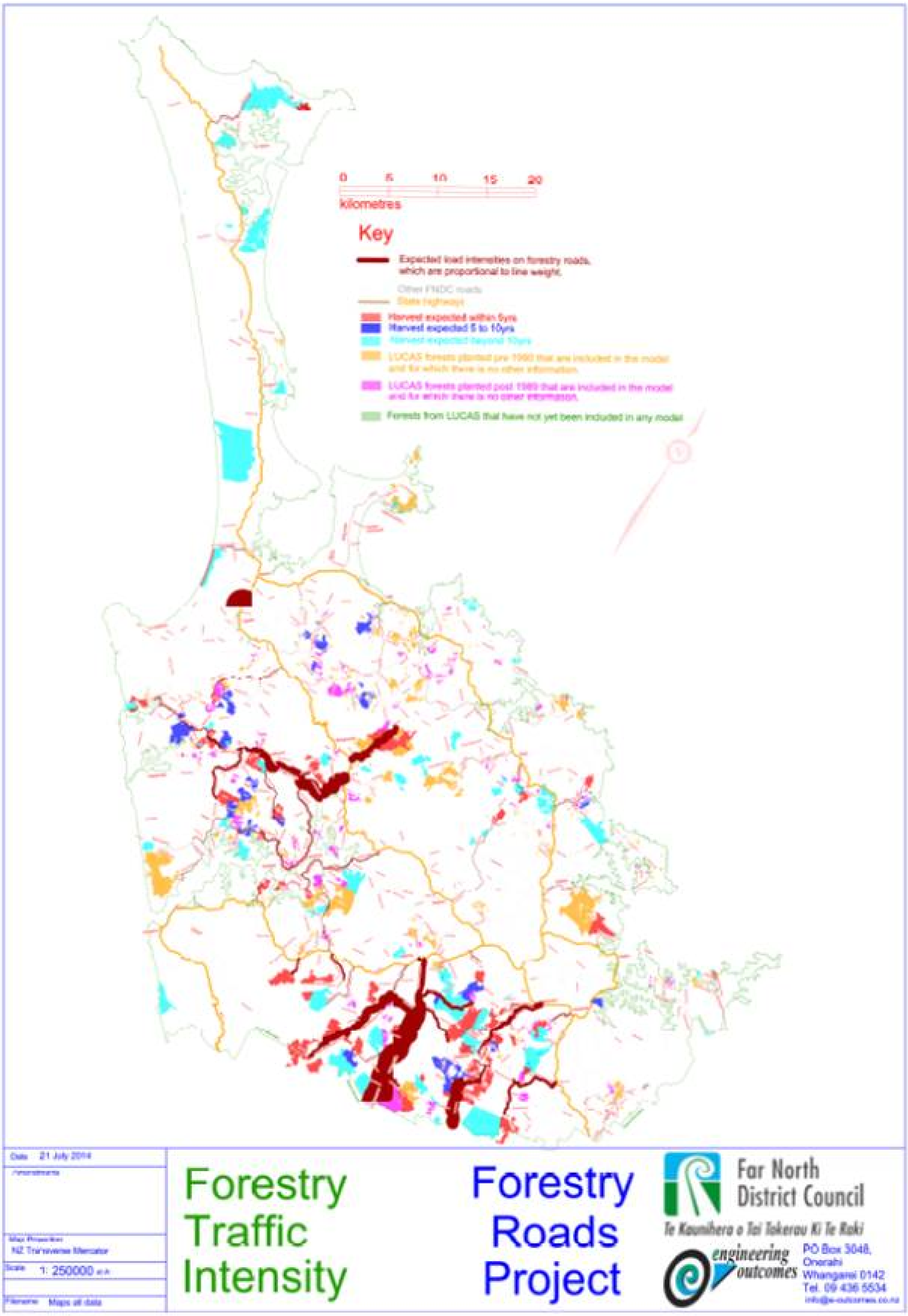
Source: Northland Regional Council (2004)

Figure 3.3 shows that the base geological material around Mataraua Road is sedimentary rocks, with areas close by based on basalt volcanic rock. The base material of Mataraua Road is clay, which is covered with crushed river metal to a depth of approximately 80mm. Mataraua Road is graded approximately once every two months. The design and construction method used to build Mataraua Road is typical of other unsealed roads within the Northland region. The maintenance schedule is also typical of other unsealed roads in the Far North District. However, the metal used to cover the road bases in Northland varies from road to road with metals being supplied from close by sources. Therefore the metal type used for Matararua Road is site specific and not necessarily representative of metals used to cover other roads in the Far North District (pers comm Mike Grimshaw, Branch Manager, Far North Transfield Services email dated 16 September 15 and pers comm Wil Pille Far North District Council Roading Business Unit - Performance Development email dated 28 September 15).

Figure 3.4 shows potential or 'expected' log traffic intensity over the three years to June 2018. Far North District Council notes there are limitations on the quality of the data used to generate figure 3.4. Therefore figure 3.4 only provides relatively accurate predictions of forestry traffic intensity for the busier routes. It does not give an accurate prediction for most minor roads and/or those with small catchments. However, the data presented in figure 3.4 is suitable for comparing forestry traffic intensity over the entire district.

Notwithstanding these limitations, figure 3.4 shows the forestry traffic intensity on Mataraua Road (as indicated by the blue oval) is at the high end of that experienced on Northland's road network. The only road where forestry traffic intensity is significantly higher is Mangakahia Road (as indicated by the green oval), which is a sealed road.

Figure 3.4 Forestry traffic intensity in Northland (source Far North District Council)



3.4 Monitoring equipment

There are a number of technologies that can be used to monitor dust concentrations. These vary from high-quality, high-cost methods that are compliant with the requirements of the NES, through to methods that are relatively cheap and provide good measures of relative dust concentrations, but do not necessarily deliver precise quantitative data. The most appropriate method used to monitor dust for a specific project is determined by the purpose for which the data will be used. In this project, the dust data is used for three main purposes to assess the following:

- impacts of dust on human health
- effectiveness of dust mitigation methods
- extent of the dust plume discharged from the unsealed road.

Assessing the impacts of dust on human health requires a monitoring method that will provide good quality data for comparison with the NES value of $50\mu g/m^3$ (24-hour average). For this project, obtaining data at a fine temporal resolution (sub one-hour) was highly desirable, and there were practical constraints such as power supply, equipment security and budget that had to be considered. These factors resulted in the selection of beta attenuation monitors (BAMs) as the monitoring method that best fitted the project's aim to assess the impacts of dust on human health.

To assess the effectiveness of dust mitigation methods and the extent of the dust plume requires dust data to be recorded on a fine temporal scale and to be collected at transects of up to 100m from the roadside at a number of locations in and around the trial area. To provide the dust data with the temporal resolution and spatial scale required by this project necessitated the use of a network of optical nephelometers.

Two types of dust monitoring technology were therefore employed during this project, each with advantages and disadvantages. These two technologies are described below, along with a summary of the other data collection technologies that were deployed as part of the monitoring programme.

3.4.1 Beta attenuation monitors

Beta attenuation monitoring is a widely used technique for monitoring airborne PM. This technique is based on the principle of beta radiation (electrons) being attenuated by solid matter through which it passes. Air is drawn into the BAM and passed through a filter tape so that the particles are collected on a specific area of the tape. Beta radiation is passed through the filter exposed to the particles and then passed through an area of the tape not exposed to the particles. The intensity of beta rays detected through the exposed and clean areas of the filter tape is compared, and the mass of particulate collected on the tape calculated. Knowing the flow rate of the air into the BAM allows the concentration of particles in the air to be calculated.

To allow different particulate size factions to be measured, size selective air inlets are attached to the BAM. For this project BAMs were used to collect data on total suspended particulate (TSP) and particulate with an aerodynamic diameter of less than 10 microns ($1x10^{-6}$m) (PM_{10}).

The two main advantages BAMs have over optical monitors are that they:

- operate at a higher flow rate, thus allowing the large TSP to be monitored
- provide a precise and accurate measurement of mass, making the results more comparable to other particle mass based measurement methods.

The disadvantages of BAMs are that they:

- are more expensive and complex than nephelometers
- require mains power
- have relatively slow response times (10–15 minutes)

For this project two Met-One E-BAMs were used to determine road dust concentrations of TSP and PM_{10} at varying locations during the monitoring programme. The BAM data was also used to provide correction factors for the PM_{10} data collected by the optical nephelometers.

The BAMs were sited and operated to meet the requirements set out in MfE's (2009) *Good practice guide for air quality monitoring and data management*. The processing of the BAM data was also carried out to meet MfE's (2009) requirements.

3.4.2 Optical nephelometers (Dustmotes)

Optical nephelometry is becoming increasingly used as a monitoring technique for airborne PM. Optical nephelometry works by directing a laser beam through a sample of air containing particulate and measuring the light scattered by the particles in the sample.

The main advantages of optical nephelometers over BAMS include:

- They are low cost.
- They are very fast (one-second response time), stable and precise.
- They use much less power than other continuous monitors, which allows them to be run with solar panels and batteries, instead of mains power.
- They have a simpler mechanical/electrical design which reduces the risk of monitor failure.

The major drawbacks of optical nephelometers are:

- They infer the mass of particles from the optical properties of particles. Particle mass is not measured directly.
- Their sensitivity starts to drop for particles larger than about 15 microns.
- They are sensitive to the colour of particles. Measurements of dark-coloured particles contain more uncertainty than light-coloured particles.
- Their use is restricted to:
  - $PM_{10}/PM_{2.5}$ studies
  - studies where the source of particles is consistent so that reliable correlations with particulate reference methods can be determined

For this study, PM_{10} was measured using a continuous optical nephelometry with a Met-One MD-E optical engine. The optical nephelometers were built by Air Quality Limited and are known by the name 'Dustmote'. While between-instrument reproducibility has been shown to be very good, optical nephelometry is not a standard reference method and PM_{10} measurements should be considered as indicative.

The instruments have a built-in global positioning system (GPS) for location tracking and timing control, which reduces the chance of errors in subsequent data analysis. Particle size selection is performed by a sharp cut cyclone. The monitors have a heated inlet to drive out moisture, controlled by an internal relative humidity sensor. In heavy fog, the heater may be insufficient to drive out all moisture and the measurements may be artificially high. The instruments provide one second measurements, which are averaged over one-minute intervals.

The main reason Dustmotes were selected for use in this study is that they are relatively cost effective and can be operated without mains power, and therefore a greater number can be deployed to obtain a better understanding of the spatial variation of PM_{10} concentrations around the roadway.

However, the main limitation with light-scattering instruments is that the instrument response depends on the size distribution and the number of particles, rather than the total mass of airborne particulate. Therefore, PM_{10} data obtained from Dustmotes is not as accurate as data measured by BAMs. However, this limitation was (to some extent) overcome in this project by experimental design which meant that:

- the difference between BAM and Dustmote PM_{10} data at this site was quantified
- the Dustmote data could be calibrated to make it BAM equivalent.

A summary of the method used and results from calibrating the Dustmote PM_{10} data is provided in section 3.5. It is important to note that the Dustmote data is not compliant with the PM_{10} monitoring requirements set out in the NES and should not be used to assess compliance against the NES. However, when calibrated to BAM equivalent data the Dustmote data provides good indicative (although not definitive in regard to the NES) data, which was fit for the purpose of this project.

3.4.3 Other monitoring technology

To better understand the sources and effects of road dust, meteorological monitoring (including wind speed, wind direction and rainfall) and traffic monitoring (vehicle counting and vehicle type) were undertaken at the site.

Meteorological monitoring was carried out with a high-quality weather station mounted on a 6m tower located 80m north of the roadway (monitoring site locations are discussed in detail in section 3.7). Parameters measured included rainfall, wind speed and direction, temperature, atmospheric pressure and relative humidity. The weather station used a Gill ultrasonic anemometer with pressure and temperature transducers. The instruments provided one second measurements which were averaged over one-minute intervals. The weather station was sited and operated to meet the requirements set out in MfE (2009). The processing of the meteorological data was also carried out to meet the requirements set out in MfE (2009).

The traffic monitoring programme and equipment was designed to, as far as practical, meet the requirements set out in *Traffic monitoring for state highways* (NZ Transport Agency 2004). The traffic data, vehicle number, vehicle speed and vehicle type were measured using a two tube pneumatic recorder system.

To monitor the degree to which an unsealed road creates dust nuisance effects, four dust deposition gauges were deployed at the site. The dust deposition gauges were designed, sited and operated to be compliant with the requirements of AS/NZS 3580.10.1:2003 *Methods for sampling and analysis of ambient air – determination of particulate matter – deposited matter – gravimetric method.*

To measure the amount of respirable quartz being discharged from the unsealed road a number of filter samples of dust were collected and analysed for this specific contaminant. The respirable silica samples were collected using a Gillian 3,500 pump with a flow rate of 2,000ml per minute though a 25mm polycarbonate filter. The gravimetric analysis of the respirable silica filters was based on Australia/NZ Standards AS3640 2009 and AS2985 2009. The quantitative analysis of respirable silica was based on the method described in Annals of Occupational Hygiene (1977).

Two video cameras were set up to operate for the duration of the dust monitoring programme. Time-lapse cameras were set up at the north 5m untreated and treated sites to provide images of sufficient quality to identify broad vehicle class during the daytime only. The video record was not analysed for this project. The prime purpose of capturing the video was to future-proof any additional analysis that might be undertaken as result of the recommendations made by the current study, or any other follow-up actions resulting from the outcomes of this project.

3.5 Dustmote particulate matter data processing

As noted in section 3.4.2, PM_{10} data obtained from Dustmotes is not as accurate as data measured by BAMs. Figure 3.5 compares PM_{10} data from a BAM and Dustmote co-located at the 30m north untreated site (monitoring site locations are discussed in detail in section 3.7) for the period 9 to 15 March 2015.

Figure 3.5 PM_{10} BAM and uncorrected Dustmote data from the 30m untreated north site, 9–15 March 2015

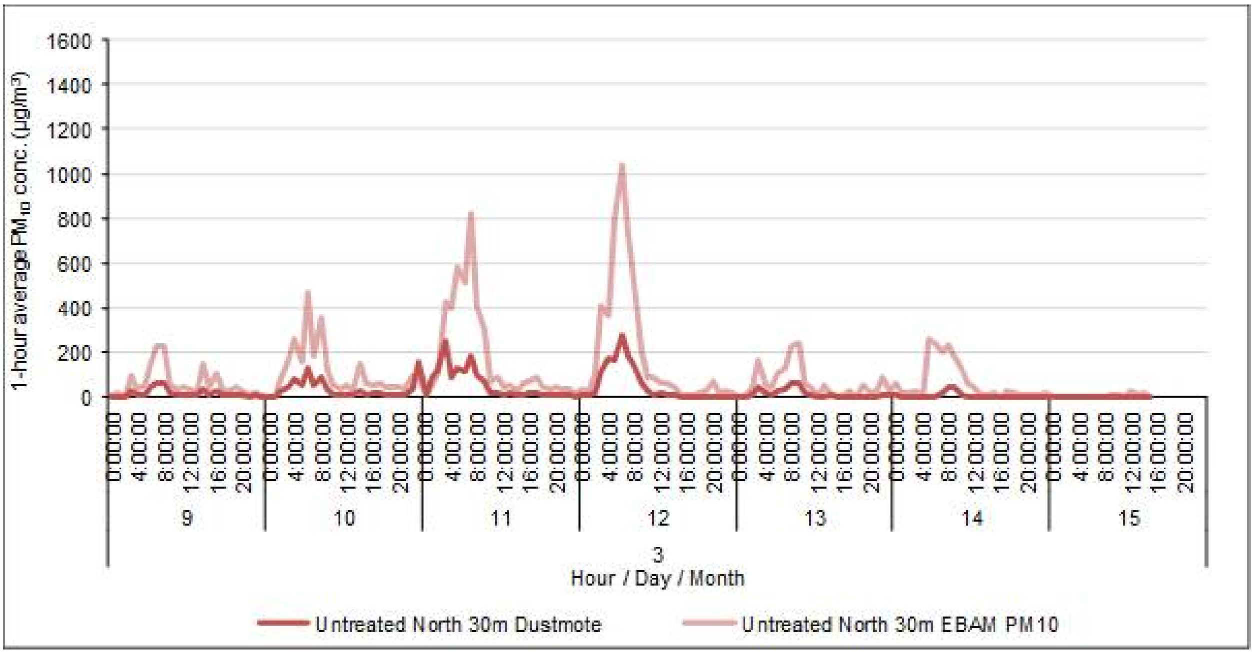


Figure 3.5 shows that the Dustmote PM_{10} match BAM measurements well, but the Dustmote values are significantly lower than the BAM. To overcome this issue, data from a co-located BAM and Dustmote was used to establish a correlation (called a k-factor) between the two data types. The k-factor was then applied to data from nearby Dustmotes to provide a BAM equivalent to the PM_{10} concentration.

In this monitoring programme BAM and Dustmote PM_{10} monitors were co-located at the untreated north 5m and 30m sites. This co-located monitoring was used to establish site-specific k-factors between the BAM and Dustmote data. The k-factors were used to calibrate all Dustmote data to make it BAM equivalent. The k-factor adjustments significantly enhanced the value of data collected by the other Dustmotes in the monitoring network.

The details on how the Mataraua Road k-factors were established are provided in appendix A. A summary of the k-factors used in this project are provided in table 3.1. Figure 3.6 shows PM_{10} BAM and k-factor corrected Dustmote data from the 30m north untreated site for 9 to 15 March 2015. It is clear that the k-factor adjusted Dustmote PM_{10} values match the BAM well (R^2 = 0.77).

Table 3.1 K- factors used to adjust the PM_{10} Dustmote data to BAM equivalent data

Site location (location from the road)	k- factor
5m	6.1
30m	3.4
80m	3.4

Figure 3.6 PM_{10} BAM and k- factor corrected Dustmote data from the 30m untreated north site, 9–15 March 2015

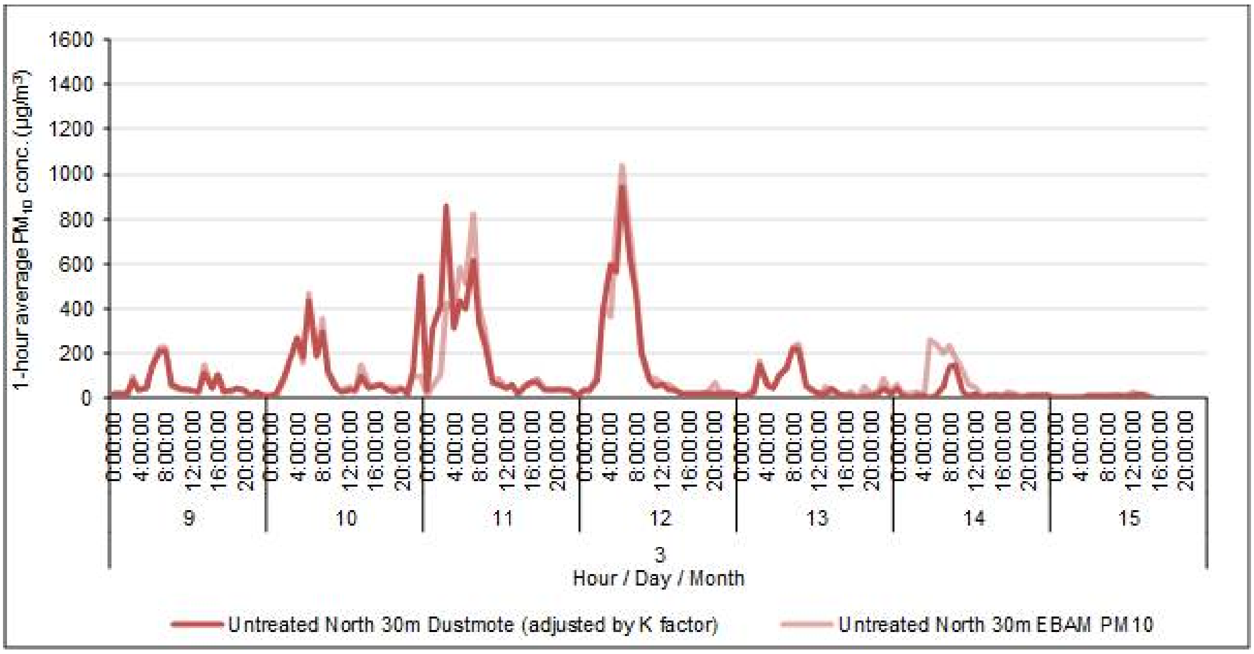


Table 3.1 shows the k-factors decrease with increasing distance from the road. This occurs because the size distribution of the particulate changes as the larger particles drop out of the plume as it moves away from the road. BAM and Dustmote co-located monitoring did not occur at the 80m site and therefore a site-specific k-factor was not established. In the absence of data to produce a k-factor for the 80m site, the 80m k-factor was assumed to be the same as for the 30m site. This probably resulted in conservative (high) estimates of BAM equivalent Dustmote data at sites 80m from the road.

3.6 Dust suppression

Having considered the three options of dust suppressant suitable for the purposes of this programme (see section 2.4), magnesium chloride ($MgCl_2$) was selected as the suppressant to be used in the trial. The reasons for the selection of $MgCl_2$ included:

- easy application
- remains effective for a reasonably long period (three months)
- the need to make a second application of suppressant was unlikely
- good performance in light and medium traffic; fair performance in heavy traffic
- better maintenance of surface binding during rains than lignin sulphate

- product non-odorous or sticky
- costs of supply and delivery for MgCl2 were similar to that of lignin sulphate.

The application of dust suppressant on Mataraua Road was undertaken on 19 February 2015. Figure 3.7 shows the application of the dust suppressant to Mataraua Road, while figure 3.8 shows sections of Mataraua Road with and without the suppressant applied.

Figure 3.7 Application of magnesium chloride to Mataraua Road

Figure 3.8 Treated (dark upper) and un- treated (light lower) sections of Mataraua Road

3.7 Monitoring site layout and equipment network

Figure 3.9 shows an aerial photograph of the section of Mataraua Road where the dust monitoring and suppression trial was undertaken. The section of the road which was not treated with dust suppressant is marked with a red line, while the area in which the dust from the untreated section of road was monitored is marked with a red oval. The section of the road which was treated with dust suppressant is marked with a blue line and the area in which the dust from the treated section was monitored is marked with a blue oval.

Figure 3.9 Aerial photograph of Mataraua Road showing the sections of road where the dust suppression trial and dust monitoring were undertaken

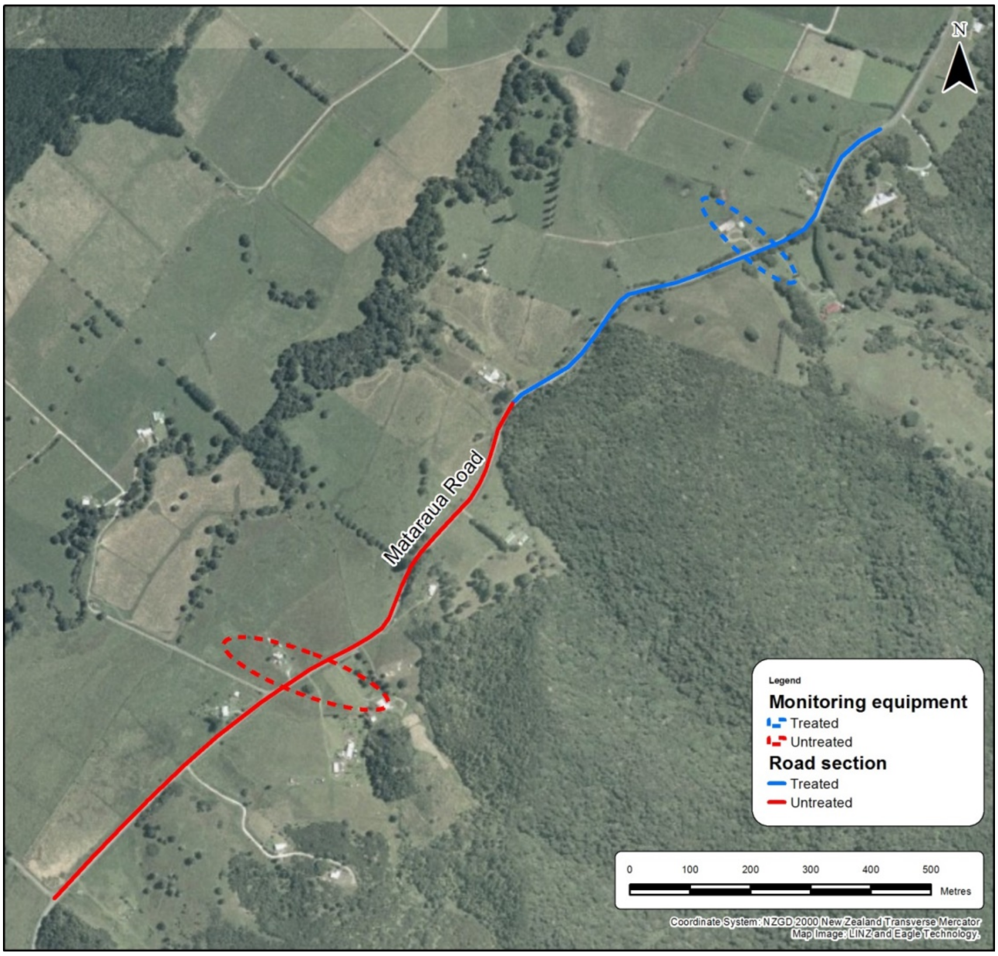
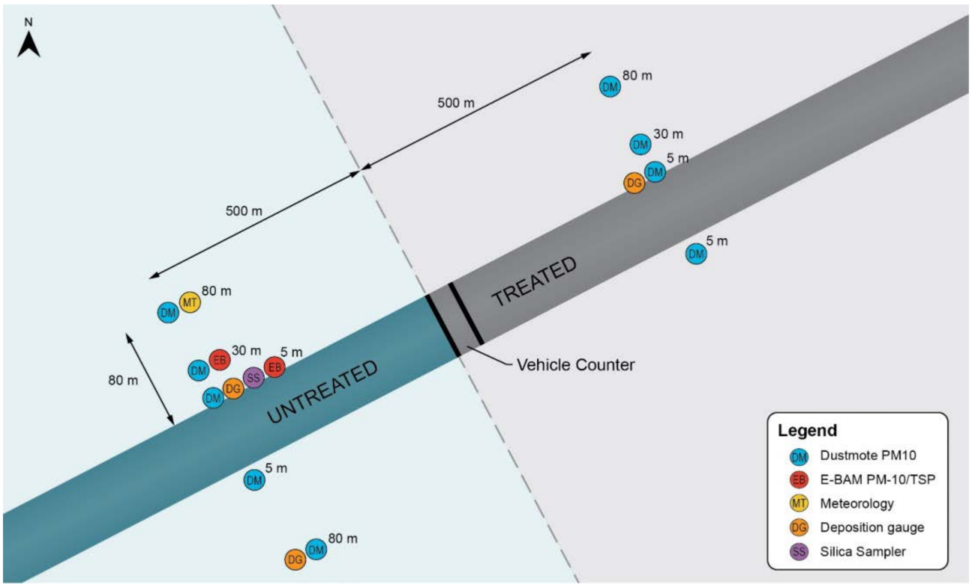


Figure 3.10 is a schematic diagram of the site showing the location of the equipment used in the monitoring programme.

Figure 3.10 Schematic diagram showing the network of the monitoring equipment



The network of monitoring equipment was designed to achieve the following purposes:

- Understand the meteorology of the site (meteorological equipment located at untreated north 80m).
- Profile vehicle numbers and types passing the site (vehicle counter).
- Compare dust concentrations from the treated and untreated sections of the road (Dustmotes on treated and untreated sections of the road).
- Assess the extent of the dust plume generated from the unsealed road (Dustmotes at 5m, 30m and 80m transects).
- Assess background dust (sources other than the road).
- Calibrate the Dustmote data against BAMs (untreated north 5m and 30m).
- Assess dust deposition rates (dust gauges at 5m on treated and untreated sections of the road, and at a background site at 80m on southern side of the untreated section of the road.
- Assess respirable silica concentrations (silica sampler at untreated north 5m).

The monitoring equipment was installed on 19 and 20 February 2015. Figure 3.11 shows an aerial photograph of the untreated section of Mataraua Road and indicates the location of the monitoring sites. Figure 3.12 shows a photograph of the equipment (BAM TSP, BAM PM$_{10}$ and Dustmote PM$_{10}$) installed at the untreated northern 5m site. Figure 3.13 shows an aerial photograph of the treated section of Mataraua Road and indicates the location of the monitoring sites.

Figure 3.11 Monitoring site locations on the untreated section of Mataraua Road

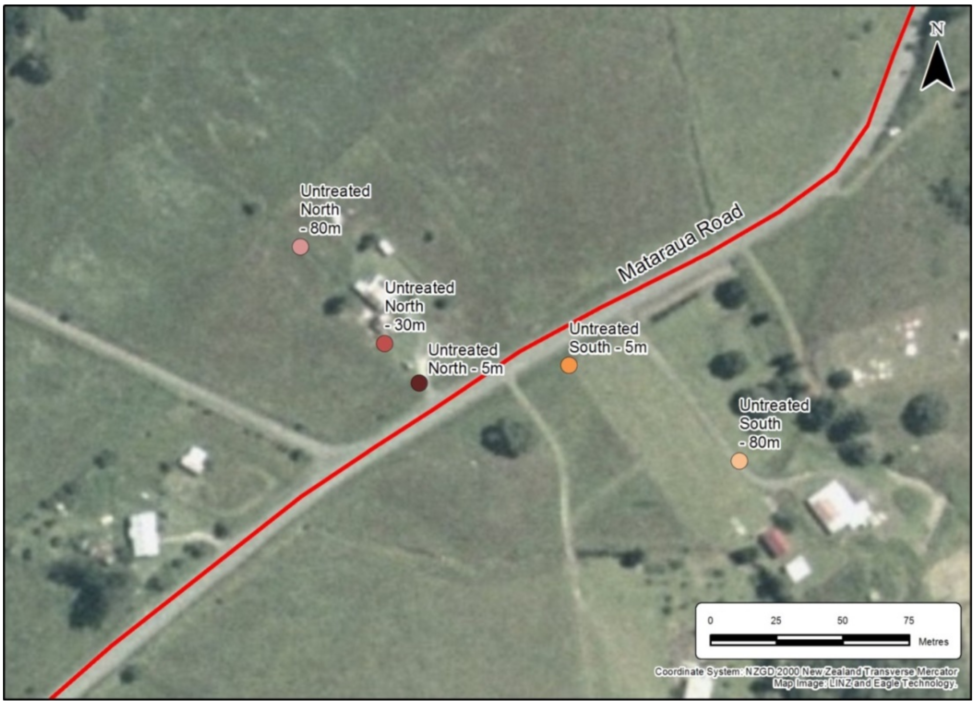
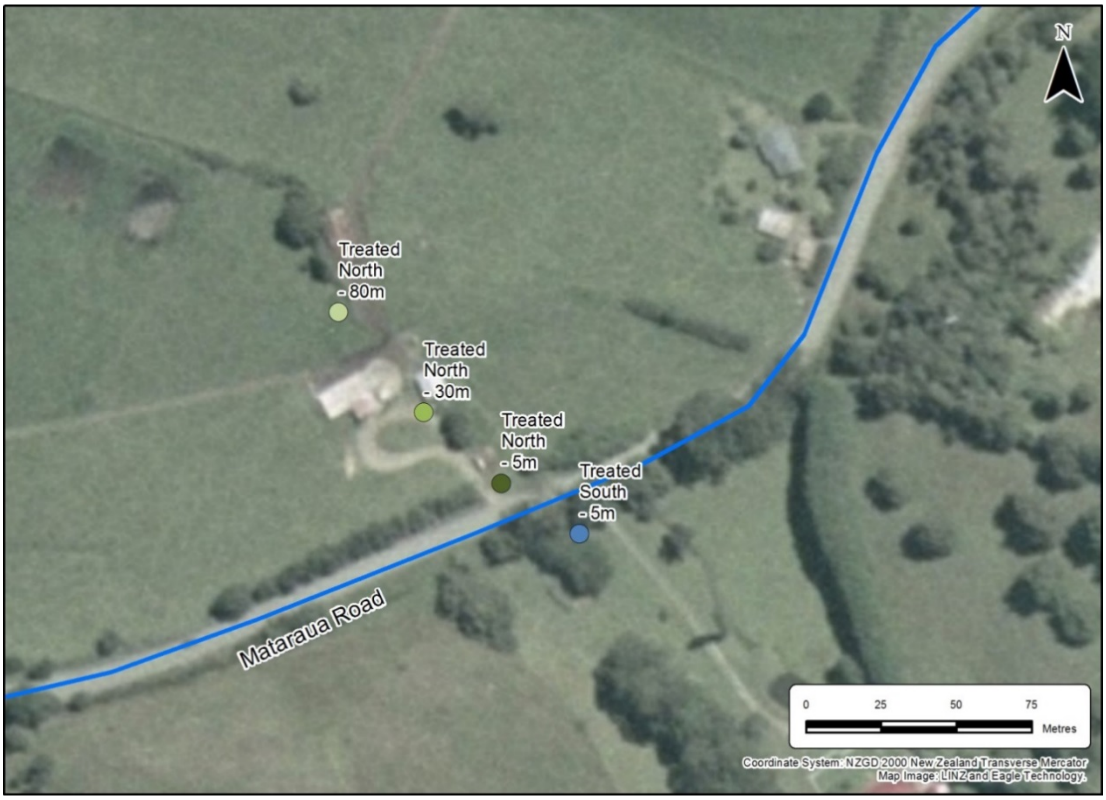


Figure 3.12 BAM TSP (left), BAM PM_{10} (right) and Dustmote PM_{10} (centre) installed at untreated north 5m site

Figure 3.13 Monitoring site locations on the treated section of the Mataraua Road



The Dustmotes located on the northern side of the untreated and treated sections of the road were commissioned in a transect perpendicular to the road at distances of 5m, 30m and 80m. The 5m site was designed to capture roadside concentrations of dust. The dust concentrations monitored at the 5m site were relatively high and could not be considered representative of the dust exposure experienced by people living beside an unsealed road. The 30m site was placed to represent the typical distance a dwelling would be located back from the roadside. The dust concentrations monitored at the 30m site can be considered representative of the dust exposure experienced by people living beside an unsealed road. The main purpose of the 80m site was to assess the extent of the dust plume discharged from the road. A distance of 80m was chosen as this was the largest practical distance that could be achieved while being linked to the mains power supply, which was also used for the 5m and 30m sites.

Table 3.2 details the equipment type and operational dates for the monitoring sites located on the untreated section of Mataraua Road. Table 3.3 details the equipment type and operational dates for the monitoring sites located on the treated section of Mataraua Road. Note that the sites are colour coded for ease of identification and to differentiate results presented in the figures contained in chapters 4 and 5.

Table 3.2 Equipment location and operational dates for the monitoring sites located on the untreated section of Mataraua Road

Location	Dustmote	BAM	Other equipment
Untreated north – 5m	PM_{10}: 20 Feb to 16 April 2015	PM_{10}:18 Mar to 16 April 2015 TSP: 18 Mar to 16 April 2015	Dust deposition Silica sampler (filter sampler) Video camera Vehicle counter
Untreated north – 30m	PM_{10}: 20 Feb to 16 April 2015	PM_{10}: 25 Feb to 18 Mar 2015 TSP: 20 Feb to 18 Mar 2015	
Untreated north – 80m	PM_{10}: 20 Feb to 16 April 2015		Meteorology
Untreated south – 5m	PM_{10}: 20 Feb to 16 April 2015		
Untreated south – 80m	PM_{10}: 25 Feb to 16 April 2015		Dust deposition

Table 3.3 Equipment locations on the treated section of the roadway

Location	Dustmote	BAM	Other equipment
Treated north – 5m	PM_{10}: 25 Feb to 16 April 2015		Video camera Vehicle counter
Treated north – 30m	PM_{10}: 19 Feb to 16 April 2015	TSP: 19 Feb to 25 Feb 2015	
Treated north – 80m	PM_{10}: 19 Feb to 16 April 2015		
Treated south – 5m	PM_{10}: 20 Feb to 16 April 2015		Dust deposition

4 Monitoring results

The information presented in this section addresses the second part of research objective number 2:

- Characterise the dust and quantify the impacts of dust from unsealed roads.

4.1 Meteorology

The meteorology of the monitoring site is an important factor to consider when interpreting the dust data. For example, understanding the meteorology of the site can assist with answering the following questions:

- Which measured dust comes from the road?
- Which measured dust is background (other sources)?
- When and why do high (or low) dust concentrations occur?

Figure 4.1 shows a plot of the diurnal profile of wind speed (one-hour average, 20 February to 16 April 2015). The data is displayed as box and whisker plots. The top of the box represents the 75th percentile value, the line in the middle of the box is the median value, the bottom of the box represents the 25th percentile value. The whiskers extend from the 5th percentile to the 95th percentile values. The mean value is marked with a blue dot. Figure 4.2 shows a plot of the diurnal profile of temperature (one-hour average, 20 February to 16 April 2015).

Figure 4.1 Diurnal profile of wind speed (1- hour average, 20 February to 16 April 2015)

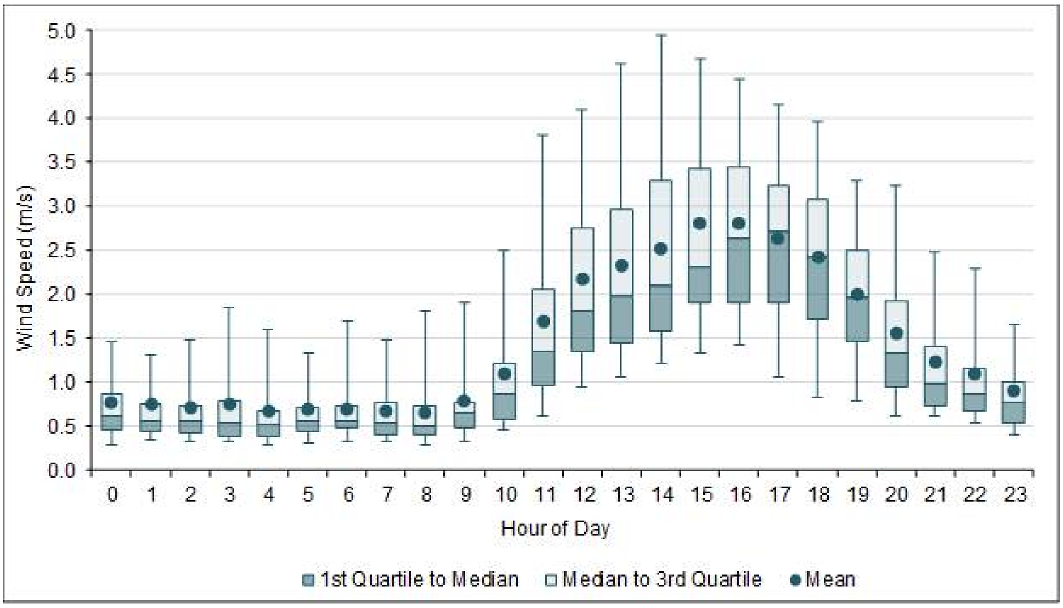


Figure 4.1 shows the site has a strong diurnal pattern of wind speed. The mean values of windspeed show:

- low wind speeds (<1m/s) from midnight to 9am
- wind speeds increase steadily from 10am to 3pm, up to an average daily maximum value of 2.81m/s
- wind speeds decrease steadily from 4pm to 11pm down to average values of less than 1m/s.

Figure 4.2 Diurnal profile of temperature (1- hour average 20 February to 16 April 2015)

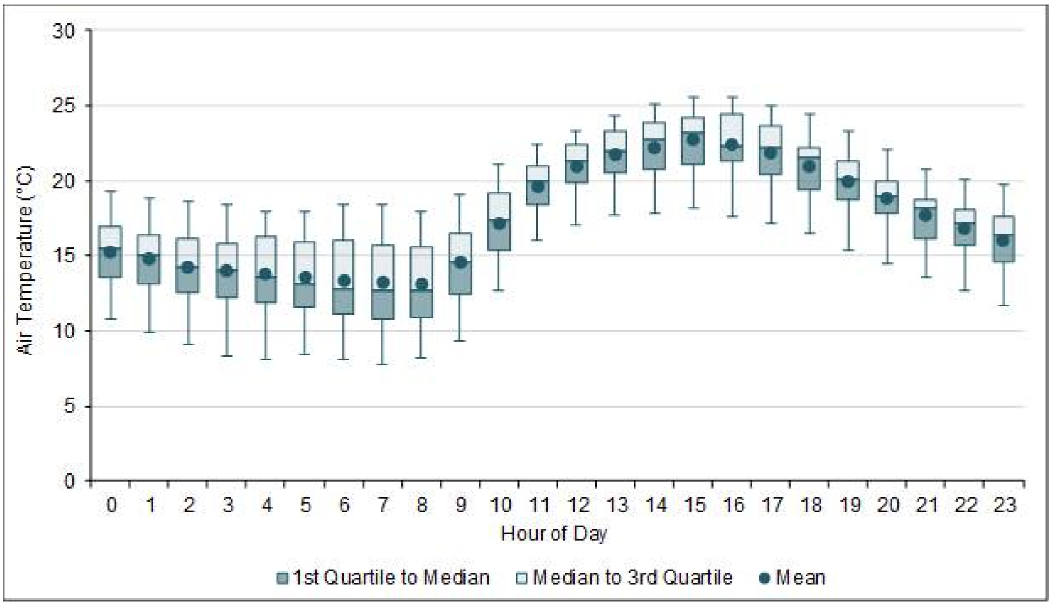


Figure 4.2 shows the site has a strong diurnal pattern of temperature. The mean values of temperature show:

- steadily decreasing temperatures from midnight to 8am, to reach an average daily minimum temperature of approximately 13ºC
- temperatures increase from 8am to 1pm up to an average daily maximum value of approximately 23ºC
- temperatures hold steady from 1pm to 4pm at approximately 22ºC
- steadily decreasing temperatures from 5pm to midnight to reach an average temperature of approximately 16ºC at midnight.

Figures 4.1 and 4.2 show that from midnight to 9am there is relatively little ventilation of the site due to the lower temperatures and wind speeds.

Figure 4.3 shows the wind rose for the period 20 February to 16 April 2015, indicating that the predominant wind directions are north-northwest (NNW) and south-southeast (SSE). These two directions are cross-road winds that will take any dust discharged from the road away from or towards the dust monitors (depending on direction). Figure 4.3 also shows that calms (wind speed < 0.5m/s) persist for approximately 11% of hours, and for the majority of the time wind speeds experienced were below 2.1m/s for all directions.

Figure 4.3 Wind rose for the period 20 February to 16 April 2015

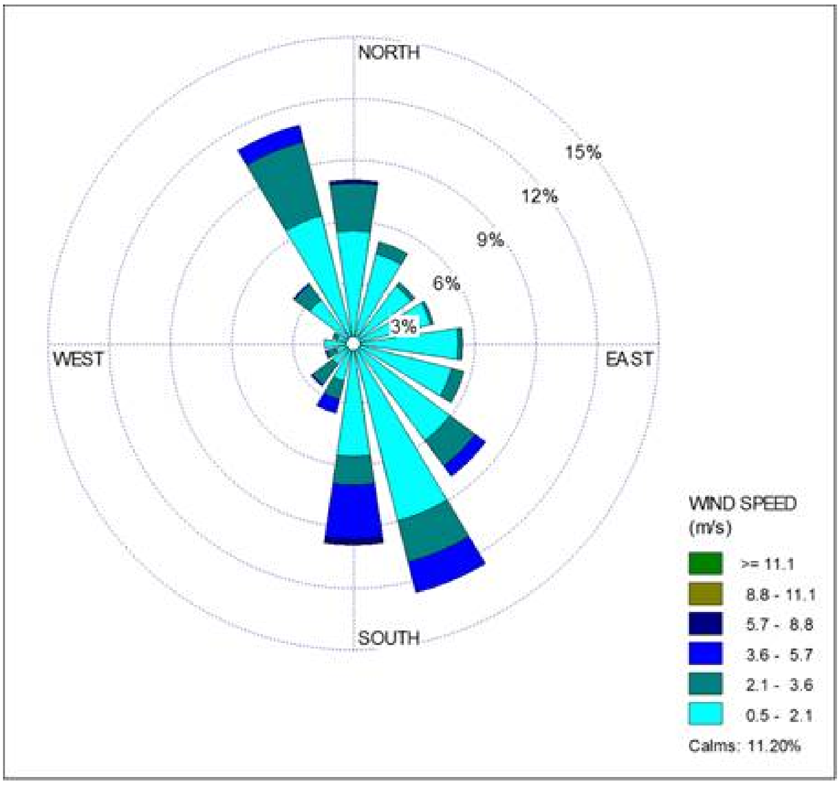
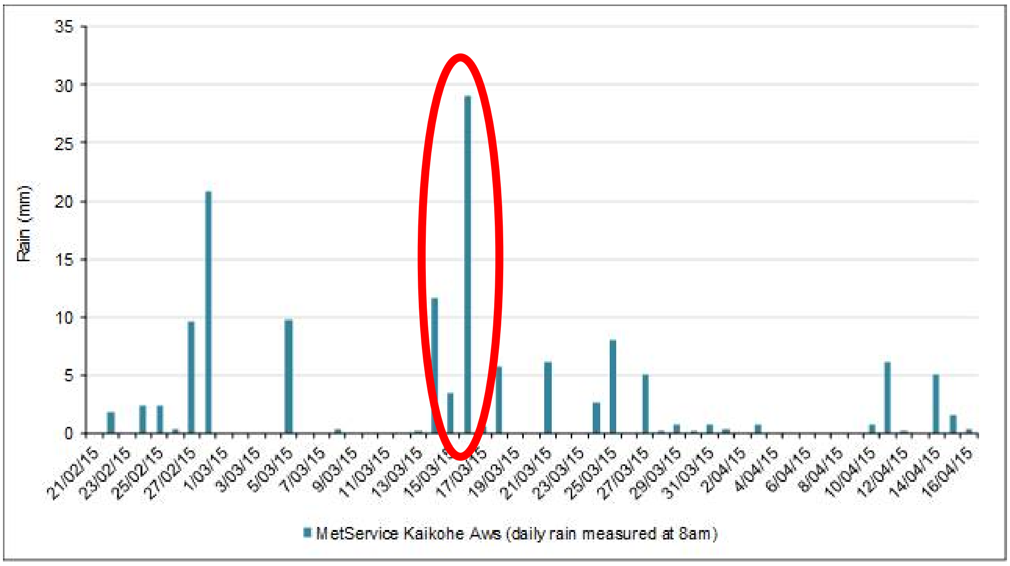


Figure 4.4 shows the rainfall for the period 20 February to 16 April 2015. The data shown in figure 4.4 was sourced from MetService's Kaikohe automatic weather station (AWS) located approximately 10km to the northwest of the site. Rainfall was recorded on site at Mataraua Road; however, the rain gauge failed a number of times and the on-site rainfall data record was not complete. The data collected on-site was compared with the Kaikohe AWS, which showed a very good correlation. The Kaikohe AWS data was therefore adopted for this project as representative of the on-site rainfall.

Figure 4.4 Rainfall for the period 21February to 16 April 2015



An analysis of the rain data showed some rain occurred on 30 days of the 57-day monitoring period, while 27 days had no rain. Figure 4.4 shows 22 days had rain greater than 1mm and nine days had greater than 5mm of rain. Cyclone Pam hit the area on 14 to 16 March, as indicated by the red oval on figure 4.4, and resulted in the peak rainfall day of 29mm.

For the purpose of this study 'wet days' are defined as days on which the rain fall exceeds 5mm. Using this criterion there were nine wet days during the monitoring programme.

4.2 Traffic volume, fleet composition and vehicle speed

It is important to understand traffic flow patterns and fleet composition when interpreting the road dust data. For example, understanding the traffic flow patterns of the site can assist with answering the following questions:

- Are roadside dust concentrations related to traffic flow and vehicle type?
- Do certain types of vehicle generate more dust?

Figure 4.5 shows the seven-day average traffic flow during the period 20 February to 16 April 2015. Classes 1–3 vehicles are defined as light duty vehicles (LDV) and classes 4–13 are defined as heavy duty vehicles (HDV) with a gross vehicle mass of greater than 3,500kg. A small proportion of vehicles passing through the site could not be classified.

Figure 4.5 Seven- day average traffic flow, 20 February to 16 April 2015

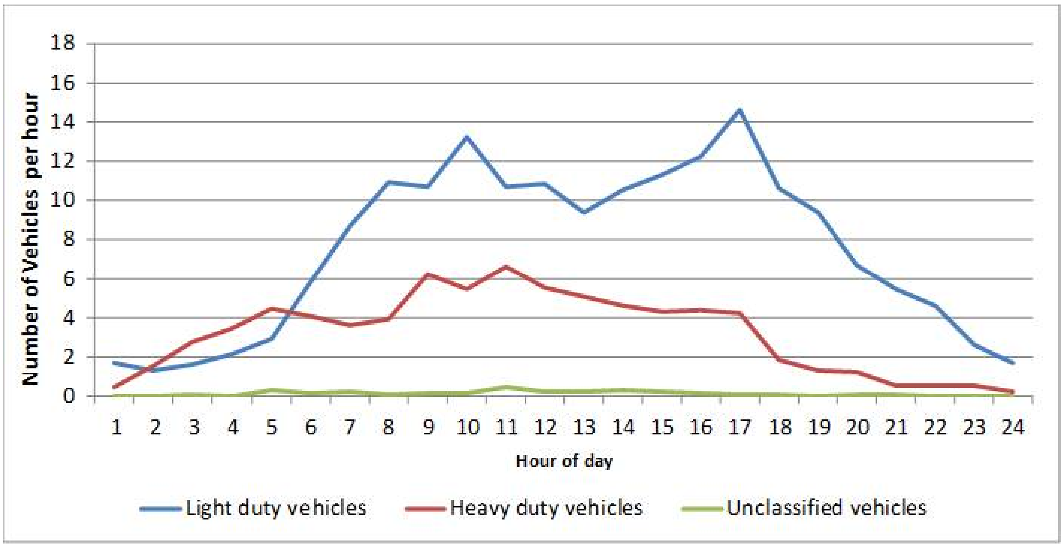


Figure 4.5 shows that LDV traffic numbers demonstrate a weekday commuter type pattern. LDV traffic volumes build from 5am to a peak at around 9am as people travel to work, show a dip over the working day hours (10am to 4pm) and then increase to an afternoon peak value at around 5pm as people return home. LDV traffic volumes then steadily decrease from 5pm to 11pm. Figure 4.5 shows that HDVs have a different type of traffic flow that reflects an extended working day. HDV traffic numbers build from 1am to 5am, are reasonably steady from 6am to 4pm, then decrease from 5pm to 11pm. The seven-day average daily traffic over the monitoring period was approximately 260 vehicles per day. LDVs comprised 69% of the total traffic, HDVs comprised 30% of the total traffic, and 1% of the vehicles were not classified into either of those two vehicle types.

Figure 4.6 shows the weekday (Monday to Friday) average traffic flow during the period 20 February to 16 April 2015.

Figure 4.6 **Weekday traffic flow, 20 February to 16 April 2015**

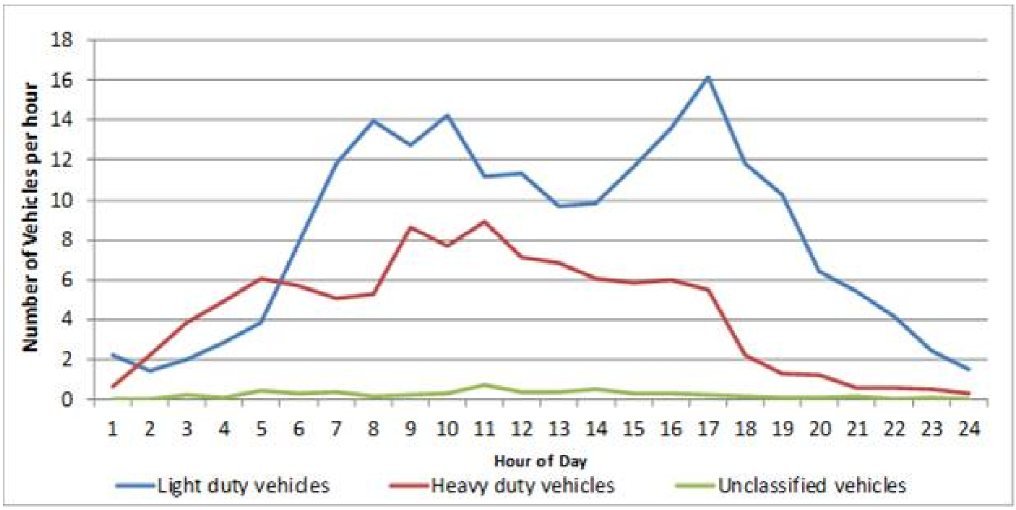
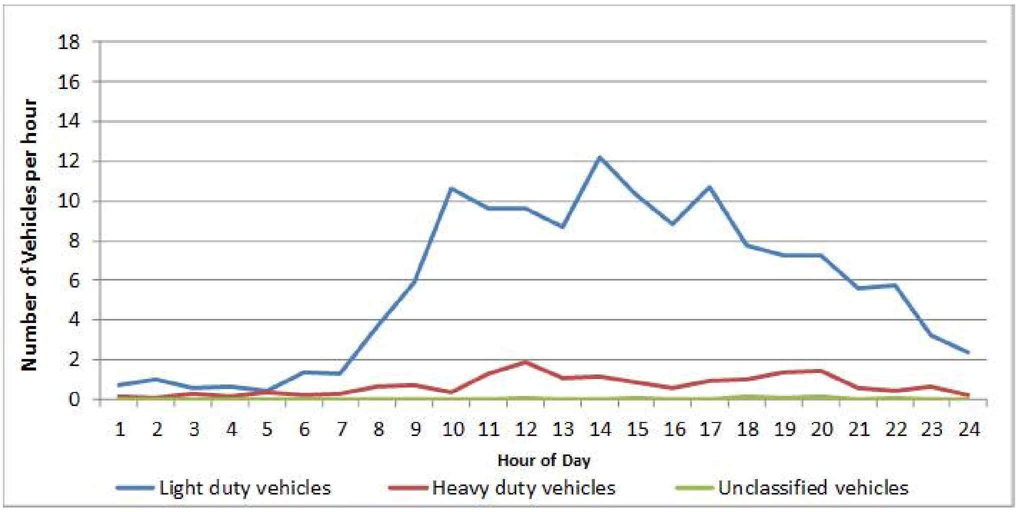


Figure 4.6 shows the weekday traffic flow pattern for LDVs and HDVs is similar to that seen in the seven-day average traffic flow, albeit with higher traffic volumes. The weekday average daily traffic during this period was approximately 310 vehicles per day. LDVs comprised 65% of the total traffic, HDVs comprised 34% of the total weekday traffic, and 1% of the vehicles were not classified.

Figure 4.7 shows the weekend days (Saturday and Sunday) average traffic flow during the period 20 February to 16 April 2015. Figure 4.7 shows that LDV traffic numbers demonstrate a weekend (non-work) activity type pattern. LDV traffic volumes are very low from 1am to 6am and then build from 7am to a weekend day peak at around 10am, which is maintained until around 6pm. LDV traffic volumes then steadily decrease from 7pm to 11pm. Figure 4.7 shows HDV traffic volumes are low (<2 HDV per hour) and relatively steady during all hours of weekend days. The weekend day average daily traffic during this period was approximately 152 vehicles per day (approximately half of the weekday traffic numbers). LDVs comprised 89% of the total traffic, HDVs comprised 10% of the total weekend traffic, and 1% of the vehicles were not classified into either of those two vehicle types.

Figure 4.7 **Weekend traffic flow – 20 February to 16 April 2015**

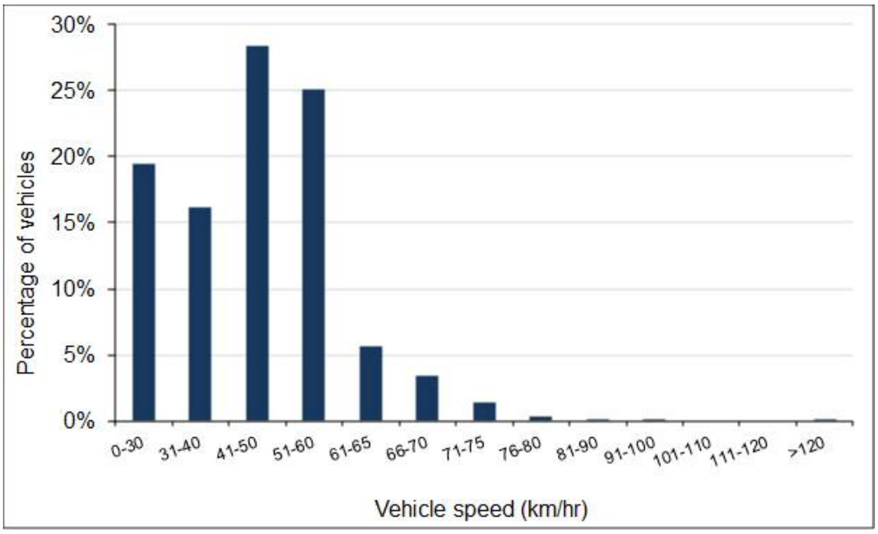


In summary, the Mataraua traffic monitoring shows:

- distinct weekday diurnal patterns for LDVs (commuting) and HDVs (working)
- distinct weekend diurnal patterns for LDVs and HDVs
- relatively high proportion of HDVs during weekdays
- low proportion of HDVs during weekend.

Figure 4.8 shows the speed distribution of vehicles passing through the monitoring site during the period 20 February to 16 April 2015. The average speed of the vehicles passing through the monitoring site was approximately 50km/h. Figure 4.8 shows approximately 36% of vehicles were travelling at less than 40km/h, 54% between 41 and 60km/h, and 10% greater than 60km/h.

Figure 4.8 Distribution of vehicle speeds, 20 February to 16 April 2015



4.3 Non-NES compliant PM_{10} data

The PM_{10} data derived from the Dustmote monitoring that is presented in the figures and tables in sections 4.4 to 4.6 of this report is the k-factor adjusted Dustmote data. The Dustmote data is not compliant with the PM_{10} monitoring requirements set out in the NES and should not be used to assess compliance against the NES. The adjusted Dustmote data provides a good indication of PM_{10} concentrations (although not definitive in regard to the NES) that is fit for the purpose of this project.

4.4 Total suspended particulates and PM_{10}

To assess what fraction of the road dust has the potential to cause adverse effects in humans, a comparison was undertaken of the BAM TSP and PM_{10} data at the untreated north 5m and 30m sites. A comparison of the TSP and PM_{10} data at the untreated north sites indicated:

- 5m site shows that PM_{10} made up approximately 25% of the TSP
- 30m site shows that PM_{10} made up approximately 32% of the TSP.

The literature search, which investigated road dust composition and size distribution (section 2.1.2), suggests that PM$_{10}$ was found to be in the range 15 to 30% of TSP. The results obtained at Mataraua Road are therefore broadly consistent with the values found in the literature.

An increase in the proportion of PM$_{10}$ within TSP is observed as the distance from the road increases. This is expected as the larger dust particles fall out of the dust plume closer to the road (the dust source), while the smaller particles remain suspended for a longer period. Therefore, the proportion of PM$_{10}$ in the dust plume increases with distance from the road.

4.5 PM$_{10}$ NES concentrations

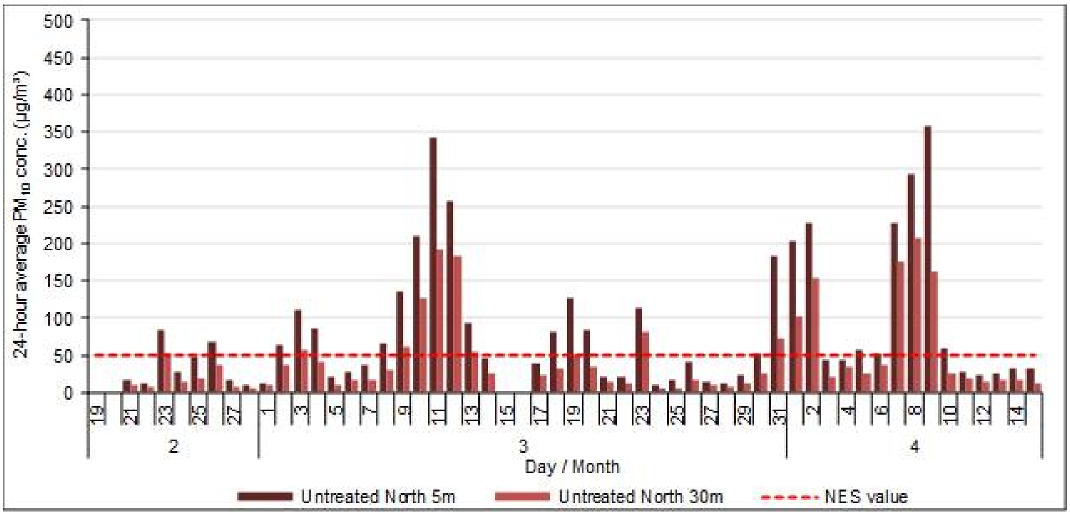
To quantify the potential human health impacts of dust from unsealed roads, PM$_{10}$ was monitored at distances of 5m and 30m from the roadside. There are two key elements to assessing human exposure to road dust PM$_{10}$: 1) the concentration of PM$_{10}$; and 2) the amount of time people are exposed to the dust. It is important to note that people are unlikely to be at locations 5m from the roadside for any extended period (ie greater than one hour). Therefore the high concentrations measured at this location are unlikely to indicate a high exposure for people. Because houses are generally set back some distance from the roadside, PM$_{10}$ concentrations measured at 30m are considered to provide a more realistic representation of the maximum human exposure to PM$_{10}$ from road dust over a 24-hour time frame.

The PM$_{10}$ concentrations were indicatively assessed against the NES criterion of 50µg/m^3 (24-hour average).

4.5.1 Untreated road surface

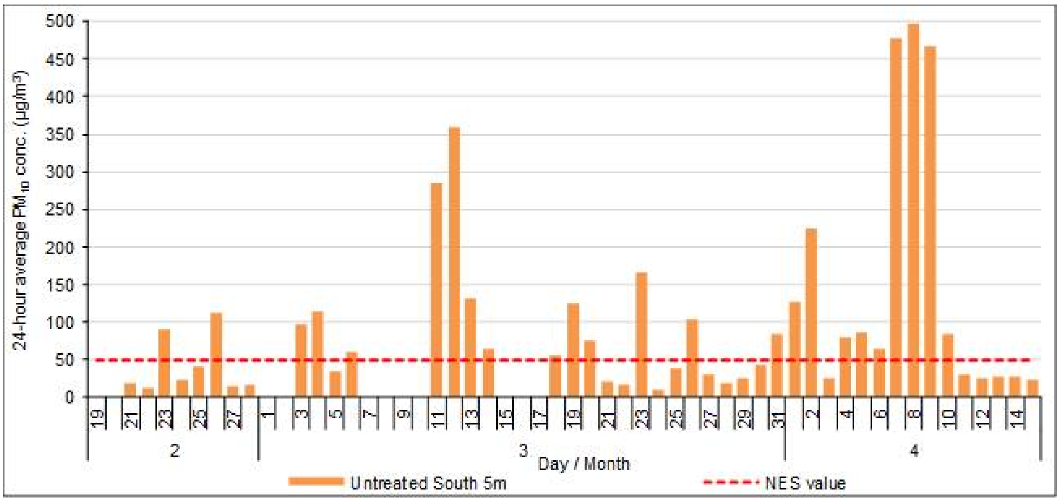
Figure 4.9 shows the PM$_{10}$ concentrations measured on the untreated section of the road at the north 5m and 30m sites. Figure 4.10 shows the PM$_{10}$ concentrations measured on the untreated section of the road at the south 5m site. The dashed red line on figures 4.9 and 4.10 shows the PM$_{10}$ NES concentration. Table 4.1 provides the summary statistics for PM$_{10}$ monitoring on the untreated section of the road at the north 5m, north 30m and south 5m sites.

Figure 4.9 PM$_{10}$ concentrations on the untreated roadway: north 5m and north 30m sites, 19 February to 16 April 2015



NOTE: Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

Figure 4.10 PM₁₀ concentrations on the untreated roadway: south 5m site, 19 February to 16 April 2015



NOTE: Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

Table 4.1 Summary statistics for daily average PM₁₀ monitoring – untreated section of the road

Site	Number of days with data	Number of days with PM₁₀ concs. >50(µg/m³)	Campaign mean PM₁₀ conc. (µg/m³)	Campaign median PM₁₀ conc. (µg/m³)
Untreated north – 5m	52	25	83	47
Untreated north – 30m	52	15	47	25
Untreated south – 5m	45	24	101	61

NOTE: Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

Figures 4.9 and 4.10 and table 4.1 show that PM$_{10}$ concentrations measured on the untreated section of the road:

- exceeded the NES target of 50µg/m³ (24-hour average) between 53% (south site) and 48% (north site) of days monitored at the 5m sites
- had a campaign mean concentration that ranged between 83 and 101µg/m³ at the 5m sites
- exceeded the NES for more than 29% of days monitored at the 30m site
- had a campaign mean concentration of 47µg/m³ and a campaign median concentration of 25µg/m³at the 30m site

In summary, the monitoring undertaken at Mataraua Road indicates that the NES for PM$_{10}$ was exceeded frequently at the 30m site[2]. Therefore, we can conclude there is significant potential for adverse human health impacts to occur from dust discharged from untreated unsealed roads.

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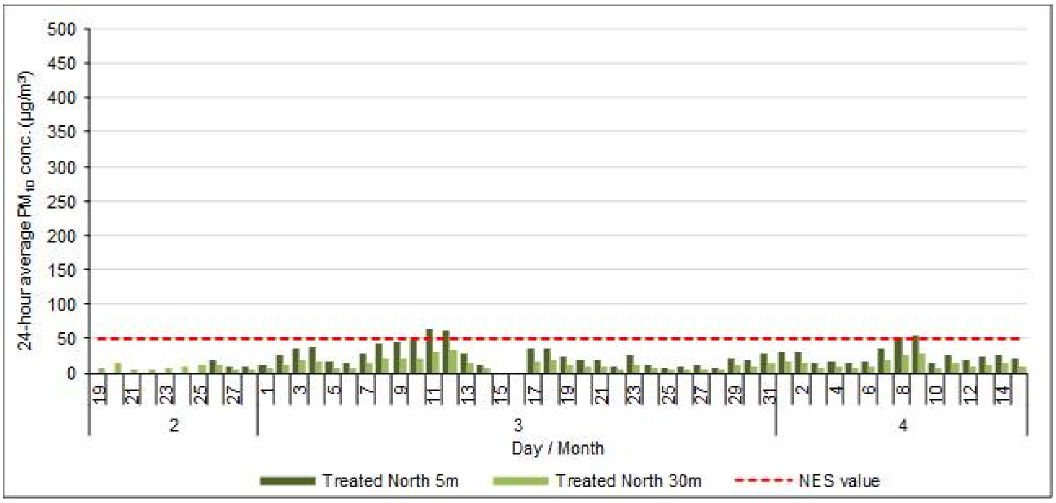
[2] Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

4.5.2 Treated road surface

Figure 4.11 shows the PM_{10} concentrations measured on the untreated section of the road at the north 5m and 30m sites. Figure 4.12 shows the PM_{10} concentrations measured on the treated section of the road at the south 5m site. The dashed red line on figures 4.11 and 4.12 shows the PM_{10} NES concentration.

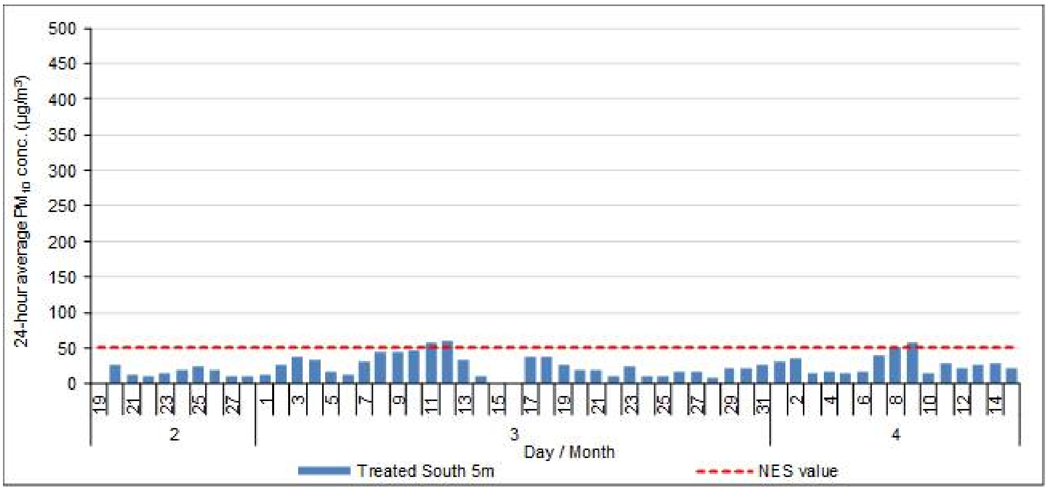
Table 4.2 provides the summary statistics for PM_{10} monitoring on the treated section of the road at the 5m north, 30m north and 5m south sites.

Figure 4.11 PM_{10} concentrations on the treated roadway: north 5m and north 30m sites, 19 February to 16 April 2015



NOTE: Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

Figure 4.12 PM_{10} concentrations on the treated roadway: south 5m site, 19 February to 16 April 2015



NOTE: Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

Table 4.2 Summary statistics for daily average PM_{10} monitoring – treated section of the road

Site	Number of days with data	Number of days with PM_{10} concs. > 50(µg/m³)	Campaign average PM_{10} conc. (µg/m³)	Campaign median PM_{10} conc. (µg/m³)
Treated north – 5m	47	4	26	21
Treated north –30m	55	0	12	11
Treated south – 5m	53	3	25	21

NOTE: Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

Table 4.2 shows that PM_{10} concentrations measured on the treated section of the road:

- exceeded the NES between 6% (south site) and 9% (north site) of days monitored at the 5m sites
- had a campaign average concentration that ranged between 25 and 26µg/m³ at the 5m sites
- did not exceed the NES at the 30m site
- had a campaign average concentration of 12µg/m³ at the 30m site (approximately 25% of the concentration measured at the untreated 30m site)

In summary, the monitoring undertaken at Mataraua Road indicates that, because the NES for PM_{10} is not exceeded at the 30m site, potential adverse human health impacts from the dust discharged is lower when unsealed roads are treated with dust suppressants.

4.6 Extent of dust plume impact

To assess human exposure and to investigate the effectiveness of buffer distances in mitigating the effects of dust discharged from unsealed roads it is important to understand how far dust plumes from unsealed roads extend and the following two key elements need to be quantified:

- background PM_{10} concentrations (concentrations of PM_{10} from sources other than the unsealed road)
- the distance at which the impact of the PM_{10} discharged from the unsealed road reduces to background concentrations.

4.6.1 Background concentrations of PM_{10}

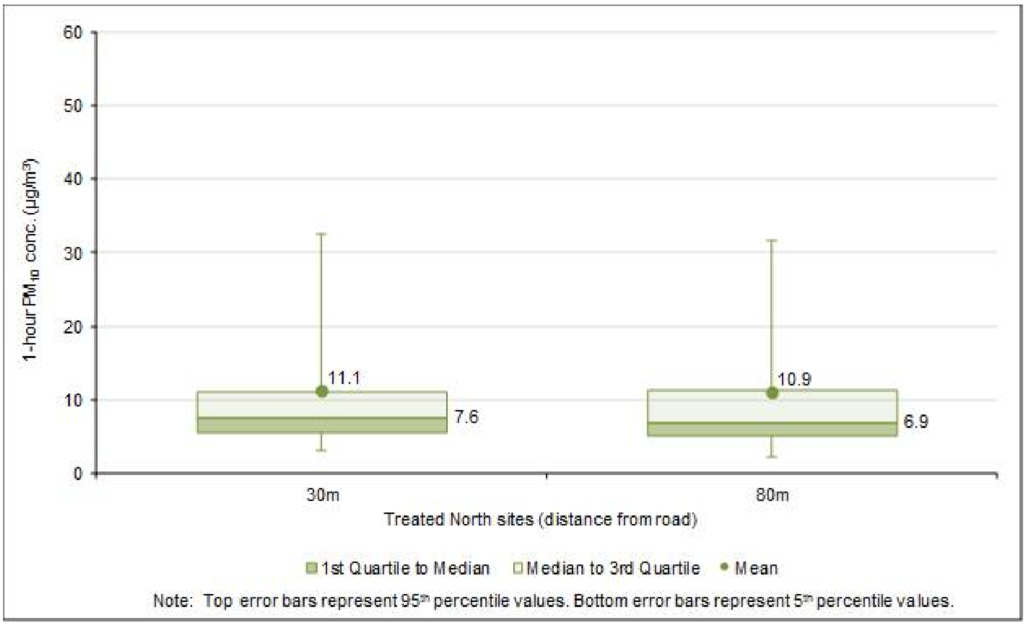
For this study, background PM_{10} concentrations are defined as PM_{10} from sources other than the unsealed road. To quantify the background PM_{10} concentrations, an analysis of the PM_{10} data was undertaken when the wind direction was from the northwest (towards the road from the north) for the monitors closest to the treated section of the unsealed road. Only PM_{10} data from the 30m and 80m north sites was used in the analysis of background concentrations because the 5m north and south sites showed the influence of road dust no matter what direction the wind was blowing from because of the effects of traffic induced turbulence. Figure 4.13 shows the wind direction during measurements of background PM_{10} for the treated section of the road.

Figure 4.13 Wind direction (blue arrow) during measurements of background PM_{10} at treated north sites

An analysis of the PM_{10} concentrations at these two sites (treated 30m and 80m) during northwest winds was undertaken and the results displayed as box and whisker plots in figure 4.14. In figures 4.14 to 4.16 the whiskers extend from the 95th percentile value to the 5th percentile value. The boxes extend from the 75th to the 25th percentile values. The median value is marked with a line within the box. The mean value is marked with a dot.

Figure 4.14 shows the mean one-hour PM_{10} concentration during northwest winds was approximately 10µg/m³. This value has been adopted as representative of the background concentrations for this project and is consistent with background concentrations of PM_{10} in other rural locations measured in New Zealand.

Figure 4.14 PM_{10} concentrations at the treated north 30m and 80m sites during winds from the northwest

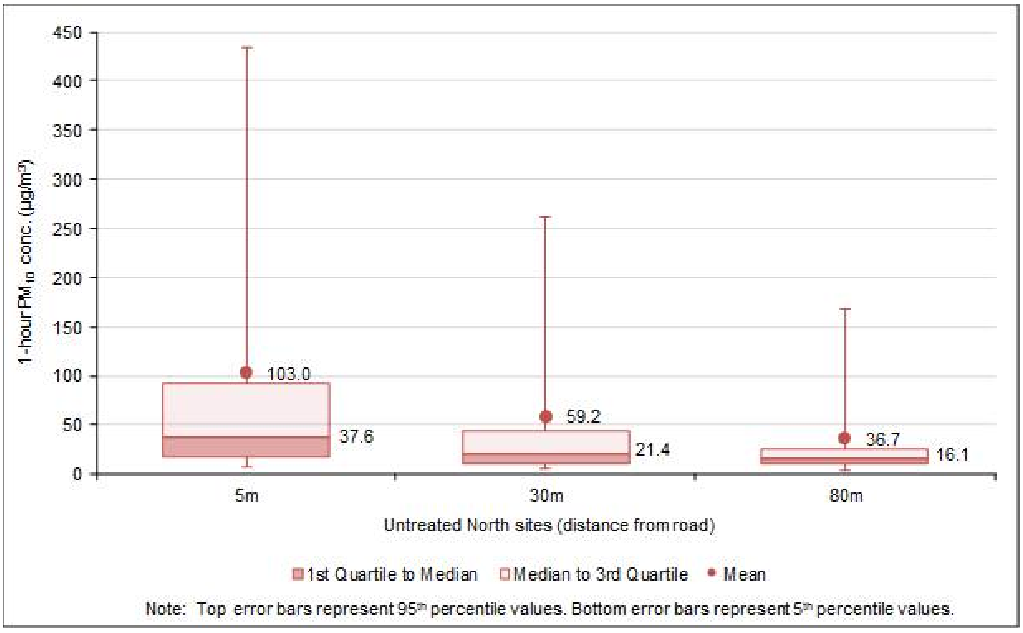


Note: Top error bars represent 95th percentile values. Bottom error bars represent 5th percentile values.

4.6.2 Untreated road surface

Figure 4.15 shows the one-hour average PM_{10} concentrations measured at the 5m, 30m and 80m north sites located on the untreated section of the unsealed road during southeast winds (from the road towards the monitors). Figure 4.15 shows that during southeast winds, the one-hour concentration of PM_{10} is higher than 16μg/m³ at the 80m site for more than half of the measurements made. The mean value of one-hour average PM_{10} concentration at the 80m site is 38μg/m³. Assuming the background PM_{10} concentration is 10μg/m³, figure 4.15 suggests that the effect of the untreated road PM_{10} dust plume extends for a distance of greater than 80m.

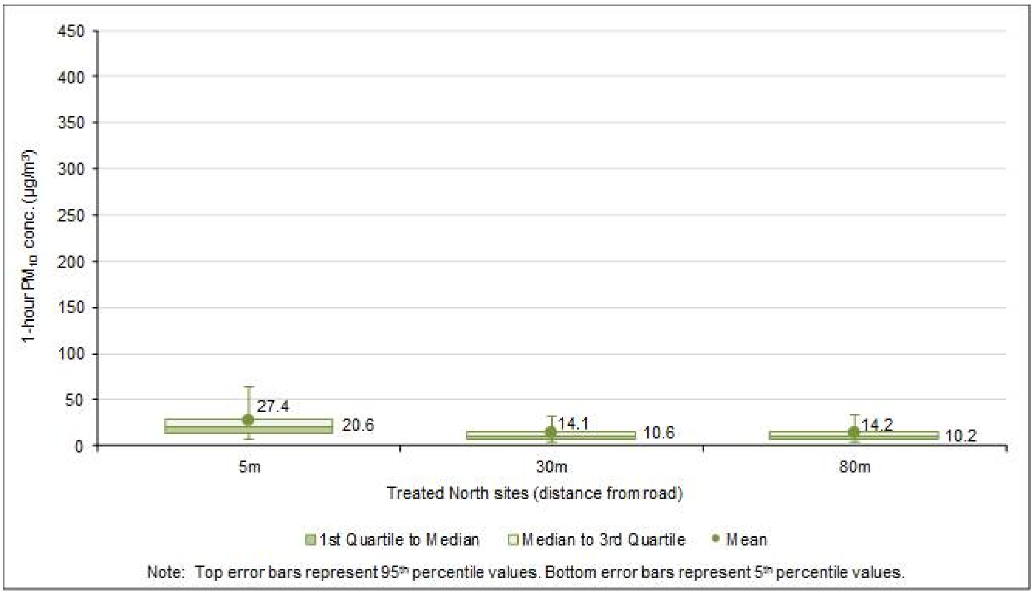
Figure 4.15 Transect of PM_{10} concentrations from untreated road surface during winds from the southeast



4.6.3 Treated road surface

Figure 4.16 shows the one-hour average PM_{10} concentrations measured at the 5m, 30m and 80m north sites located on the treated section of the unsealed road during southeast winds (from the road towards the monitors) for all wind speeds. Figure 4.16 shows the one-hour concentrations of PM_{10} measured at the 30m and 80m sites are very similar (mean values ~ 14μg/m³ and median values ~ 10μg/m³). While the mean and median values are slightly higher than the background values shown in figure 4.14, the observation that the PM_{10} concentrations do not increase between the 30m and 80m sites suggests the effect of the dust plume from the treated section of the road does not extend further than 30m.

Figure 4.16 Transect of PM_{10} concentrations from treated road surface – all wind speeds



Note: Top error bars represent 95th percentile values. Bottom error bars represent 5th percentile values.

4.7 Vehicle speed as a dust mitigation measure

Vehicle speed has been shown to have a significant effect on the amount of dust discharged from an unsealed roadway. To reduce dust generated on mine or quarry haul roads, air discharge permit conditions frequently restrict vehicle speed to a maximum of 20km/h. On the section of Mataraua Road where the dust monitoring was undertaken the forestry transport companies had agreed to a voluntary speed restriction of 20km/h (see figure 4.17). This voluntary speed restriction was adhered to only by forestry staff and contractors. The legal speed limit on this section of road was 100km/h.

Figure 4.17 Voluntary speed restriction sign

In an effort to investigate if a voluntary speed restriction was effective at reducing dust emissions consultation was undertaken with the forestry transport companies and the residents of Mataraua Road. Far North District Council staff engaged both sets of stakeholders and garnered support to raise the speed limit to 50km/h for the last two weeks of the monitoring programme (6 to 20 April 2015). Consequently, for the last two weeks of the campaign the 20km/h speed limit signs were removed and replaced with 50km/h signs.

Table 4.3 compares the monitored vehicle speed data for the six weeks of the monitoring campaign when the voluntary speed limit was 20km/h with the last two weeks of the monitoring campaign when the speed limit was increased to 50km/h. A major limitation to this analysis was that the traffic counters did not provide individual vehicle records, therefore a direct comparison of HDV speed was not possible. To make the best use of the data available, table 4.3 presents weekday data only to minimise the effect of any change in the speed profile of LDVs. A comparison of the composition of the vehicle fleet passing through the site for the first six weeks and last two weeks showed it was unchanged at 69% LDV and 31% HDV.

Table 4.3 Comparison of vehicle speeds for weekdays during the period of 20 and 50km/h speed limits

Vehicle speed categories (km/h)	Percentage of vehicles in each category	Percentage of vehicles in each category	Percentage increase (+) or decrease (-) in last 2 weeks
	Average first 6 weeks	Average last 2 weeks	
0–30	21.7%	22.0%	0.32%
31–40	16.9%	15.7%	-1.20%
41–50	27.6%	25.5%	-2.08%
51–60	23.7%	24.7%	0.94%
61–65	5.1%	6.4%	1.29%

Notwithstanding the limitations of the available data and analysis undertaken, table 4.3 suggests that the percentage of all vehicle classes passing through the site travelling less than 30km/h did not reduce during the last two weeks of the monitoring campaign when the voluntary speed restriction had been lifted. The lack of impact of a change in the speed limit along the road could have been due to drivers having become accustomed to driving at the slower speed, so changing the signs would not be expected to have any effect until sometime in the future when they had had the time to re-adapt.

If any change in driver behaviour had occurred, the percentage of the fleet travelling at less than 31km/h would have resulted in an appreciable decrease and the percentage of the fleet travelling at between 31 and 50km/h would have increased. However, the change in the percentage of vehicles in each vehicle speed category was insignificant, which suggests driver behaviour did not change with the increase in the HDV speed limit through the site. Due to the lack of individual vehicle record data this conclusion is applicable only to the complete vehicle fleet and not specific to HDV vehicles. The confounding factor of any change in LDV speed could not be controlled for.

Therefore an assessment of the effectiveness of HDV speed limits on dust emissions was not undertaken as it was considered that any such analysis would be inconclusive.

For any future research programme looking to quantitatively assess the effect of HDV speed restrictions on dust emissions, it is recommended that vehicle counters must be set and checked to record individual vehicle speeds. This recommendation is covered in section 9.1.

4.8 Dust deposition

Nuisance effects of dust can be assessed using dust deposition gauges (figure 4.18). Dust deposition gauges are set up and left to collect dust for a period of between 20 and 30 days. At the end of that period, the water contained in the jar is filtered to collect the dust, then dried and weighed to quantify the amount of dust collected over the monitoring period. The method for collection and analysis of deposited dust is defined in the standard ISO DIS-4222.2. MfE (2001) recommends a mitigation trigger level for deposited dust of $4g/m^2/30$ days above background.

Figure 4.18 Dust deposition gauge

To assess the degree to which an unsealed road creates nuisance dust effects, dust deposition gauges were deployed at three locations around the site. Dust deposition gauges were commissioned for two roadside locations, being the treated and untreated north 5m sites, while a background site was established at the 80m north untreated site. The roadside locations were chosen for the dust deposition monitoring to provide a worst case scenario and to provide the strongest indicator of the effectiveness of the dust suppressant on larger particles. The dust deposition rates experienced at the 30m sites are likely to have been lower than those measured at the 5m sites.

The results of the dust deposition monitoring are provided in appendix B, while table 4.4 presents a summary of the results. Table 4.4 shows:

- the deposited dust adjacent to the untreated section of the road was much higher than the MfE trigger level of 4g/m^2/30 days
- a large variation was observed in the two results from the untreated section of the road (12 to 48g/m^2/month)
- the deposited dust adjacent to the treated section of the road was no greater than background levels and consistent over both measurement periods.

Table 4.4 Dust deposition results

Site	Start date	Finish date	Raw deposition rate (g/m^2/30 days)	Deposition rate adjusted for background (g/m^2/30 days)
Background (untreated south 80m)	25/02/2015	16/04/2015	5	NA
Untreated north 5m	19/02/2105	4/04/2015	17	12
Untreated north 5m	4/04/2015	16/04/2015	53	48
Treated north 5m	19/02/2105	4/04/2015	5	0
Treated north 5m	4/04/2015	16/04/2015	4	0

The dust deposition rates displayed in table 4.4 suggest the dust suppressant was very effective at reducing nuisance dust effects from the unsealed road.

4.9 Respirable silica

One of the potentially hazardous components of road dust is respirable crystalline silica. To assess the concentrations of respirable silica experienced at the Mataraua Road site a pump and filter sampling system was set up and run for four periods at the untreated north 5m site. The results of the respirable monitoring are provided in appendix C. Table 4.5 shows a summary of the respirable silica sampling results. It is important to note t the mass of silica captured on all filters was below the detection limits of the laboratory. However, to provide an estimate of the maximum possible silica concentration it was assumed the mass of silica captured on all filters was equal to the detection limit of 5µg and this mass of silica was divided by the volume of air taken for each specific sample. For this reason the results presented in table 4.5 can only be considered as an indicative and very conservative estimate.

There is no ambient air quality standard for crystalline silica in New Zealand. However, USEPA (1996) concluded that 'for healthy individuals not compromised by other respiratory ailments and for ambient environments expected to contain less than 10% crystalline silica fraction in PM_{10}, the maintenance of 50µg/m^3 as an annual average for PM_{10} should be adequate to protect against the silicotic effects from ambient crystalline silica exposures. Assuming a maximum of 10% silica in dust, an interim standard of 5µg/m^3 as an annual average for ambient silica can be assumed'.

Table 4.5 Respirable silica sampling results (untreated north 5m site)

Sample number	Start date	Sample time (hours)	Total dust (μg/m³)	Respirable dust (μg/m³)	RD/TD	Respirable silica mass (μg)	Maximum possible respirable silica concentration (μg/m³)
144921	18/03/2015	5	200	90	0.45	<5	9
144922	23/03/2015	12	240	230	0.96	<5	4
144923	31/03/2015	21	10	10	1.0	<5	2
144920	1/04/2015	21	120	110	0.92	<5	2

Comparing the estimated maximum silica concentrations measured at Mataraua Road with the USEPA interim standard shows that one sample (144921) exceeded the interim standard, and one sample (144922) was 80% of the interim standard. However, to put these results into a useful context it is important to note:

- The Mataraua Road results were calculated based on the conservative assumption that the mass of silica in the sample was equal to the limit of detection.
- The samples were taken:
  - 5m from the roadside, a location where long-term human exposure is unlikely
  - during summer when dust emissions are relatively high compared with the winter average and the annual average emissions (the long-term average is likely to be significantly lower than recorded in table 4.5).

In summary, the results presented in table 4.5 are unlikely to be realistic estimates of long-term human exposure to respirable silica at this site and are almost certainly conservative over-estimates. Notwithstanding the limitations of the respirable silica data, using a number of conservative assumptions, it is suggested that the residents of Mataraua Road are unlikely to be exposed to annual average concentrations of greater than 5μg/m³. However to confirm this conclusion, a more detailed monitoring programme of longer duration would be required. This issue is covered in section 9.1.

5 Dust mitigation

The information presented in this section addresses research objective number 3:

- Determine the effectiveness and costs of the dust mitigation measures and discuss other issues to consider when selecting the most appropriate dust mitigation measure.

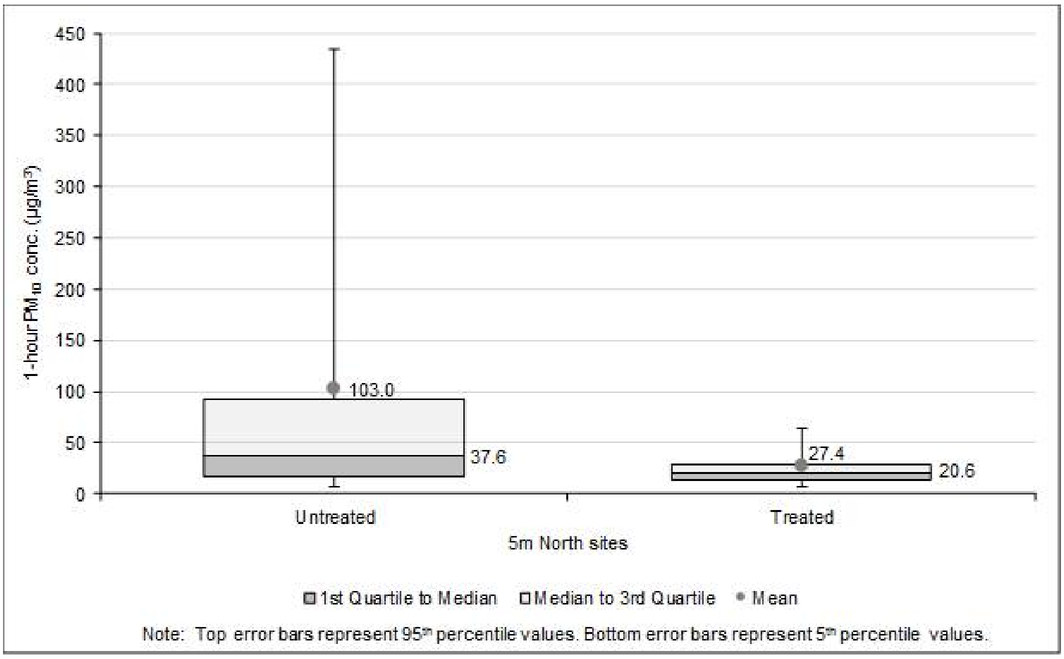
5.1 Effectiveness of dust mitigation

The effectiveness of the dust mitigation was assessed by comparing PM_{10} concentrations at the north 5m, 30m and 80m sites for the untreated and treated sections of the road when the wind direction was across the road and toward the north monitors (south-easterly wind).

Figures 5.1, 5.2 and 5.3 compare box and whisker plots of PM_{10} concentrations from the untreated and treated sections of the road for the north 5m, 30m and 80m monitors, respectively. In these figures the whiskers extend from the 95th percentile value to the 5th percentile value. The boxes extend from the 75th to the 25th percentile values, the median value is marked with a line within the box and the mean value is marked with a dot.

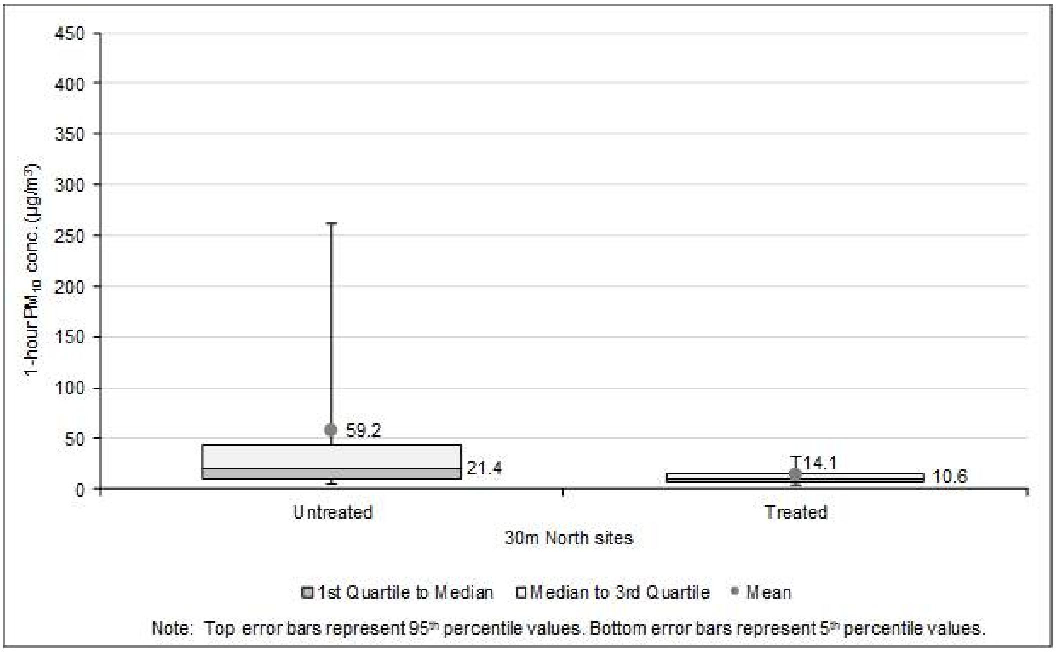
Table 5.1 presents the summary statistics for the PM_{10} concentrations from the north 5m, 30m and 80m sites for the untreated and treated sections of the road.

Figure 5.1 PM_{10} concentrations for the 5m north sites – untreated and treated sections of the road



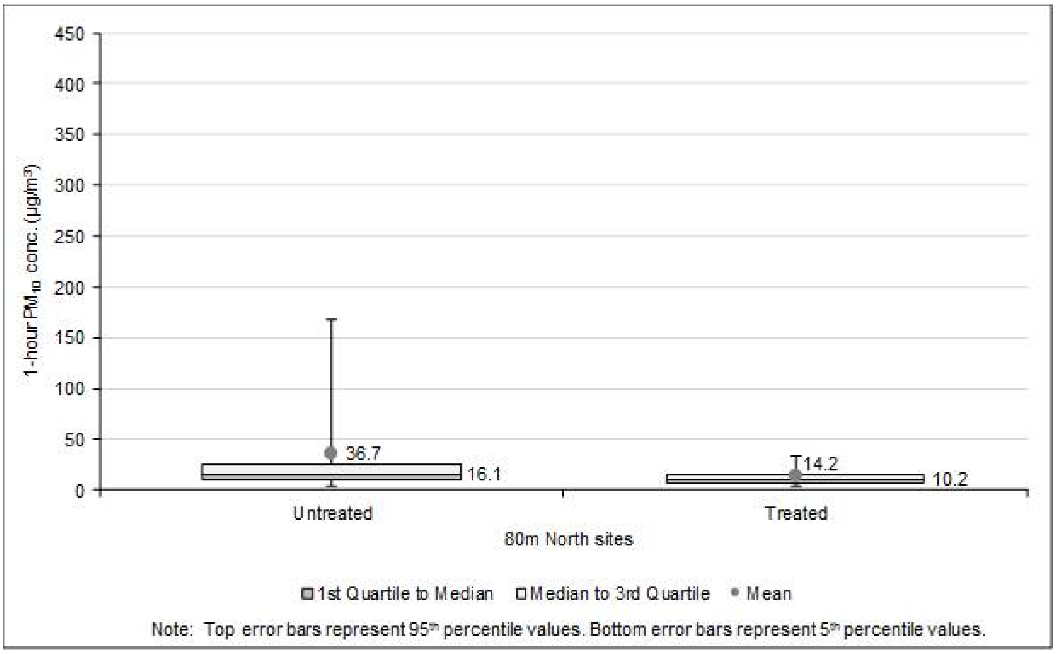
Note: Top error bars represent 95th percentile values. Bottom error bars represent 5th percentile values.

Figure 5.2 **PM_{10} concentrations for the 30m north sites – untreated and treated sections of the road**



Note: Top error bars represent 95th percentile values. Bottom error bars represent 5th percentile values.

Figure 5.3 **PM_{10} concentrations for the 80m north sites – untreated and treated sections of the road**



Note: Top error bars represent 95th percentile values. Bottom error bars represent 5th percentile values.

Table 5.1 PM_{10} concentrations from the north 5m, 30m and 80m sites for the untreated and treated sections of the road

Site	**5m**		**30m**		**80m**	
Road surface	**Untreated**	**Treated**	**Untreated**	**Treated**	**Untreated**	**Treated**
Maximum PM_{10} 1-hr average (μg/m^3)	1,402	441	940	143	746	170
90th percentile value PM_{10} 1-hr average (μg/m^3)	251	47	136	25.5	69.6	25
75th percentile PM_{10} 1-hr average (μg/m^3)	92.3	28.9	43.9	15.4	25.9	15.7
50th percentile PM_{10} 1-hr average (μg/m^3)	37.6	18.2	21.4	10.6	16.1	10.2
Mean PM_{10} 1-hr average (μg/m^3)	103	25.7	59.2	14.1	36.7	14.2
25th percentile PM_{10} 1-hr average (μg/m^3)	17.5	14.4	11.2	7.46	10.3	7.01

A comparison of the PM_{10} concentrations monitored at the untreated and treated sites shows the application of the suppressant significantly reduces the dust discharged from the road. The maximum and 90th percentile values are reduced by a factor of between three and six. The 75th percentile and average values are reduced by a factor of between three and four for the 5m and 30m sites, and a factor of between 2 and 3 for the 80m site. The 50th and 25th percentile values are reduced by a factor of between 1.5 and 2. The beneficial effect of the suppressant is seen most strongly in the higher values at the sites closest to the road. While the improvement is still significant at the more distant 80m site, the beneficial effect of the suppressant is observed at lower percentile values. This is because at the 80m treated site the PM_{10} mean, 50th and 25th percentile values are close to the background concentration and therefore less likely to be affected by the impact of the suppressant.

5.2 Longevity of the dust suppressant

The suppliers of the dust suppressant used for this trial advised the $MgCl_2$ product should remain effective for a period of up to four months, depending mainly on the amount of traffic and rainfall that occurred. A qualitative assessment was undertaken to investigate whether the effectiveness of the dust suppressant was maintained or decreased over the eight weeks of the monitoring programme.

Table 5.2 and figure 5.4 compare PM_{10} concentrations at the treated 5m sites for the first and last two weeks of the monitoring programme. The four bars presented in figure 5.4 for each site and time period represent the 90th percentile, 75th percentile, average and 50th percentile values, respectively. Table 5.2 and figure 5.4 show the concentrations of PM10 monitored in the first two weeks of the programme are either greater than or approximately equal to the concentrations of PM10 monitored in the last two weeks of the programme.

Table 5.2 Comparison of 1- hour PM_{10} concentrations at the treated 5m sites for the first and last two weeks of the monitoring programme

		Treated south 5m		Treated north 5m	
		First 2 weeks	Last 2 weeks	First 2 weeks	Last 2 weeks
1h PM_{10} conc.	**Maximum**	425	223	441	254
	90th %ile	50	48	58	44
	75th %ile	32	32	32	29
	50th %ile	21	21	20	19
	Average	29	29	29	28

Figure 5.4 Comparison of dust concentrations for the first and last two weeks of monitoring programme (treated south and north 5m sites)

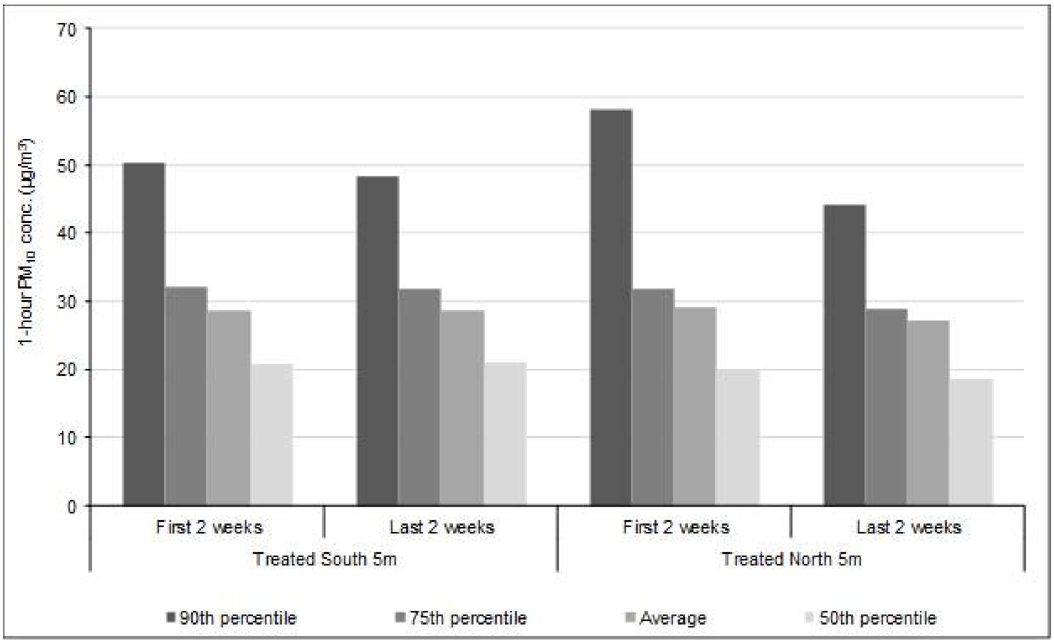


Table 5.3 presents a summary of meteorological conditions and vehicle numbers monitored at the site during the first and last two weeks of the monitoring programme. Figures 5.5 and 5.6 compare the dust concentrations, vehicle counts and rainfall for first and last two weeks of monitoring programme at the treated north 5m and 30m sites respectively.

Table 5.3 Comparison of summary meteorological conditions and vehicle numbers during the first and last two weeks of the monitoring programme

Variable	First 2 weeks	Last 2 weeks
Total rain (mm)	43.4	15.0
No. hours with winds <1 m/s	173	192
Average wind speed (m/s)	1.35	1.52
No. light vehicles	3,008	2,131
No. heavy vehicles	990	1,052

Figure 5.5 **Comparison of dust concentrations, vehicle counts and rainfall for the first and the last two weeks of monitoring programme (treated north 5m site)**

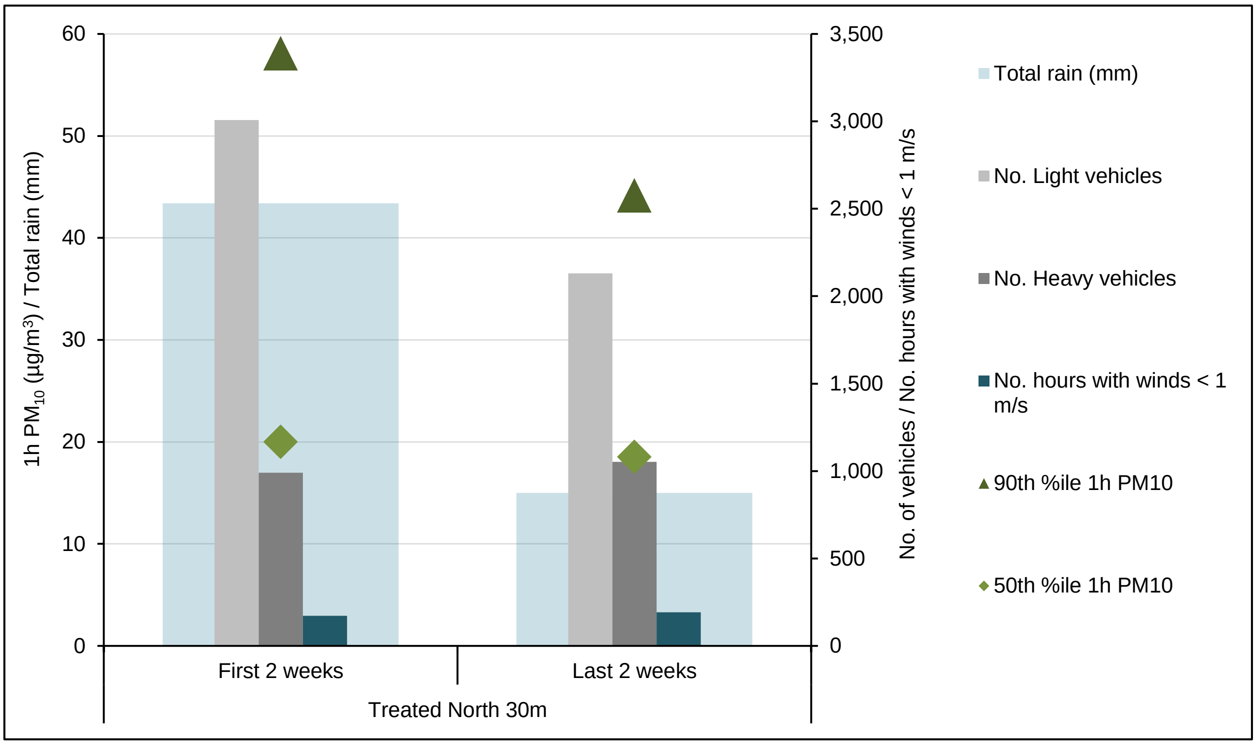
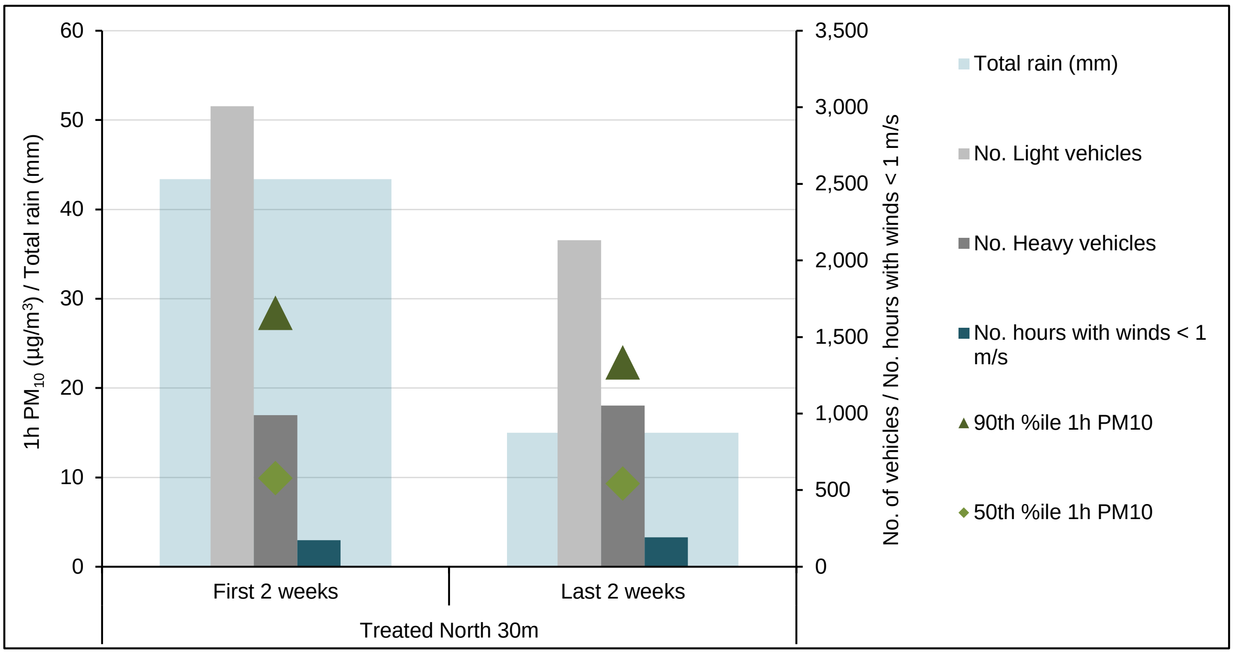


Figure 5.6 **Comparison of dust concentrations, vehicle counts and rainfall for the first and the last two weeks of monitoring programme (treated north 30m site)**



The information presented above suggests the following:

- The meteorological conditions of the last two weeks of the monitoring programme resulted in a higher potential for dust events to occur than in the first two weeks (primarily less driving rain).

- The number of LDVs passing the site was approximately 50% higher in the first two weeks and the number of HDVs was very similar.
- PM_{10} concentrations in the last two weeks were similar to or lower than first two weeks.

In conclusion, the data suggests the effectiveness of the dust suppressant did not decrease during the monitoring programme. This is a qualitative assessment, which could be checked using multivariate statistics. However, given that any change in the effectiveness of the dust suppressant between the two periods is small and the Mataraua Road monitoring programme duration is well within the longevity of the product as claimed by the supplier, the benefit of undertaking such a detailed statistical analysis is considered small.

It is noteworthy that Cyclone Pam generated approximately 45mm of rainfall within 48 hours midway through the monitoring programme. Despite the volume and intensity of the rain it does not appear, at least in the short term, to have had a significant impact on the effectiveness of the dust suppressant.

5.3 Cost of dust mitigation strategies

This section provides cost estimates of the factors considered in the assessment of health and economic impacts of changes in PM_{10} concentrations, as detailed in chapter 6. Two dust mitigation strategies are described:

- Treating an unsealed road with a dust suppressant
- Sealing the road surface.

5.3.1 Baseline scenario – maintaining an unsealed road

The baseline scenario for the assessment of health and economic impacts is an unsealed road. The two key elements to the maintenance of an unsealed road are grading and road metal. These and other factors relevant to maintaining an unsealed road are detailed in table 5.4.

The maintenance costs for an unsealed road as presented in table 5.4 are based on an economic evaluation undertaken by Whangarei District Council in 2015 for a seal extension for Wright Road and McCardle Road, located approximately 20km west of Whangarei. Whangarei District Council costs for Wright Road and McCardle Road were scaled to match the dimensions of the section of Mataraua Road, which was used in the dust suppression and monitoring trials. While there may be some site-to-site variation in costs, the Whangarei District Council estimate provides a reasonable basis for the costs that would be incurred at Mataraua Road.

Table 5.4 Estimated annual costs of maintaining 1km of unsealed road.

Factor	Value
Length of road	1,000m
Width of road	5m
Area of road to treat	5,000m^2
Roadway maintenance–- grading the road (assuming grading is undertaken 6 times per year and costs $200 per km)	$1,200
Metal for road surface (assuming 230m^3 of metal)	$4,000
Total annual cost of maintaining and treating 1km of unsealed road without dust suppressant	$5,200
Net present value (over 40 years, assuming 6% discount rate)	$83,000

Based on the figures and assumptions presented above, the total cost of maintaining 1km of unsealed road for one year is approximately $5,200 (NPV $83,000).

5.3.2 Treating an unsealed road with dust suppressant

The factors relevant to estimating the costs of treating an unsealed road with dust suppressant are detailed in table 5.5. In addition to the application of the suppressant to the unsealed road, the road must still undergo routine maintenance, with the two key elements of the maintenance schedule (grading and road metal) included in table 5.5. The grading of the road regenerates the effectiveness of the suppressant, by bringing the base material which is still rich in suppressant to the surface. The design life of the suppressant is three to four months according to the supplier. The Far North District Council contractor undertakes road maintenance grading once every two months, so that the frequency of maintenance grading fits in nicely with the life of the suppressant. The road will be graded as part of suppressant application, after which a scheduled maintenance grading should take place about half way through the life of the suppressant – regenerating its efficiency.

The dust suppressant cost presented in table 5.5 is based on the cost incurred by the project at Mataraua Road, but scaled up to 1km of road (from the 800m that was treated on site). It is important to note that costs will vary based on the type of suppressant being used and the volume of suppressant purchased.

The maintenance costs presented in table 5.5 are based on an economic evaluation undertaken by Whangarei District Council in 2015 for a potential seal extension for Wright Road and McCardle Road.

Table 5.5 Estimated annual cost of dust suppressant treatment and maintenance of 1km unsealed road

Factor	Value
Length of road	1,000m
Width of road	5m
Area of road to treat	5,000m^2
Application rate of suppressant	2 litres per m^2
Total amount of suppressant required	10,000 litres
Cost of suppressant (per application, one application per year)	$13,000 per km
Application of suppressant (one application requires 3 machines @$225 per hour for 3 hours each machine (total $2,025))	$2,000
Roadway maintenance – grading the road (assuming 6 gradings per year and $200 machine costs per km). Scheduled grading is continued in the period during which the suppressant is active.	$1,200
Metal for road surface (assuming 230m^3 of metal required for 5,000m^2 of road surface)	$4,000
Total annual cost of maintaining and treating 1km of unsealed road with dust suppressant (assuming one application of suppressant per year)	$20,200
Net present value (over 40 years assuming 6% discount rate)	$324,000

Assuming one application of dust suppressant per year, based on the figures and assumptions presented above, the total cost of chemically treating and maintaining 1km of unsealed road for one year is approximately $20,000 (NPV 324,000).

5.3.3 Sealing the road surface

The factors relevant to sealing the surface of an unsealed road are detailed in table 5.6. The cost information presented in table 5.6 is based on the economic evaluation undertaken by Whangarei District Council in 2015 for a potential seal extension for Wright Road and McCardle Road, but scaled to match the dimensions of the section of interest of Mataraua Road.

Table 5.6 Cost of sealing the road surface

Factor	Value – 40- year useful road life	Value – 10- year useful road life
Length of road	1,000m	1,000m
Width of road	5m	5m
Area of road to seal	5,000m^2	5,000m^2
Initial cost of sealing	$250,000	$250,000
Maintenance and resealing costs over the useful year life of the road	$160,000	$40,000
Annual maintenance and resealing costs over the useful year life of the road	$4,000	$4,000
Total annual cost of sealing and maintaining a road surface	$21,000	$38,000
Net present value (40-year life assuming 6% discount rate)	$314,000	$575,000

Based on the figures and assumptions presented above, the total cost of sealing and maintaining 1km of unsealed road for one year is approximately $21,000 (NPV $314,000) assuming a 40-year roadway life and $38,000 (NPV $575,000) assuming a useful roadway life of 10 years.

6 Health and economic impacts of changes in PM_{10} concentrations

The information presented in this section addresses research objective number 4:

- Estimate the costs of the health impacts of dust from the unsealed road and the benefits of mitigating the dust.

Assessing health and economic impacts of changes in PM_{10} concentrations due to the suppression of road dust are resource intensive and complex tasks that require specific expertise in these two fields and hence undertaking a full health and economic impact assessment is beyond the scope of this project. The assessments provided in this section are, while robust, necessarily simplistic to fit within the available project resources. However, the costs and benefits data collected by this project are of a type and quality that will enable more detailed health impact and economic assessments to be undertaken in the future, such as to meet the requirements of a business case analysis (BCA) as defined in the EEM.

To match this project's scope for the health and economic impact assessments and to achieve the objectives of this section, four discrete steps were taken:

1 Establish annual average PM_{10} exposure for untreated and treated sections of road

2 Estimate the population exposed to annual average PM_{10} concentrations

3 Estimate health impacts of dust from untreated, treated and sealed sections of road

4 Calculate cost-to-benefit ratios for the application of suppressant and sealing of the roadway.

6.1 Annual average PM_{10} exposure

Estimates of annual average PM_{10} exposure were made for three road dust scenarios:

- unsealed and untreated road
- unsealed and treated road
- sealed road.

Figure 6.1 shows the estimated monthly average PM_{10} concentrations at a distance of 30m from the untreated roadway. The 30m distance was chosen as being a representative setback from the road for most dwellings. The February and March monthly average PM_{10} concentrations are taken from the Mataraua Road monitoring programme results. The monthly average concentrations for the other months have been estimated by qualitatively considering the meteorological conditions for each month relative to February and March and relating these to road dust emission potential. The hot dry months have been assigned relatively high PM_{10} concentrations and the cool wet months have been assigned relatively low PM_{10} concentrations. The seasonal variation of estimated monthly average PM_{10} concentrations illustrated in figure 6.1 shows relatively low concentrations occurring in winter (July and August) and a steady increase from September through to a peak value in January, a slight step down in February and March and then a steady decrease over April and May to the winter time low (June). These assumptions combine to give an estimate of approximately 33µg/m^3 for the annual average PM_{10} concentration at 30m from an untreated unsealed road.

Given the lack of monitoring data available, the values of the annual average PM_{10} concentration presented in this section should be considered as initial estimates which contain a degree of uncertainty (perhaps +/- 20%).

The estimated values of the annual average PM_{10} could be refined if additional longer-term PM_{10} monitoring data was available (see section 9.1). While there are limitations around the certainty of the estimated annual average PM_{10} concentrations presented in this section, they are considered to be fit for the purpose of the project. Also, the use of refined values of annual average PM_{10} concentrations is not likely to change (to any large degree) the relative difference in annual average PM_{10} concentrations for the three selected road surface scenarios. This approach provides an estimate of approximately 33µg/m³ for the annual average PM_{10} concentration at 30m from an untreated section of the road.

Figure 6.1 Estimated monthly average PM_{10} concentrations at 30m from the untreated roadway

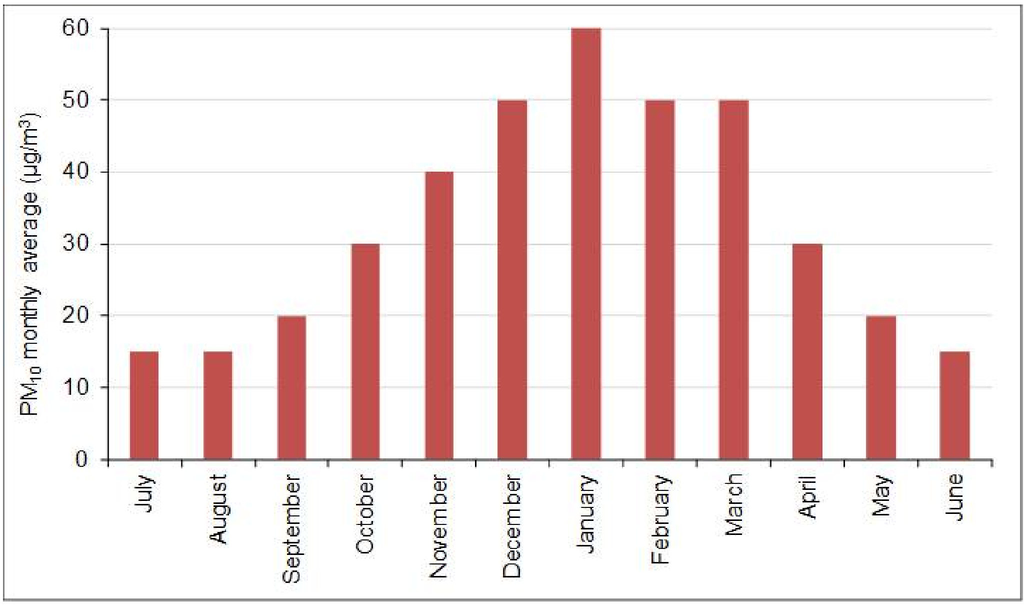


Figure 6.2 shows the estimated monthly average PM_{10} concentrations 30m from a treated roadway. The February and March monthly average PM_{10} concentrations are taken from the Mataraua Road monitoring programme results. It is assumed that the suppressant is applied in December and it remains effective for a period of four months, with reduced effectiveness in April and May. The assumed PM_{10} concentrations for the months of May, June, July, August, September and October are the same for both the untreated and treated scenarios.

These assumptions combine to give an estimate of approximately 19µg/m³ for the annual average PM_{10} concentration at 30m from a treated section of the road.

Figure 6.2 Monthly average PM_{10} concentrations at 30m from the treated roadway

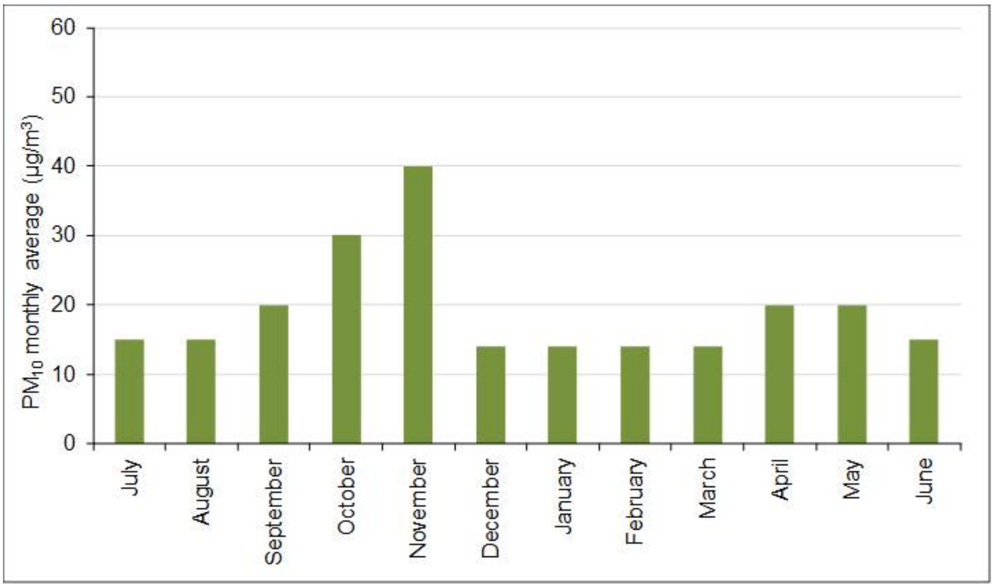
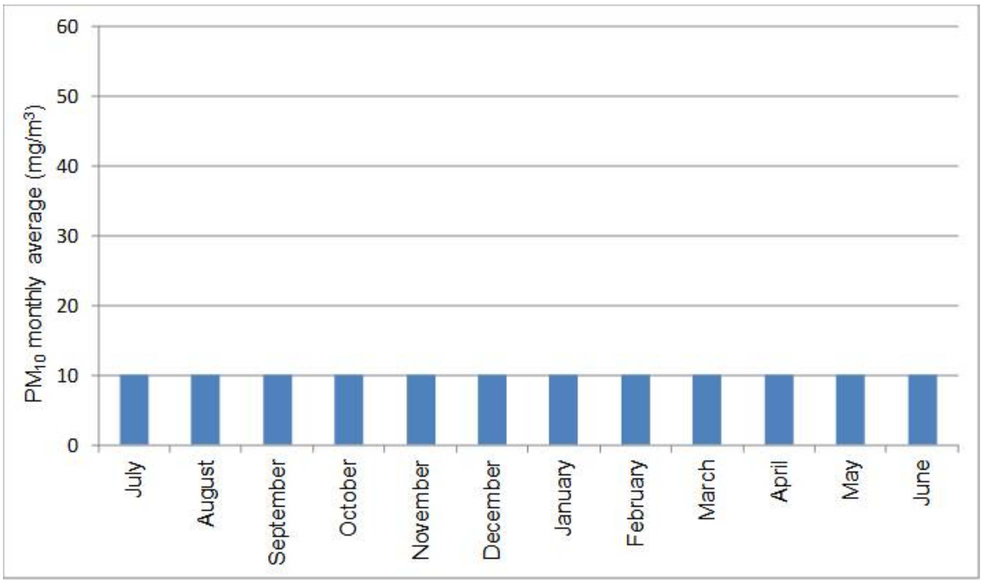


Figure 6.3 shows the estimated monthly average PM_{10} concentrations 30m from a sealed roadway. For the sealed roadway it is assumed that the predominant source of PM_{10} is the background. These assumptions combine to give an estimate of approximately 10µg/m^3 for the annual average PM_{10} concentration at 30m from a sealed section of the road.

Figure 6.3 Monthly average PM_{10} concentrations at 30m from the sealed roadway



In summary, the estimate of annual exposure to PM_{10} at 30m from the roadway for the three scenarios considered provides the following annual average PM_{10} concentrations:

- 33µg/m^3 – unsealed road with an untreated surface
- 19µg/m^3 – unsealed road with the surface treated once per year (42% reduction from unsealed and untreated)
- 10µg/m^3 – sealed road (70% reduction from unsealed and untreated).

The values of annual exposure to PM_{10} at 30m from the roadway for the three scenarios considered should be treated as first order estimates that may vary greatly from site to site. However, given the available information, the estimates provide useful starting point values and good estimates of the relative change in PM_{10} exposure under the scenarios considered.

The estimates of annual exposure to PM_{10} could be improved with an extended PM_{10} monitoring programme, preferably over a complete year.

6.2 Population exposed to annual average PM_{10} concentrations

Table 6.1 provides an estimate of the number of people exposed to the annual average PM_{10} concentrations alongside the 1km trial site. The estimate is based on counts of houses on Mataraua Road and estimates of occupancy rates. The estimate excludes short-term stays of people at Kaiangahoa Marae.

Table 6.1 Estimate of population exposed to annual average PM_{10} concentrations on Mataraua Road

Variable	Value
Length of roadway	1,000m
Number of houses	8
Estimate of the number of people living in each house[a]	2.9
Total number of people living alongside the 1km trial site	23

[a] Occupancy rate taken from New Zealand census data 2013 for Ngapuhi-Kaikou census area unit (CAU) number 501634), population 2,397, households 819.

6.3 Health cost impacts of dust from untreated, treated and sealed sections of road

An assessment was made of the health cost impacts of dust from untreated, treated and sealed sections of the road. The input data for the assessment was the estimated annual average PM_{10} concentration (section 6.1) and the estimated number of people exposed to this PM_{10} concentration (section 6.2). The cost of the impacts was estimated using an epidemiological exposure-response model to assess the human-health benefits of changes in exposure to PM_{10}. The epidemiological exposure-response model used was an output of the health and air pollution in New Zealand (HAPINZ) study (2012 update http://www.hapinz.org.nz/).

The human health effects of the PM_{10} discharged from the surface of roadways were assessed for three scenarios:

- unsealed and untreated road
- road surface treated with chemical suppressant
- sealed road surface.

The HAPINZ model was run for the Ngapuhi-Kaikou Census Area Unit (CAU) (CAU number 501634) as Mataraua Road sits within this CAU. Due to localised variations in population demographics errors can occur when using the HAPINZ model at CAU level. For this reason output data from applying the HAPINZ model for the Ngapuhi-Kaikou CAU assuming a population of 32 must be treated with caution. To ensure that results for these HAPINZ model runs are not distorted by the population assumption, the results from the Ngapuhi-Kaikou CAU were compared against larger geographic areas and larger populations.

Another limitation to utilising the HAPINZ model for estimating the health impact costs in this study is that the model does not directly assess acute effects of high levels of particulate exposure and the linear response model may not be applicable to the range and variation of particulate concentrations measured in this study. Despite these limitations HAPINZ is still the only New Zealand specific model available and any uncertainty contained in the estimation of the cost of health effects is not anticipated to change the conclusions on the relative benefits of the two mitigation measures considered here.

The inputs and outputs for the HAPINZ model runs are presented in table 6.2.

Table 6.2 Estimated health costs from the PM_{10} discharged from untreated, treated and sealed sections of road

Scenario	Annual ave. PM_{10} conc. ($\mu g/m^3$)	Pop.	Total annual health cost ($000)	NPV[(a)] health costs ($000)	Prem. mortality (% of total cost)	Hospital admiss. (cardiac) (% of total cost)	Hospital admiss. (resp.) (% of total cost)	Restricted activity (% of total cost)
Unsealed and untreated road	33	23	$41	$639	98.8%	0.1%	0.1%	1.0%
Unsealed and treated road	19	23	$24	$368	98.8%	0.1%	0.1%	1.0%
Sealed road surface	10	23	$12	$194	98.8%	0.1%	0.1%	1.0%

(a) Net present value calculated over a 40-year period at a 6% discount rate.

In summary, the assessment of the health cost impacts of dust from untreated, treated and sealed sections of road shows an annual health cost saving arising from:

- the application of a chemical suppressant of approximately $17,000 (NPV $271,000)
- sealing the road of approximately $29,000 (NPV $445,000).

6.4 Benefit-to-cost ratio of dust mitigation

Tables 6.3 and 6.4 show the calculated BCR ratio of mitigating the dust from the section of unsealed road of Mataraua Road using chemical suppressants and sealing the road surface using annualised and net present value (NPV) approaches, respectively. The main difference between the annualised and NPV approach is timing of costs and benefits. The NPV approach traditionally books costs at the start of a period and benefits at the end, while the annualised approach assumes simultaneity. To provide a comparison of the results, table 6.3 presents the annualised approach and table 6.4 presents the NPV approach. Details of how the annualised and NPV values were calculated are presented in appendix D.

Table 6.3 Benefit- to- cost ratio of treating and sealing sections of the road surface (annualised approach)

Scenario	Annual av. PM_{10} conc. ($\mu g/m^3$)	Annual health cost ($000)	Annual health benefit of PM_{10} mitigation ($000)	Annual roading costs ($000)	Annual additional cost of M&M[(a)] ($000/km)	Benefit/cost ratio (mitigation vs no mitigation)	Incremental benefit/cost ratio (sealing vs treatment)
Unsealed and untreated road	33	41	NA	10	NA	NA	NA
Unsealed and treated road	19	24	17	$20.2	15	1.2	NA
Sealed road surface (40-yr life)	10	12	29	$20.6	$15.4	1.9	26.9
Sealed road surface (10-yr life)	10	12	29	$37.9	$32.7	0.9	0.6

(a) M&M = maintenance and mitigation

Table 6.4 Benefit- to- cost ratio of treating and sealing sections of the road surface (NPV approach)

Scenario	Annual ave. PM_{10} conc. ($\mu g/m^3$)	NPV health cost (40 years) ($000)	NPV health benefit of PM_{10} mitigation ($000)[(a)]	NPV roading costs ($000)	NPV additional cost of M&M ($000)	Benefit/cost ratio (mitigation vs no mitigation)	Incremental benefit/cost ratio (sealing vs treatment)
Unsealed and untreated road	33	$639	NA	$83	NA	NA	NA
Unsealed and treated road	19	$368	$271	$324	$241	1.1	NA
Sealed road surface (40-yr life)	10	$194	$445	$314	$231	1.9	-17.5[(b)]
Sealed road surface (10-yr life)	10	$194	$445	$575	$492	0.9	0.7

(a) NPV for health benefits have been moved by 6 months relative to the costs, rather than the standard year.

(b) Costs lower for sealing on an NPV basis.

Both the annualised and NPV approaches to assessing the BCR ratio of treating or sealing the section of the road surface lead to the same conclusions. In summary, the analysis shows that for the Mataraua Road site the cost of:

- treating the surface of the road with chemical suppressant is slightly less the health benefits gained from the reduction in PM_{10} concentrations (BCR = 1.1)
- sealing the surface of the road is less than the health benefits gained from the reduction in PM_{10} concentrations if the road has a useful life of 40 years (BCR = 1.9)
- sealing the surface of the road is greater than the health benefits gained from the reduction in PM_{10} concentrations if the road has a useful life of 10 years (BCR = 0.9)

For the sealed road option, there is a significant upfront cost ($250,000) associated with constructing the road surface, and a maintenance cost of approximately $4,000 per year (which is comparable to the maintenance required for the baseline unsealed road). In New Zealand, unsealed roads are often used for short-to-medium term activities, such as logging, and then revert back to lower intensity rural/residential use. It is estimated that it would take approximately 14 years for the mitigation benefit provided by sealing the road to equal the cost (BCR=1), assuming the same traffic conditions as the baseline scenario.

The BCR above is not comprehensive and considers only the incremental cost of dust mitigation and the resulting human-health benefit related to reduced dust exposure. There may be additional benefits (and costs) associated with the mitigation options, such as improvements to travel time and road safety that are not included in the analysis.

6.5 Other factors to consider when fully assessing the cost and benefits of dust suppression

The BCR analysis is simplistic in that it considers only the cost of road maintenance and mitigation and the health benefits associated with the dust mitigation. The assessment provided in this report does not attempt to calculate the NPVs undertaken over a 40-year analysis, (using the 6% discounting as recommended by the EEM). A BCA undertaken in line with the requirements of the EEM would incorporate and also consider the benefits of:

- travel time savings
- productivity improvements
- vehicle operating cost savings
- crash cost savings.

The use of chemical dust suppressants on unsealed roadways (and other surfaces) is regulated by the rules in the relevant regional plan. Broadly speaking, dust suppression may be considered a discharge to land and classified as a permitted, controlled, restricted discretionary, discretionary, non-complying or prohibited activity depending on the type of suppressant used, and the region within which the activity is being undertaken. If the use of chemical dust suppressants is permitted, a resource consent must be obtained from the relevant regional council. The development of an application for resource consent (including an assessment of environmental effects) and the processing of the application by the council have associated time, cost and uncertainty risks which should be considered when assessing the relative costs of different dust control measures.

There are three other classes of effects that have not been considered in the Mataraua Road case study cost–benefit analysis:

- nuisance effects of dust (including the degradation of amenity values)
- ecological effects
- agricultural and horticultural effects.

The cost of the above effects of road dust and the benefits of mitigation of these is not easy to quantify. The literature review revealed a general lack of guidelines to aid in the assessment of adverse health effects. There also appears to be a lack of information that would allow the calculation of the costs of dust impacts and benefits of dust mitigation in relation to the three types of adverse effect listed above. For the Mataraua Road case study none of the three issues was considered significant, so they were not included in the cost-benefit assessment. However, due consideration of these three issues may be relevant to particular sites.

7 Dust mitigation – decision- making process

The information presented in this section addresses research objective number 5:

- Detail a methodology that can be used to support decision making about mitigation options.

Using the experience and data gained during the Mataraua Road dust monitoring and suppression trial a dust risk assessment framework (as detailed in sections 7.1 to 7.4) was developed to support the decision-making process of any TLA when considering whether they need to mitigate dust from unsealed roads.

It is important to note the dust risk assessment framework presented in this report is only intended as a starting point and should not be regarded as a tool that can be used immediately at any site across New Zealand to provide a definitive answer on the need for mitigating dust from a specific unsealed road. The dust risk assessment framework was tested on the Mataraua site and considered to provide a robust assessment for that particular site. It will undergo trials and refinement by the Transport Agency and relevant TLA staff before being finalised and formally integrated into the Transport Agency's assessment frameworks. Until that process has been completed, the dust risk assessment framework presented in this report should be used with due caution.

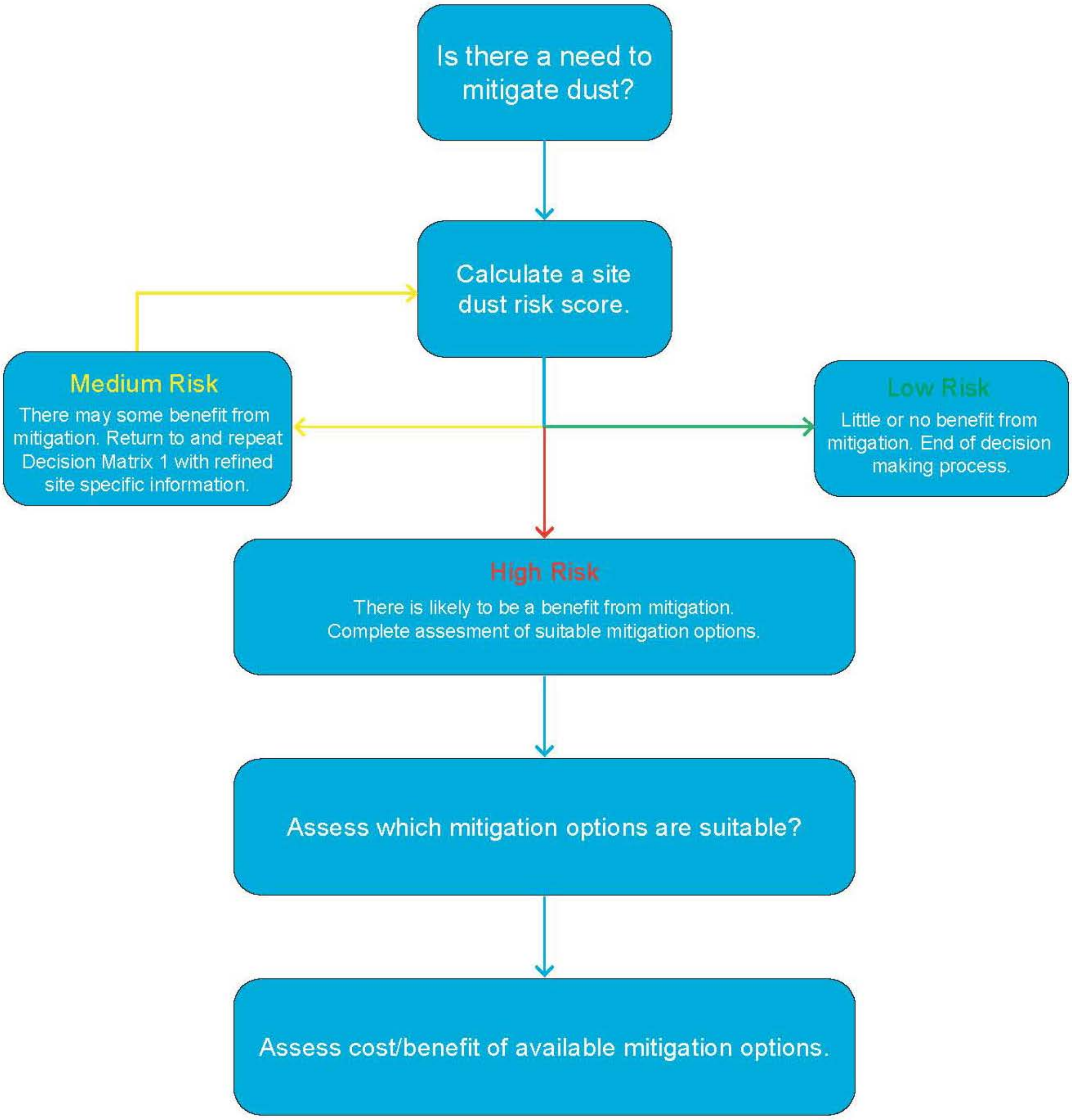
7.1 Key questions

The decision-making process involved in assessing the need to mitigate dust from unsealed roads is based on three key questions:

- Is mitigation required?
- What road dust mitigation options are suitable for the site?
- Which mitigation option provides the best benefit-to-cost outcome?

A decision-making process that integrates these three questions is shown in figure 7.1.

Figure 7.1 Dust mitigation – decision- making process



7.2 Is mitigation required?

A first order assessment on whether there is a need to mitigate road dust for a particular section of road can be completed by calculating a site dust risk score. The site dust risk score can also be used to assess the relative risk posed by different roads or different sections of the same road. A total of 12 factors are considered in the risk assessment. Each of the 12 factors falls into one of three key categories:

1. Traffic
2. Receptors
3. Site characteristics.

The site dust risk score is calculated by assigning each of 12 risk factors a score, the higher the score the greater the risk. The risk factors and their scores are detailed in table 7.1. The relative risk assigned to each of the factors listed in table 7.1 is based on a qualitative assessment of the findings from the road dust monitoring undertaken at Mataraua Road. The two highest risk factors, AADT of HDV and number of dwellings within 80m of the roadway are given a higher weighting that all other risk factors. The five-day AADT for HDVs and LDVs is used as the traffic risk factor because this metric provides the strongest indicator of HDV activity. Note some boxes within table 7.1 are intentionally left empty as assigning a risk factor to these factors is not considered informative to the risk assessment.

Table 7.1 Site dust risk factors and scores

Risk factor/score	0	1	2	3	4	5
Traffic						
5 day AADT of HDVs	0	1–5	6–10	11–25	26–50	More than 50
Speed limit of HDVs (km/h)	No HDVs	20 km/hr	50 km/h or greater			
5 day AADT of LDVs	Less than 100	101–300	More than 300			
Speed of LDVs (km/h)	Less than 50	50–70	Greater than 70			
Receptors (within 80m of roadway)						
Number of dwellings (houses/km)	0	1	2–4	5–7	8–10	More than 10
Other locations where people are likely to be exposed. (eg schools, marae, or hospitals) (sensitive locations/km)	None	1–2	3 or more			
Nuisance effects for residents (complaints/year)	None	1–2	3 or more			
Ecologically sensitive areas such as rare species habitats or wetlands (sensitive locations/km)	None	1–2	3 or more			
Horticultural sensitive areas such as fruit orchards (sensitive locations/km)	None	1–2	3 or more			
Site characteristics						
Location of roadway	Open plains or costal area	Some land features likely to slow winds	Inland enclosed valley			
Frequency of rain days (>5mm)	More than 2 events per week	0–1 events per week	Less than one event every two weeks			
Longevity of logging route use	Not a logging route	1–2 years	Longer than 3 years			

The site dust risk score is calculated by totalling the scores for each of the 12 individual factors. The site dust risk score will fall into one of three dust risk categories detailed in table 7.2. Table 7.2 provides a first order assessment on the potential benefits gained by mitigating that section of unsealed road. Finally table 7.2 indicates what action (if any) is needed to complete the decision-making process.

Table 7.2 Dust risk category and action to be taken

Total dust risk score	Dust risk category	Potential benefit from dust mitigation	Action to be taken
0 to 9	Low	Little or no benefit from mitigation.	End of decision-making process.
10 to 19	Medium	There may some benefit from mitigation.	Return to and repeat the 'Site dust risk factors and scores' with refined site-specific information.
20 to 30	High	There is likely to be a benefit from mitigation.	Complete assessment of suitable mitigation options.

If the site dust risk falls into the low category, no further action is required. The actions required if the dust risk score falls into either the medium or high-risk categories are detailed in sections 7.3 and 7.4 respectively.

Two worked examples of site dust risk assessments are provided in appendix D.

7.3 Medium dust risk

The site dust risk score is intended to give a conservative assessment on whether some benefit may be gained from mitigating the dust discharged from a particular section of unsealed road. If the dust risk score for a particular site falls into the medium dust risk category, it is recommended that a more detailed and quantitative site-specific assessment is undertaken.

The key site-specific elements to provide the basis for the assessment are:

- The concentrations of PM_{10} people may be exposed to, primarily driven by:
  - AADT of HDV
  - the distance at which dwellings are located from the road.
- The number of people potentially exposed to road dust PM_{10}, primarily driven by
  - the number of dwellings in close proximity to the road
  - the number of people living in each dwelling.
- Topography (road dust plume confined by surrounding hills?)
- Meteorology (windier and/or wetter?).

A more detailed site-specific assessment of the dust risk would consider how the site being assessed for dust risk differs from (or is similar to) Mataraua Road. Given this comparison the site dust risk score can be re-assessed and move into either the high- or low-risk category. If after the refined assessment, the site dust risk moves into the high-risk or remains in the medium-risk category it is recommended the high dust risk route in the assessment pathway be taken (see section 0).

7.4 High dust risk

If the dust risk score obtained for a particular site falls into the high-risk category, then the second 'What road dust mitigation options are suitable for the site?' and third 'Which mitigation option provides the best benefit to cost outcome?' key questions must be answered.

Table 7.3 provides assessment criteria that can be used to define which (if any) dust mitigation measures are suitable for the specific site being considered. The objectives of this project determined only chemical suppressants that are commercially available, do not have any significant adverse environmental effects, are reasonably priced and easy to apply should be considered. The chemical suppressants that met these criteria are included in table 7.3. There are a large number of other chemical suppressants available (see section 2.4) and if a particular site or TLA has different requirements, which determine alternative chemical suppressants, these should be added to the list of mitigation options contained in table 7.3.

Table 7.3 Assessment criteria for defining suitable dust mitigation options

Mitigation option	Permitted or discretionary activity under the relevant regional resource management plan	Suitable traffic volume	Longevity of the dust mitigation option	Rainfall frequency and intensity
Sealing the road	Yes	High – unlimited	10+ years	
Magnesium chloride	To be confirmed	Medium ~250 AADT	Medium – three to four months	Duration of effectiveness is reduced in high rainfall areas. Roadway can become slippery.
Lignin sulphate	To be confirmed	Light <100 AADT	Short – requires frequent refreshing	Duration of effectiveness is reduced in high rainfall areas.
Synthetic polymer emulsions	To be confirmed	Light <100 AADT	Short – requires frequent refreshing	Duration of effectiveness is reduced in high rainfall areas.

After identifying suitable dust mitigation measures, the final step in the decision-making process is to determine the mitigation option that provides the best benefit-to-cost outcome. A description of how a basic cost benefit assessment can be undertaken is provided in sections 6.1 to 6.4. An introduction into how this basic cost benefit assessment may be enhanced and/or integrated into the Transport Agency's BCA (as defined in the EEM) is provided in section 6.5.

8 Conclusion

The primary purpose of this research was to improve our understanding of the impacts dust emissions from unsealed roads have on people and to investigate the mitigation measures that are likely to be effective at reducing those impacts, as well as environmentally sustainable and financially cost effective. The project was conducted to address the following key research objectives:

1. Characterise the dust and quantify the impacts of dust from unsealed roads on people.
2. Determine the effectiveness and cost of available dust mitigation measures.
3. Estimate the costs of the health impacts of dust from the unsealed road and the benefits of mitigating the dust.
4. Propose a methodology that can be used to support decision making about mitigation options.

8.1 Characterise the dust and quantify the impacts of dust

A two-month road dust monitoring campaign was undertaken to characterise the dust and quantify the impacts of dust from unsealed roads on people. The monitoring was undertaken on a section of Mataraua Road, 10km southwest of Kaikohe in the Far North District during February, March and April 2015. The monitoring campaign was designed to collect representative data that would allow an assessment of dust levels against relevant health and nuisance effects guidelines. To provide an indicator of the effectiveness of dust suppression, a section of the unsealed road was treated with a suppressant and dust levels also monitored at that location.

The meteorology of the monitoring site is an important factor to consider when interpreting the dust data. Wind speed, wind direction, temperature, relative humidity and rainfall were therefore monitored on-site for the duration of the field campaign.

It is also important to understand traffic flow patterns and fleet composition when interpreting the road dust data. Two traffic counters were set up and run for the duration of the field campaign. The seven-day average daily traffic over the monitoring period was approximately 260 vehicles per day. LDVs comprised 69% of the total traffic, HDVs comprised 30% of the total traffic, and 1% of the vehicles were not classified. The traffic monitoring showed distinct weekday and weekend diurnal patterns for LDVs and HDVs, which included a relatively high proportion of HDVs during weekdays and a relatively low proportion of HDVs during weekend. While the legal speed limit on the road was 100km/h, the average speed of the vehicles passing through the monitoring site was approximately 50km/h.

To assess what fraction of the road dust has the potential to cause adverse effects on humans, a comparison was undertaken of the TSP and PM_{10} data. At 5m and 30m from the roadside, PM_{10} was found to make up 25% and 32% of the TSP, respectively. The results obtained at Mataraua Road are broadly consistent with the values found in the literature for unsealed roads.

PM_{10} concentrations measured on the untreated section of the road were found to exceed the daily average NES value of 50µg/m^3 for 15 of the 52 days monitored (approximately 30% of days monitored) at locations where people are most likely to be exposed[3]. The monitoring results indicate that potential adverse human health impacts may occur due to the dust discharged from untreated unsealed roads.

PM_{10} concentrations measured on the treated section of the road were not found to exceed the NES value for any of the 52 days monitored at locations where people are most likely to be exposed. The monitoring results indicate the potential adverse human health effects related to dust are reduced when dust suppressants are used on unsealed roads.

Measurements across the PM_{10} monitoring network suggest the untreated road PM_{10} dust plume extends for a distance of greater than 80m from the roadside, and the PM_{10} concentrations approach background levels at a distance of approximately 30m from the treated road section.

Dust deposition monitoring showed the deposited dust at the roadside adjacent to the untreated section was between 4 and 12 times greater than the MfE trigger level of $4g/m^2/30$-days above background. Dust deposition monitoring showed the deposited dust on the treated section of the road was no greater than background levels.

Despite the limitations of the respirable silica data, it is concluded that the residents of Mataraua Road are unlikely to be exposed to a concentrations of greater than $5\mu g/m^3$ when averaged over a year. However to confirm this conclusion, a more detailed monitoring programme of longer duration is required.

8.2 Determine effectiveness and the cost of available dust mitigation measures

A comparison of the PM_{10} concentrations monitored at the untreated and treated sites shows that the application of the suppressant significantly reduces the impact of dust discharged from the road. The maximum and 90th percentile values are reduced by a factor of between three and six. The 50th and 25th percentile values are reduced by a factor of between 1.5 and 2. The impact of the suppressant is seen most strongly in the higher values at the sites closer to the road. While the improvement is still significant, less impact of the suppressant is observed at lower percentile values and at the more distant (80m) site.

A qualitative assessment of the PM_{10} data measured over the two months of the monitoring programme suggests the effectiveness of the dust suppressant did not decrease over the duration of the monitoring programme. It is noteworthy that Cyclone Pam generated approximately 45mm of rainfall within 48 hours midway through the monitoring programme. Despite the volume and intensity of rainfall from this event it does not appear, at least in the short term, to have had any significant adverse effect on the effectiveness of the dust suppressant.

The total cost of applying a chemical suppressant once per year to an unsealed road was estimated to be $15,000 per km of road. The total annual cost of sealing and maintaining a road surface was estimated to be $21,000 per year per km of road assuming a 40-year life and 40 years of logging truck movements. However, if it was assumed that the forestry resource and the logging truck movements persisted for a period of 10 years on that road the total annual cost increased to $38,000 per km of road.

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[3] Comparison against NES criterion is indicative. Refer Section 4.3 for more detail.

8.3 Costs of the health impacts of dust and benefits of mitigating the dust

A high-level approach to estimating the BCR of mitigating the dust from the unsealed section of Mataraua Road showed the cost of:

- treating the surface of the road with chemical suppressant is slightly less than the health benefits gained from the reduction in PM10 concentrations (BCR = 1.1)
- sealing the surface of the road is less than the health benefits gained from the reduction in PM_{10} concentrations if the road has a useful life of 40 years (BCR = 1.9)
- sealing the surface of the road is slightly higher than the health benefits gained from the reduction in PM_{10} concentrations if the road has a useful life of 10 years (BCR = 0.9).

8.4 Decision making on mitigation options

Using the experience and data gained during the Mataraua Road dust monitoring and suppression trial a framework was developed to support the decision-making process of any TLA considering whether they need to mitigate dust from unsealed roads. Three key questions are considered:

- Is there a need to mitigate road dust?
- What road dust mitigation options are suitable for the site?
- Which mitigation option provides the best benefit to cost outcome?

A framework and tools are provided to help answer these questions.

A first order assessment of whether there is a need to mitigate road dust for a particular section of road is made by calculating a site dust risk score. The site dust risk score categorises the site as low, medium or high risk. For high-risk sites, assessment criteria are provided to define which (if any) dust mitigation measures are suitable for the specific site being considered. An introduction on how to use the information gained from the Mataraua Road monitoring programme to undertake a basic cost-benefit assessment of suitable dust mitigation measures is provided.

9 Recommendations

9.1 Enhancing future monitoring programmes

From the experiences gained during planning and executing the Mataraua Road monitoring programme recommendations are made that may enhance the value of any future road dust monitoring programmes.

Discussions with the residents of Mataraua Road suggest that the dust emissions from unsealed roads peak in January. It is recommended that any future road dust monitoring campaigns be run from December through to the end of March. This extended time period would capture the lead up to and the dustiest months of the year. The extended monitoring campaign would also provide a period when HDV traffic would be minimal due to the Christmas and New Year holiday break. This data record would assist in differentiating between dust generated by LDVs and by HDVs. The extended monitoring period would also allow a more comprehensive assessment of the longevity of the effectiveness of the dust suppressant.

It is recommended that if optical nephelometers are to be used in future road dust monitoring campaigns, the monitoring programme is designed as far as practical to allow k-factors (which scale nephelometer data to BAM equivalent data) to be generated for each of the key locations on transects away from the road and for each type of road-surface being monitored.

The literature and practical experience demonstrate that vehicle speed is one of the key factors in determining the amount of dust generated by a specific vehicle type. An unsuccessful attempt was made in this programme to assess the effectiveness of speed limits in controlling dust discharged from unsealed roadways. It is recommended that any future road dust monitoring programmes are designed to provide data to assess the effectiveness of speed limits in controlling dust discharged from unsealed roadways.

The results presented in this report are specific to the sites where the monitoring was undertaken. Road dust concentrations will vary from site to site and reflect the construction and geology of the roadway and the number and type of vehicles using the road. To generalise the results presented in this report to other areas with different roadway construction and geology, it is recommended that any future road dust monitoring programmes take place in an area significantly different from the road construction and geology of Mataraua Road.

The method used to monitor respirable crystalline silica should be refined to provide results that are above the limit of detection of the chemical analysis technique used or alternatively an analysis method with a lower level of detection should be used. Either of these refinements would provide a more definitive conclusion on this issue.

In the study, the potential health costs caused by road dust have necessarily been assessed against annual average concentrations of PM_{10}. Given that the peak impacts of road dust actually occur on a much finer temporal timeframe (minutes to hours) there is a mismatch between the timeframes defining the peak impacts of road dust and the health assessment criteria. It is possible that roadside residents are more adversely affected by shorter duration, higher intensity events (hourly or 24-hour exposure), rather than longer duration lower intensity events (annual average exposure). While there are published workplace exposure standards for respirable dust (eight-hour average concentrations), these are not appropriate for use in residential areas. Therefore it is recommended that a watching brief be maintained by this project's stakeholders on developments in shorter duration dust health risk assessment criteria. If shorter duration dust health risk assessment criteria are developed, it is recommended that these be carefully considered in the design, monitoring and analyses phases of any future unsealed road dust monitoring projects.

9.2 Additional data analyses

From the experience gained during the data analysis phase of this project, recommendations are made that aim to extract additional value from the data collected during the Mataraua Road monitoring programme. It is recommended that the stakeholder interest in and the costs and benefits of the following analyses are investigated. If stakeholder interest is identified and appropriate resourcing available it is recommended relevant analyses are undertaken.

Measurements across the PM_{10} monitoring network suggest the untreated road PM_{10} dust plume extends further than 80m from the roadside. The data from the untreated north 5m, 30m and 80 transect could be integrated into a dust dispersion model to provide a refined estimation of the extent of plume impact.

The literature shows a relationship between unpaved road dust emissions and a number of key properties such as the road surface and the number and characteristics of vehicles travelling along it. The Mataraua Road monitoring programme collected data that would allow the main drivers behind the generation of road dust (eg HDV vs LDV, high or low wind speeds) to be identified and quantitatively determined.

The primary driver of dust emissions is likely to be vehicle numbers, type and speed. However, meteorological conditions will also have a significant impact on emissions and the dispersion of the dust plume. The dust data could be analysed to assess the impact of different meteorology variables such as wind speed, temperature and relatively humidity.

There were a number of wet days experienced during the monitoring campaign. The literature and general experience show water can be an effective dust mitigation measure. The rain and dust data could be analysed to assess the effectiveness of natural rainfall on dust suppression at Mataraua Road.

Using inverse modelling techniques, the PM_{10} data obtained from the Mataraua Road monitoring programme could be used to provide estimates of unsealed road dust emission factors. These emission factors could then be used in combination with meteorological data and dispersion models to undertake assessments of environmental effects or be used to produce longer-term estimates of ambient dust levels under different treatment regimes.

The data obtained from the Mataraua Road monitoring programme could be used to develop a road dust PM_{10} exposure model based on:

- number of vehicles using the road
- type of vehicles using the road
- distance from the road
- number and locations of dwellings
- local meteorology and rainfall patterns.

A road dust PM_{10} exposure model would allow the data collected at Mataraua Road to be extrapolated to other sites around New Zealand. This would help identify particular locations at relatively high risk from road dust and which of these might benefit significantly from dust mitigation programmes.

The Mataraua Road monitoring programme collected a time and date stamped video record that captures the vehicles travelling past the sites during daylight hours. This video record was not analysed as part of this project, but it may contain useful information. For example, ‘Are the dust plumes from loaded and empty logging trucks visibly different’? It is recommended that the video record be reviewed with the aim of identifying ways in which it could complement or supplement the outcomes of the data analysis undertaken to date.

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Appendix A: Dustmote k- factors

The Dustmote response to PM_{10} matches a BAM well, but the Dustmote values are significantly lower than the BAM. To overcome this issue, data from collocated BAM and Dustmote monitors was used to establish a correlation (called a k-factor) between the two data types. The k-factor is then applied to Dustmote data to provide a BAM equivalent PM_{10} concentration.

The Dustmote response to PM_{10} depends on the size and nature of the particles being monitored. If the source and nature of particulate being monitored changes the Dustmote response to that PM_{10} will also change. Therefore, it is important to investigate if and how the k-factor may vary at Mataraua Road and use this information to select an appropriate k-factor for the analyses included in this report.

To investigate the variation of k-factors at Mataraua Road, comparisons of Dustmote and BAM data were undertaken for the following scenarios:

- all data
- high vehicle counts (predominantly vehicle sourced dust)
- low vehicle counts (predominantly background dust)
- weekday afternoons (high proportion of HDVs)
- weekend afternoons (high proportion of LDVs).

To determine the k-factors presented in this appendix:

- scatter plots of Dustmote verses BAM data were created
- a linear trend line was fitted to the data and forced through zero
- k-factor was taken as the slope of the linear trend line.

A1 All data

Figure A.1 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 5m site monitored from 18 March to 16 April 2015.

Figure A.1 **Scatter plot of Dustmote and BAM PM_{10} data – untreated north 5m site, 18 March to 16 April 2015**

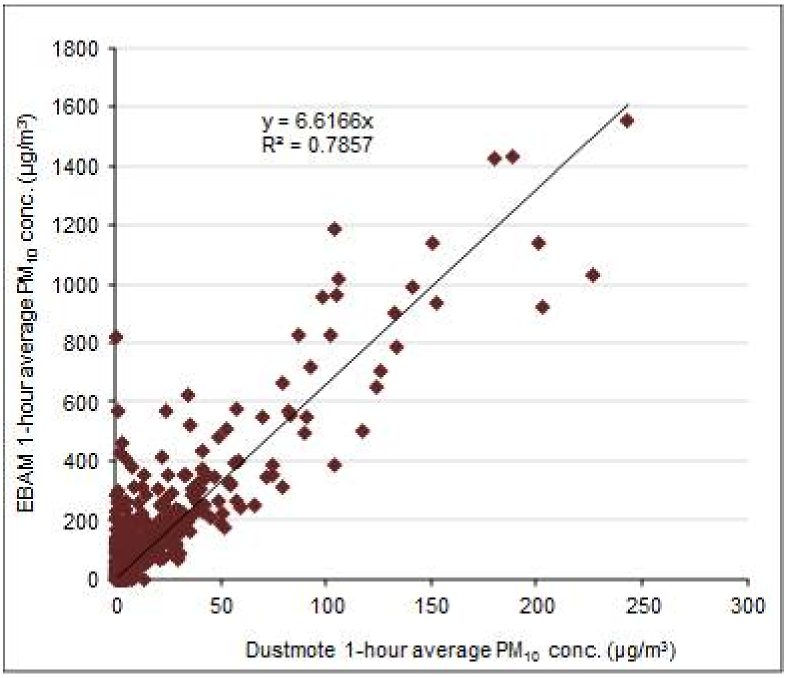
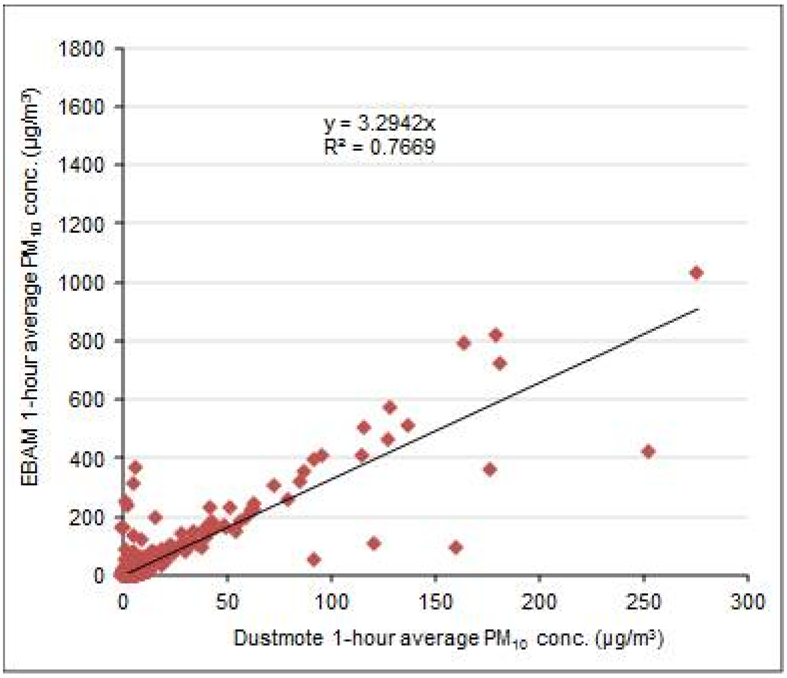


Figure A.2 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 30m site monitored from 25 February to 15 March 2015.

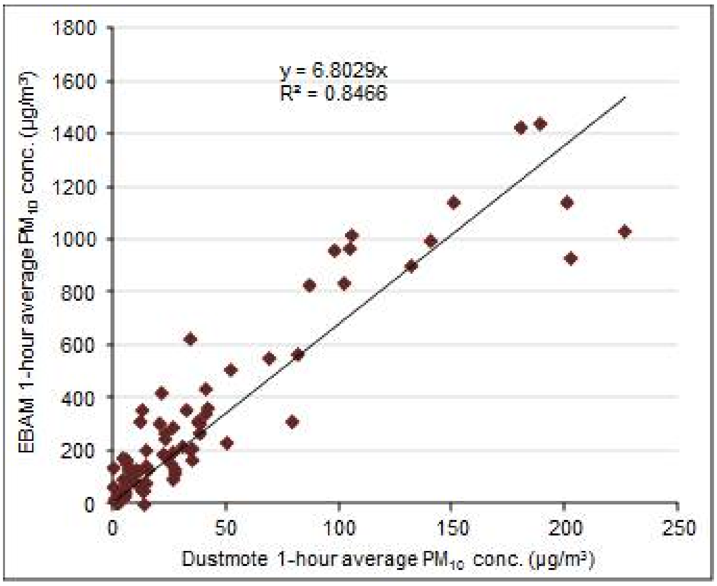
Figure A.2 **Scatter plot of Dustmote and BAM PM_{10} data – untreated north 30m site, 25 February to 15 March 2015**



A2 High vehicle counts

To investigate if the Dustmote response to PM_{10} changed during periods of high vehicle traffic past the site, the Dustmote and BAM data sets were filtered to provide a high vehicle count data set defined by weekdays with vehicle counts of greater than 10 vehicles per hour. Figure A.3 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 5m site monitored from 18 March to 16 April 2015, for hours with high vehicle counts.

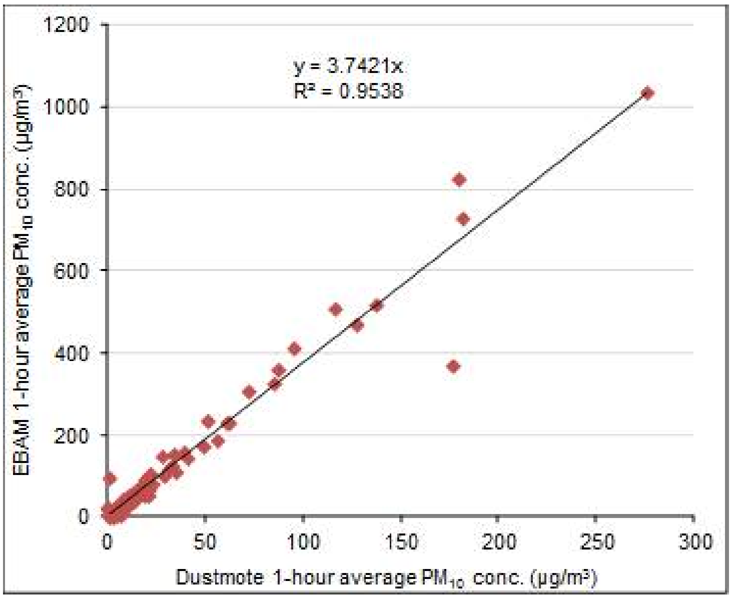
Figure A.3 Scatter plot of Dustmote and BAM PM_{10} data – untreated north 5m site,_18 March to 16 April 2015



for hours with high vehicle counts

Figure A.4 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 30m site monitored from 25 February to 15 March 2015, for hours with high vehicle counts.

Figure A.4 Scatter plot of Dustmote and BAM PM_{10} data – untreated north 30m site, 25 February to 15 March 2015 for hours with high vehicle counts



A3 Low vehicle counts

To investigate if the Dustmote response to PM_{10} changes during periods of low vehicle traffic past the site, the Dustmote and BAM data sets were filtered to provide a low vehicle count data set defined by weekdays with vehicle counts of less than 10 vehicles per hour. Figure A.5 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 5m site monitored from 18 March to 16 April 2015, for hours with low vehicle counts.

Figure A.5 Scatter plot of Dustmote and BAM PM_{10} data – untreated north 5m site, 18 March to 16 April 2015 for hours with low vehicle counts

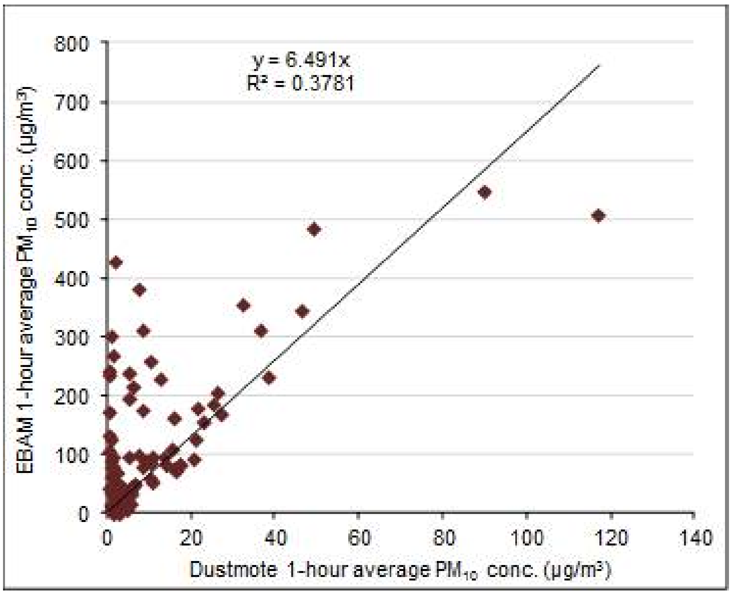
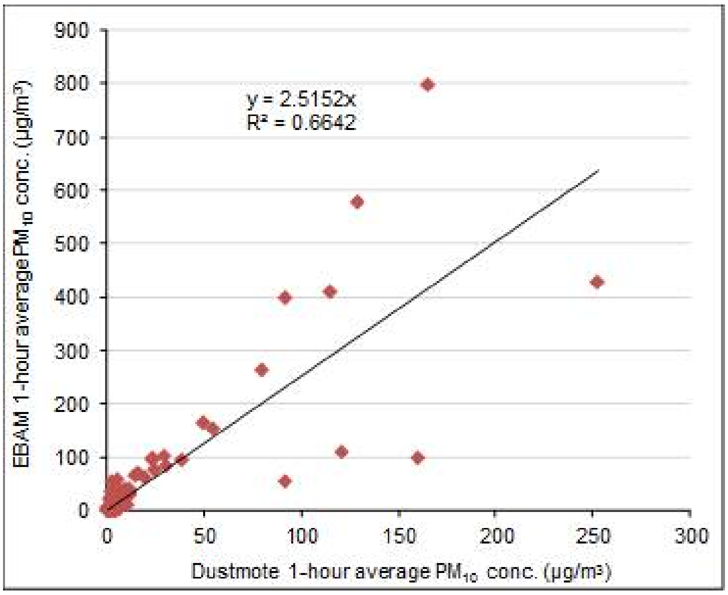


Figure A.6 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 30m site monitored from 25 February to 15 March 2015, for hours with low vehicle counts.

Figure A.6 Scatter plot of Dustmote and BAM PM_{10} data – untreated north 30m site, 25 February to 15 March 2015 for hours with low vehicle counts



A4 High proportion of HDVs

To investigate if the Dustmote response to PM_{10} changes during periods of a relatively high proportion of HDVs passing the site, the Dustmote and BAM data sets were filtered to provide a data set defined by weekdays from midday to 5pm. Figure A.7 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 5m site monitored from 18 March to 16 April 2015, for hours with a relatively high proportion of HDVs.

Figure A.7 Scatter plot of Dustmote and BAM PM_{10} data - untreated north 5m site, 18 March to 16 April 2015 for hours with a relatively high proportion of HDVs

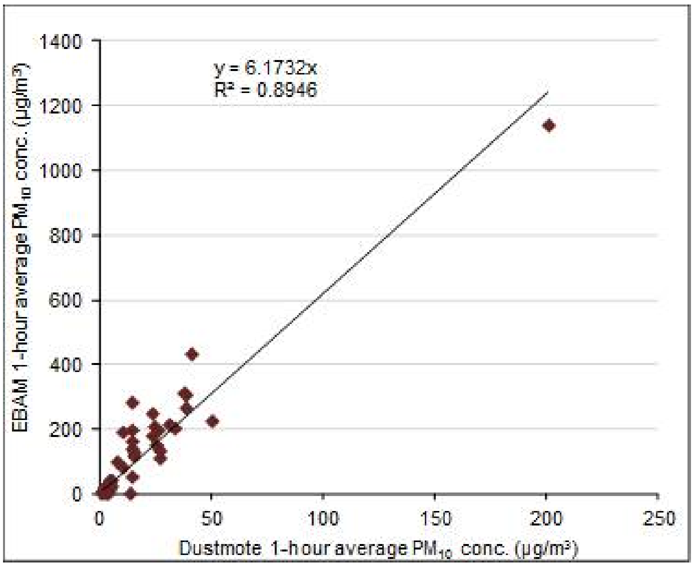
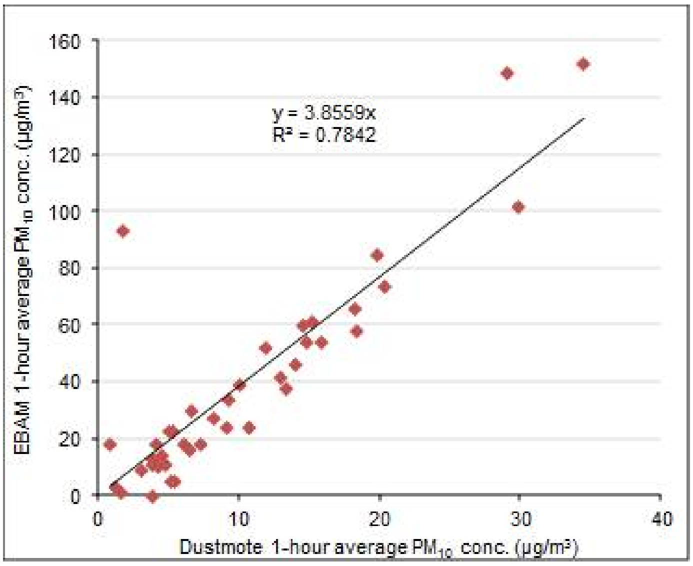


Figure A.8 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 30m site monitored from 25 February to 15 March 2015, for hours with a relatively high proportion of HDVs.

Figure A.8 Scatter plot of Dustmote and BAM PM_{10} data – untreated north 30m site, 25 February to 15 March 2015 for hours with a relatively high proportion of HDVs



A5 High proportion of LDVs

To investigate if the Dustmote response to PM_{10} changes during periods of a relatively high proportion of LDVs passing the site, the Dustmote and BAM data sets were filtered to provide a data set defined by weekend days from midday to 5pm. Figure 12-7 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 5m site monitored from 18 March to 16 April 2015, for hours with a relatively high proportion of LDVs.

Figure A.9 Scatter plot of Dustmote and BAM PM_{10} data – untreated north 5m site, 18 March to 16 April 2015 for hours with a relatively high proportion of LDVs

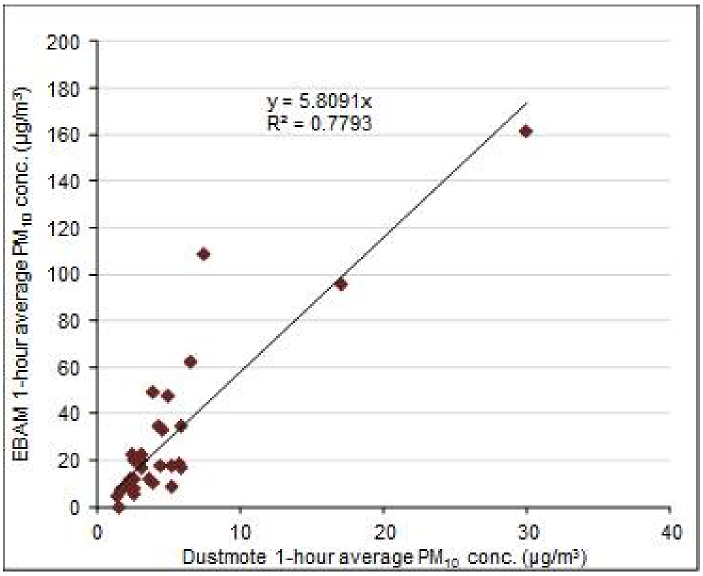
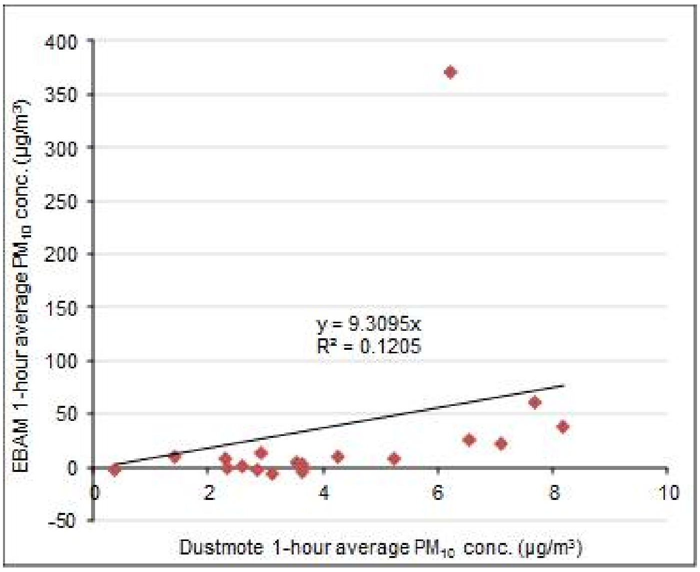


Figure A.10 shows a scatter plot of all Dustmote versus BAM PM_{10} data for the untreated north 30m site monitored from 25 February to 15 March 2015, for hours with a relatively high proportion of LDVs.

Figure A.10 Scatter plot of Dustmote and BAM PM_{10} data – untreated north 30m site, 25 February to 15 March 2015 for hours with a relatively high proportion of LDVs



A6 Summary of k-factor scenario investigations

Table A.1 presents a summary of the k-factor scenario investigations where the k-factor is taken as the slope of the linear trend line from the respective scatter plot with the trend line forced through zero. The k-factors used for the adjustment of the Dustmote data presented in this report were taken as the average of the scenario k-factors at the 5m and 30m sites.

Table A.1 Summary of k- factor investigations

Scenario	5m k- factor	30m k- factor
All data	6.6	3.3
High vehicle counts	6.8	3.7
Low vehicle counts	6.5	2.5
High proportion of HDVs	6.2	3.9
High proportion of LDVs	5.8	9(a)
K-factor used for the adjustment of Dustmote data	6.2	3.3

(a) Not considered in the summary of k-factors due to low R^2 value.

A7 Limitations of k-factor investigations

The monitoring programme had limited resources in regard to available BAM monitors and it was not possible to determine site-specific k-factors for all sites. Therefore, a number of limitations to the k-factor investigation must be considered. The two most significant limitations were:

- no specific BAM and Dustmote comparison at the untreated north 80m site
- no specific BAM and Dustmote comparison at the treated sites.

To overcome these limitations two assumptions were made:

- The k-factor for the 80m untreated site was the same as for the 30m site.
- The k-factors for the treated 5m, 30m and 80m sites were the same as for the respective untreated sites.

The assumption that the k-factor for the 80m untreated site was 3.3 is most likely a conservative one as the k-factor appears to decrease with increasing distance from the roadway. The decrease in the k-factor with increasing distance is most likely due to the change in particulate size profile, as the larger particles drop out of the road dust plume relatively quickly as it travels further from the road. In summary, the use of a k-factor of 3.3 for the 80m untreated site is likely to produce higher PM_{10} concentrations than if the monitoring had been undertaken with a BAM at that site.

With the data available it was not possible to calculate site-specific k-factors for the treated section of the roadway. The assumptions made in regard to the treated site k-factors introduce a source of uncertainty into the analysis which must be acknowledged. The Dustmote response to dust discharged from the treated road surface is likely to be different if the particle size profile of dust within the plume is different to that from the untreated road surface. This situation may occur if the chemical suppressant was more effective on say large particles than small particles. However, inspection of the treated road surface showed a relatively solid surface that appears to supress all particle sizes (ie there were no obvious loose fine particles on the surface). In addition to this, the magnesium chloride suppressant works by drawing moisture into the roadway surface, an action that is likely to result in the control of both large and smaller particles.

In summary, the lack of treated site-specific k-factors does introduce uncertainty into the adjusted Dustmote data. However, it is considered that any change in k-factors between untreated and treated sites is likely to be small, and given the relatively low PM_{10} concentrations measured at the treated sites, a small change in k-factor is very unlikely to change the conclusions reached using the treated site Dustmote data.

To overcome this issue, it is recommended for any future road dust monitoring trials that the k-factor issue be carefully considered in the monitoring programme design, and resources allocated to ensure site-specific k-factors can be calculated for all key sites monitored by Dustmotes.

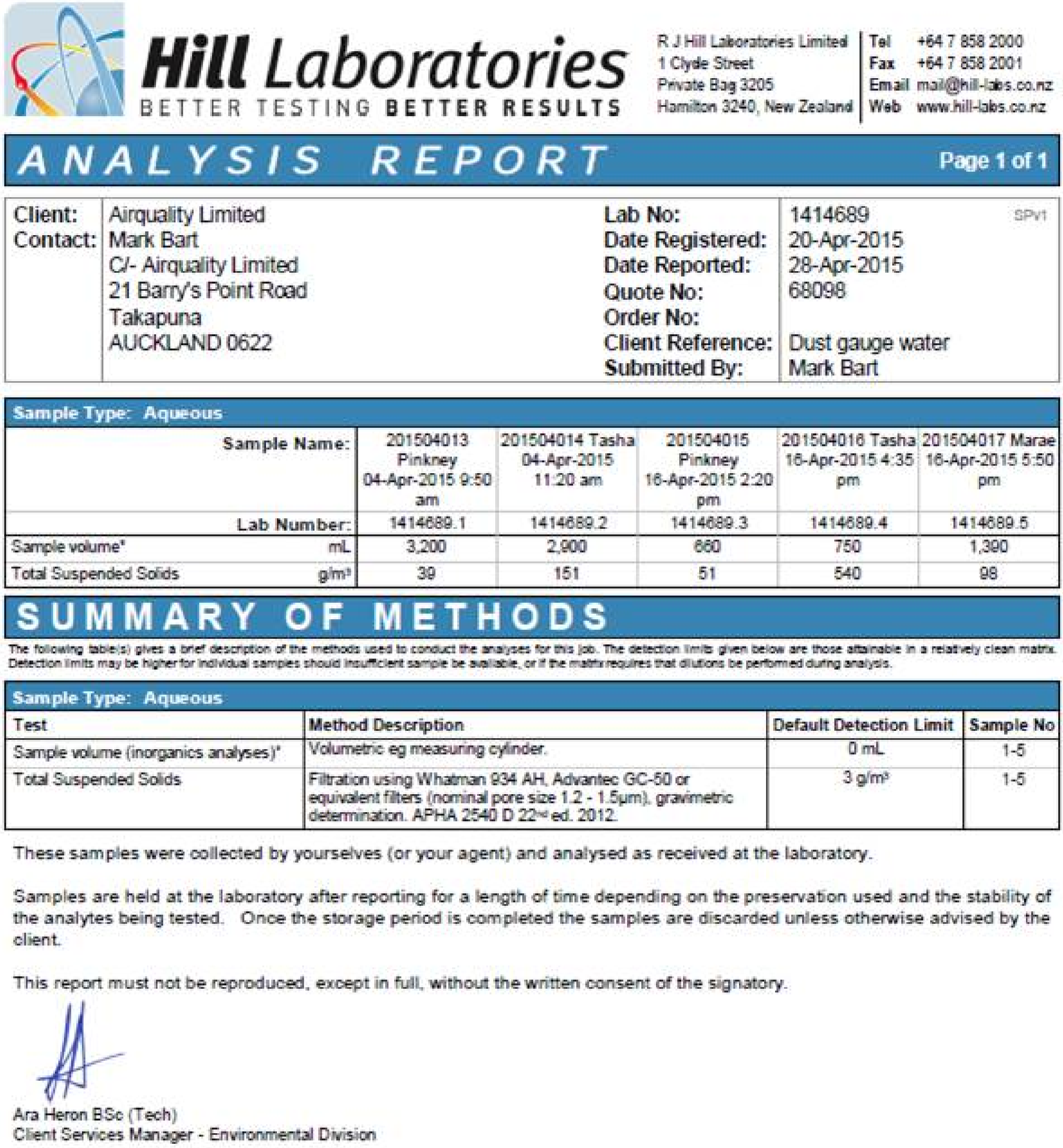
A8 k-factors used for this study

Table A.2 presents the k-factors used for the adjustment of the Dustmote data set out in this report. The k-factors were taken as the average of the scenario k-factors at the 5m and 30m sites. In the absence of any BAM data at the 80m site it was assumed the 80m k-factor was equal to the 30m k-factor. This is most likely a conservative assumption as the profile of particle sizes within the PM_{10} plume at the 80m site would be different from those at the 30m site and a lower k-factor expected.

Table A.2 k- factors used for this study

	5m k- factor	30m k- factor	80m k- factor
Untreated sites	6.1	3.4	3.4
Treated sites	6.1	3.4	3.4

Appendix B: Laboratory results: dust deposition



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ANALYSIS REPORT

Page 1 of 1

SPv1

Client:	Airquality Limited	**Lab No:**	1414689
Contact:	Mark Bart C/- Airquality Limited 21 Barry's Point Road Takapuna AUCKLAND 0622	**Date Registered:**	20-Apr-2015
		Date Reported:	28-Apr-2015
		Quote No:	68098
		Order No:	
		Client Reference:	Dust gauge water
		Submitted By:	Mark Bart

Sample Type: Aqueous

Sample Name:		201504013 Pinkney 04-Apr-2015 9:50 am	201504014 Tasha 04-Apr-2015 11:20 am	201504015 Pinkney 16-Apr-2015 2:20 pm	201504016 Tasha 16-Apr-2015 4:35 pm	201504017 Marae 16-Apr-2015 5:50 pm
Lab Number:		1414689.1	1414689.2	1414689.3	1414689.4	1414689.5
Sample volume*	mL	3,200	2,900	660	750	1,390
Total Suspended Solids	g/m^3	39	151	51	540	98

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

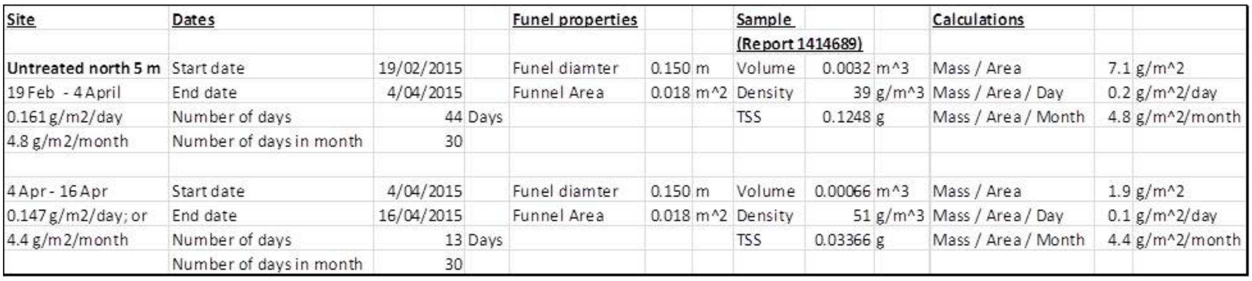
Test	Method Description	Default Detection Limit	Sample No
Sample volume (inorganics analyses)*	Volumetric eg measuring cylinder.	0 mL	1-5
Total Suspended Solids	Filtration using Whatman 934 AH, Advantec GC-50 or equivalent filters (nominal pore size 1.2 - 1.5µm), gravimetric determination. APHA 2540 D 22nd ed. 2012.	3 g/m^3	1-5

These samples were collected by yourselves (or your agent) and analysed as received at the laboratory.

Samples are held at the laboratory after reporting for a length of time depending on the preservation used and the stability of the analytes being tested. Once the storage period is completed the samples are discarded unless otherwise advised by the client.

This report must not be reproduced, except in full, without the written consent of the signatory.

Ara Heron BSc (Tech)
Client Services Manager - Environmental Division

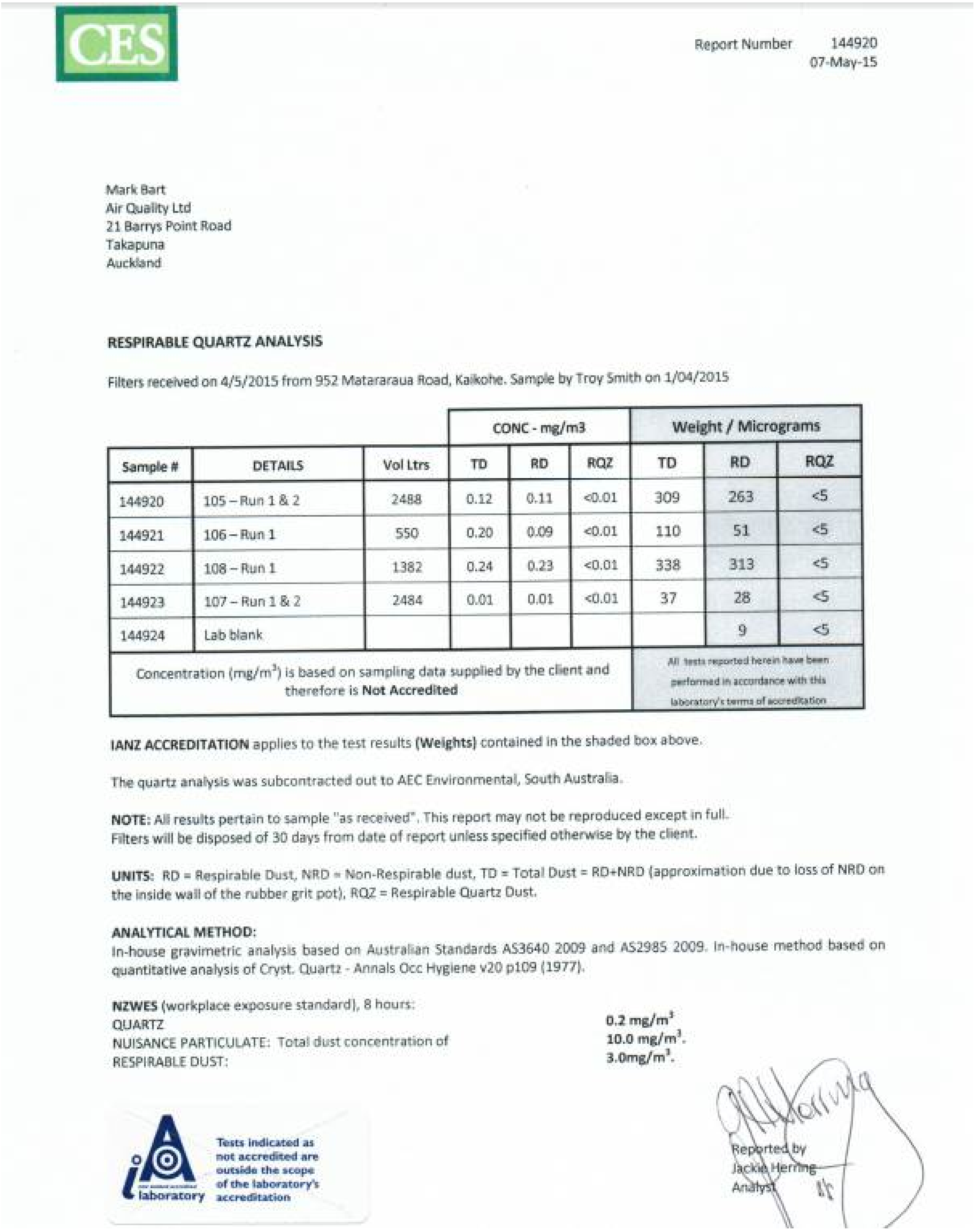


Site	Dates			Funel properties			Sample			Calculations		
							(Report 1414689)					
Untreated north 5 m	Start date	19/02/2015		Funel diamter	0.150	m	Volume	0.0032	m^3	Mass / Area	7.1	g/m^2
19 Feb - 4 April	End date	4/04/2015		Funnel Area	0.018	m^2	Density	39	g/m^3	Mass / Area / Day	0.2	g/m^2/day
0.161 g/m2/day	Number of days	44	Days				TSS	0.1248	g	Mass / Area / Month	4.8	g/m^2/month
4.8 g/m2/month	Number of days in month	30										
4 Apr - 16 Apr	Start date	4/04/2015		Funel diamter	0.150	m	Volume	0.00066	m^3	Mass / Area	1.9	g/m^2
0.147 g/m2/day; or	End date	16/04/2015		Funnel Area	0.018	m^2	Density	51	g/m^3	Mass / Area / Day	0.1	g/m^2/day
4.4 g/m2/month	Number of days	13	Days				TSS	0.03366	g	Mass / Area / Month	4.4	g/m^2/month
	Number of days in month	30										

Treated north 5 m	Dates			Funel properties			Sample			Calculations		
	Start date	19/02/2015		Funel diamter	0.150	m	Volume	0.0029	m^3	Mass / Area	24.8	g/m^2
19 Feb - 4 April	End date	4/04/2015		Funnel Area	0.018	m^2	Density	151	g/m^3	Mass / Area / Day	0.6	g/m^2/day
0.563 g/m2/day; or	Number of days	44	Days				TSS	0.4379	g	Mass / Area / Month	16.9	g/m^2/month
16.9 g/m2/month	Number of days in month	30										
4 Apr - 16 Apr	Start date	4/04/2015		Funel diamter	0.150	m	Volume	0.00075	m^3	Mass / Area	22.9	g/m^2
1.763 g/m2/day; or	End date	16/04/2015		Funnel Area	0.018	m^2	Density	540	g/m^3	Mass / Area / Day	1.8	g/m^2/day
52.9 g/m2/month	Number of days	13	Days				TSS	0.405	g	Mass / Area / Month	52.9	g/m^2/month
	Number of days in month	30										

Treated south 80 m	Dates			Funel properties			Sample			Calculations		
25 Feb - 16 Apr	Start date	25/02/2015		Funel diamter	0.150	m	Volume	0.00139	m^3	Mass / Area	7.7	g/m^2
0.151 g/m2/day; or	End date	16/04/2015		Funnel Area	0.018	m^2	Density	98	g/m^3	Mass / Area / Day	0.2	g/m^2/day
4.5 g/m2/month	Number of days	51	Days				TSS	0.13622	g	Mass / Area / Month	4.5	g/m^2/month
	Number of days in month	30										

Appendix C: Laboratory results: respirable silica



CES

Report Number 144920
07-May-15

Mark Bart
Air Quality Ltd
21 Barrys Point Road
Takapuna
Auckland

RESPIRABLE QUARTZ ANALYSIS

Filters received on 4/5/2015 from 952 Matararaua Road, Kaikohe. Sample by Troy Smith on 1/04/2015

			CONC - mg/m3			Weight / Micrograms		
Sample #	DETAILS	Vol Ltrs	TD	RD	RQZ	TD	RD	RQZ
144920	105 – Run 1 & 2	2488	0.12	0.11	<0.01	309	263	<5
144921	106 – Run 1	550	0.20	0.09	<0.01	110	51	<5
144922	108 – Run 1	1382	0.24	0.23	<0.01	338	313	<5
144923	107 – Run 1 & 2	2484	0.01	0.01	<0.01	37	28	<5
144924	Lab blank						9	<5

Concentration (mg/m^3) is based on sampling data supplied by the client and therefore is **Not Accredited**

All tests reported herein have been performed in accordance with this laboratory's terms of accreditation

IANZ ACCREDITATION applies to the test results **(Weights)** contained in the shaded box above.

The quartz analysis was subcontracted out to AEC Environmental, South Australia.

NOTE: All results pertain to sample "as received". This report may not be reproduced except in full.
Filters will be disposed of 30 days from date of report unless specified otherwise by the client.

UNITS: RD = Respirable Dust, NRD = Non-Respirable dust, TD = Total Dust = RD+NRD (approximation due to loss of NRD on the inside wall of the rubber grit pot), RQZ = Respirable Quartz Dust.

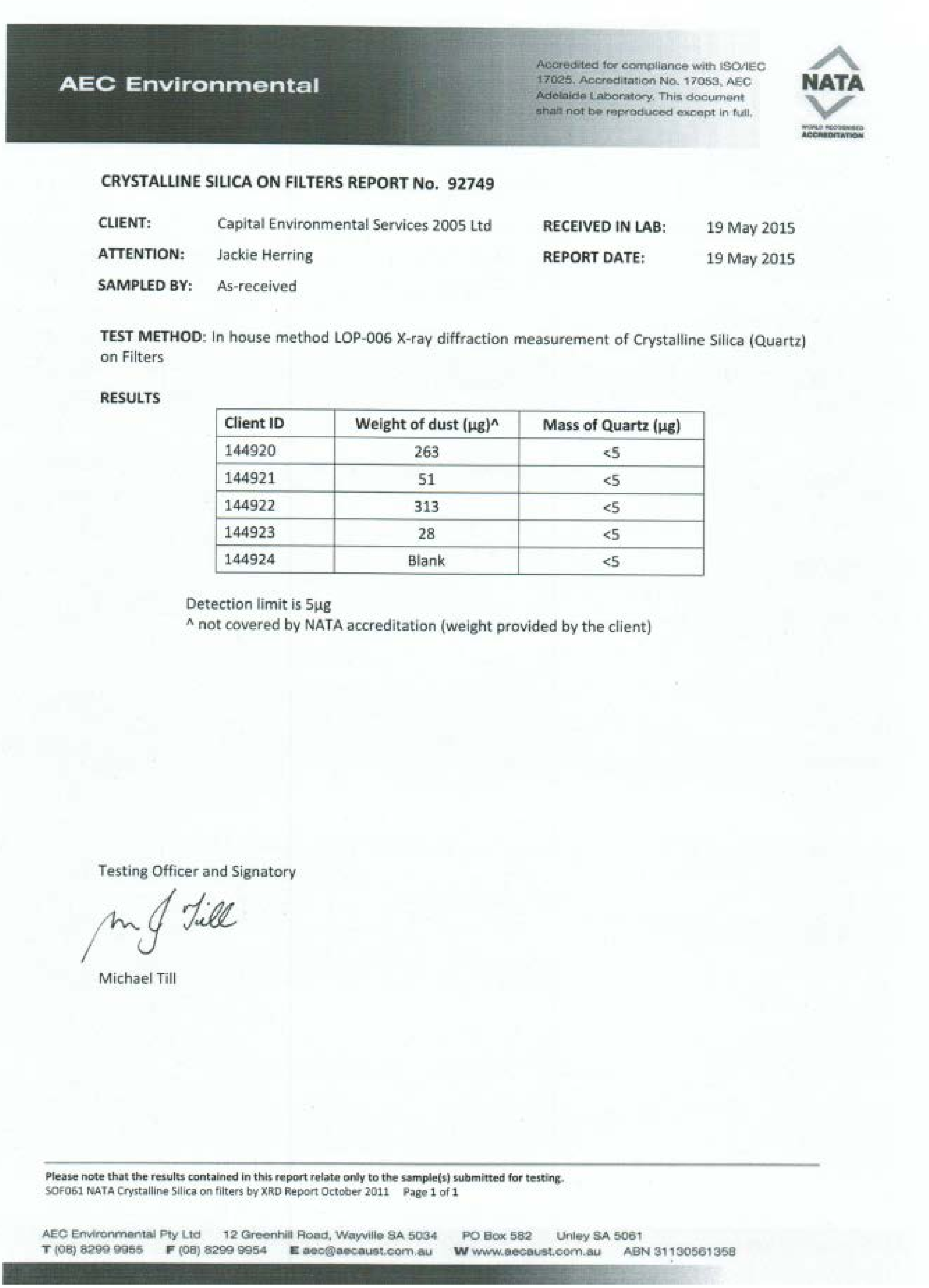
ANALYTICAL METHOD:
In-house gravimetric analysis based on Australian Standards AS3640 2009 and AS2985 2009. In-house method based on quantitative analysis of Cryst. Quartz - Annals Occ Hygiene v20 p109 (1977).

NZWES (workplace exposure standard), 8 hours:	
QUARTZ	**0.2 mg/m^3**
NUISANCE PARTICULATE: Total dust concentration of	**10.0 mg/m^3.**
RESPIRABLE DUST:	**3.0mg/m^3.**

laboratory

Tests indicated as not accredited are outside the scope of the laboratory's accreditation

Reported by
Jackie Herring
Analyst



AEC Environmental

Accredited for compliance with ISO/IEC 17025. Accreditation No. 17053, AEC Adelaide Laboratory. This document shall not be reproduced except in full.

NATA

WORLD RECOGNISED ACCREDITATION

CRYSTALLINE SILICA ON FILTERS REPORT No. 92749

CLIENT:	Capital Environmental Services 2005 Ltd	**RECEIVED IN LAB:**	19 May 2015
ATTENTION:	Jackie Herring	**REPORT DATE:**	19 May 2015
SAMPLED BY:	As-received		

TEST METHOD: In house method LOP-006 X-ray diffraction measurement of Crystalline Silica (Quartz) on Filters

RESULTS

Client ID	Weight of dust (µg)^	Mass of Quartz (µg)
144920	263	<5
144921	51	<5
144922	313	<5
144923	28	<5
144924	Blank	<5

Detection limit is 5µg

^ not covered by NATA accreditation (weight provided by the client)

Testing Officer and Signatory

M J Till

Michael Till

Please note that the results contained in this report relate only to the sample(s) submitted for testing.

SOF061 NATA Crystalline Silica on filters by XRD Report October 2011 Page 1 of 1

AEC Environmental Pty Ltd 12 Greenhill Road, Wayville SA 5034 PO Box 582 Unley SA 5061

T (08) 8299 9955 F (08) 8299 9954 E aec@aecaust.com.au W www.aecaust.com.au ABN 31130561358

Appendix D: Annualised cost and NPV data

D1 Cost assumptions

Table D.1 presents the cost assumptions used for the annualised cost and NPV calculations.

Table D.1 Cost assumptions used for the annualised cost and NPV calculations

Item	Cost/year ($)
Grading cost/event	$200
Road metal unsealed and untreated road (costs/year/km)	$4,000
Dust suppressant cost/km	$13,000
Application cost/km	$2,000
Road sealing cost/km	$250,000
Sealed road maintenance cost/km	$4,000
Grading/year unsealed and untreated	6
Grading/year unsealed and treated	6
Discount rate	6%

D2 Benefit assumptions

Table D.2 presents the benefit assumptions used for the annualised cost and NPV calculations.

Table D.2 Benefit assumptions used for the annualised cost and NPV calculations

Item	
Number of houses	8
Estimate of the number of people living in each house	2.9
Total number of people living alongside the 1km trial site	23
Health cost/person/year unsealed untreated	$1,751
Health cost/persons/year unsealed treated	$1,008
Health cost/person/year sealed	$530

D3 Unsealed and untreated road surface

Table D.3 shows the data used to calculate the annualised and NPV values applied in the unsealed and untreated road surface scenario.

Table D.3 Annualised and NPV values for the unsealed and untreated road surface scenario

	NPV	Total all years	Year 0	Year 1	Year 2	Year 3	…	…	Year 40
Dust suppressant	$0	$0	$0	$0	$0	$0			$0
Application	$0	$0	$0	$0	$0	$0			$0
Grading	$19,256	$49,200	$1,200	$1,200	$1,200	$1,200			$1,200
Road metal	$64,185	$164,000	$4,000	$4,000	$4,000	$4,000			$4,000
Total	$83,441	$213,200	$5,200	$5,200	$5,200	$5,200			$5,200

D4 Unsealed and treated road surface

Table D.4 shows the data used to calculate the annualised and NPV values applied in the unsealed and treated road surface scenario.

Table D.4 Annualised and NPV values for the unsealed and treated road surface scenario

	NPV	Total all years	Year 0	Year 1	Year 2	Year 3	…	…	Year 40
Dust suppressant	$208,602	$533,000	$13,000	$13,000	$13,000	$13,000			$13,000
Application	$32,093	$82,000	$2,000	$2,000	$2,000	$2,000			$2,000
Grading	$19,256	$49,200	$1,200	$1,200	$1,200	$1,200			$1,200
Road metal	$64,185	$164,000	$4,000	$4,000	$4,000	$4,000			$4,000
Total	$324,135	$828,200	$20,200	$20,200	$20,200	$20,200			$20,200

D5 Sealed road surface – 40-year useful life

Table D.5 shows the data used to calculate the annualised and NPV values used in the sealed road surface, 40-year useful life scenario.

Table D.5 Annualised and NPV values for the sealed road surface, 40- year useful life scenario

	NPV	Total all years	Year 0	Year 1	Year 2	Year 3	…	…	Year 40
Dust suppressant	$0	$0	$0	$0	$0	$0			$0
Application	$0	$0	$0	$0	$0	$0			$0
Sealing cost	$250,000	$250,000	$250,000	$0	$0	$0			$0
Maintenance and resealing	$64,185	$164,000	$4,000	$4,000	$4,000	$4,000			$4,000
Total	$314,185	$414,000	$254,000	$4,000	$4,000	$4,000			$4,000

D6 Sealed road surface – 10-year useful life

Table D.6 shows the data used to calculate the annualised and NPV values used in the sealed road surface, 10-year useful life scenario.

Table D.6 Annualised and NPV values for the sealed road surface, 10- year useful life scenario

	NPV	Total all years	Year 0	Year 1	Year 2	…	Year 10	…	Year 40
Dust suppressant	$0	$0	$0	$0	$0		$0		$0
Application	$0	$0	$0	$0	$0		$0		$0
Sealing cost	$511,077	$1,000,000	$250,000	$0	$0		$250,000		$0
Maintenance and resealing	$64,185	$164,000	$4,000	$4,000	$4,000		$4,000		$4,000
Total	$575,263	$1,164,000	$254,000	$4,000	$4,000				$4,000

D7 Health costs from dust

Table D.7 shows the data used to calculate the annualised and NPV values of the health effects of dust.

Table D.7 Annualised and NPV values for the health effects of dust

Health costs from dust	NPV	Total	Year 0	Year 1	Year 2	Year 3	…	…	Year 40
Unsealed untreated	$638,736	$1,681,000	$41,000	$41,000	$41,000	$41,000			$41,000
Unsealed treated	$367,757	$967,848	$23,606	$23,606	$23,606	$23,606			$23,606
Sealed 40 year	$193,556	$509,394	$12,424	$12,424	$12,424	$12,424			$12,424
Sealed 10 year	$193,556	$509,394	$12,424	$12,424	$12,424	$12,424			$12,424

Appendix E: Worked examples: dust mitigation – decision- making process

E1 Mataraua Road

E1.1 Site description and location

Location

10km, southwest of Kaikohe, Northland. Figure E.1 shows the location of Mataraua Road.

Geography – hills, valley, predominant winds

Road runs approximately north/south within a valley that opens out as it nears Kaikohe. Some shelter is provided by hills along the eastern margins of the valley. Winds predominate from northwesterly and southeasterly quarters.

Road type and construction

Predominantly a greywacke base. This is interspersed with basalt in places with crushed river rock to overlay.

Main road uses

Domestic travel (to and from work/town) and trucking – mainly forestry logging trucks.

Longevity of trucking route (if relevant)

Expect at least three more years.

Number of vehicles HDD and LDV

AADT of HDVs about 150–200, while AADT of LDVs in excess of 300.

Number of dwellings

8 –10 houses per km in northernmost parts of the valley.

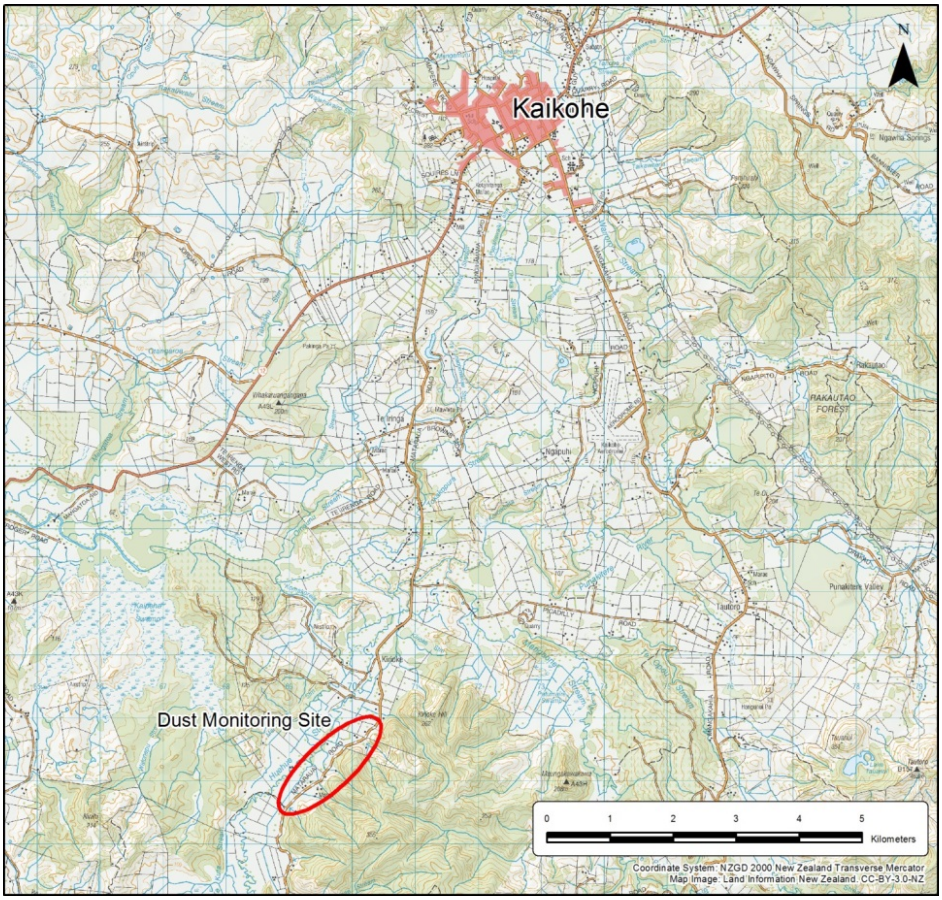
Any other sensitive receptors

Kaiangahoa Marae.

History of complaints

Numerous to do with dust from the road whether ungraded or graded.

Figure E.1 Location of Mataraua Road



E1.2 Dust risk assessment

Table E.1 details the dust risk assessment for Mataraua Road.

Table E.1 Dust risk assessment – Mataraua Road

Risk factor/score	0	1	2	3	4	5	Score
Traffic							
5-day AADT of HDVs	0	1–5	6–10	11–25	26–50	**More than 50**	5
Speed limit for HDVs	No HDVs	**20km/h**	50 km/h or greater				1
5-day AADT of LDVs	Less than 100	101–300	**More than 300**				2
Speed of LDVs (km/h)	Less than 50	**5-70**	Greater than 70				1
Receptors (within 80m of roadway)							
Number of dwellings (houses/km)	0	1	2–4	5–7	**8-10**	More than 10	4
Other locations where people are likely to be exposed (eg scools, marae, or hospitals) (sensitive locations/km)	None	**1-2**	3 or more				1

Risk factor/score	**0**	**1**	**2**	**3**	**4**	**5**	**Score**
Nuisance effects for residents (complaints/ year)	None	1 – 3	**More than 3**				**2**
Ecologically sensitive areas such as rare species habitats or wetlands (sensitive locations/km)	**None**	1–2	3 or more				**0**
Horticultural sensitive areas such as fruit orchards (sensitive locations/km)	**None**	1–2	3 or more				**0**
Site characteristics							
Location of roadway	Open plains or coastal area	Some land features likely to slow winds	**Inland enclosed valley**				**2**
Frequency of rain days (>5 mm)	More than 2 events per week	0-1 events per week	**Less than one event every two weeks**				**2**
Longevity of logging route use	Not a logging route	1-2 years	**Longer than 3 years**				**2**
Total dust risk assessment score							**22**

The dust risk assessment score for Mataraua Road is 22 which classifies the site as:

- High risk - there is likely to be a benefit from mitigation: complete assessment of suitable mitigation options.

E2 Waikakaho Valley

E2.1 Site description and location

Location

Waikakaho Valley Road, 6km west of Tuamarina township on SH1. Figure E.2 shows the location of Waikakaho Valley Road.

Geography – hills valley predominant winds

Within a narrow, steep-sided valley, which opens at its southern margin near the Wairau River. For the purposes of the assessment tool consider the valley to be an ‘inland enclosed valley’.

Road type and construction

Schist base with gravel/alluvium from valley floor overlaid.

Main road uses

Predominantly domestic travel to and from residences. Periodically forestry harvesting operations have been carried out. These have recently become a regular feature in traffic patterns and look likely to remain for some years to come.

Longevity of trucking route (if relevant)

Three years or more.

Number of vehicles HDD and LDV

AADT of HDVs about 60, while AADT of LDVs in excess of 70.

Number of dwellings

About 15 houses/km in lower (southern) parts of the valley. This thins out markedly as the further up the valley one travels.

Any other sensitive receptors

None.

History of complaints

A feature of the issue of road dust in this area has been not so much the number of complaints received but the effectiveness of the complainants in using the political system to prompt action.

Figure E.2 Location of Waikakaho Valley

E2.2 Dust risk assessment

Table E.2 details the dust risk assessment for Waikakaho Valley Road.

Table E.2 Dust risk assessment – Waikakaho Valley Road

Risk factor/score	**0**	**1**	**2**	**3**	**4**	**5**	**Score**
Traffic							
5-day AADT of HDVs	0	1–5	6–10	11–25	26–50	**More than 50**	**5**
Speed limit for HDVs	No HDVs	**20km/h**	50km/h or greater				**1**
5-day AADT of LDVs	**Less than 100**	101–300	More than 300				**0**
Speed of LDVs (km/h)	**Less than 50**	50–70	Greater than 70				**1**
Receptors (within 80m of roadway)							
Number of dwellings (houses/km)	0	1	5	5–7	8–10	**More than 10**	**5**
Other locations where people are likely to be exposed (eg schools, marae, or hospitals) (sensitive locations/km)	**None**	**1–2**	More than 3				**0**
Nuisance effects for residents (complaints/year)	None	1–2	**More than 3**				**2**
Ecologically sensitive areas such as rare species habitats or wetlands (sensitive locations/km)	**None**	1–2	More than 3				**0**
Horticultural sensitive areas such as fruit orchards (sensitive locations/km)	**None**	1–2	More than 3				**0**
Site characteristics							
Location of roadway	Open plains or coastal area	Some land features likely to slow winds	**Inland enclosed valley**				**2**
Frequency of rain days (>5mm)	More than 2 events per week	0-1 events per week	**Less than one event every two weeks**				**2**
Longevity of logging route use	Not a logging route	1-2 years	**Longer than 3 years**				**2**
Total dust risk assessment score							**20**

The dust risk assessment score for Waikakaho Valley Road is 20 which classifies the site as:

- High risk – there is likely to be a benefit from mitigation: complete assessment of suitable mitigation options.

Appendix F: Glossary

AADT	annual average daily traffic
AWS	automatic weather station
BAMs	Beta Attenuation Monitors
BCA	business case analysis
BCR	benefit-to-cost ratio
CAU	census area unit
EEM	*Economic evaluation manual* (NZ Transport Agency 2013)
GPS	global positioning system
HAPINZ	Health and Air Pollution in New Zealand model
HDV	heavy duty vehicle – vehicle with a gross vehicle mass of greater than 3,500kg
km/hr	kilometres per hour
LDV	light duty vehicle – vehicle with a gross vehicle mass of less than 3,500kg
MfE	Ministry for the Environment
$MgCl_2$	magnesium chloride
MoT	Ministry of Transport
μg	microgram
$\mu g/m^3$	microgram per cubic metre
NES	National Environmental Standard (Air Quality)
NPV	net present value
NRC	Northland Regional Council
PM	particulate matter
PM_{10}	fine particles less than 10 microns in diameter, a type of air pollutant
RH	relative humidity
TLA	territorial local authority
Transport Agency	New Zealand Transport Agency
TSP	total suspended particulate
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation