Public Health Risks Associated with Discharges to Air from Agriculture in New Zealand: Scoping Review

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1. EXECUTIVE SUMMARY

Agricultural activities discharge a range of contaminants to air including greenhouse gases, ammonia, particulate matter, endotoxins, pathogens, volatile organic compounds, and odour as well as chemicals such as pesticides, herbicides, and fungicides.

It is well established that agriculture can be a significant source of particulate pollution internationally. More recently there is growing concern internationally about the impact of air pollution from intensive livestock farms on public health.

In New Zealand, livestock are known to be a significant source of greenhouse gases, however the potential public health risks associated with discharges to air from agriculture and agricultural practices in New Zealand have not been assessed. This review focussed on emerging issues related to agricultural activities that may be associated with risks for public health including:

1. Particulate discharges to air from agriculture, including primary particulate emissions and secondary particulate formed downwind from ammonia emissions.
2. Potential health risks associated with living near intensive livestock farms.

This is a preliminary scoping review to evaluate the relevance of these issues in New Zealand and identify data gaps.

Potential risk of disease transmission from the discharge of pathogens to air from agricultural sources, including intensive farming, is outside the scope of this report. Potential public health risks associated with other agricultural discharges to air including greenhouse gas emissions, odour and agrichemicals are also outside the scope of this report.

Key findings and data gaps are provided at the end of each section and are summarised as follows.

What are the potential effects of primary particulate from agriculture in New Zealand?

Due to lack of data, it is not feasible to assess the likely effects of primary particulate discharges to air from agriculture. Due to limited ambient air quality monitoring in rural areas, there is also considerable uncertainty in assessment of public exposure and the health effects of air pollution in rural areas of New Zealand.

What are the potential effects of secondary particulate resulting from agricultural ammonia emissions in New Zealand?

Ammonia is an important contributor to secondary particulate and total anthropogenic PM globally. Secondary PM from agricultural ammonia emissions is estimated to account for more than half of anthropogenic $PM_{2.5}$ in much of the United States, Europe and China (Bauer et al 2016).

In New Zealand, the composition and sources of particulate are quite different to other parts of the world and secondary PM is much less significant. Source apportionment studies suggest that secondary particulate could account for up to 20% of PM exposure across New Zealand. However, this secondary PM has significant natural as well as anthropogenic sources, and the contribution of ammonia to this 20% is not known. This means that the contribution of ammonia, and agricultural ammonia in particular, to the health effects of exposure to PM in New Zealand is not known.

What are the potential health risks of living near intensive livestock farms?

A nascent body of research from other countries links air pollution from intensive farming with adverse respiratory outcomes in nearby communities. However, the causal relationships are not clear. The potential health risks associated with living near intensive livestock farms in New Zealand has not been evaluated.

What are the contaminants of most concern near intensive livestock farms?

International literature suggests that concentrations of particulate, bioaerosols and endotoxins (components of particulate) may be elevated in the vicinity of intensive farming operations and that health effects may be associated with these components of particulate matter (DEFRA 2018, Health Council of the Netherlands 2012, Douglas et al 2018 and Gladding et al 2020).

Are there appropriate exposure guidelines or assessment criteria that can be used to assess potential health risks near intensive livestock farms?

There are New Zealand ambient air quality criteria for assessing the potential effects of exposure to particulate. These include the national environmental standard for PM_{10} of 50 micrograms per cubic metre (μg/m^3) as a 24-hour average (with one permitted exceedance in any 12-month period) and a national guideline of 20 μg/m^3 as an annual average. The 2021 World Health Organisation guidelines for PM_{10} are 45 μg/m^3 as a 24-hour average (with 3-4 permitted exceedances per annum) and 15 μg/m^3 as an annual average.

The Health Council of the Netherlands has proposed a tentative endotoxin limit of 30 EU/m^3 for the general population living in the surroundings of livestock farms.

What are key data gaps?

- There is very limited data on PM concentrations and sources in rural/agricultural areas
- Source apportionment studies suggest that secondary particulate could account for up to 20% of $PM_{2.5}$ exposure across New Zealand. However, the likely contribution of ammonia to this secondary particulate is not known.
- PM and endotoxin concentrations in the vicinity of intensive livestock farms in New Zealand have not been measured.

2. INTRODUCTION

Agricultural activities discharge a range of contaminants to air including greenhouse gases, ammonia, **particulate matter** (PM), endotoxins, pathogens, volatile organic compounds, and odour as well as chemicals such as pesticides, herbicides, and fungicides.

Agriculture is recognised as a significant source of particulate pollution. **Primary PM** emissions (particulate matter emitted directly to the air) result from processes such as tillage, burning and crop harvesting. Agricultural burning in Richmond and the Hawke's Bay is a significant source of PM pollution (HBRC 2021, Zawar-Reza, undated).

Ammonia emissions from agriculture are an important contributor to **secondary PM** (i.e. particulate matter that is formed in the air from reactions of other pollutants) and total anthropogenic PM globally.

There is also growing concern internationally about the impact of air pollution from intensive livestock farms on public health.

This review focussed on emerging issues related to agricultural activities that may be associated with risks for public health including

(i) Particulate from agricultural emissions, including primary particulate emissions and secondary particulate from ammonia emissions.
(ii) Potential health risks associated with living near intensive livestock farms.

Potential risk of disease transmission from the discharge of pathogens to air from agricultural sources is outside the scope of this report. Potential public health risks associated with other agricultural discharges to air including greenhouse gas emissions, odour and agrichemicals are also outside the scope of this report.

This report summarises the findings of our literature review. Key findings and critical gaps in our understanding are provided at the end of each section.

2.1 DISCHARGES TO AIR FROM AGRICULTURE AND THEIR EFFECTS

Air pollution comprises a complex mixture of particles (usually referred to as particulate matter) and gases. The critical pollutants released from agricultural sources are discussed in more detail in the following subsections.

2.1.1 Particulate matter (PM_{10} and $PM_{2.5}$)

PM is classified by **aerodynamic diameter** because these determine transport and removal processes in the air and deposition sites and clearance pathways within the human respiratory tract.

Airborne PM can range in size from <1 micrometre to 100 micrometres. The finer the particle, the longer it remains suspended in the air. At 1 micrometre any settling due to gravity is negligible, whereas particles above 20 to 30 micrometres tend to settle quickly (Ministry for the Environment, 2016).

Particles less than 10 micrometres in size (PM_{10}) and particles less than 2.5 micrometres ($PM_{2.5}$) can reach the alveolar region of the lungs where inhaled gases can be absorbed by the blood. Particles between 10 and 2.5 micrometres in size ($PM_{10-2.5}$) are referred to as **coarse** particles, and particles smaller than 2.5 micrometres are referred to as **fine** particles. These fractions of airborne dust present the highest health risk because (WHO, 2006):

a. PM_{10} includes those inhalable particles that are sufficiently small to penetrate to the thoracic region; and

b. $PM_{2.5}$ has a high probability of deposition in the smaller conducting airways and alveoli.

Research shows that $PM_{2.5}$ is more hazardous to human health than coarse particles ($PM_{2.5-10}$). However, short-term exposure to coarse ($PM_{10-2.5}$) particulate, including crustal material, is associated with adverse respiratory and cardiovascular effects on health including premature mortality (WHO, 2013).

There has been significant international research to investigate whether different sources of PM are associated with different health outcomes (for example due to differences in chemical composition and particle size of PM from different sources).

There is emerging evidence that different types of particulate, emitted from different sources, can cause different health effects. However, current consensus is that that these differences cannot be accurately determined. A World Health Organisation (WHO) scientific review (WHO, 2013) stated:

> A WHO workshop in Bonn concluded in 2007 that current knowledge does not allow specific quantification of the health effects of emissions from different sources (or of individual components). In 2009, the EPA integrated science assessment concluded that "there are many components contributing to the health effects of $PM_{2.5}$, but not sufficient evidence to differentiate those sources (or constituents) that are more closely related to specific health outcomes".

From a regulatory perspective, based on current evidence, WHO recommends that all PM should be treated the same. This approach has been adopted in New Zealand good practice for assessing and managing dust (Ministry for the Environment, 2016).

2.1.2 Health effects of particulate in New Zealand

In New Zealand air pollution from anthropogenic $PM_{2.5}$ has been estimated to be associated with:

- 1,292 premature deaths
- 2,639 cardiovascular hospitalisations
- 1,985 respiratory hospitalisations
- 1.74 million restricted activity days

These estimates are for 2016 based on the updated Health and Air Pollution in New Zealand (**HAPINZ 3.0**) study (Kuschel et al 2022).

2.1.3 Ambient air quality criteria for particulate

Schedule 1 of the Resource Management (National Environmental Standards for Air Quality) Regulations 2004 (NESAQ) includes a health-based ambient air quality standard for PM_{10}. This is 50 micrograms per cubic metre (μg/m^3) as a 24-hour average with one permitted exceedance in any 12-month period.

The purpose of this standard is "to provide a guaranteed level of health protection for all New Zealanders" (MfE, 2016a). PM_{10} is a non-threshold contaminant, i.e. there is no known safe level of exposure, and thus the standard represents a tolerable level of risk.

The Ministry for the Environment national ambient air quality guidelines (NAAQG) also includes an annual average guideline of 20 μg/m^3 for PM_{10}. This guideline was set to "provide the minimum requirements that outdoor air quality should meet to protect human health and the environment" (MfE, 2016a).

The 24-hour average standard and annual guideline values for PM_{10} are numerically equivalent to global air quality guidelines published by the World Health Organisation in 2006 (WHO, 2006). However, WHO published updated guidelines in 2021 (WHO 2021). The updated guidelines for PM_{10} are 15 µg/m^3 as an annual average, and 45 µg/m^3 with 3-4 permitted exceedances as a 24-hour average.

In addition to the above, the Ministry for the Environment has published a suggested trigger threshold for managing PM_{10} from dusty sources (MfE, 2016b). The suggested trigger threshold is 150 µg/m^3 as a 1-hour average. The purpose of this short-term threshold is to proactively manage dust sources (primarily on industrial sites) and to avoid exceedance of (longer time-average) health-based standards and guidelines in sensitive receiving environments (typically residential areas).

2.1.4 Ammonia

Inhalation of relatively high concentrations of ammonia can cause health effects such as cough, sore throat and shortness of breath[1]. However, the main health impact of ammonia emissions from agriculture is its contribution to secondary PM (Air Quality Expert Group 2018). Ammonia emissions from agriculture can react with combustion emissions in the air to form secondary PM. This secondary PM consists primarily of ammonium nitrate and ammonium sulphate.

2.1.5 Bioaerosols including endotoxins and pathogens

Bioaerosols (airborne biological components of particulate) are ubiquitous in the environment and can originate from a range of sources, both natural and anthropogenic. Particulate from intensive livestock farms contains high levels of bioaerosols (Douglas et al 2018).

Human exposure to bioaerosols has been associated with a range of acute and chronic adverse health effects and diseases (Figure 1), (Douglas et al 2018).

One very potent bioaerosol is **endotoxin**, an inflammatory component of the cell wall of Gram-negative bacteria (de Rooij et al 2018). There is clear evidence that occupational exposure to high concentrations of airborne endotoxin causes respiratory inflammation, respiratory symptoms and lung function decline (Farokhi et al, 2018). High endotoxin concentrations have been measured on livestock farms and negative effects on respiratory effects were found among farmers (de Rooij et al 2019).

[1] (US) National Library of Medicine: https://pubchem.ncbi.nlm.nih.gov/

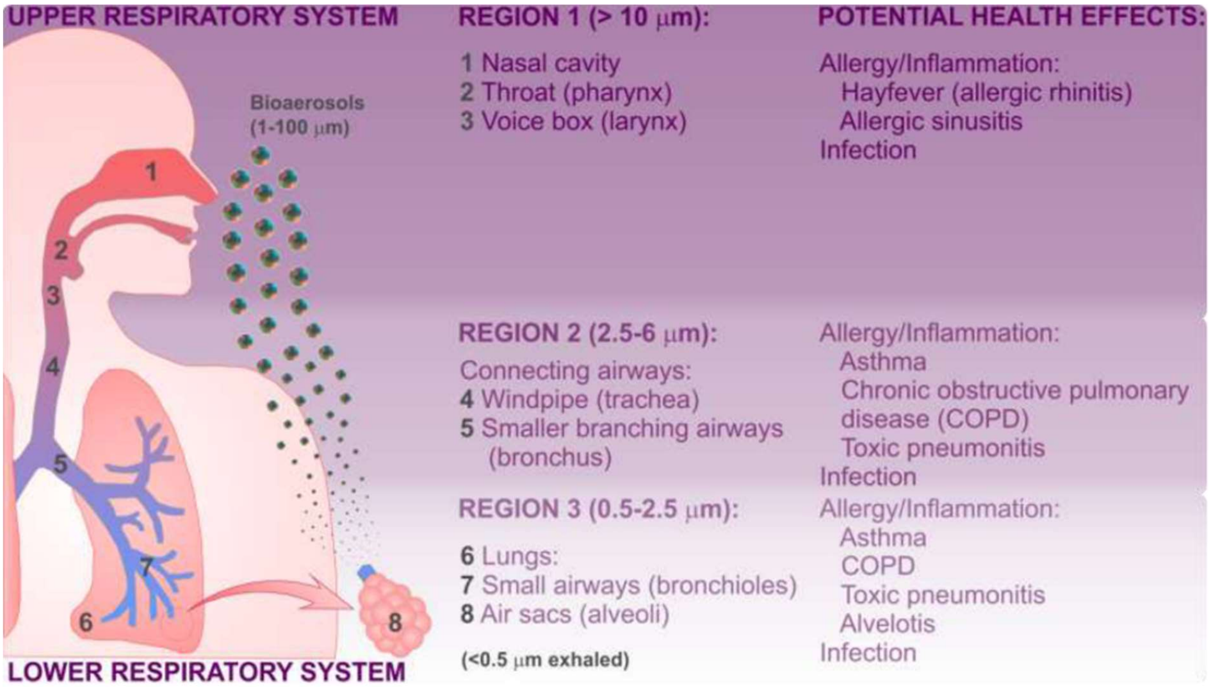

FIGURE 1: Potential health effects of bioaerosols. [Source: National Institute for Health Research][2]

Livestock farms are a potential source of microorganisms, including **pathogens**. Potential risk of disease transmission from the discharge of pathogens to air from agricultural sources is outside the scope of this report.

2.2 METHOD FOR THIS REVIEW

We undertook this scoping literature review to improve understanding of emerging issues and confirm knowledge gaps in the New Zealand context. The aim of the review was to address the following key questions:

Particulate from agricultural emissions:

- What are the potential health effects of primary particulate resulting from agricultural emissions in New Zealand?
- What are the potential health effects of secondary particulate resulting from agricultural ammonia emissions in New Zealand?
- What are the potential health implications of agricultural intensification in New Zealand for levels of secondary particulate from ammonia?

Potential health risks of living near intensive livestock farms:

- What are the potential health risks of living near intensive livestock farms?
- What are the contaminants of most concern?
- Are there appropriate exposure guidelines or assessment criteria that can be used to assess potential health risks?

[2] http://hieh.hpru.nihr.ac.uk/sites/default/files/private/secure/Sarah%20Robertson.pdf

To ensure that we reviewed information that is relevant and robust we:

- Undertook a broad search to identify the most relevant and most recently available systematic literature reviews as well as advice and guidance from international agencies and expert groups.
- We then searched for any relevant research that is more recent than the publications identified in the first step, and any relevant publications or guidance from Australia or New Zealand (for local context).

The scoping literature review was undertaken in early 2021. The findings of our review are summarised in the following sections.

3. PARTICULATE EMISSIONS FROM AGRICULTURE

Primary particulate emissions from agriculture arise from processes such as soil cultivation, application of fertilisers, burning of crop residues, vegetation fires, crop harvesting and animal housings. Particulate emissions from animal housings (i.e., intensive farming) are considered in Section 4.

Ammonia emissions from agriculture can react with combustion emissions in the air to form secondary PM. This secondary PM is known as secondary inorganic aerosol (a suspension of fine solid particles or liquid droplets in the air) and consists primarily of ammonium nitrate and ammonium sulphate.

3.1 EFFECTS OF PRIMARY PARTICULATE EMISSIONS FROM AGRICULTURE

3.1.1 Estimated emissions

The 2015 National Air Emissions Inventory (Metcalfe & Sridhar 2018) estimates PM emissions from animal housings (considered in Section 4) account for 1% and burning of agricultural crop residues accounts for 3% of total anthropogenic PM_{10} emissions in New Zealand. Vegetation burning (wildfires or controlled burning) is estimated to account for 15% of total anthropogenic PM_{10} emissions. Other potential sources of agricultural particulate emissions, such as soil cultivation, application of fertilisers and crop harvesting were not included in the inventory, and it is not known whether these sources are likely to be significant.

3.1.2 Ambient air quality measurements in rural areas

Primary particulate emissions from agriculture are most likely to affect air quality in rural areas, although emissions from wildfires can impact air quality regionally.

There is very little monitoring of PM in rural areas of New Zealand. A recent review of ambient air quality monitoring for the HAPINZ 3 update[3], found that:

- There is only one representative rural monitoring site in New Zealand. This is currently operating at Patumahoe in Auckland.
- A previous monitoring site at a representative rural monitoring site in Pongakawa in the Bay of Plenty ceased operation in 2006.
- One year of ambient air quality monitoring data is available from a rural site at West Melton in Canterbury. However, the site has been established in a proposed quarry location is so it will not provide long term representative data.

Average PM_{10} concentrations measured at these three sites are summarised as follows:

- Patumahoe, 11.3µg/m^3 (2015-2017 average)
- Pongakawa, 9.2µg/m^3 (2004-2006 average)
- West Melton, 14 µg/m^3 (2018 only)

The Auckland monitoring site is considered unlikely to be representative of all rural areas in New Zealand and only one year of monitoring was available for West Melton. In the absence of better data, results from the Pongakawa monitoring site have been used to estimate

[3] The HAPINZ 3.0 study (Kuschel et al 2022) estimates health effects of air pollution in New Zealand for a 2016 base year.

exposure and health effects of air pollution for all rural areas across New Zealand in the HAPINZ 3.0 health effects model. This means that data from a single, discontinued, monitoring site is being used to estimate air pollution exposure for approximately 15% of the population in the HAPINZ 3.0 update[4].

3.2 EFFECTS OF SECONDARY PM FROM AGRICULTURAL AMMONIA EMISSIONS

Emissions from livestock and the application of nitrogen fertilisers to land account for approximately 80% of ammonia emissions globally (Behera et al 2013). International research estimates that secondary PM from agricultural emissions accounts for more than half of anthropogenic $PM_{2.5}$ in much of the United States, Europe and China (Bauer et al 2016).

The reaction of ammonia to form secondary PM takes several hours (Air Quality Expert Group, 2018). This means that concentrations of secondary particulate are not expected to be higher at a very local scale around livestock farms (Health Council of the Netherlands, 2018). Secondary particulate from ammonia is likely to cause effects at a regional or national level.

3.2.1 Estimated emissions

As far as we are aware, there is no emissions inventory of ammonia discharges to air in New Zealand.

3.2.2 Secondary PM measurements in New Zealand

The composition and sources of pollution in New Zealand are quite different to other parts of the world. Here, in contrast to Europe, China and the US, except for rare events such as bushfires and dust storms from Australia, New Zealand generates its own pollution (Ministry for the Environment & Stats NZ 2018).

Substantial work has been undertaken in New Zealand to directly measure the contribution of emission sources to particulate pollution. Source apportionment studies use elemental analysis of real-world monitoring results to identify the relative contributing sources as well as the contribution of secondary PM.

These studies have found that anthropogenic PM in urban areas is typically dominated by emissions from biomass burning (wood burners used for winter home heating) and motor vehicles (near busy roads and in larger cities), while natural sources of PM are dominated by marine aerosol (Davy & Trompetter 2020).

Figure 2 compares several source apportionment studies undertaken in New Zealand and shows that biomass burning typically contributes between 50% and 90% of daily wintertime PM_{10} at urban monitoring sites (Davy & Trompetter 2017).

Detailed analysis undertaken for the HAPINZ 3.0 project, based on source apportionment data, estimates that biomass burning accounts for approximately 48% of $PM_{2.5}$ exposure on an annual basis across New Zealand (Kuschel et al, 2022). Secondary sulphate is estimated to account for approximately 16% of $PM_{2.5}$ exposure cross New Zealand (Kuschel et al, 2022). Other types of secondary particulate have not been quantified. However, mass closure analysis (estimating the mass of particulate that is not assigned to specific sources in source apportionment analyses) suggests that the mass contribution of other secondary particulate is likely to be somewhat less than 5% in urban areas (Kuschel et al, 2022).

The proportion of secondary particulate in rural areas is unknown. However, it is known that secondary particulate is likely to cause effects at a regional level, so it is unlikely that

[4] Based on population and exposure data in the HAPINZ 3.0 health effects model

secondary particulate concentrations will be substantially higher in rural areas compared with urban areas.

Overall, this means that secondary particulate could account for up to approximately 20% of $PM_{2.5}$ exposure across New Zealand. However, secondary particulate comes from both natural and anthropogenic sources, and the likely contribution of ammonia to secondary particulate is not known.

We contacted Dr Perry Davy (GNS science, pers comm) to discuss the results of source apportionment studies and their relevance for understanding the likely contribution of ammonia to secondary particulate in New Zealand. Dr Davy noted that:

- There have been very few studies that have included measurement of ammonium species in New Zealand. Measurements have been undertaken in Takapuna (Auckland) from January 2009 to December 2013, Timaru (Canterbury) from May 2006 to May 2007 and Tokoroa (Waikato) from May to October 2014.
- The lack of ammonium measurements is partly due to challenges in sampling and analysis (which cannot be undertaken in New Zealand) but is primarily due to a focus on (other) sources that are known to be responsible for the majority of anthropogenic air pollution in New Zealand.
- Additional analysis of existing monitoring data could improve our understanding of the likely contribution of ammonia to secondary particulate in New Zealand.

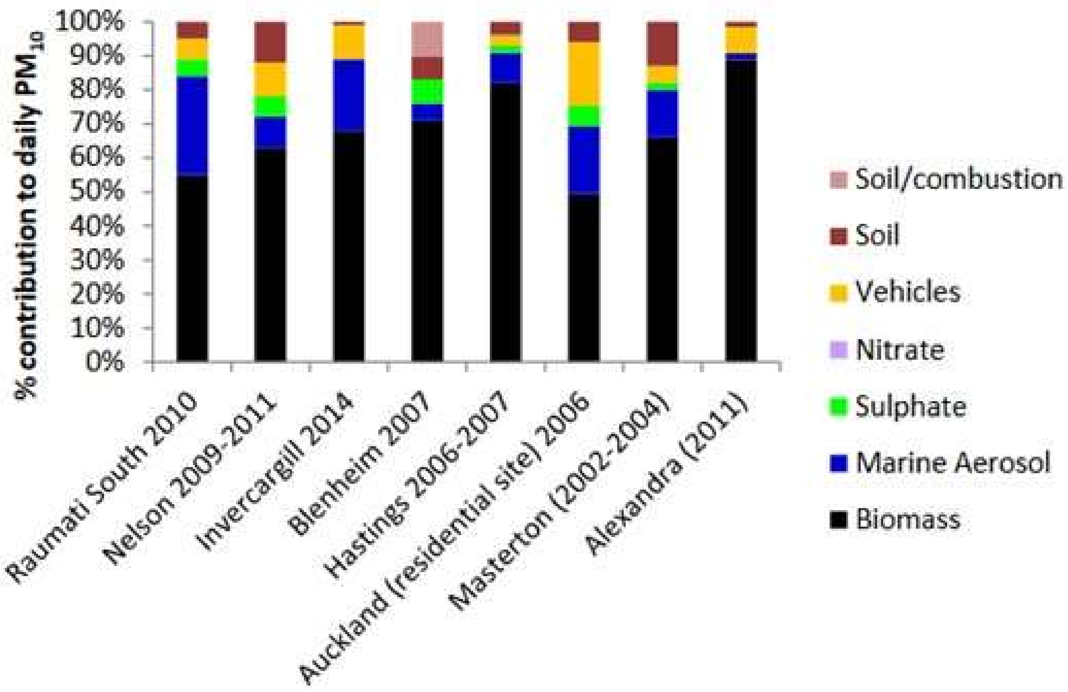

FIGURE 2: Comparison on wintertime source apportionment studies [Davy & Trompetter, 2017]

3.3 KEY FINDINGS AND DATA GAPS

3.3.1 What are the potential effects of primary PM resulting from agricultural emissions in New Zealand?

Due to lack of data, it is not feasible to assess the likely effects of primary particulate emissions from agriculture. Due to limited ambient air quality monitoring in rural areas, there is also considerable uncertainty in the assessment of the health effects of air pollution in rural areas of New Zealand.

3.3.2 What are the potential effects of secondary PM resulting from agricultural emissions in New Zealand?

Ammonia is an important contributor to secondary particulate and total anthropogenic PM globally. In New Zealand, the composition and sources of particulate are quite different to other parts of the world and secondary PM is much less significant. Source apportionment studies suggest that secondary particulate could account for up to 20% of $PM_{2.5}$ exposure across New Zealand. However, this secondary PM has significant natural as well as anthropogenic sources, and the contribution of ammonia to this 20% is not known. This means that the contribution of ammonia to the health effects of exposure to PM in New Zealand is not known.

3.3.3 What are the potential implications of agricultural intensification in New Zealand for levels of secondary particulate from ammonia?

There has been a marked increase in the intensity of farming in New Zealand over recent years and this trend is expected to continue (Ministry for the Environment & Stats NZ, 2018). Intensification of agriculture is known to increase the amount of ammonia emitted to the air, however in New Zealand the potential implications of this increase are not known.

3.3.4 What are the key data gaps?

Data gaps identified include:

- There are very limited data on PM concentrations and sources in rural areas
- Source apportionment studies suggest that secondary particulate could account for up to 20% of $PM_{2.5}$ exposure across New Zealand. However, the likely contribution of ammonia to this secondary particulate is not known.

4. HEALTH EFFECTS OF AIR POLLUTION FROM INTENSIVE FARMING

In order to accommodate large numbers of animals and poultry, **intensive farms** generally use confinement buildings, which typically share the following characteristics:

- An enclosed structure accommodating a large number of animals in a relatively small space
- A ventilation system
- A system for watering and feeding the animals
- A system for handling animal waste

By increasing the density of animals and holding them in enclosed buildings, the concentrations of airborne dust and microorganisms are increased (Environment Agency, 2008).

In New Zealand intensive farming operations are generally required to obtain a resource consent to discharge contaminants to air under the Resource Management Act (1991). These consents have historically focussed on managing odour effects only.

4.1 WHAT ARE THE POTENTIAL HEALTH RISKS OF LIVING NEAR INTENSIVE LIVESTOCK FARMS?

A large-scale government funded study in the Netherlands (the VGO study[5]) used data from general practitioners (GPs) of approximately 110,000 patients and approximately 14,000 questionnaires about respiratory complaints and almost 2,500 medical examinations including pulmonary function tests. [6] Data from the Dutch VGO study have been analysed and published by various researchers. Results are published in English in various papers (for example Borlee et al 2017, Kalkowska et al 2018), and a PhD thesis (Borlee, 2018). Key results from the Dutch VGO study are (Health Council of the Netherlands 2018):

- People who live near livestock farms often suffer less from asthma and allergies,
- There are fewer people with chronic obstructive pulmonary disease (COPD) living near livestock farms, but those that do have more severe symptoms and use more medication,
- People in livestock dense areas can have decreased lung function. This effect has been found in particular, for people who live within 1km of 15 or more livestock farms,
- People who live near poultry and goat farms get pneumonia more often. For poultry farms the association was found every year between 2009 and 2014, but no significant association was found for 2015 and 2016 (Kalkowska et al 2018, Post et al 2019). The Dutch National Institute for Public Health and the Environment considers these additional pneumonia cases are probably caused by particulates and endotoxins (emitted by the farms), which irritate the respiratory tract, possibly making people more susceptible to pneumonia (Ministry of Health, Welfare and Sport, 2017).

[5] Livestock farming and neighbouring residents health (in Dutch Veehourderij en Gezondheid Omwonenden, the VGO study)

[6] https://www.rivm.nl/en/news/pneumonia-occurs-more-often-near-livestock-farms

- People throughout the area surveyed have reduced lung function if the ammonia concentration in the air is high. The authors note that, although health effects were associated with ammonia concentration, ammonia alone is unlikely to cause a direct effect on respiratory health. They hypothesise that ammonia levels serve as a marker for airborne emissions from livestock farms (Borlee et al 2017, Borlee 2018).
- Studies into infectious diseases that can be transferred from animals to humans (zoonoses) and into resistant microorganisms among local residents showed no indication of increased risk, except that residents in the vicinity of goat farms were at increased risk of infections for Q fever (Health Council of the Netherlands 2018).

Several studies in other locations have shown an association between livestock farming exposure proxies and respiratory health of neighbouring residents including:

- A study in Pennsylvania, USA reported that living near poultry farms may increase the risk of community acquired pneumonia (Poulsen et al, 2018).
- A study in Germany found an association between proximity to intensive farms and sensitisation to allergens and reduced lung function (Schulze et al 2011)
- A study in North Carolina, USA found associations between proximity to pig farms and respiratory symptoms including wheeze and reduced lung function (Schinasi et al 2011).

Some studies have found an association with asthma symptoms (Pavilonis et al 2013, Mirabelli et al 2006, Sigurdarson and Kline 2006) and asthma exacerbations (Rasmussen et al 2017, Pavalonis et al 2013). However, other studies have found a lower incidence of asthma in the vicinity of livestock farms (Elliot et al 2004, Borlee 2018).

In their follow up advice on the health risks associated with livestock farms the Health Council of the Netherlands assessed the results of the Dutch VGO study and also considered international literature (Health Council of the Netherlands, 2018). They noted that while studies had confirmed that residents living near livestock farms more often do have decreased lung function and an increased risk of pneumonia, it could not be concluded that the associations were causal in nature. The Council also cautioned that that the results of the Dutch study may not be generalizable to other areas of the Netherlands or elsewhere and recommended additional research and sensible measures such as (Health Council of the Netherlands, 2018):

> *“Further reductions in emissions of particulate matter (including all living and dead organic material) are important, as are ammonia reductions.*”

In his letter to the Ministers of Health & Agriculture supporting the follow-up advice, the President of the Health Council added (Health Council of the Netherlands, 2018b):

> *“In my judgement, there are indications that living in proximity to livestock farms is associated with specific health risks. The evidential strength for a causal link is however insufficient. It is the case that elevated concentrations of particulate matter do occur around livestock farms. Tackling hot spots such as these is recommended in the advisory report ‘Health benefits through cleaner air‘. Reducing emissions of ammonia (which contributes to the formation of particulate matter) from livestock farms is also important for improving public health as a whole.”*

4.2 WHAT ARE THE POTENTIAL EFFECTS OF PARTICULATE EMISSIONS FROM INTENSIVE FARMS?

The Netherlands government has identified poultry farms as a substantial source of particulate emissions and is concerned about the health effects of particulate emissions from poultry farms. Research into methods to reduce particulate emissions from poultry farms is being undertaken in response to these concerns[7].

4.2.1 Are particulate levels likely to be high in the vicinity of intensive farms?

There is a body of literature from Europe, USA and Australia quantifying PM_{10} and $PM_{2.5}$ emissions from intensive farming (for example, Rural Industries Research and Development Corporation, 2010., Australian Poultry CRC 2011., Pollard, 2012., Winkel et al, 2015, European Environment Agency, 2019).

Particulates released from animal housing (i.e. intensive farming) consist mainly of faecal particles, particles of skin and feathers, and food ingredients, along with any associated living and dead organic material. The particle emissions from livestock farms are influenced by the species and number of animals there, the type of housing, and the season of the year (Health Council of the Netherlands, 2012).

In New Zealand, intensive farming[8] is estimated to account for just 1% of primary PM_{10} emissions at a national level, with poultry accounting for more than 90% of these emissions (Metcalfe & Sridhar 2018). These emissions have the potential to cause high PM_{10} concentrations in the vicinity of animal housings because the emissions are released at a relatively low height, are typically horizontal or vertically impeded, have little thermal buoyancy and are typically subject to building downwash.

A review of particulate monitoring undertaken in the vicinity of poultry farms in the UK concluded that poultry farms have the potential to significantly increase daily mean concentrations of PM_{10} near farms (Pollard 2012). Monitoring results were used to develop a relationship between maximum incremental contribution to 24-hour PM_{10} concentration (MD) for a given number of broiler chickens (b) at a given distance (d) as follows:

$$MD\ PM_{10} = (-0.000161 \ln d + 0.000793) \times b$$

This screening assessment equation has been incorporated into UK Government guidance for local air quality management (DEFRA 2018). The guidance requires local authorities to use the screening assessment to identify poultry farms where there is a risk of air quality objectives being exceeded. Where the screening assessment shows that there is a risk of PM_{10} air quality objectives being exceeded, a monitoring survey or dispersion modelling assessment is required.

The effects of PM_{10} emissions from intensive farms are not typically assessed in any detail in resource consents for discharge of contaminants to air in New Zealand. We are not aware of any particulate emission tests and have not been able to source any ambient air quality monitoring undertaken to date in the vicinity of intensive farms in New Zealand. To provide a preliminary indication of potential worst case PM_{10} concentrations in the vicinity of intensive farms we have applied the UK Government screening assessment equation to a hypothetical

[7] https://www.government.nl/topics/livestock-farming/particulate-emissions-from-poultry-farms

[8] The National Air Emissions Inventory (Metcalfe and Sridhar, 2018) includes estimated emissions from animal housings (i.e. intesive farming), including pigs and chickens. It was assumed that housing of other animals is not significant.

farm with 300,000 broilers as shown in Figure 3. In our experience, around 300,000 birds is typical for new broiler farms in applications for resource consents in New Zealand[9].

The screening equation (Pollard 2012) predicts a downwind PM_{10} concentration excluding any background concentrations (i.e. the predicted concentration is the contribution of the poultry sheds and does not include the existing PM_{10} from other sources). For a typical rural New Zealand background PM_{10} concentration of around 20 µg/m^3 as a 24-hour average (existing without the poultry sheds), the screening equation suggests that a poultry farm of 300,000 birds could result in exceedance of the national environmental standard for PM_{10} (50 µg/m^3) at distances up to 90 m from poultry sheds. This distance would increase if background PM_{10} concentrations were higher (for example if agricultural burning was underway).

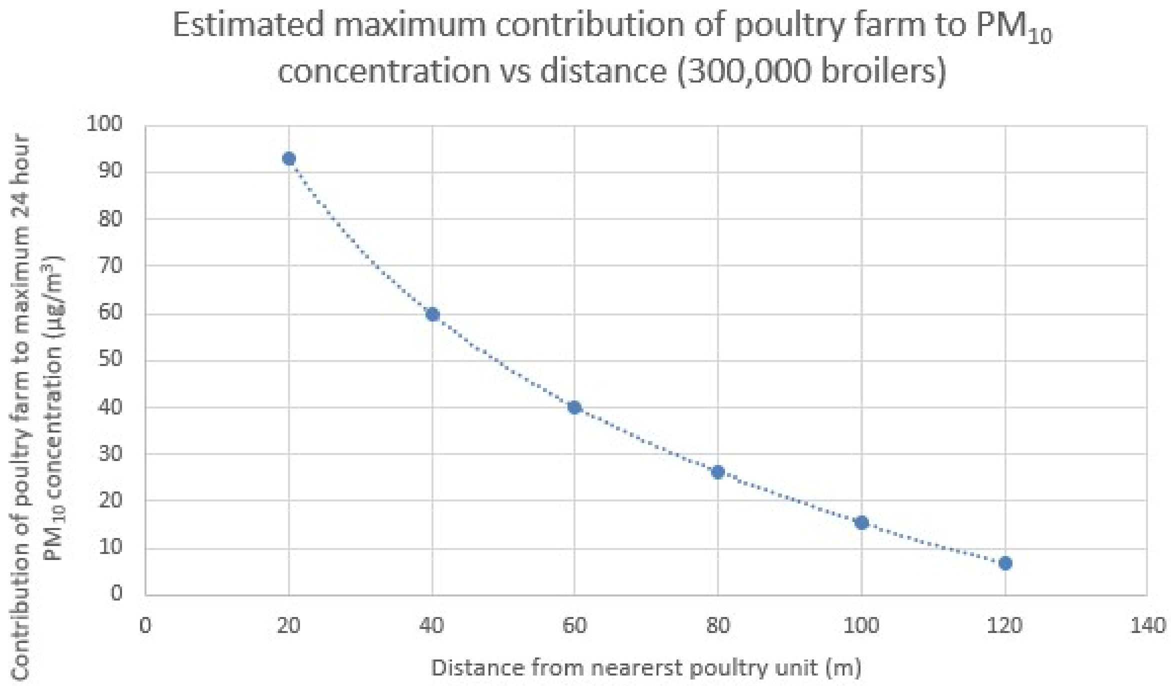

FIGURE 3: Estimated maximum contribution of a 300,000 broiler farm to 24-hour PM_{10} concentration

4.2.2 What about the size and composition of particulate?

Little research has been carried out into the health effects of particulate from intensive farming. Nevertheless, the Health Council of the Netherlands has concluded that the spectrum of health effects from exposure to particulate from intensive farming might differ to the effects from exposure to particulate in urban areas because of the higher concentrations of endotoxins and microorganisms (bacteria, parasites, fungi and viruses) in the cocktail of particulates found in the vicinity of livestock farms. (Health Council of the Netherlands, 2012 and 2018).

There is research to suggest that bioaerosols (airborne biological components of particulate) and endotoxins (an inflammatory component of the cell wall of Gram-negative bacteria) from intensive farms might be associated with health effects (Douglas et al 2018, de Rooij et al 2019).

[9] This is an approximation based on our recent involvement in resource consent applications. It is notable that Tegel foods proposed a farm in Northland with up to 1.325 million broilers, however this consent application was withdrawn.

There is clear evidence that occupational exposure to high concentrations of airborne endotoxin cause respiratory inflammation, respiratory symptoms, and lung function decline (Farokhi et al, 2018, Health Council of the Netherlands, 2010).

A large-scale study in the Netherlands found that the concentration of endotoxins in air is elevated in the vicinity of livestock farms (de Rooij, 2019). The health effects of exposure to these relatively low levels of endotoxin are less well understood compared with occupational exposures. However, a systematic review of health effects of exposure to low levels of airborne endotoxin considered that respiratory health effects of exposure to low levels of airborne endotoxin less than 100 Endotoxin Units per cubic metre (**EU/m^3)** was plausible (Farokhi et al, 2018).

4.3 ARE THERE APPROPRIATE ASSESSMENT CRITERIA?

Ambient air quality criteria for particulate are described in Section 2.

The Dutch Expert Committee on Occupational Safety (DECOS) of the Health Council recommends a health-based occupational exposure limit of 90 EU/m^3. (Health Council of the Netherlands, 2010). DECOS regards an exposure level of 90 EU/m^3 as a NOEL (no observed effect level). Based on the occupational exposure limit, a tentative limit of 30 EU/m^3 was recommended for the general population living in the surroundings of livestock farms by the Health Council of the Netherlands (2012).

We are not aware of any measurement or assessment of endotoxin levels in the vicinity of farms in New Zealand.

4.4 KEY FINDINGS AND KEY DATA GAPS

4.4.1 What is the likely risk posed to public health?

A nascent body of research from Europe and the United States links air pollution from intensive farming with adverse respiratory outcomes in nearby communities. However, the causal relationships are not clear.

Intensive farming (i.e. keeping animals indoors) is much less common for some animals (cows, goats) in New Zealand compared with locations where epidemiological studies have been undertaken in Europe and the United States.

However, intensive farming methods are broadly similar everywhere. This means that exposure to emissions from intensive farms is likely to be much lower at a population level in New Zealand compared with locations in Europe or the United States where epidemiological research has been undertaken. However, at an individual level, there is no reason to expect that effects would be different in New Zealand for residents living in close proximity to intensive farming operations (e.g. poultry farms).

4.4.2 What are the contaminants of most concern

A screening assessment methodology from the UK suggests that PM_{10} concentrations could be significantly elevated in the vicinity of poultry sheds. Farming practices and environmental conditions in the UK might be quite different to New Zealand, so conclusions cannot be drawn about the applicability of the screening method here. However, we are not aware of any ambient monitoring undertaken in the vicinity of farms in New Zealand.

International literature suggests that concentrations of bioaerosols and endotoxins (components of particulate) may be elevated in the vicinity of intensive farms and that health effects may be associated with these components of PM (Health Council of the Netherlands 2012, Health Council of the Netherlands 2018, Douglas et al 2018 and Gladding et al 2020).

It is outside the scope of this report to consider risks associated with the discharge of pathogens from agriculture.

4.4.3 Are there appropriate exposure guidelines or assessment criteria that can be used to assess potential health risks?

There are New Zealand ambient air quality criteria for assessing the potential effects of exposure to PM_{10} including the ambient air quality standard of 50 micrograms per cubic metre ($\mu g/m^3$) as a 24-hour average.

The Health Council of the Netherlands has proposed a tentative endotoxin limit of 30 EU/m^3 for the general population living in the surroundings of livestock farms.

4.4.4 What are the key data gaps?

PM and endotoxin concentrations in the vicinity of intensive livestock farms in New Zealand have not been measured.

GLOSSARY

Aerodynamic diameter	Airborne particles have irregular shapes, and how they behave in the air is expressed in terms of the diameter of an idealised spherical particle known as *aerodynamic diameter*. This is the size of a unit-density sphere with the same aerodynamic characteristics as the particle of interest. Particles having the same aerodynamic diameter may have different dimensions and shapes.
Aerosol	An aerosol is a suspension of fine solid particles or liquid droplets in air.
Anthropogenic	generated by human activities, such as the combustion of fuels or processing of raw materials
Bacteria	Bacteria are single-celled prokaryotic. Bacteria are usually between 1 and 5 µm in size and are divided into Gram-negative bacteria (predominantly of animal origin) and Gram-positive bacteria (predominantly of plant origin).
Bioaerosol	An aerosol of biological origin
CFU	Colony forming units is a unit of measure for micro-organism numbers that relies on bacteria to grow to form colonies on nutrient plates that can be subsequently counted
Coarse particulate	Particles in the 2.5 µm to 10 µm size range, also known as $PM_{10-2.5}$
EU	Endotoxin unit is a unit which indicates endotoxicity
Endotoxin	Endotoxins are an inflammatory component of the outer membrane of Gram-negative bacteria. They are released into the environment during growth of bacteria and after the cell dies. Endotoxins can also be found in a range of industries, such as composting, cotton production, hay or grain storage as well as intensive farming.
Epidemiology	The study and analysis of the distribution (who, when and where), patterns and determinants of health and disease conditions in defined populations.
Fine particulate	Particles in the $PM_{2.5}$ fraction.
Gram-negative	Gram-negative refers to the inability of a microorganism to accept a certain stain (in the laboratory). This inability is related to the cell wall composition of the bacteria and has been useful in classifying bacteria.
HAPINZ	Health and Air Pollution in New Zealand study
Intensive farming	Intensive farming refers to agricultural production carried out primarily indoors or in closely fenced outdoor runs where the stocking density precludes the maintenance of pasture or ground cover and the primary purpose being the commercial production of livestock for sale or slaughter.

microgram (μg)	One millionth of a gram (1×10^{-6} g)
microorganism	A microorganism is an organism that is too small to see with the naked eye that is capable of living on its own
micrometre (μm)	One millionth of a metre (1×10^{-6} m)
Pathogen	Any organism capable of producing disease through infection
PM	Particulate matter
$PM_{2.5}$	Particulate matter less than 2.5 μm in diameter, sometimes referred to as fine particulate – also known as respirable particulate because it deposits deeper in the gas-exchange region, e.g. in the bronchioles and alveoli
PM_{10}	Particulate matter less than 10 μm in diameter, includes fine particulate (less than 2.5 μm) and coarse particulate (2.5 μm to 10 μm) – also known as thoracic particulate because it deposits within the lung airways and the gas-exchange region, including the trachea, bronchi, and bronchioles
Primary particulate	Primary particulate matter (or PM) arises directly from anthropogenic or natural sources, as opposed to secondary particulate which forms in the atmosphere from the reaction of precursor gases.
Secondary particulate	Secondary particulate matter (or PM) is formed in the atmosphere from the reaction of precursor gases.
Systematic literature review	Literature review designed to provide a complete, exhaustive summary of current evidence that is methodical, comprehensive, transparent, and replicable.
Staphylococcus (plural staphylococci)	*Staphylococcus* is a genus of Gram-positive bacteria in the family Staphylococcaceae from the order Bacillales
$\mu g/m^3$	Microgram per cubic metre, a unit of concentration
μm	Micrometre, one millionth of a metre
VGO study	Livestock farming and neighbouring residents health study (acronym from the Dutch: Veehourderij en Gezondheid Omwonenden)
Zoonotic disease	A zoonosis or zoonotic disease is a disease that can be passed from animals to humans. Zoonotic pathogens may be bacterial, viral or parasitic, or may involve unconventional agents and can spread to humans through direct contact or through food, water or the environment.

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