Air Pollution: Health Risk Assessment Mount Maunganui

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PREPARED FOR: **Toi Te Ora Public Health**

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EXECUTIVE SUMMARY

This report is an air pollution health risk assessment for the Mount Maunganui area, prepared in response to a request by Toi Te Ora Public Health. The intent is to provide information to polluters, regulatory agencies, and the affected community on the potential scale of adverse health outcomes from existing air quality with the aim of working together to reduce discharges.

The approach taken has been to qualitatively and, where practicable, quantitatively describe and assess potential health risks of exposure to identified air pollutants in the Mount Maunganui area in accordance with good practice (WHO, 2014). The qualitative assessment reviews available data for the period ending 31 December 2021. The quantitative assessment uses a base year of 2019, which pre-dates potential impacts of the COVID-19 pandemic on ambient air quality.

The pollutants assessed were:

- Particulate matter (PM) less than 10 micrometres (µm) in diameter (PM_{10}) and less than 2.5 µm in diameter ($PM_{2.5}$)
- Nitrogen dioxide (NO_2)
- Sulphur dioxide (SO_2)
- Hydrogen sulphide (H_2S)
- Benzene (C_6H_6)
- Odour

Toi Te Ora Public Health also requested assessment of polycyclic aromatic hydrocarbons (PAHs) but this was unable to be undertaken due to a lack of ambient air quality monitoring data. Methyl bromide was excluded from consideration.

First, we briefly described the potential health effects of these pollutants with reference to the most up to date state of knowledge on the science of the health effects of key pollutants (PM_{10}, $PM_{2.5}$ and NO_2) in New Zealand (Hales et al., 2021) and globally (WHO, 2022). Next, we reviewed available ambient air quality monitoring data in Mount Maunganui and surrounding areas. This showed that concentrations of some air contaminants are elevated in some locations relative to health and wellbeing-based ambient criteria.

Our assessment was in two parts – quantitative and qualitative. It should be noted that our assessment addresses only identified pollutants, individually, which excludes consideration of potential synergistic or cumulative impacts. It also does not consider wider impacts including positive social benefits arising from the sources of discharges to air (for example, contribution to the local and national economy).

Quantitative Assessment

The quantitative assessment focused on long-term exposure which, for PM and NO_2, is known to result in an order of magnitude greater significance to public health than acute exposure (WHO, 2021). Our assessment was comparative, using current monitoring of annual average concentrations as a chronic exposure metric.

Specifically, we compared public exposure to key pollutants (PM_{10}, $PM_{2.5}$ and NO_2) in Mount Maunganui which is immediately adjacent to the Port and industrial area, with public exposure in Otūmoetai, a residential suburb of Tauranga around five kilometres away. The health effects of these pollutants (only) have recently been quantified for New Zealand (Hales *et al.*, 2021, Kuschel *et al.*, 2022).

Our approach to estimating chronic population exposure to key pollutants was one of caution to avoid overstating potential impacts. This means the estimates are not conservative and likely underestimate effects.

The modelling estimates show that, compared with Otūmoetai, in Mount Maunganui there were:

- Around five additional premature deaths in adults (>30 years) each year associated with exposure to long-term concentrations of **$PM_{2.5}$ and NO_2**. For context, the total mortality from all non-external causes[1] in Mount Maunganui for the year 2019 was 145 so this estimate represents around 3% of deaths in that year.
- An additional four cardiovascular and six respiratory hospitalisations per year associated with long-term exposure to $PM_{2.5}$ and NO_2.
- An additional 1,256 restricted activity days per year across the population associated with long-term exposure to $PM_{2.5}$.
- Two additional cases of asthma per year in under 18-year-olds associated with long-term exposure to NO_2.
- Estimated social costs due to additional mortality and morbidity of $22 million (NZ$2019).

A statistical sensitivity analysis estimates that:

- The number of additional premature deaths for adults (>30 years) per year associated with long-term exposure to $PM_{2.5}$ and NO_2 in Mount Maunganui as compared with Otūmoetai has a 95% confidence interval of 3 to 6 (relative to the base case of 5 deaths).
- The low and high social cost estimates associated with long-term exposure to $PM_{2.5}$ and NO_2 in Mount Maunganui as compared with Otūmoetai are between $19 million and $29 million per year (relative to the base case of $22 million, all in NZ$2019).

Single-pollutant modelling for **PM_{10}** (only) estimated that the Mount Maunganui area had 13 additional premature deaths in adults (> 30 years) each year (95% confidence interval 11 to 15) when compared with Otūmoetai. This estimate represents around 9% of total mortality from all non-external causes in Mount Maunganui that year, which is higher than the estimates associated with long-term exposure to $PM_{2.5}$ and NO_2. It should be noted that the PM_{10} modelling is not additive to the estimate of effects associated with $PM_{2.5}$ and NO_2, rather it is a separate estimate.

At Toi Te Ora Public Health's request, we modelled the hypothetical scenario of all areas, including Otūmoetai, meeting the annual WHO 2021 global air quality guidelines for $PM_{2.5}$ (5 $\mu g/m^3$) and NO_2 (10 $\mu g/m^3$). This would have a modest impact in averting two premature deaths per year with an associated averted social cost of $11 million (NZ$2019) due to hypothetical reductions in annual $PM_{2.5}$ (as our assessment assumed all areas already meet the annual WHO guideline for NO_2).

[1] i.e., deaths excluding accidents and violence

Our assessment of uncertainty concludes there is a moderate degree of confidence in the modelling estimates.

Qualitative Assessment

Sulphur Dioxide

Following complaints of adverse health effects by residents', Bay of Plenty Regional Council (BOPRC) commenced ambient air quality monitoring at Whareroa Marae in 2015. This revealed breaches of the national environmental standards for SO_2 caused by a neighbouring fertiliser works. Regulatory action by BOPRC, coupled with mitigation by the fertiliser works, significantly reduced emissions and there have been no breaches of national environmental standards for SO_2 since 2016. The elevated acute (10-minute) SO_2 concentrations may have resulted in some short-term, transient effects (bronchoconstriction, nose or throat irritation) at nearby locations such as Whareroa Marae.

In late 2018 BOPRC commenced monitoring for SO_2 at five other locations of the Mount Maunganui Airshed. In 2019 there were occasional 10-minute and hourly concentrations that could cause asthma and adverse respiratory effects with multiple exceedances of WHO guidelines and national environmental standards for SO_2 at these monitoring stations. However, from 1 January 2020, the short-term peaks disappeared at most monitoring locations. This date coincides with reductions in ship emissions due to the implementation of MARPOL Annex VI from this date.

The exceptions were Whareroa Marae and Tauranga Bridge Marina monitoring locations, which continued to record occasional exceedances of WHO 10-minute and daily guidelines. The elevated concentrations at these two locations appear to be influenced primarily by SO_2 emissions from the adjacent fertiliser works.

It is less clear what the effects of the elevated daily levels of SO_2 would be. A recent systemic review and meta-analysis concluded that rises in short-term SO_2 concentration increases the risk of all-cause mortality and respiratory mortality (Orellano *et al.,*2021). This relationship was considered to have a high degree of certainty (WHO, 2021). Another recent systemic review and meta-analysis reported short-term exposure to SO_2 increased the risk of asthma-associated emergency room visits and hospital admissions (Zheng *et al.,* 2021). This relationship is considered causal (WHO, 2021).

The evidence suggests that residents and visitors including manuhiri (guests) to Whareroa Marae and kohanga reo, residents (on boats) and visitors to the Tauranga Bridge Marina may have been, and continue to be, adversely affected by SO_2 emissions.

Hydrogen Sulphide

Ambient air quality monitoring at Whareroa Marae and source investigation by BOPRC provides clear evidence that industrial emissions of hydrogen sulphide (H_2S) regularly exceeded the national guideline set to prevent against offensive odours (BOPRC, 2020). This would reduce the quality of life and impact adversely on the wellbeing of Marae users, including manuhiri, and Whareroa Marae residents.

Benzene

Limited, short-term monitoring of benzene (C_6H_6)[2] in industrial locations of the Mount Maunganui Airshed have measured ambient concentrations above a health-based, air quality

[2] Whilst benzene is not a PAH, it is also emitted as a by-product of incomplete combustion (like PAHs) and is also a known carcinogen (like PAHs).

criterion for acute exposure to benzene. Workers in these locations may have elevated acute exposure to benzene, however, the data are limited, and therefore no firm conclusions can be drawn.

We note that Whareroa Marae is within 200 metres of a bulk fuel storage facility and within 300 metres of an oil re-refining facility. Residents and visitors, including manuhiri, to Whareroa Marae and kohanga reo may have been exposed to elevated concentrations of benzene over acute and/or chronic time frames. Benzene exposure may disproportionately impact infants and children (OEHHA, 2014). However, in the absence of any data no firm conclusions can be drawn.

Benzene is a known carcinogen, however, there are no long-term air quality monitoring data for benzene in or around the Mount Maunganui Airshed. This is a significant data gap. No conclusions can be drawn about either worker or residential chronic exposure to benzene.

Odour

Odour is a well-established issue in Mount Maunganui, with more than 500 complaints to the regional council each year.

Based on the frequency of complaints it is apparent that offensive and objectionable odours are reducing the quality of life and adversely impacting on the wellbeing of residents in and around the Mount Maunganui Airshed.

Recent literature suggests that industrial odours are often associated with adverse health impacts in surrounding communities (Government of Alberta, 2017, Guadualupe-Fernandez *et al.*, 2021). Some chemicals, such as benzene, can be harmful even when present below their respective odour thresholds. This suggests that, in addition to negative impacts on wellbeing, odorous emissions may also be adversely impacting residents' health.

Data Gaps

The assessment has highlighted a lack of data for some pollutants of potential concern. Specifically, there is a dearth of ambient air quality monitoring for PAHs and benzene. This has constrained our ability to assess potential cancer risks.

1. INTRODUCTION

In May 2022, Toi Te Ora Public Health requested the following analysis and advice: :

1. Provide an estimate of health impacts on the population in the Mount Maunganui area from exposure to air contaminants of public health concern where concentrations are known or can reasonably be estimated e.g., particulates (PM_{10}, $PM_{2.5}$), sulphur dioxide (SO_2), methyl bromide (CH_3Br), hydrogen sulphide (H_2S). Depending on readily available data possible health impacts for consideration may include:

    a. Number of excess deaths

    b. Restricted activity days

    c. Additional hospital admissions

    d. Extra presentations for health care

2. Where applicable provide an estimate in the differences in health impacts between compliance with the National Environmental Standards (NES) for Air Quality and meeting relevant health guideline levels.

Toi Te Ora Public Health intends that the information be used to:

a. Inform polluters, regulatory agencies, and the affected community on the potential scale of adverse health outcomes from current levels of air contaminants; and

b. Inform parties what reductions in health impacts might be achieved by lowering discharge targets, with the aim of getting the relevant industries and regulators to work together to reduce discharges.

Further to a meeting on 28 June 2022, and following the publication of the third Health and Air Pollution in New Zealand (HAPINZ 3.0) study (Kuschel *et al.,*2022), Toi Te Ora advised in an email on 18 July 2022 that:

- Nitrogen dioxide (NO_2), $PM_{2.5}$, SO_2, H_2S and polycyclic aromatic hydrocarbons (PAHs) were to be included in the assessment;
- Odour impacts on well-being to be included on a qualitative basis; but
- Methyl bromide was not to be included.

1.1 BACKGROUND

Whareroa Marae and the adjoining community are situated on the shore of Tauranga Harbour. The Whareroa Marae is a traditional pa site and key marae for Ngai Tukairangi and Ngāti Kuku hapū of the Ngāi Te Rangi Iwi. Whareroa Pā has been present for around 150 years, making it one of the oldest kāinga (settlements) in the area.

The Mount Maunganui residential area is low lying and represents a relatively constrained geographic area situated between the Tauranga Harbour and the coast. It is a popular residential area but also home to the largest port in New Zealand and a significant industrial estate, generally contained within the Mount Maunganui Airshed – refer **Figure 1**. Whareroa Marae, and some residential areas, pre-date the establishment of the Mount Maunganui industrial estate in the 1940s.

Figure 2 shows activities sensitive to air pollution in and around the Mount Maunganui Airshed. Of note, there are currently five childcare facilities inside the Mount Maunganui Airshed, including a kohanga reo at Whareroa Marae.

Key industrial activities in the Mount Maunganui Airshed with potentially significant discharges to air currently include:[3]

- Port of Tauranga Ltd (shipping, container, fuel, bulk materials and log loading and unloading)
- Ballance Agri-Nutrients Ltd (sulphuric acid & superphosphate fertiliser manufacture)
- Lawter, Hexion (chemical & resin manufacture)
- Multiple bulk fuel storage and handling facilities
- Multiple bulk materials manufacture, transport, storage & handling (aggregate, cement, coal, fertiliser, stock feed)
- Multiple log transport, storage and handling areas
- Three asphalt plants
- Waste Management Ltd (waste oil refining)

In 2015, Bay of Plenty Regional Council (BOPRC) installed ambient air quality and meteorological monitoring instruments at Whareroa Marae as shown in **Figure 3**. The monitoring revealed significant exceedances of health-based air quality criteria.

In late 2018, BOPRC commenced ambient air quality monitoring at additional locations in the Mount Maunganui Airshed (refer **Figure 3)**.

[3] Compost and pet food manufacturing activities have recently exited the Mount Maunganui Airshed.

FIGURE 1: Mount Maunganui Airshed (red outline) and adjacent residential areas (orange outline approx. 2013 census area units) [Source: Google Earth, 2 Aug 19]

FIGURE 2: Early childhood education centres in (yellow stars) and around (red boxes) the Mount Maunganui Airshed (black outline) [Source: Toi Te Ora Public Health]

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FIGURE 3: Locations of Bay of Plenty Regional Council ambient air quality monitoring for PM_{10} and SO_2 in the Mount Maunganui Airshed* [Source: BOPRC]

*Totara St also measures $PM_{2.5}$, De Havilland Way measures only PM_{10}

1.2 PRINCIPLES OF ASSESSMENT

This assessment was prepared in accordance with the World Health Organisation (WHO) recommendations for good practice air pollution health risk assessments (WHO, 2014) as follows:

- *Health effects assessment should address an area of uncertainty and an unmet need for information (particularly with respect to social costs).*

The assessment was prepared in response to questions from the local community, industry and Bay of Plenty Regional Council about potential health impacts of air pollution on residents.

- *The assessment reflects the core WHO value of the "right to health".*

The assessment includes odour, and other pollutants known to be emitted but not monitored in the Mount Manganui Airshed. It considers not only health but also potential impacts on wellbeing.

- *The process of undertaking an assessment is explicit and transparent so the end user can see how health impacts and social costs were selected and calculated.*

Section 2 outlines the methodology for the assessment approach with all references provided.

- *The process of undertaking an assessment is multidisciplinary and includes all relevant expertise and perspectives, including input from stakeholders.*

The quantitative assessment relies on the national health effects model (Sridhar *et al.* 2022) prepared for the HAPNZ Study 3.0 (Kuschel *et al.* 2022). The HAPINZ 3.0 study was prepared by a multidisciplinary team for a steering group comprising officials from the Ministry for the Environment, Ministry of Transport, Waka Kotahi, Ministry of Health and regional councils who all had input to the design and outcomes. The HAPINZ 3.0 study was extensively peer reviewed with strong input from stakeholders.

We understand this assessment will be provided to the community, industry and BOPRC for consideration of wider impacts.

- *The evidence used to develop the assessment is publicly available.*

Cost data were sourced from the Ministry of Transport (refer section 3.2.2).

Exposure response functions developed for New Zealand (Hales et al., 2021) were used for quantitative risk assessment (refer section 3.2.4).

Population data were provided by NZStats (refer section 3.2.5).

Health statistics were provided by the Ministry of Health (refer section 3.2.6).

Air quality and meteorological data were sourced from the BOPRC (refer section 4).

- *Assessment outputs (in the form of exposure and effects models) can be implemented in, and adapted to, local settings and contexts.*

The quantified risk assessment is an adaptation of an existing national tool (HAPINZ 3.0) for the Mount Maunganui setting. Health incidence, air quality and population data are specific to each census area unit.

- *Assessment communication products should be tailored to the general public.*

This document is a technical report outlining, in a transparent manner, the approach and findings. Given the highly technical nature of the material it may not be suitable for the general public, and it is likely that additional material (e.g., summary graphics) will need to be prepared for a lay audience.

2. HEALTH EFFECTS OF AIR CONTAMINANTS

WHO has identified air quality as the world's largest environmental health risk and among the largest global health risks – comparable with 'traditional' health risks such as smoking, high cholesterol, and obesity. The WHO estimates that indoor and outdoor air pollution exposure currently kills seven million people worldwide every year due to cardiovascular diseases, such as strokes and ischaemic heart disease, as well as respiratory diseases including acute respiratory infections, chronic obstructive pulmonary diseases and lung cancer (WHO, 2021).

The impacts of air pollution are assessed through short-term (acute) or long-term (chronic) exposure. Short-term exposures cover minutes, hours, or days. Long-term exposures are usually over months or years. The major impacts of air pollution occur due to chronic exposure (WHO, 2021).

Accordingly, the quantified assessment of health effects of air pollutants in this document focus on chronic (long-term) exposure.

2.1 PARTICULATE MATTER (PM_{10} AND $PM_{2.5}$)

Particulate Matter (PM) is a collective term for solid and liquid particles suspended in the air and small enough to be inhaled. The major components of PM are sulphate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water.

PM is classified by particle size defined through aerodynamic diameter:

- **PM_{10}** – particulate less than 10 microns; known as coarse particulate
- **$PM_{2.5}$** – particulate less than 2.5 microns; known as fine particulate.
- **PM_1** – particulate less than 1 micron; known as ultrafine particulate.

In general, $PM_{2.5}$ and smaller tends to be more closely associated with anthropogenic activities, whereas $PM_{10-2.5}$ can have a substantial natural source component. The main sources of PM in New Zealand are home heating, industry, agricultural practices, road dust and sea salt. The main anthropogenic (human caused) sources of PM in New Zealand are domestic fires, industry and motor vehicles.

Different sizes of PM can result in different health effects. This is because they deposit in different parts of the respiratory tract, they have diverse sources, and they can interact through different biological mechanisms (WHO, 2013). In general, the smaller a particle is, the farther into the respiratory tract it can penetrate to interact and cause adverse health effects.

There is scientific consensus that exposure to particulate pollution causes predominantly respiratory and cardiovascular effects, ranging from subclinical functional changes (e.g. reduced lung function) to symptoms (increased cough, exacerbated asthma) and impaired activities (e.g. school or work absenteeism) through to doctors' or emergency room visits, hospital admissions and death (WHO, 2006). The effects, in terms of escalating severity, are described as increased visits to doctors for many individuals, hospital admission for some individuals and death for a few individuals. People with pre-existing heart or lung disease, young children, and the elderly, are most likely to suffer adverse health effects. The exposure-response relationship is essentially linear and there is no 'safe' threshold; adverse health effects are observed at all measured levels (US EPA 2020; WHO 2013, WHO, 2021).

In 2013, the International Agency for Research on Cancer (IARC) classified particulate matter (as a component of outdoor pollution) as carcinogenic based on an increased risk of lung cancer (IARC, 2013). Additional research further indicates particulate matter is associated with atherosclerosis, adverse birth outcomes, childhood respiratory disease (WHO, 2013) as well as Alzheimer's disease and other neurological endpoints, cognitive impairment, diabetes, systemic inflammation and aging (WHO 2016b).

More recently, WHO has concluded that chronic exposure to PM is causal, or likely to be causal, for (WHO, 2021):

- All-cause mortality
- Cardiovascular mortality (all, cerebrovascular, ischaemic heart disease)
- Respiratory mortality (any, chronic obstructive pulmonary disease, acute lower respiratory infections)
- Lung cancer

Table 1 presents New Zealand and WHO air quality guidelines and standards for particulate matter.

TABLE 1: New Zealand and WHO air quality guidelines and standards for particulate matter

Time Average / Jurisdiction (Year)	Guideline / Standard (µg/m^3)	Permitted Exceedances per Year
$PM_{2.5}$		
24-hours		
New Zealand (2002)*	25	–
WHO (2021)	15	3 – 4
Annual		
WHO (2021)	5	–
PM_{10}		
24-hours		
New Zealand (2004)	50	1
WHO (2021)	45	3 – 4
Annual		
New Zealand (2002)	20	–
WHO (2021)	15	–

*Reporting guideline only

2.2 NITROGEN DIOXIDE (NO_2)

Nitrogen dioxide (NO_2) is a reddish brown coloured acidic gas with a characteristic pungent odour. The main sources of NO_2 worldwide are combustion processes such as motor vehicles, domestic heating, industrial combustion sources, electricity generation, shipping and construction machinery. NO_2 is both a primary and secondary pollutant i.e., it is both emitted and forms downwind from other pollutants (including $PM_{2.5}$).

Nitrogen dioxide is the main source of nitrate aerosols, which form an important fraction of $PM_{2.5}$ and, in the presence of sunlight, ozone. It is also a major component of brown haze. In

New Zealand the main source of nitrogen dioxide is motor vehicles. In Mount Maunganui, ships and industry are also likely to be significant sources of nitrogen dioxide.

Long-term exposure to NO_2 increases the risk of premature death (mortality) and respiratory illnesses (morbidity) (WHO, 2021). Epidemiolocal studies have also shown that symptoms of bronchitis in asthmatic children increase with long-term exposure to NO_2. Reduced lung function is also linked to measured levels within cities of Europe and North America (WHO, 2006). Recent evidence also suggests exposure may increase the risk of premature death and trigger heart attacks (USEPA, 2016).

Short-term exposure to high concentrations of nitrogen dioxide (NO_2) causes significant inflammation of the airways and respiratory problems and can also trigger asthma attacks (WHO, 2021).

Table 2 presents New Zealand and WHO air quality guidelines and standards for NO_2.

TABLE 2: New Zealand and WHO quality guidelines and standards for NO_2

Time Average / Jurisdiction (Year)	NO_2 Guideline / Standard (µg/m^3)	Permitted Exceedances per Year
1-hour		
New Zealand (2004)	200	9
WHO (2000)	200	–
24-hours		
New Zealand (2002)	100	–
WHO (2021)	40	3 – 4
Annual		
WHO (2021)	10	–

2.3 SULPHUR DIOXIDE (SO_2)

Sulphur dioxide is a colourless gas that is readily soluble in water. It has a characteristic pungent smell and an odour threshold of 870 micrograms per cubic metre (µg/m^3) or 0.33 parts per million (ppm) (AIHA, 2013). The odour threshold is the level at which 50% of the population can just detect the odour.

Sulphur dioxide is both a primary and secondary pollutant, it is a precursor for the formation of $PM_{2.5}$. Sulphur dioxide arises naturally from volcanic sources, with White Island being New Zealand's largest source of sulphur dioxide (PAE, 2009). Away from industrial and volcanic sources, background levels of sulphur dioxide in New Zealand are typically very low, less than 5 µg/m^3 as a one-hour average.

In New Zealand the major anthropogenic sources are industrial processes (aluminium manufacture, fertiliser manufacturing, chemicals manufacture) and the combustion of fossil fuels that contain sulphur. The main sources of sulphur dioxide in Mount Maunganui are shipping (745 tonnes/year) and industry (232 tonnes/year) (Wilton & Iseli, 2019). It should be noted that the inventory estimate of shipping SO_2 emissions was for the year 2018 and predates the implementation of Annex VI of MARPOL on 1 January 2020.[4]

[4] This requires ships to burn low sulphur fuel or implement abatement technology to mitigate emissions of SO_2.

Sulphur dioxide can cause respiratory problems, such as bronchitis, and it can irritate the nose, throat and lungs. This is because inhaled sulphur dioxide readily reacts with the moisture of mucous membranes to form sulphurous acid (which is a severe irritant). It may cause coughing, wheezing, phlegm and asthma attacks (MfE, 2011).

Studies have shown that asthmatics and people with lung disease are particularly sensitive to sulphur dioxide. Children may also be more sensitive to the effects of sulphur dioxide due to their relatively higher respiration rate and smaller body mass.

In 2021, WHO published two systematic reviews and meta-analyses on the effects of short-term exposure to ambient sulphur dioxide (SO_2) on:

- all-cause and respiratory mortality (Orellano *et al.,*2021); and
- emergency room visits and hospitalisations for asthma (Zheng *et al.,*2021).

Orellano *et al.,*2021 found that **short term increases in SO_2 increased the risk of all-cause mortality (daily SO_2) and respiratory mortality (1-hour SO_2) with a high certainty of evidence.** In general, concentration response functions showed linear behaviour with no thresholds. Orellano *et al.,*2021 considered the epidemiological evidence supports a causal relationship.

Zheng *et al.,*2021 found that short term increases in SO_2 correlate with increased risk of asthma-associated emergency room visits and hospital admissions. Children and to a lesser extent the elderly are more susceptible. The positive correlation between daily SO_2 and asthma-associated emergency room visits and hospital admissions was judged as having a moderate certainty of evidence and warrants further investigation. SO_2 was not found to have a daily threshold of effects.

The speed with which people show health effects from exposure to SO_2 necessitates a focus on acute exposure. National environmental standards and ambient air quality guidelines for SO_2 are presented in **Table 3**.

TABLE 3: New Zealand and WHO short-term air quality guidelines and standards for SO_2

Time Average / Jurisdiction (Year)	SO_2 Guideline / Standard (µg/m^3)	Permitted Exceedances per Year
10-minutes		
WHO (2000)	500	0
1-hour		
New Zealand (2004)	350	9
	570	0
24-hours		
New Zealand (2002)	120	–
WHO (2021)	40	3 – 4

2.4 HYDROGEN SULPHIDE (H_2S)

Hydrogen sulphide (**H2S**) is a flammable, colourless gas with the characteristic odour of rotten eggs. H_2S is odorous at extremely low concentrations (0.06 µg/m^3) (AIHA, 2019). H_2S gas is found naturally in geothermal areas and is also emitted from volcanoes, undersea vents, swamps and stagnant bodies of water. H_2S is also emitted from industrial processes such as oil refining, pulp and paper manufacture, tanneries and wastewater treatment.

H_2S is heavier than air and can build up in confined or low-lying, still spaces. Sanitation workers are most at risk from exposure to H_2S when working in or near sewers, septic tanks and sump holes, however, geothermal areas, such as Rotorua, also pose risks to the general public. There have been 11 deaths linked with H_2S exposure in geothermal spa pools and confined spaces in New Zealand between 1946 and 2008.[5]

H_2S is a gas that affects the nervous system and cardiovascular system leading to a range of symptoms such as nausea, headache and dizziness. The physiological response is rapid, even one or two breaths at high concentrations (> 75,000 – 150,000 µg/m^3) can cause 'knock down'. Single exposures to very high concentrations may rapidly cause breathing difficulties and death (PHE 2009).

WHO, 2003 notes:

> *Health effects that have been reported as being associated with odour exposures include nausea, headaches, retching, difficulty breathing, frustration, annoyance, depression, stress, tearfulness, reduced appetite, and being woken in the night. There are also social effects such as reduced enjoyment of the outdoors and embarrassment in front of visitors. All of these contribute to a reduced quality of life for the individuals who are exposed. People can also develop physiological effects from odour even when their exposure is much lower than that normally associated with the reported physical health effects. This effect is sometimes termed 'odour worry' and is due to the perception that if there is a smell it must be doing physical harm.*

The New Zealand guideline for H_2S is 7 µg/m^3 as a 1-hr average (MfE, 2002). This was set to prevent odour annoyance and the resulting impacts on well-being, rather than specific health effects.

For context, the California Office of Environmental Hazard and Health Assessment (OEHHA) has established a reference exposure level (REL) of 42 µg/m^3 as a 1-hour average that it is "protective against mild adverse effects (headaches and nausea)" noting that at this concentration around 40% of the general population would find H_2S to be objectionable (OEHHA 1999).[6]

Table 4 presents health effects of H_2S at varying concentrations.

[5] Rotorua Daily Post (2008). *The Death Toll*. 13 June 2008.

[6] Appendix D2. Acute RELs and toxicity summaries using the previous version of the Hot Spots Risk Assessment guidelines.

TABLE 4: Acute health effects of H_2S at varying concentrations [Source: ESR 2022]

Concentration (µg/m^3)	Symptoms/Effects
0.2 – 0.5	Typical background concentrations
0.06 – 2,130*	Odour threshold (rotten egg smell is noticeable)
3,000 – 7,500	- Odour becomes more offensive - Prolonged exposure may cause nausea, tearing of the eyes, headaches or loss of sleep. - Airway problems (bronchial constriction) in some asthma patients
30,000	- Possible fatigue - Loss of appetite - Headache - Irritability - Poor memory - Dizziness - Above 45,000 µg/m^3 odour described as sweet or sickeningly sweet
75,000 – 150,000	- Slight conjunctivitis ("gas eye" or pink eye) and respiratory tract irritation after 1 hour - May cause digestive upset and loss of appetite
150,000	- Coughing, eye irritation, loss of smell after 2-15 minutes (olfactory fatigue) - Altered breathing, drowsiness after 15-30 minutes - Throat irritation after 1 hour - Gradual increase in severity of symptoms over several hours - Death may occur after 48 hours
150,000 – 230,000	**Loss of smell (olfactory fatigue or paralysis)**
300,000 – 450,000	- Marked conjunctivitis and respiratory tract irritation after 1 hour - Pulmonary oedema may occur from prolonged exposure
750,000 – 1,000,000	- Staggering, collapse in 5 minutes - Serious damage to the eyes in 30 minutes - Death after 30-60 minutes
1,000,000 – 1,500,000	- Rapid unconsciousness - "Knockdown" or immediate collapse within 1 to 2 breaths - Breathing stops - Death within minutes
1,500,000 – 3,000,000	Nearly instant death

*AIHA, 2019

2.5 BENZENE

Benzene (C_6H_6) is a colourless, clear liquid with a boiling point of 80ºC (MfE, 2002).

Motor vehicles and household fires are significant sources of benzene in New Zealand's air. There are also some industrial activities that use and discharge benzene. Motor vehicle exhaust emissions of benzene are thought to derive partly from unburnt benzene in the fuel, and partly from the dealkylation of other aromatic hydrocarbons (MfE, 2002). In the Mount Maunganui Airshed, petroleum re-refining, tank filling and 'breathing' losses from petroleum storage are likely sources of benzene. 'Breathing' losses refer to vapours in the headspace of the storage tank discharging to atmosphere due to changes in the tank temperature and pressure throughout the day and throughout the year.

Benzene is a known human carcinogen (IARC Group 1; leukaemia) and is known to have haemotoxic, genotoxic & mutagenic effects. The New Zealand guideline for benzene is 1 part per billion (ppb) as an annual average (MfE, 2002).[7] This was set on a precautionary basis for a carcinogen in 2002.

With respect to non-cancer effects, acute, high inhalation exposure to benzene may lead to eye, nose, and throat irritation and central nervous system depression in humans. Prolonged or repeated exposures have been associated with both blood cell proliferation and reduction in blood cell numbers due to bone marrow suppression, including peripheral lymphocytopenia, pancytopenia, and aplastic anaemia (OEHHA 2014).

OEHHA determined there is valid concern that benzene exposure may disproportionately impact infants and children. This is based on the wide-spread exposure to benzene, the documented toxicokinetic variability in benzene metabolism, the transplacental genotoxicity and developmental toxicity of benzene, the documented increased sensitivity of early in life exposure to benzene carcinogenicity in animals, as well as the dynamic haematopoiesis that occurs during human development (OEHHA, 2014).

2.5.1 Chronic Benzene Criteria

For known carcinogens good practice in New Zealand is to quantitatively estimate risk using factors for carcinogens provided by the United States Environment Protection Agency (US EPA) Integrated Risk Information System (IRIS) database. The IRIS database has been developed from toxicological data using a rigorous and transparent methodology with an ongoing process of review and revision. The recommended approach for air quality assessments in New Zealand is to adopt an acceptable environmental risk for exposure by residential receptors to individual environmental pollutants of 1 in 1,000,000 (i.e., one in a million).[8]

The US EPA inhalation unit risk factor for benzene is 2.2 x 10^{-6} per µg/m^3, set to protect against leukaemia.[9]

2.5.2 Acute Benzene Criteria

New Zealand has no acute (short-term) air quality guideline for benzene. In the absence of any local guidance, good practice is to refer to criteria established using transparent derivation from toxicological data, whilst explaining the purpose of the guideline (MfE, 2016).

The OEHHA reference exposure levels (RELs) have been developed from toxicological data using a rigorous and transparent methodology with an ongoing process of review and revision to take into account new information and sensitive subpopulations including infants and children. Acute RELs are concentrations that are not likely to cause adverse effects in a human population, including sensitive subgroups, exposed to that concentration on an intermittent basis for one hour. Acute RELs are intended to protect the individuals who live or work in the vicinity of emissions of these substances. The focus of acute RELs is generally a one-hour exposure for *non-cancer health impacts*.

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[7] 3.6 µg/m^3 when converted at 0°C, 101.3 kPa (MfE, 2009)

[8] MfE, 2016. At section 4.5 (page 54).

[9] https://iris.epa.gov/ChemicalLanding/&substance_nmbr=276. Accessed 13 Dec 2022.

The OEHHA has set a 1-hour REL for benzene of 8 parts per billion (ppb, OEHHA, 2014).[10] This was set to protect against developmental effects.

2.6 ODOUR

Current good practice guidance states (MfE, 2016b):

> "*People have reported effects of odour that include nausea, headaches, retching, difficulty breathing, frustration, annoyance, depression, stress, tearfulness, reduced appetite, being woken in the night, … All of these contribute to a reduced quality of life for the individuals who are exposed … people can develop physiological effects from odour even when their exposure is much lower than that typically required to cause direct health effects. This effect is sometimes termed 'odour worry' and is due to effects brought on by stress or the perception that if there is a smell it must be doing physical harm. …"*

Traditionally odour has been considered an amenity issue because of the lack of any relationship with toxicological effects. However, there is a nascent body of epidemiology associating adverse odours from industrial sources with adverse health effects.

A review of more than 50 studies published between 1975 and 2013 found that residents of communities located near odour emitting facilities were found to report a higher number of health symptoms compared to residents of control communities (Government of Alberta, 2017). Reported outcomes included respiratory symptoms, nausea, congestion, eye irritation, headache, dizziness, sleep problems, and diarrhoea. These symptoms were observed in response to odours from a range of sources including petroleum refineries, livestock operations, hazardous waste sites, municipal landfills, and industrial plants.

More recently, a systematic review and meta-analysis of 30 odour studies found a statistically significant association between populations exposed to odour pollution and adverse health effects such as headache and cough/phlegm (Guadualupe-Fernandez *et al.*, 2021), noting:

> "*Meta analysis results showed that residential odour exposure was associated to an increased risk of headache and cough/phlegm, and to a borderline risk of nausea and vomiting. We found suggestive associations for the other outcomes investigated (e.g., asthma, mucus irritation, mood states) but evidence is sparse.*
>
> *The associations with headache, cough/phlegm and nausea/vomiting have a biological plausibility. Unpleasant odours are able to modulate autonomic system responses, such as vagal nerve inducing nausea or vomiting [5]. Another mechanism involves stress, consequent to environmental worry [18], and stress-related psychosomatic reactions such as chronic muscular tension, headaches, sleep disturbance. Chemicals responsible for odour may cause irritation, supporting the higher risk for cough/phlegm. Eye and nose irritation and asthma exacerbations can also be related to this odour-related irritation, but only limited evidence was found in this review.*"

[10] 27 µg/m^3 when converted at 0°C, 101.3 kPa (OEHHA, 2014)

3. METHODOLOGY

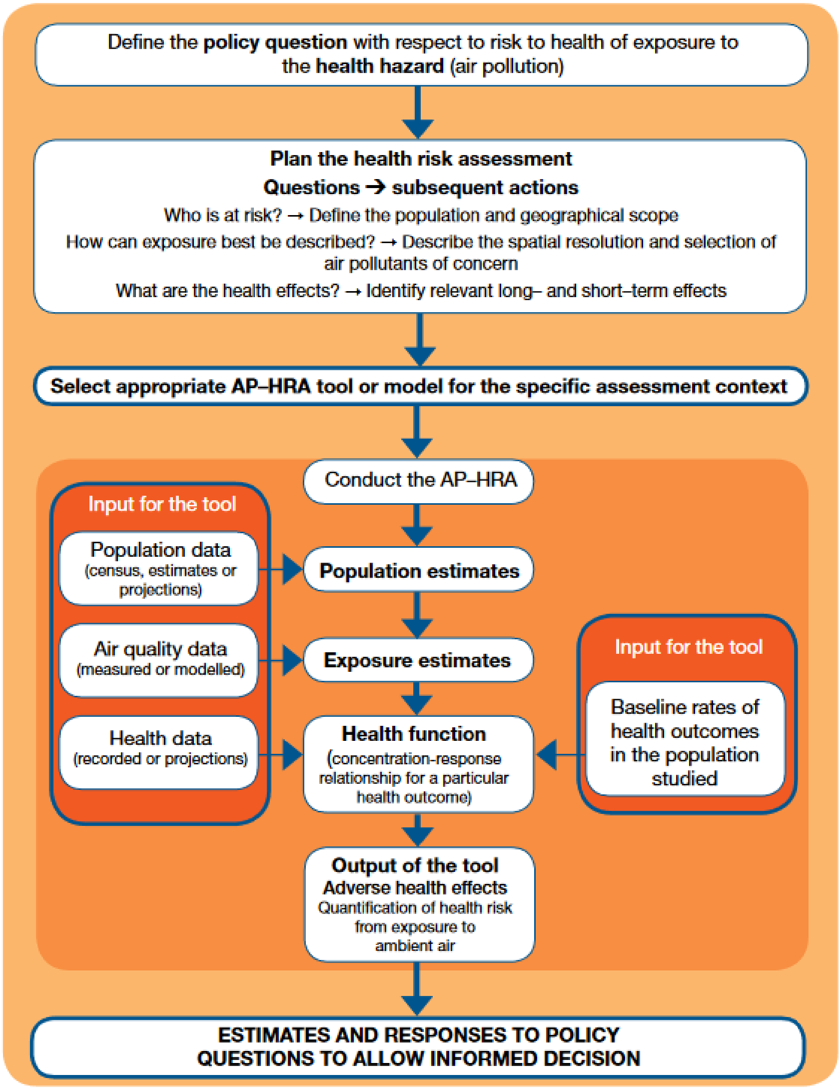
A health hazard can be defined as a source of risk to human health or wellbeing. A health risk assessment is the scientific evaluation of potential adverse health effects resulting from human exposure to a particular hazard (WHO 2016a). In the context of this document, the health hazard of interest is air pollution.

An air pollution health risk assessment (AP-HRA) aims to estimate the risks of past, current or future exposure to air pollution. An AP-HRA may be quantitative or qualitative; it assesses:

- The amount of air pollution present (i.e., pollutant concentrations);
- The amount of contact (exposure) of the selected population; and
- How harmful the pollutant concentrations are for human health.

Figure 4 provides an overview of the AP-HRA process.

FIGURE 4: Overview of an Air Pollution Health Risk Assessment process [Source: WHO 2016a]



While an AP-HRA tends to look into particular hazards and their effects on human health, a health impact assessment (HIA) takes a broader perspective. For example, when considering the impacts of industry in Mount Maunganui on public health, an HIA would look into not only the quantitative and qualitative risks associated with discharges to air, but also issues such as noise and soil and water pollution, as well as the positive economic benefits on the population from the Port of Tauranga and associated business.

This assessment is more akin to an AP-HRA as opposed to a broader HIA considering the wider impacts (i.e., both positive and negative impacts). It seeks to address the policy question:

> "*What are the health impacts of air contaminants of public health concern in the Mount Maunganui area?"*

3.1 CONTAMINANTS OF PUBLIC HEALTH CONCERN

Toi Te Ora Public Health specified the following contaminants for assessment:

- Hydrogen sulphide (H_2S)
- Nitrogen dioxide (NO_2)
- Particulates (PM_{10}, $PM_{2.5}$)
- Polycyclic aromatic hydrocarbons (PAHs)
- Sulphur dioxide (SO_2)
- Odour

Polycyclic aromatic hydrocarbons (PAHs) are a class of organic compounds composed of multiple aromatic rings. PAHs are produced by incomplete combustion of organic material, for example in ships and vehicles or domestic home heating. PAHs generally have a low degree of acute toxicity to humans following exposures of short duration. Repeated exposure to PAHs over a long(er) period of time, usually in occupational settings, has been associated with increased incidence of lung, skin, and bladder cancers. It is difficult to ascribe observed health effects in epidemiological studies to specific PAHs because most exposures are to PAH mixtures (ATSDR 2009). Any carcinogenic risk associated with PAHs will be a function of exposure intensity (concentration) and exposure duration.

We are not aware of any emissions data or ambient air quality monitoring for PAHs in the Mount Maunganui Airshed. Therefore, PAHs were not able to be included in this assessment.

We are, however, aware that some industries undertake intermittent (screening), speciated, ambient monitoring for volatile organic compounds (VOCs), including benzene, and report this to BOPRC. Benzene is a known carcinogen, and (like PAHs) it is emitted as a product of incomplete combustion from ships and vehicles. Being volatile, benzene is also emitted from bulk fuel storage and transfer. Given the presence of bulk fuel storage at the Port of Tauranga we consider benzene may be a contaminant of public health concern in the Mount Maunganui Airshed. We have therefore, included benzene in this assessment.

We also note that hydrogen fluoride (HF) is discharged to air by the fertiliser works, which is adjacent to Whareroa Marae. Unfortunately, due to monitoring instrument failure, there are insufficient data to assess current levels of hydrogen fluoride. Previous reporting by BOPRC (BOPRC 2020) has shown regular exceedances of the national daily general land use critical level for protecting ecosystems for hydrogen fluoride (2.9 µg/m^3, MfE 2002) at the Whareroa Marae monitoring site.

3.2 QUANTIFIED RISK ASSESSMENT: PM_{10}, $PM_{2.5}$ AND NO_2

Air pollution health risk assessments typically compare the estimated health effects in a population exposed to a source of concern, with the estimated health effects in the same population without the source of concern. This is known as the counterfactual approach.

The source of concern here is shipping and industrial emissions in the Mount Maunganui Airshed. Therefore, the counterfactual approach would be to compare the estimated health effects of air quality in Mount Maunganui with and without industry or shipping emissions. This is somewhat hypothetical. A slightly more realistic comparison was adopted in this assessment.

The approach in this assessment was to compare the estimated health effects in a population exposed to shipping and industrial emissions (i.e., air quality in Mount Maunganui) with the estimated health effects in a similar population without these emissions (i.e., air quality in Otūmoeti).

A valid criticism of this approach is that Otūmoetai is located close to the Mount Maunganui Airshed (around 5 km) and may similarly be affected by emissions from industrial and shipping activity. We are comfortable that this means the estimates are not conservative and likely underestimate effects.

Modelling was undertaken using the Health and Air Pollution in New Zealand (HAPINZ 3.0) exposure model (Sridhar *et al.,*2022). The HAPINZ 3.0 exposure model has New Zealand specific exposure response functions for key air pollutants developed by Hales *et al.* (2021).

3.2.1 Calculating the health burden

For each area under assessment, the health impacts are estimated as follows:

$$\boldsymbol{Health\ Effects\ (cases) = Cases\ (total)\ x\ PAF}$$

Where:

Health effects (cases) are the number of deaths, hospital admissions or restricted activity days (depending on the health outcome being assessed) due to air pollution.

Cases (total) is the total number of health cases (e.g., deaths, hospital admissions) in the area of interest (i.e., health incidence data based on analysis of Ministry of Health mortality and hospitalisations datasets by census area unit).

PAF (population attributable fraction) is the estimated percentage of total health cases that are attributable to the air pollution exposure.

The PAF is calculated using the exposure–response function (the relative increase in the health effect for every increment of air pollution (for example, 1.105 for every 10 µg/m^3 of annual average PM_{10})[11] and the exposure (the average pollution concentration in the area of interest - for example, an annual average PM_{10} concentration of 20 µg/m^3).

[11] A relative risk of 1.105 means the risk increases by 10.5% per pollution increment, in this case per 10 µg/m^3 of annual average PM_{10}.

This approach estimates the health effects that would be prevented if exposure to the pollutant (e.g., PM_{10}) was at the minimum risk level possible, recognising there being no safe threshold for most air pollutants.

3.2.2 Estimating social costs

Mortality and morbidity impacts amount to loss of life and loss of quality of life for people exposed to air pollution. These costs can be estimated to arrive at a total cost to society (the *social* cost) resulting from exposure to air pollution. Adverse effects resulting from air pollution place a significant burden on society and health systems (Kuschel et al., 2022).

The social costs of air pollution are then calculated as follows:

$$\textbf{Social Costs} = \textbf{Health Effects (cases)} \times \textbf{Cost per case}$$

In simple terms, the health effects cases estimated as per the previous formula (for example, the number of premature deaths) are combined with published health-cost data to estimate costs.

Mortality

We used a value of statistical life (VoSL) approach, whereby the estimated change in the number of premature deaths was multiplied by the current New Zealand VoSL based on transport risk (road safety), as was done in HAPINZ 3 (Kuschel et al., 2022). This assessment utilises a value of statistical life of $4,527,300 per death (MoT 2020).

The 95% confidence interval estimates of a value of statistical life were $4,050,742 - $5,242,137. All costs are in $NZD 2019.

Morbidity

The social cost of hospital admissions were estimated from the financial costs per hospitalisation (based on the average number of bed nights for each type of disease), productivity losses from time off work or school for those hospitalised, family and friends, and recovery costs after discharge from hospital including any long-term disability (quality of life). Full details and assumptions for estimates are provided in Kuschel et al., 2022 and are not repeated here.

The total costs per case with low and high-end estimates were:

- $36,666 ($10,809, $473,294) for cardiac admissions; and
- $31,748 ($5,891, $462,770) for respiratory admissions.

The social cost of restricted activity days (RADs) was $89 per case, estimated based on lost average income per day. The low and high-end cost estimates for sensitivity analysis were $49 and $125 respectively.

Childhood asthma costs included those resulting from general practitioner visits, medication ($128 per case) and hospitalisations ($1,822 per case). The low and high-end cost estimates for sensitivity analysis were arbitrarily increased or decreased by 50%. All costs are in $NZD 2019.

3.2.3 Base year

Council commenced monitoring for PM_{10} in 2014 in Otūmoetai. To undertake this investigation it was initially proposed to use an extended time average (e.g., a ten-year period ending 2021) for the period of assessment. This would increase the stability of the key exposure metric, ambient air pollutant concentrations. It may, however, underestimate the potential population exposed (which has increased during this period) and overestimate health impacts (some key incidence statistics have decreased). However, there are insufficient data for the Mount Maunganui Airshed, where monitoring of PM_{10} and $PM_{2.5}$ only commenced at the end of 2018, to make this feasible. The 2019 – 2021 period was used as the base period for assessment.

Council commenced monitoring for total suspended particulate (**TSP**) at Totara Street in 2015, with a full year of data available from 2016. Although TSP will include some larger size fractions (up to 100 µm), it is generally taken to represent particulate matter less than 30 µm (i.e., **PM_{30}**). PM_{10} is, therefore, a component of TSP. **Figure 5** presents annual average PM_{10} concentrations measured in (residential) Otūmoetai (2014 – 2021) for comparison with TSP and PM_{10} measured in the (industrial parts of) Mount Maunganui Airshed (2019 – 2021).

FIGURE 5: Annual total suspended particulate (TSP) and PM_{10} measured in Otūmoetai and select Mount Maunganui industrial locations [Source: BOPRC]

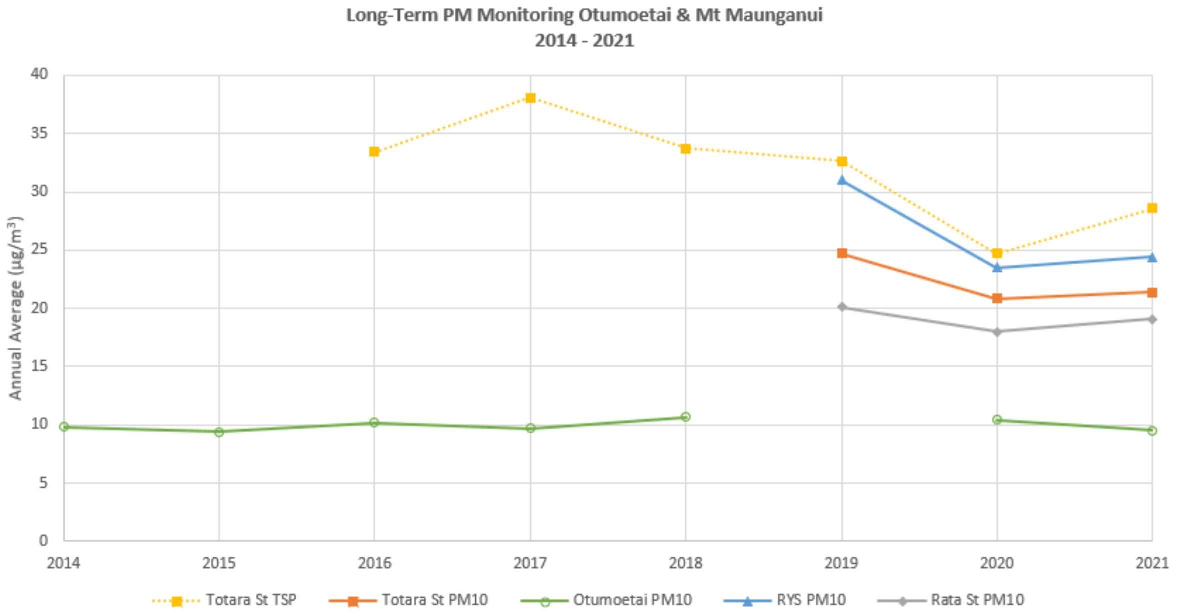


Figure 5 shows there were reductions in annual PM concentrations measured at all industrial locations[12] in the Mount Maunganui Airshed in 2020 and 2021 compared with 2019. The air quality expert consensus view[13] is that these reductions were due to a combination of improved emissions control by the Port and reductions in shipping emissions required under international law (specifically Annex VI of MARPOL).[14] However, these reductions may also reflect changes due to the COVID-19 pandemic which, through stay-at-home restrictions, may have reduced long-term concentrations of key pollutants in and around the Mount Maunganui Airshed.

Irrespective, using data averaged over the three years ending 2021 may significantly underestimate public exposure in previous and future years. We have therefore, selected the year 2019 as the base year for assessment purposes. This is the most recent year for which there is comprehensive ambient air quality monitoring data, but which excludes step changes

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[12] Specifically, reductions in annual average PM_{10} of 11% (Rata Street), 24% (Rail Yard South) and 15% (Totara Street).

[13] Joint Witness Statement of Air Quality Experts Dr Emily Wilton, Mx Lou Wickham, Ms Jenny Simpson, Mr Paul Baynham, Mr Peter Stacey & Mr Andrew Curtis dated 27 May 2021 for the Environment Court ENV-2019-AKL-000065 and ENV-2019-AKL-000073. At [Q15].

[14] In force from 1 January 2020.

in emissions due to mitigation, regulatory changes and/or any changes due to activity restrictions from COVID-19. Where available, population and health data have been averaged over 2018-2019.

3.2.4 Exposure response functions

The mortality and morbidity dose response functions for $PM_{2.5}$ and NO_2 are from Hales *et al.,* 2021 which was a New Zealand (national) cohort study.[15] This means that these dose response functions provide a robust estimate of health effects of exposure to air pollution across New Zealand using $PM_{2.5}$ and NO_2, together, as indicators of exposure to air pollution. These were (all Hales *et al.*, 2021 except where noted):

$PM_{2.5}$

- Premature mortality risk (per 10 µg/m^3) for all adults (30+years) associated with annual $PM_{2.5}$ exposure 1.105 (95% CI 1.065 – 1.145)
- Cardiovascular hospitalisation risk (per 10 µg/m^3) for all ages associated with annual $PM_{2.5}$ exposure 1.115 (95% CI 1.084 – 1.146)
- Respiratory hospitalisation risk (per 10 µg/m^3) for all ages associated with annual $PM_{2.5}$ exposure 1.070 (95% CI 1.021 – 1.122)
- Restricted activity days risk (per 10 µg/m^3) for all ages associated with annual $PM_{2.5}$ exposure 0.9 (lower/upper bounds 0.5 – 1.7, Ostro, 1987)

NO_2

- Premature mortality risk (per 10 µg/m^3) for all adults (30+years) associated with annual NO_2 exposure 1.097 (95% CI 1.074 – 1.120)
- Cardiovascular hospitalisation risk (per 10 µg/m^3) for all ages associated with annual NO_2 exposure 1.047 (95% CI 1.031 – 1.064)
- Respiratory hospitalisation risk (per 10 µg/m^3) for all ages associated with annual NO_2 exposure 1.130 (95% CI 1.102 – 1.159)
- Asthma prevalence risk (per 4 µg/m^3) for 0 – 18-year-olds associated with annual NO_2 exposure 1.05 (95% CI 1.02 – 1.07, Khreis *et al*., 2017)[16]

The premature mortality dose response function for PM_{10} is also from Hales *et al.,* 2021. This means that the dose response function provides a robust estimate of health effects of exposure to air pollution across New Zealand using PM_{10} as an indicator of exposure to air pollution. This was:

- Premature mortality risk (per 10 µg/m^3) for all adults (30+years) associated with annual PM_{10} exposure 1.111 (95% CI 1.089 – 1.133)

NB: The exposure response function for PM_{10} is from a single pollutant model and is separate to the exposure response functions developed by Hales *et al.,*2021 for $PM_{2.5}$ and NO_2 from a two-pollutant model. **This means that the estimate of effects associated with PM_{10} is not**

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[15] With two additions; restricted activity days (Ostro, 1987) and prevalence of asthma (Khreis *et al*., 2017)

[16] Toi Te Ora requested an assessment of additional presentations for health care, which was not estimated by Hales et al., 2021. However, asthma prevalence in children (under 18-year-olds) associated with long-term NO_2 was assessed and is included here.

additive to the estimate of effects associated with $PM_{2.5}$ and NO_2, rather it is a separate estimate.

The specific mix and composition of air pollutants in and around Mount Maunganui is likely to be quite different to typical urban air pollution in New Zealand. This is because typical urban air pollution in New Zealand is influenced by traffic (all year round) and domestic solid fuel burning during winter (only). In Mount Maunganui, however, long-term levels of:

- PM_{10} are likely to be dominated by emissions from the Port and industrial activities.
- $PM_{2.5}$ and NO_2 are likely to be dominated by emissions from ships and transport, with some influence from industry.

This means that the selected exposure response functions may not accurately estimate the effects of air pollution in and around the Mount Maunganui areas.

It is uncertain whether a Mount Maunganui dose response function would increase or decrease the estimates. However, given the relatively small population exposed (<50,000), it is not feasible to develop a specific dose response function for these pollutants in this locale, and the New Zealand specific functions are the best available estimates.

3.2.5 Population assessed

Figure 1 presents the NZ Stats 2013 census area units[17] (orange outline) assessed and the Mount Maunganui Airshed (red outline).[18] We selected the five census area units in and around Mount Maunganui (light blue shaded areas) that include the Mount Maunganui Airshed for assessment. These are:

- Mount Maunganui North
- Omanu
- Tauranga City-Marinas
- Arataki
- Sulphur Point

We also assessed the following four (orange NZ Stats 2013) census area units as representative of the Otūmoetai residential area for comparison:

- Matua
- Otūmoetai North
- Otūmoetai South
- Bellevue

The HAPINZ national exposure model has population statistics by census area unit for a base year of 2016. This was updated using StatsNZ usual resident population data averaged for the period 2018 – 2019 (Metcalfe and Kuschel, pending). The usual resident population does not include the working population present in Mount Maunganui each day of the working week.

[17] Health statistics are disaggregated to 2013 census area units and are not available by 2018 (census) statistical area units.

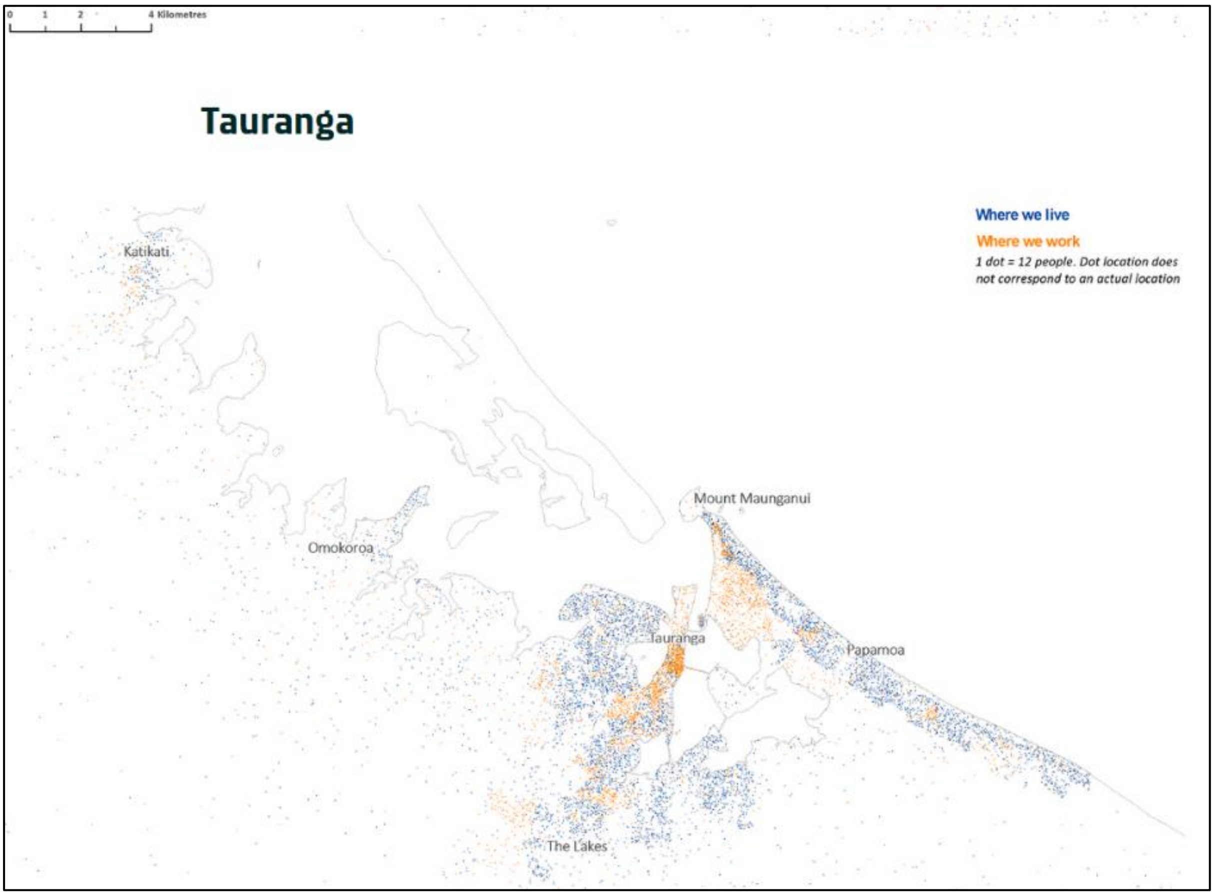
[18] Approximate only for illustrative purposes

2018 census data suggests this is around an additional 10,000 people[19] which may be compared with the usual resident population of the Mount Maunganui and Otūmoetai areas under assessment (around 35,000 in total) - refer **Figure 6**.

Whilst the working population is only present for around 40 hours per week, they are likely to be exposed to higher daily and annual concentrations of some pollutants than residents as they are physically closer to the primary sources (transport and industry). However, some of the working population may also be wearing personal protective equipment at least some of the time.

The exclusion of the exposed working population is likely to underestimate potential exposure and therefore, likely underestimate associated effects.

FIGURE 6: Where we live versus where we work (using 2018 census data) (Source NZ Stats (2020))[20]



[19] 2018 Census employed statistical areas (SA) and did not employ census area units (CAU) so a direct comparison cannot be made. Estimate of around 10,000 comprises SA2 (Mount Maunganui Central), SA1 – 7013954 and SA1 – 7013955 main means of travel to work (2)(4)(7), by workplace address (12) for the employed census usually resident population count aged 15 years and over (5)

[20] https://storymaps.arcgis.com/stories/6f8b5f981ad34f11bedaf1725e9cb698

3.2.6 Health statistics

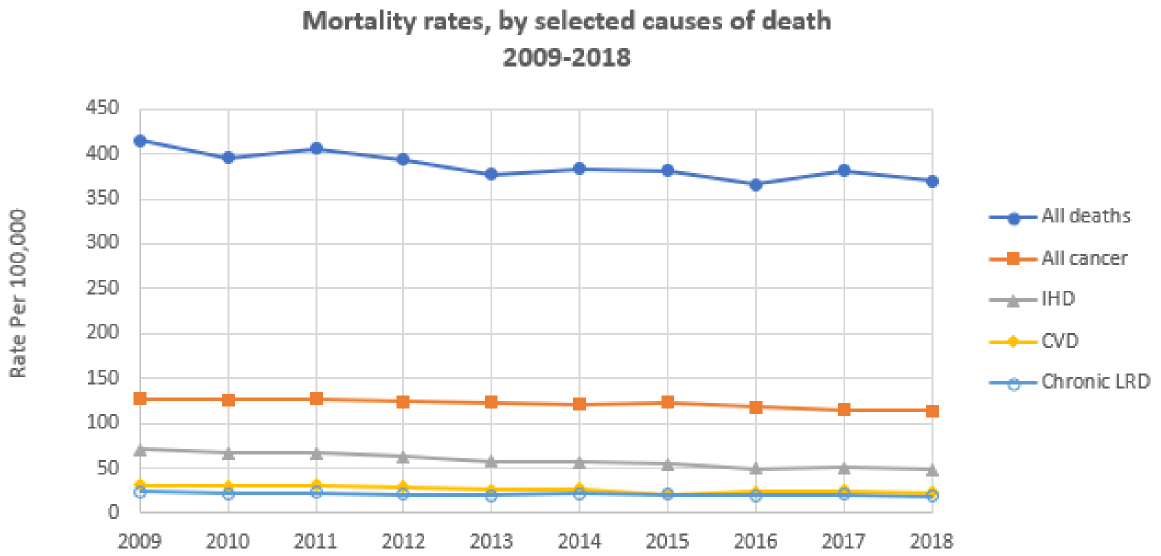
Health statistics by census area unit were provided in HAPINZ 3 and sourced, in turn, from the New Zealand Mortality Collection data (MoH 2021a) and the National Minimum Dataset of publicly funded hospital discharges (MoH 2021b).

The health incidence baseline data in the national health effects model is for a base year 2016 (Sridhar *et al.,*2022).[21] We used updated mortality and morbidity data for the two-year period 2018 – 2019 (Metcalfe and Kuschel, pending). It should be noted that our assessment focusses (only) on the relevant census area units with this updated data.

Historical mortality statistics (MoH, 2021c) reveal a slow but steady decline in mortality rates as shown in **Figure 7**. This means that using 2019 as a base year is not likely to overestimate effects.

It should be noted that the impacts of COVID-19 are excluded from this assessment, not least because mortality statistics for 2020 and 2021 will not be available until 2023 and 2024 respectively.

FIGURE 7: National mortality rates 2009-2018 [Source: New Zealand Mortality Collection Records 1996-2018]



3.3 QUALIFIED RISK ASSESSMENT: SO_2, H_2S, BENZENE AND ODOUR

The approach taken was to review the available ambient air quality monitoring data for comparison with health-based standards and guidelines and undertake a qualified assessment considering:

- identified health effects of each pollutant;
- likely emission sources; and
- potentially exposed populations.

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[21] NB: Health incidence data are specific to the census area units under assessment (refer Figure 1)

4. QUANTIFIED CHRONIC EXPOSURE: PM_{10}, $PM_{2.5}$ & NO_2 IN MOUNT MAUNGANGUI

4.1 PM_{10}

Otūmoetai

The monitoring station is located at Otūmoetai Primary School which is located in the Otūmoetai South census area unit. The area is residential, and concentrations measured at this location should be representative of the adjacent census area units. This value was therefore adopted as representative of Otūmoetai and surrounding residential suburbs (Otūmoetai South, Otūmoetai North, Bellevue & Matua census area units) for the base year 2019.

Otūmoetai has no annual average PM_{10} data for the year 2019 due to instrument failure. However, annual PM_{10} concentrations measured at this location have been stable, averaging 10 µg/m^3 for the eight years ending 2021 (max 11, min 9, std dev 0.5).

An annual average concentration of 10 µg/m^3 was assumed for PM_{10} for the year 2019 for all Otūmoetai census area units.

Mount Maunganui

Figure 8 shows the BOPRC PM_{10} monitoring site locations in the Mount Maunganui Airshed.

Ambient air quality monitoring is undertaken in three of the five census area units under assessment, notably Mount Maunganui North (Rata Street), Tauranga City Marinas (Tauranga Bridge Marina) and Sulphur Point. We used the PM_{10} mean concentration from 2019 measured at these monitoring site locations as the key metric for exposure in these census area units.

For the two remaining census areas units, Omanu and Arataki, it is important to consider spatial variation. The Totara Street monitoring site is in the middle of the industrial area and measurements at this location may not be representative of long-term concentrations in other parts of Omanu, or Arataki.

Figure 8 includes a wind rose for the year 2019, overlaid on the monitoring locations in the Mount Maunganui Airshed. The wind rose shows the predominant wind directions are (from the) south-west quadrant. This means that, over the year, emissions from the industrial and port activities will be directed towards to the north-east more than other locations.

This directional trend is evident when comparing annual PM_{10} concentrations measured on the south-west boundary of the Mount Maunganui Airshed (Sulphur Point, Bridge Marina and Whareroa Marae) with those measured inside the airshed and to the north (Rata Street, Rail Yard South and Totara Street refer **Table 5**).[22] Annual concentrations are ~60% higher, on

[22] Long-term PM_{10} measured at De Havilland Way is dominated by adjacent industrial sources and excluded from this consideration.

average, inside and to the north of the Mount Maunganui Airshed compared with monitoring locations on the predominantly upwind, south-west boundary.

FIGURE 8: 2019 PM_{10} monitoring locations and annual PM_{10} concentrations measured in the Mount Maunganui Airshed [Source: BOPRC. Insert 2019 wind rose from Whareroa Marae (refer Fig A10)]

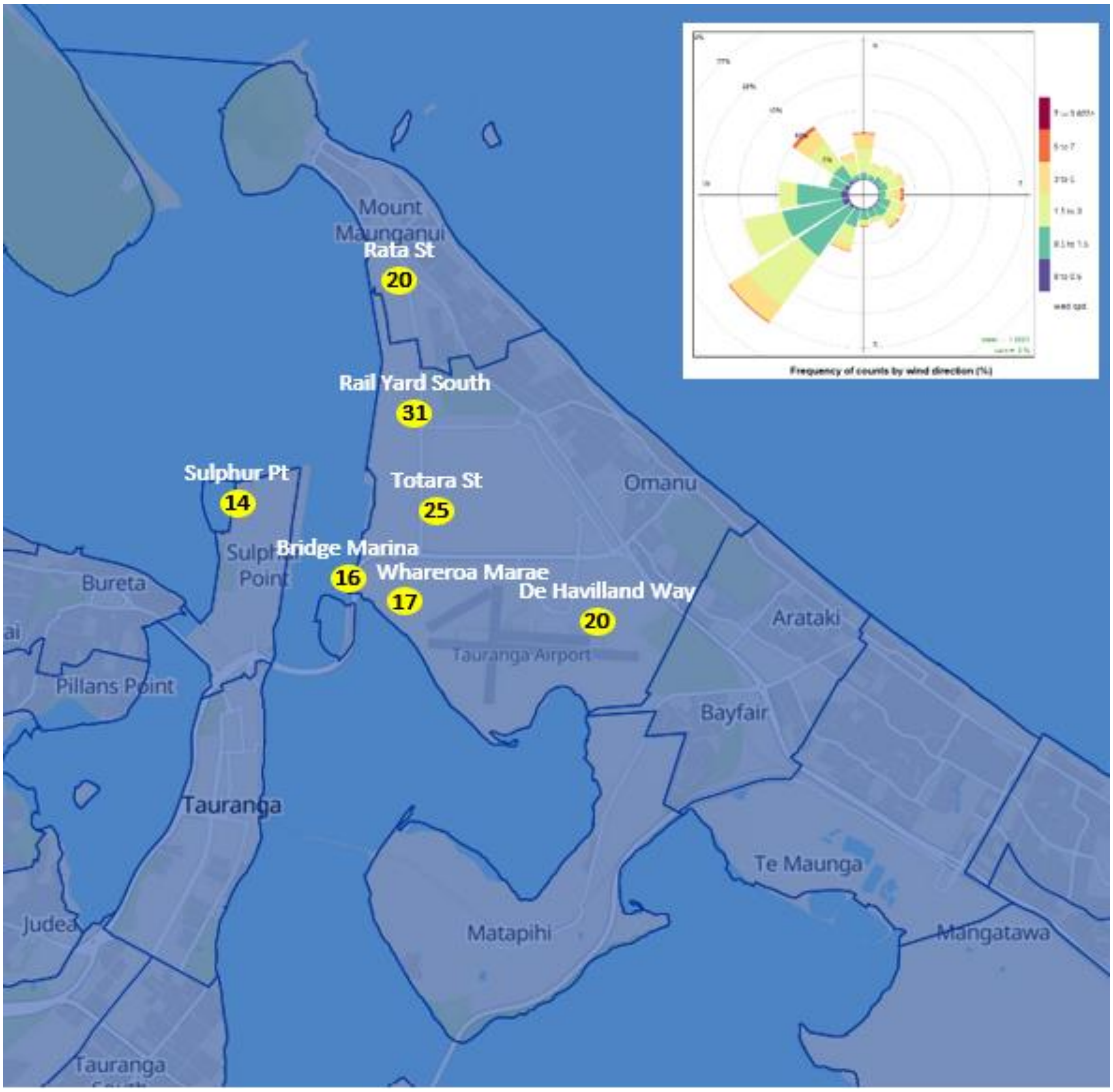

TABLE 5: Comparison of mean 2019 PM_{10} concentrations at Mount Maunganui monitoring locations

South-West Boundary Monitoring Site	2019 PM_{10} (µg/m^3)	Northern / Inside Airshed Monitoring Site	2019 PM_{10} (µg/m^3)
Sulphur Point	14	Rata Street	20
Tauranga Bridge Marina	16	Rail Yard South	31
Whareroa Marae	17	Totara Street	25
		De Havilland Way	20
Average:	**15**	**Average:**	**24**
Difference: 8 (55%)			

It is also notable, however, that mean 2019 PM_{10} concentrations measured on the south-west boundary of the Mount Maunganui Airshed (Sulphur Point, Bridge Marina and Whareroa Marae average 15 µg/m^3) are elevated in comparison with the residential suburb of Otūmoetai (10 µg/m^3).

The Rata Street monitoring location was selected as indicative of long-term PM_{10} levels in Omanu & Arataki on the basis that:

- Mean 2019 concentrations measured at Totara Street and Rail Yard South were impacted by adjacent industrial & port activities and are too high to be representative of Omanu & Arataki;
- The Rata Street monitoring site is in a residential location that is often downwind of emissions from the Port activities;
- The De Havilland Way monitoring site is adjacent to residential activity with the same mean 2019 PM_{10} value (20 µg/m^3) as Rata Street;
- There will necessarily be some attenuation with distance, although how much is uncertain; and
- Whilst the Rata Street location may underestimate long-term PM_{10} levels in Omanu & Arataki, this serves to ensure that the estimate of associated health effects is not an overestimate.

Table 6 presents mean PM_{10} concentrations assigned to each census area unit for assessment purposes.

TABLE 6: Mean 2019 PM_{10} concentrations assigned to each census area unit

Census Area Unit	2019 mean PM_{10} (µg/m^3)	Reference
Otūmoetai South	10	Otūmoetai monitoring station
Otūmoetai North	10	Otūmoetai monitoring station
Bellevue	10	Otūmoetai monitoring station
Matua	10	Otūmoetai monitoring station
Mount Maunganui North	20	Rata Street monitoring station
Omanu	20	Rata Street monitoring station
Tauranga City-Marinas	16	Tauranga Bridge Marina monitoring station
Arataki	20	Rata Street monitoring station
Sulphur Point	14	Sulphur Point monitoring station

4.2 $PM_{2.5}$

Otūmoetai

There is no $PM_{2.5}$ monitoring station in Otūmoetai. $PM_{2.5}$ is a component of PM_{10} and the two size fractions will correlate with each other. Kuschel *et al.,*(2022) assigned a ratio of 0.51 for

$PM_{2.5}$:PM_{10} in Otūmoetai South based on an empirical relationship with biomass. We similarly used this ratio to estimate mean 2019 $PM_{2.5}$ concentrations from available PM_{10} data.

A $PM_{2.5}$ annual average concentration of 5.3 µg/m^3 was estimated for the year 2019 for all Otūmoetai census area units.

Mount Maunganui

There is only one $PM_{2.5}$ monitoring station in the Mount Maunganui area, located at Totara Street in the Mount Maunganui Airshed.

$PM_{2.5}$ is a component of PM_{10} and the two size fractions will correlate with each other (noting that this correlation differs between industrial & residential settings). The ratio of (annual) $PM_{2.5}$ to PM_{10} measured at Totara Street in 2019 was 0.32. This is similar to $PM_{2.5}$ to PM_{10} ratios measured in other industrial settings (Sridhar *et al.,*2022).

The mean 2019 Totara Street $PM_{2.5}$:PM_{10} ratio was used to estimate mean 2019 $PM_{2.5}$ concentrations for all Mount Maunganui census area units based on their previously estimated PM_{10} data. This may underestimate $PM_{2.5}$ in these locations, as $PM_{2.5}$ in residential areas is typically higher (fraction of PM_{10}). However, it serves to ensure the estimate does not overestimate concentrations of $PM_{2.5}$ and associated health effects.

Table 7 presents mean 2019 $PM_{2.5}$ concentrations assigned to each census area unit for assessment purposes.

TABLE 7: Mean 2019 $PM_{2.5}$ concentrations assigned to each census area unit

Census Area Unit	2019 mean $PM_{2.5}$ (µg/m^3)	Reference
Otūmoetai South	5.3	2019 PM_{10} Otūmoetai, ratio 0.51 (Sridhar et al., 2022)
Otūmoetai North	5.3	2019 PM_{10} Otūmoetai, ratio 0.51 (Sridhar et al., 2022)
Bellevue	5.3	2019 PM_{10} Otūmoetai, ratio 0.51 (Sridhar et al., 2022)
Matua	5.3	2019 PM_{10} Otūmoetai, ratio 0.51 (Sridhar et al., 2022)
Mount Maunganui North	6.4	2019 PM_{10} Rata St, ratio 0.32 (Totara St, 2019)
Omanu	6.4	2019 PM_{10} Rata St, ratio 0.32 (Totara St, 2019)
Tauranga City-Marinas	5.1	2019 PM_{10} Bridge Marina, ratio 0.32 (Totara St, 2019)
Arataki	6.4	2019 PM_{10} Rata St, ratio 0.32 (Totara St, 2019)
Sulphur Point	4.5	2019 PM_{10} Sulphur Point, ratio 0.32 (Totara St, 2019)

4.3 NO_2

Concentrations assigned to each census area unit in the HAPINZ 3 model for a base year 2016 were updated to 2019 by applying a scalar of 0.9354 to all locations as recommended in Kuschel *et al.,*2022.

NB: This will not assess peak NO_2 concentrations likely to be experienced by residents living (and working) close to roads and motorways. Roadside monitoring by Waka Kotahi in the

Mount Maunganui Airshed[23] indicates significantly higher annual average levels in 2018-2019 (34 µg/m^3) to that assigned for the Omanu census area unit (6 µg/m^3).

Table 8 presents mean 2019 NO_2 concentrations assigned to each census area unit for assessment purposes.

TABLE 8: Mean 2019 NO_2 concentrations assigned to each census area unit

Census Area Unit	2019 mean NO_2 (µg/m^3)
Otūmoetai South	6.0
Otūmoetai North	7.9
Bellevue	6.0
Matua	5.1
Mount Maunganui North	7.8
Omanu	6.2
Tauranga City-Marinas*	12
Arataki	8.1
Sulphur Point	12

* Tauranga City-Marinas not assigned NO_2 value in HAPINZ 3 – value from Sulphur Point assumed

[23] HAM008 Maunganui Rd / Golf Rd12

5. QUANTIFIED HEALTH IMPACTS: PM_{10}, $PM_{2.5}$ & NO_2 IN MOUNT MAUNGANGUI

5.1 $PM_{2.5}$ AND NO_2

Table 9 presents estimated premature mortality and morbidity associated with long-term exposure to $PM_{2.5}$ and NO_2 in Mount Maunganui and Otūmoetai for a base year of 2019.

TABLE 9: Estimated premature mortality and morbidity associated with annual $PM_{2.5}$ and NO_2

Health Effect	Mount Maunganui (5xCAU)	Otūmoetai (4xCAU)	Difference (∆)
Population (2019)	16,975	17,835	860
	Cases due to $PM_{2.5}$		
Premature death (adults 30 years+)	9	7	2
Cardiovascular hospitalisations (all ages)	16	13	3
Respiratory hospitalisations (all ages)	11	9	2
Restricted activity days (all ages)	9,764	8,507	1,256
Cost (2019 $NZD)	$43.2 M	$33.6 M	$9.6 M
	Cases due to NO_2		
Premature death (adults 30 years+)	10	7	3
Cardiovascular hospitalisations (all ages)	8	7	1
Respiratory hospitalisations (all ages)	23	19	4
Asthma prevalence (0-18 years)	40	38	2
Cost (2019 $NZD)	$46.4 M	$34.0 M	$12.4 M
	Cases due to $PM_{2.5}$ and NO_2		
Premature death (adults 30 years+)	19	14	5
95% Confidence intervals	(14, 25)	(10, 19)	(3, 6)
Cardiovascular hospitalisations (all ages)	24	20	4
Respiratory hospitalisations (all ages)	34	28	6
Restricted activity days (all ages) ($PM_{2.5}$)	9,764	8,507	1,256
Asthma prevalence (0-18 years) (NO_2)	40	38	2
Cost (2019 $NZD)	$90 M	$68 M	$22 M

The population in the areas assessed are very similar (~17,000), with Otūmoetai having slightly more (860) people. Thus, the difference between estimates of health impacts for each area is assumed to be attributable to the difference in exposure to air pollution.

The modelling estimates that the Mount Maunganui area has around five premature deaths each year associated with increased exposure to long-term concentrations of $PM_{2.5}$ and NO_2 when compared with Otūmoetai. For context, the total mortality from all non-external causes in Mount Maunganui for the year 2019 was 145 so this estimate represents around 3% of deaths in that year.

5.2 PM_{10}

Table 10 presents estimated premature mortality associated with long-term exposure to PM_{10} in Mount Maunganui and Otūmoetai for a base year of 2019. The population in the areas assessed are very similar (~17,000), with Otūmoetai having slightly more (860) people. Thus, the difference between estimates of health impacts for each area can be assumed to be primarily attributable to the difference in exposure to air pollution.[24]

The modelling estimates that the Mount Maunganui area has 13 premature deaths (95% confidence interval 11 to 15) each year associated with increased exposure to long-term concentrations of PM_{10} when compared with Otūmoetai. For context, the total mortality from all non-external causes[25] in Mount Maunganui for the year 2019 was 145 so this estimate represents around 9% of deaths in that year.

TABLE 10: Estimated premature mortality associated with annual PM_{10}

Health Effect	Mount Maunganui (5xCAU)	Otūmoetai (4xCAU)	Difference (Δ)
Population (2019)	16,975	17,835	860
	Cases due to PM_{10}		
Premature death (adults 30 yrs+)	26	13	13
95% Confidence intervals	(22, 31)	(11, 16)	(11,15)
Cost (2019 $NZD)	$119 M	$61 M	$59 M

5.3 MEETING THE WHO AQG 2021 GUIDELINES

Toi Te Ora Public Health requested assessment of the health impacts avoided if all areas met the WHO 2021 global air quality guidelines. The hypothetical scenario of all census area units were modelled, including Otūmoetai, meeting an annual $PM_{2.5}$ guideline of 5 $\mu g/m^3$ and an annual NO_2 guideline of 10 $\mu g/m^3$. **Table 11** presents the health impacts avoided if the WHO guidelines were met in all areas (i.e., both Otūmoetai and Mount Maunganui).

All areas except Tauranga Bridge Marina and Sulphur Point, both of which have very low usually resident populations, already meet the WHO 2021 global air quality guideline for NO_2. Consequently, the improvements outlined in **Table 11** would be entirely due to (hypothetical) reductions in annual $PM_{2.5}$.

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[24] Assuming base health incidence rates in each area are similar (mean 2019 all-cause mortality was 8% higher in Mount Maunganui)

[25] i.e., deaths excluding accidents and violence

TABLE 11: Estimated avoided health impacts and social costs if WHO guidelines met in Otūmoetai and Mount Maunganui versus base case

Health Effect	2019 Air Quality	Meet WHO AQG	Δ
Premature death (adults 30 years +)	34	31	-2
Cardiovascular hospitalisations (all ages)	43	39	-4
Respiratory hospitalisations (all ages)	63	60	-3
Restricted activity days (all ages)	18,271	15,663	-2,608
Asthma Prevalence (0-18 years)	78	78	0
Cost (2019 $NZD)	$157 M	$146 M	-$11 M

5.4 SENSITIVITY TESTING

The HAPINZ 3 Health Effects Model includes 95% confidence intervals for the (New Zealand specific) exposure response functions and value of statistical life as well as low and high-end social cost estimates. Using these ranges, we tested the sensitivity of the model estimates for $PM_{2.5}$ and NO_2.

Table 12 summarises the results of the sensitivity testing in terms of social costs for the modelling of effects associated with $PM_{2.5}$ and NO_2.

NB: The base case under consideration is the difference (Δ) in estimates between Mount Maunganui and Otūmoetai as this the fraction that can be attributed to anthropogenic emissions from industrial and port activities ($PM_{2.5}$ and NO_2), and transport (NO_2).

Using the high estimates for the social cost values would have the greatest impact (+34%) on total anthropogenic social costs.

TABLE 12: Sensitivity of the HAPINZ 3 social cost estimates for $PM_{2.5}$ and NO_2 to different parameters versus the base case (in 2019 NZD)

Scenario	Social Cost (2019 $million)			
	Δ Mortality	Δ Morbidity	Δ Total	vs base case
Base case				
Default values	21.5	0.4	22	-
Exposure response function values				
Lower bound 95% CI	15.5	0.3	16	-28%
Upper bound 95% CI	27.1	0.6	28	+26%
Social cost values				
Lower estimate	19.3	0.1	19	-12%
High estimate	24.9	4.5	29	+34%

5.4.1 Effect of exposure response function values

If the **lower bounds of the confidence intervals** for the exposure-response functions were used, then the impacts would be 28% less than those in the base case.

If the **higher bounds of the confidence intervals** for the exposure-response functions were used, then the impacts would be 26% higher than those predicted using the base case.

Overall effect: Within these two bounds, the social cost of anthropogenic air pollution health impacts are between $16 million and $28 million (relative to the base case of $22 million) in Mount Maunganui as compared with Otūmoetai.

Note: The number of premature deaths for adults due to anthropogenic air pollution ($PM_{2.5}$ and NO_2) in Mount Maunganui as compared with Otūmoetai would be between 3 and 6 (relative to the base case of 5 deaths).

5.4.2 Effect of social cost values

If the **low estimates** for the social cost values were used, then the impacts would be 12% less than those in the base case.

If the **high estimates** for the social cost values were used, then the impacts would be 34% more than those in the base case.

Overall effect: Within these two bounds, anthropogenic air pollution health impacts in Mount Maunganui as compared with Otūmoetai are between $19 million and $29 million (relative to the base case of $22 million).

Note: The increase in the high-cost estimate scenario is largely due to factoring in loss of life quality from prolonged illness and suffering which is not included in the base case. Many overseas jurisdictions use a specific environmental value of statistical life which is considerably higher than a transport (road safety) risk value to adequately account for these loss-of-life quality costs.

5.5 UNCERTAINTY & CONFIDENCE ASSESSMENT

The key sources of uncertainty in this assessment of air pollution health impacts are described as follows.

Air pollutants exist as a complex mixture

There is a considerable body of evidence from epidemiological studies confirming the adverse health effects associated with exposure to air pollution. Notably, WHO determined all PM-outcome associations were deemed causal, or likely to be causal (WHO, 2021). However, the adverse effects attributed to nitrogen dioxide may actually be attributable to other pollutants in the mixture.

Baseline disease burden

Data on the number of deaths and cases of disease can be uncertain, particularly if data from a number of sources are combined or if projections of future cases are made. In this study, health incidence statistics in the HAPINZ 3.0 model for a base year 2016 were updated with Ministry of Health statistics for a base year 2019 (Metcalfe & Kuschel, pending).

We have a high degree of confidence in the data.

Pollution exposure level

This is a potentially significant limitation of the modelling. The approach in this study was to estimate long-term exposure based on:

- Available measured pollutant concentrations at representative monitoring locations for PM_{10};
- An assigned ratio (for $PM_{2.5}$:PM_{10}) based on an empirical relationship with biomass (Kuschel *et al.,* 2022) to establish $PM_{2.5}$ in Otūmoetai;
- A measured ratio (for $PM_{2.5}$:PM_{10}) to establish $PM_{2.5}$ in Mount Maunganui;
- Spatial estimates for NO_2 in the national model updated for base year 2019 by applying a scalar as recommended in Kuschel *et al.,*2022.

The general approach in estimating long-term levels of key pollutants was one of caution to avoid overstating potential impacts. This means the estimates are not conservative (i.e., likely underestimates).

The base year of 2019 pre-dates potential impacts of the pandemic on ambient air quality pollutants in the Mount Maunganui and Otūmoetai areas.

We estimate the exposure assessment is within +/-25%.

The exposure-response function

Exposure response functions are derived from epidemiological studies, in which assumptions made in the analysis inevitably introduce some uncertainty into the results. The HAPINZ 3.0 model utilises New Zealand specific exposure-response functions for NO_2 and $PM_{2.5}$. This means that the uncertainty in the exposure assessment is captured (to some extent) in the uncertainty of the exposure-response functions (and represented in the quoted 95% confidence intervals).

The counterfactual level of air pollution

The counterfactual level of air pollution is the baseline or reference exposure against which the health impacts of air pollution are calculated (e.g., having no air pollution). This is not a source of uncertainty in itself.

The modelling was comparative, i.e., only the difference between long-term exposure in Mount Maunganui and Otūmoetai was assessed. As such the modelling estimates are not sensitive to the counterfactual.

Confidence Assessment

Hales et al., assessed the risk of bias in accordance with WHO, 2020 and concluded it was low for all factors except potential confounding due to the inability to control for BMI due to a lack data in NZ health incidence statistics. This increased the overall risk of bias to low-to-moderate.

The HAPINZ 3.0 model has been internationally peer reviewed and warrants a high degree of confidence for the base case 2016 (Kuschel et al., 2022).

The HAPINZ 3.0 model has been updated with 2018-2019 air quality, population and health incidence data which increases its representativeness. Significantly higher uncertainties are associated with the assumptions used to estimate pollution exposure. Cumulatively, the overall uncertainty associated with the estimates is around +/-30%.

Overall, we have a moderate degree of confidence in the model estimates.

5.6 MODEL LIMITATIONS

It should be noted that the quantified assessment relies on a published model (HAPINZ 3.0) to assess the specified health outcomes for chronic exposure to $PM_{2.5}$, NO_2 or PM_{10} only. Other potential adverse health outcomes associated with exposure to chronic levels of other pollutants that may be present in Mount Maunganui are not, and cannot be, considered. Such effects could include, for example, reproductive fertility, developmental toxicity and cancer risk (e.g., known benzene specific cancers).

6. QUALITATIVE ASSESSMENT: SO_2, H_2S, BENZENE & ODOUR IN MOUNT MAUNGANGUI

The above quantified assessment of PM_{10}, $PM_{2.5}$ and NO_2 using internationally peer reviewed, quantified risk ratios has inevitably focussed attention on PM and NO_2. This provides a good indication of overall health impacts due to exposure to air pollution from industry, motor vehicles and domestic fires in Mount Maunganui as compared with Otūmoetai.

However, residents of Mount Maunganui are also exposed to elevated levels of other contaminants from location-specific industries. For example, ambient concentrations of SO_2 are known to be elevated in some locations due to emissions from shipping and manufacturing. Impacts from these pollutants are not addressed in the above quantified assessment. This section addresses other pollutants known or suspected to be elevated in and around Mount Maunganui.

It is important to note that total ship visits to the Port of Tauranga dropped by 20% in 2020 and 2021, compared with 2018 and 2019, due to the global COVID-19 pandemic.[26] Overall industrial activity and associated vehicle movements in the Mount Maunganui Airshed were also reduced during intermittent lockdown periods during this time. The scale and duration of reduced activity, and any associated reduction in emissions, is not known.

6.1 SULPHUR DIOXIDE

6.1.1 Air quality exposure to SO2

Figure 8 shows the BOPRC SO_2 monitoring site locations in the Mount Maunganui Airshed.

Appendix A (Tables A1-A9) presents summary data for 10-minute, hourly and daily SO_2 monitoring in the Mount Maunganui Airshed for the years 2019 – 2021 respectively for comparison with health-based standards and guidelines.

Also in **Appendix A** are:

- Time series ambient air quality data are presented graphically in for 10-minute, hourly and daily concentrations for the years 2019 – 2021 respectively (Figures A1 – A9); and
- Frequency of wind direction (from) and wind speeds (wind roses) measured at Whareroa Marae for the years 2019 – 2021 respectively (Figures A10 – A13). These show that winds are predominantly from the southwest quadrant (nearly ~30%), and to a lesser extent (just under ~10%) from the northeast.

Discussion

Monitoring at Whareroa Marae commenced in September 2015 following repeated public complaints to BOPRC regarding *inter alia* poor air quality and wide-ranging respiratory issues, watering eyes and sore throats.

[26] Difference calculated from average total ship visits in 2018 and 2019 compared with the average total ship visits in 2020 and 2021.

Our review of this monitoring reveals multiple breaches of the national environmental standard for SO_2 (upper limit 570 µg/m^3, zero permitted exceedances). These breaches were attributed to the fertiliser works, which is located adjacent to Whareroa Marae, by BOPRC who undertook regulatory action in 2016. The plant significantly reduced its emissions and ambient levels of SO_2 measured at Whareroa Marae have not breached national environmental standards since 2016.

In late 2018, continuous, ambient air quality monitoring data commenced at six other locations in **Figure 8**. As evident from the data summary and time series graphs, the data show intermittent, elevated short-term levels of sulphur dioxide continued to occur at all locations throughout 2019.

A dramatic reduction in ambient levels of SO_2 appears to coincide with ships (registered overseas) implementing Annex VI of MARPOL on 1 January 2020.[27] Annex VI of MARPOL requires ships to burn low sulphur fuel or implement abatement technology to mitigate emissions of SO_2.

This reduction was most evident at monitoring sites located closest to (i.e., within 500 metres), and predominantly downwind of, the berths; namely Rata Street and Sulphur Point, Rail Yard South and Totara Street (refer graphs of 10-minute SO_2, Figure A1 and A2, 1-hour SO_2, Figure A4 and A5 and daily SO_2, Figure A7 and A8). Since 1 January 2020 there have been no exceedances of either the 10-minute (2006) or daily (2021) WHO guidelines for SO_2 at these locations, whereas prior to 1 January 2020, exceedances of these guidelines occurred regularly.

Whareroa Marae and Tauranga Bridge Marina monitoring sites, which are residential/mixed use locations, continue to record occasional exceedances of WHO 10-minute and daily guidelines. We have carefully reviewed this data for monthly and annual reporting to Toi Te Ora and noted temporal coincidence of elevated concentrations with wind directions from the adjacent fertiliser works towards these monitoring sites.[28] The occasional exceedances of the WHO 10-minute and daily SO_2 guidelines at these two locations appear to be influenced primarily by SO_2 emissions from the fertiliser works. [29]

6.1.2 Assessment: SO2

Ambient levels of SO_2 above the WHO 10-minute guideline may have resulted in some short-term, transient effects at locations such as Whareroa Marae and Tauranga Bridge Marina including:

- Bronchoconstriction (particularly asthmatics when exercising); and/or
- Nose or throat irritation

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[27] New Zealand acceded to Annex VI in late 2021 so this reduction likely reflects the majority of ships visiting the Port of Tauranga being registered in countries that have already ratified Annex VI.

[28] For example, Memo from L. Wickham (EIL) to S. Halligan (MoH) dated 7 April 2022 Re: *Three-year review (2019-2021) of air quality monitoring at Mount Maunganui*.

Memo from L. Wickham (EIL) to C. Lochore (Toi Te Ora) dated 12 March 2021 Re: *Two-year review (2019/2020) of air quality monitoring at Mount Maunganui.*

Memo from L. Wickham (EIL) to S. Layne & J. Miller (Toi Te Ora) dated 7 February 2020. Re: *Annual review: 2019 air quality monitoring at Mount Maunganui*.

[29] NB: Exceedance of a WHO (global) air quality guideline has no regulatory status in New Zealand. This is different to a 'breach' of a national environmental standard for SO_2 (which previously led to regulatory action by BOPRC as noted above).

Those most likely to experience effect would be asthmatics, babies and infants, children and elderly people. However, being transient, any effects are likely to have been short-lived (i.e., over within minutes or hours of ambient sulphur dioxide levels returning to normal).

It is less clear what the effects of continued exceedances of the WHO daily guideline would be. Recent epidemiological evidence supports daily increases in SO_2 being causal for increased risk of all-cause mortality and respiratory mortality (Orellano *et al.,*2021) with a high certainty of evidence (WHO, 2021). This would not be reflected in the quantified mortality estimates generated separately for PM_{10} and $PM_{2.5}$ and NO_2. Recent epidemiological evidence further correlated daily increases in SO_2 with increased risk of asthma-associated emergency room visits and hospital admissions (Zheng *et al.,*2021) and this relationship is causal (WHO, 2021).

The daily levels of SO_2 in the referenced studies above are not dissimilar to daily levels of SO_2 measured at Whareroa Marae and Tauranga Bridge Marina (Appendix A). No threshold for effects has been identified (WHO, 2021).

The evidence suggests that people living at Whareroa Marae and the Tauranga Bridge Marina (on boats) may have been, and continue to be, adversely affected by SO_2 emissions. The focus in this assessment has been on chronic exposure and we have not quantified these effects.

6.2 HYDROGEN SULPHIDE

6.2.1 Air quality exposure to H2S

BOPRC monitored H_2S at Whareroa Marae between September 2015 and October 2020, after which time monitoring ceased. **Figure 9** presents a time series of hourly H_2S data during this period and **Table 12** presents summary statistics. **Table 12** shows that the New Zealand guideline for H_2S was regularly exceeded at Whareroa Marae.

FIGURE 9: Hourly H_2S concentrations measured at Whareroa Marae; 26 Sep 2015 – 14 Oct 2020 [Source: BOPRC]

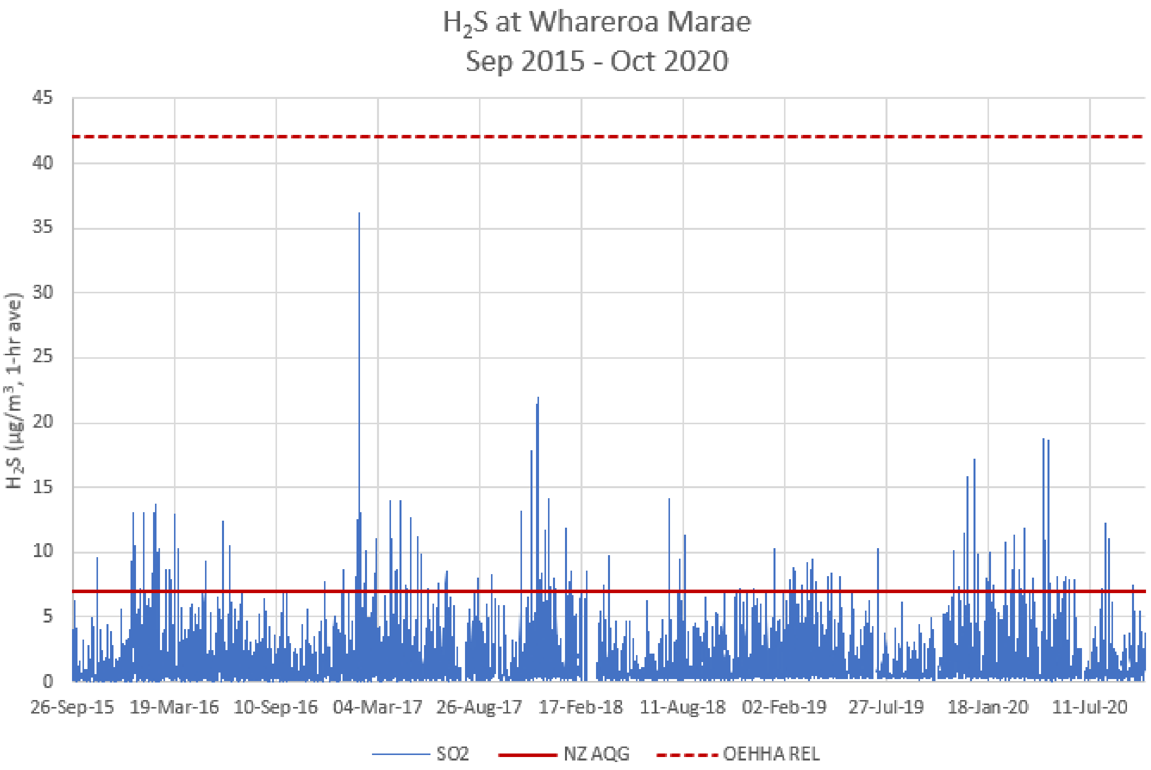

TABLE 13: Summary hourly H_2S concentrations at Whareroa Marae 2016 – 2020

Year	Maximum	99th Percentile	Standard Deviation	No. exceedances NZAAQG (7 µg/m³)
	(µg/m³, 1-hour average)			
2016	14	3	1	81
2017	36	4	2	100
2018	14	3	1	22
2019	17	4	1	35
*2020**	*19*	*4*	*1*	*54*

*Partial year (to 14 Oct only)

6.2.2 Assessment: Hydrogen Sulphide

The monitoring record at Whareroa Marae shows many exceedances of the New Zealand H_2S guideline that was set to protect against offensive odours. A detailed source apportionment by BOPRC supports several industrial sources to the north of Whareroa Marae as responsible, with odours from natural sources possibly playing a part during summer (BOPRC 2020).

There is an established history of odour complaint from the marae to BOPRC (BOPRC, 2020). We note that Te Rūnanga o Ngai Te Rangi Iwi Trust have provided evidence to the Environment Court stating tangata whenua have experienced adverse cultural impacts due to industrial odours.[30]

We conclude that industrial emissions of H_2S have regularly caused offensive odours at Whareroa Marae. This would be reducing the quality of life and impacting adversely on the wellbeing of residents and visitors, including manuhiri (guests).

6.3 BENZENE

Benzene is discharged to air from motor vehicles as well as industrial sources in the Mount Maunganui area. Of note are the presence of multiple bulk fuel storage facilities at the port that will have fugitive emissions of benzene. Emissions of benzene have not been quantified or assessed, however, given the presence of an oil re-refinery and the number of large fuel tanks present (Refer **Figure 10**), ambient concentrations of benzene may be significant.

Background levels of benzene in areas with no vehicle or industry are typically very low (< 1 ppb, WHO 2000).

[30] Statement of Evidence of Mr Reon Tuanau dated 14 August 2020. At [30]. ENV-2019-AKL-000065.

FIGURE 10: Benzene sources Mount Maunganui (traffic, fuel tanks, oil re-refinery) in relation to Whareroa Marae & Tauranga Bridge Marina

6.3.1 Air quality exposure to benzene

Acute

There has been limited ambient monitoring of benzene in the Mount Maunganui Airshed. Two industry reports include monitoring of ambient benzene (i.e., beyond the site boundary) in industrial locations of the Mount Maunganui Airshed (Ecocific 2020, 2021). These consistently measured ambient concentrations of benzene above the OEHHA REL for benzene as shown in **Table 14**. The maximum concentration was 130 ppb as a 1-hour average, measured in a location that was within 150 metres of a tank farm. However, some of the data may not be robust (lower detection limit reported as 70 ppb). Monitoring in an industrial location in Christchurch measured similar 1-hour average concentrations of benzene (8 – 93 ppb, n = 8).[31]

[31] Specifically downwind of a wastewater treatment plant under upset conditions. Source: Christchurch City Council, unpublished data

TABLE 14: Hourly benzene concentrations measured at Mount Maunganui, 2020-2021

Ecocific 2020, 2021	Benzene (ppb, 1-hour average)
OEHHA REL	**8**
Maximum	130
Average	47
Minimum	10
n*	12

*Number of hourly measurements

Chronic

We are not aware of any long-term monitoring of benzene in Mount Maunganui. This precludes comparison with the New Zealand long-term ambient air quality guideline or quantification of risk due to carcinogenicity.

Long-term ambient monitoring in Auckland suggests people living close to busy roads (~13,000 vehicles per day) and petrol stations may be exposed to annual concentrations of benzene of around 0.6 - 1 ppb respectively (Auckland Council, 2014). A 2012 literature review prepared for Auckland Council (Emission Impossible Ltd, 2012) concluded annual concentrations of benzene may be elevated within 150 metres of busy roads, but this is of uncertain relevance for Mount Maunganui in 2022.

6.3.2 Assessment: acute benzene

There are several potentially significant sources of benzene in the Mount Maunganui Airshed, however, these have not been quantified or comprehensively assessed to date. Short-term ambient monitoring for benzene in the Mount Maunganui Airshed has recorded 1-hour average concentrations above the OEHHA reference exposure level (8 ppb) set to protect against developmental effects. These measurements were undertaken in industrial locations however, they were ambient measurements, i.e., beyond the boundary of the industrial site that was undertaking the measurement. The monitoring suggests that workers in these locations may have elevated, acute exposure to benzene. However, the monitoring data are limited (12 hours sampling over two years only) and in the absence of an emissions inventory or more detailed assessment, no firm conclusions can be drawn.

If is further unclear if, and how, these elevated acute measurements relate to residential exposure in other parts of the Mount Maunganui Airshed (e.g., Whareroa Marae, Rata Street). Whareroa Marae is within 200 metres of a bulk fuel storage facility and within 300 metres of an oil re-refining facility. Residents and visitors (including manuhiri) to Whareroa Marae and kohanga reo *may* be exposed to elevated concentrations of benzene over acute and/or chronic time frames. Benzene exposure may disproportionately impact infants and children (OEHHA, 2014).

There are no long-term monitoring data for benzene in the Mount Maunganui Airshed. This is a significant data gap. No conclusions can be drawn about either worker or residential chronic exposure to benzene.

6.4 ODOUR

Odour is an established issue for Mount Maunganui. In the year ending 1 September 2021, BORC received 512 odour complaints to their pollution hotline for the Mount industrial area (BOPRC, undated). The majority of these complaints were about pet food, bitumen, and ‘rotten egg’ (H_2S).

The large number of industrial sources and the significance of the odour issues in the Mount Maunganui Airshed (more than 500 complaints a year) are such that assessment of any, single, “indicator” compound (e.g., hydrogen sulphide) would be insufficient to understand the extent of potential public health impacts from odour. This is because odour is made up multiple contaminants.

It is apparent that offensive and objectionable odours are reducing the quality of life and adversely impacting on the wellbeing of residents in and around the Mount Maunganui Airshed.

A nascent body of epidemiology suggests that industrial odours are associated with adverse health impacts in surrounding communities (e.g., Guadualupe-Fernandez *et al.*, 2021). This suggests that, in addition to negative impacts on wellbeing, odorous emissions may also be adversely impacting residents’ health.

7. CONCLUSIONS

Our review of ambient air quality monitoring data shows that concentrations of some air contaminants are elevated in some locations relative to health and wellbeing-based ambient criteria.

Quantitative Assessment

The modelling estimates that, compared with Otūmoetai, in Mount Maunganui there were:

- Around five premature deaths each year associated with increased exposure to long-term concentrations of **$PM_{2.5}$ and NO_2**. For context, the total mortality from all non-external causes[32] in Mount Maunganui for the year 2019 was 145 so this estimate represents around 3% of deaths in that year.
- An additional four cardiovascular and six respiratory hospitalisations associated with increased long-term exposure to $PM_{2.5}$ and NO_2.
- An additional 1,256 restricted activity days associated with increased long-term exposure to $PM_{2.5}$.
- Two additional cases of asthma in under 18-year-olds associated with increased long-term exposure to NO_2.

Sensitivity testing estimates that:

- The number of premature deaths for adults associated with long-term exposure to $PM_{2.5}$ and NO_2 in Mount Maunganui as compared with Otūmoetai have a 95% confidence interval of 3 and 6 (relative to the base case of 5 deaths).
- The low and high social cost estimates associated with long-term exposure to $PM_{2.5}$ and NO_2 in Mount Maunganui as compared with Otūmoetai are between $19 million and $29 million (relative to the base case of $22 million, all in NZ$2019).

Single-pollutant modelling estimated that the Mount Maunganui area has 13 premature deaths each year (95% confidence interval 11 to 15) associated with increased exposure to long-term concentrations of **PM_{10}** when compared with Otūmoetai. This estimate represents around 9% of total mortality from all non-external causes in that year, which is higher than the estimates associated with long-term exposure to $PM_{2.5}$ and NO_2. It should be noted that the PM_{10} modelling is not additive to the estimate of effects associated with $PM_{2.5}$ and NO_2, rather it is a different estimate.

At Toi Te Ora Public Health's request, we modelled the hypothetical scenario of all areas, including Otūmoetai, meeting the annual WHO 2021 global air quality guidelines for $PM_{2.5}$ (5 µg/m^3) and NO_2 (10 µg/m^3). This would have a modest impact in averting 2 premature deaths per year with an associated averted social cost of $11 million (NZ$2019) due to hypothetical reductions in annual $PM_{2.5}$ (as our assessment assumed all areas already meet the annual WHO guideline for NO_2).

An assessment of uncertainty concludes there is a moderate degree of confidence in the modelling estimates.

[32] i.e., deaths excluding accidents and violence

Qualitative Assessment

A known limitation of the qualitative assessment is that comparing concentrations of single contaminants with available, established ambient air quality criteria does not address additive or synergistic health effects that may occur due to exposure to mixtures of compounds.

Sulphur Dioxide

Ambient levels of SO_2 above the WHO 10-minute guideline may have resulted in some short-term, transient effects at locations such as Whareroa Marae and Tauranga Bridge Marina including:

- Bronchoconstriction (particularly asthmatics when exercising); and/or
- Nose or throat irritation

Those most likely to experience effects would be asthmatics, babies and infants, children and elderly people. However, being transient, it is likely any effects would have been short-lived (i.e., over within minutes or hours of ambient sulphur dioxide levels returning to normal).

It is less clear what the effects of the elevated daily levels of SO_2 would be. A recent systemic review and meta-analysis concluded that rises in short-term SO_2 concentration increases the risk of all-cause mortality and respiratory mortality (Orellano *et al.,*2021) and this was judged to have a high degree of certainty (WHO, 2021). In addition, further evidence has been reported between short-term exposure to SO_2 and an increased risk of asthma-associated emergency room visits and hospital admissions (Zheng *et al.,*2021) and this relationship is considered causal (WHO, 2021).

This suggests that residents and visitors including manuhiri (guests) to Whareroa Marae and kohanga reo, residents (on boats) and visitors to the Tauranga Bridge Marina may have been, and continue to be, adversely affected by SO_2 emissions on occasion.

Hydrogen Sulphide

Ambient air quality monitoring at Whareroa Marae and source investigation by BOPRC provides clear evidence that industrial emissions of hydrogen sulphide regularly exceeded the national guideline set to prevent against offensive odours (BOPRC, 2020). This would be reducing the quality of life and adversely impacting on the wellbeing of residents and visitors, including manuhiri.

Benzene

Limited, short-term monitoring of benzene in industrial locations of the Mount Maunganui Airshed have measured ambient concentrations above a health-based, air quality criterion for acute exposure to benzene. Workers in these locations may have elevated acute exposure to benzene, however, the data are limited, and no firm conclusions can be drawn.

Whareroa Marae is within 200 metres of a bulk fuel storage facility and within 300 metres of an oil re-refining facility. Residents and visitors, including manuhiri, to Whareroa Marae and kohanga reo *may* be exposed to elevated concentrations of benzene over acute and/or chronic time frames. Benzene exposure may disproportionately impact infants and children (OEHHA, 2014). However, in the absence of any data no firm conclusions can be drawn.

There are no long-term air quality monitoring data for benzene in or around the Mount Maunganui Airshed. No conclusions can be drawn about either worker or residential chronic exposure to benzene.

Odour

Odour is a well-established issue in Mount Maunganui, with more than 500 complaints to the regional council each year.

It is apparent that offensive and objectionable odours are reducing the quality of life and adversely impacting on the wellbeing of residents in and around the Mount Maunganui Airshed.

Recent literature suggests that industrial odours are associated with adverse health impacts in surrounding communities (Government of Alberta, 2017, Guadualupe-Fernandez *et al.*, 2021). This suggests that, in addition to negative impacts on wellbeing, odorous emissions may also be adversely residents' health.

Data Gaps

The assessment has highlighted a lack of data for some pollutants of potential concern. Specifically, there is a dearth of ambient air quality monitoring for PAHs and benzene. This has constrained our ability to assess potential cancer risks.

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APPENDIX A: MOUNT MAUNGANUI SO_2 DATA

Table A1: Summary SO_2 10-minute concentrations in Mount Maunganui for 2021

Monitoring location	Maximum 10-minute SO_2	99th percentile	Standard deviation	Exceedances WHO Guideline
	(µg/m³)	(µg/m³)	(µg/m³)	(no.)
Rata Street	75	24	5	0
Sulphur Point	127	31	6	0
Bridge Marina	**1,247**	45	10	**1**
Whareroa Marae	361	70	13	0
Rail Yard South	82	21	4	0
Totara Street	96	29	6	0
WHO 10-min Guideline SO_2 = 500 µg/m³				

Table A2: Summary SO_2 10-minute concentrations in Mount Maunganui for 2020

Monitoring location	Maximum 10-minute SO_2	99th percentile	Standard deviation	Exceedances WHO Guideline
	(µg/m³)	(µg/m³)	(µg/m³)	(no.)
Rata Street	80	27	6	0
Sulphur Point	142	35	7	0
Bridge Marina	275	44	10	0
Whareroa Marae	432	72	15	0
Rail Yard South	109	22	5	0
Totara Street	90	34	6	0
WHO 10-min Guideline SO_2 = 500 µg/m³				

Table A3: Summary SO_2 10-minute concentrations in Mount Maunganui for 2019

Monitoring location	Maximum 10-minute SO_2	99th percentile	Standard deviation	Exceedances WHO Guideline
	(µg/m³)	(µg/m³)	(µg/m³)	(no.)
Rata Street	**775**	197	42	**10**
Sulphur Point	287	106	19	0
Bridge Marina	232	76	15	0
Whareroa Marae	472	113	23	0
Rail Yard South	393	154	32	0
Totara Street	359	85	19	0
WHO 10-min Guideline SO_2 = 500 µg/m³				

Table A4: Summary SO_2 1-hour concentrations in Mount Maunganui for 2021

Monitoring location	Maximum 1-hour SO_2	99th percentile	Exceedances NES lower limit (350 µg/m³)	Exceedances NES upper limit (570 µg/m³)
	(µg/m³)	(µg/m³)	(no.)	(no.)
Rata Street	63	23	0	0
Sulphur Point	96	29	0	0
Bridge Marina	312	40	0	0
Whareroa Marae	125	59	0	0
Rail Yard South	38	18	0	0
Totara Street	60	27	0	0

Table A5: Summary SO_2 1-hour concentrations in Mount Maunganui for 2020

Monitoring location	Maximum 1-hour SO_2	99th percentile	Exceedances NES lower limit (350 µg/m³)	Exceedances NES upper limit (570 µg/m³)
	(µg/m³)	(µg/m³)	(no.)	(no.)
Rata Street	57	25	0	0
Sulphur Point	100	33	0	0
Bridge Marina	161	40	0	0
Whareroa Marae	251	60	0	0
Rail Yard South	68	20	0	0
Totara Street	64	29	0	0

Table A6: Summary SO_2 1-hour concentrations in Mount Maunganui for 2019

Monitoring location	Maximum 1-hour SO_2	99th percentile	Exceedances NES lower limit (350 µg/m³)	Exceedances NES upper limit (570 µg/m³)
	(µg/m³)	(µg/m³)	(no.)	(no.)
Rata Street	**575**	173	**4**	**1**
Sulphur Point	208	96	0	0
Bridge Marina	157	65	0	0
Whareroa Marae	206	97	0	0
Rail Yard South	226	126	0	0
Totara Street	167	72	0	0

Table A7: Summary SO_2 daily concentrations in Mount Maunganui for 2021

Monitoring location	Maximum daily SO_2	99% percentile	Standard deviation	Exceedances WHO 2021 AQG
	(µg/m³)	(µg/m³)	(µg/m³)	(no.)
Rata Street	15	13	3	0
Sulphur Point	39	19	4	0
Bridge Marina	36	24	5	0
Whareroa Marae	**42**	24	6	**1**
Rail Yard South	12	11	2	0
Totara Street	26	14	3	0
WHO 2021 AQG Daily SO_2 = 40 µg/m³				

Table A8: Summary SO_2 daily concentrations in Mount Maunganui for 2020

Monitoring location	Maximum daily SO_2	99% percentile	Standard deviation	Exceedances WHO 2021 AQG
	(µg/m³)	(µg/m³)	(µg/m³)	(no.)
Rata Street	16	13	3	0
Sulphur Point	24	18	4	0
Bridge Marina	**54**	29	6	**3**
Whareroa Marae	**54**	28	6	**1**
Rail Yard South	17	12	2	0
Totara Street	19	15	3	0
WHO 2021 AQG Daily SO_2 = 40 µg/m³				

Table A9: Summary SO_2 daily concentrations in Mount Maunganui for 2019

Monitoring location	Maximum daily SO_2	99% percentile	Standard deviation	Exceedances WHO 2021 AQG
	(µg/m³)	(µg/m³)	(µg/m³)	(no.)
Rata Street	**140**	**90**	21	**50**
Sulphur Point	**93**	**60**	12	**11**
Bridge Marina	**44**	33	7	**1**
Whareroa Marae	**48**	**42**	10	**5**
Rail Yard South	**92**	**72**	18	**62**
Totara Street	**54**	**40**	9	**4**
WHO 2021 AQG Daily SO_2 = 40 µg/m³				

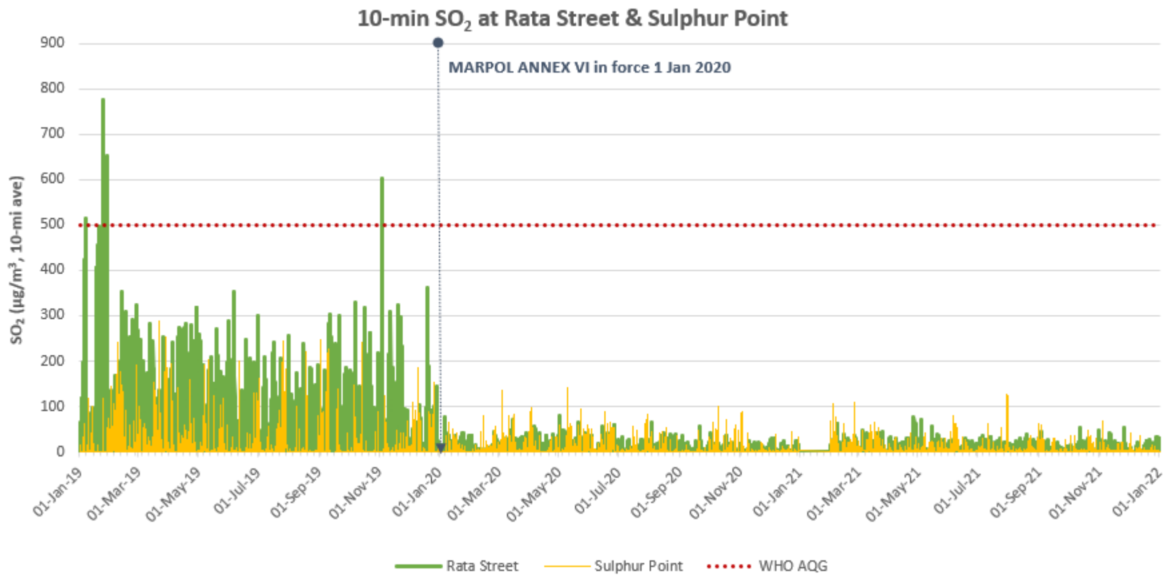

Figure A1: 10-minute SO_2 at Rata Street and Sulphur Point: 2019 – 2021

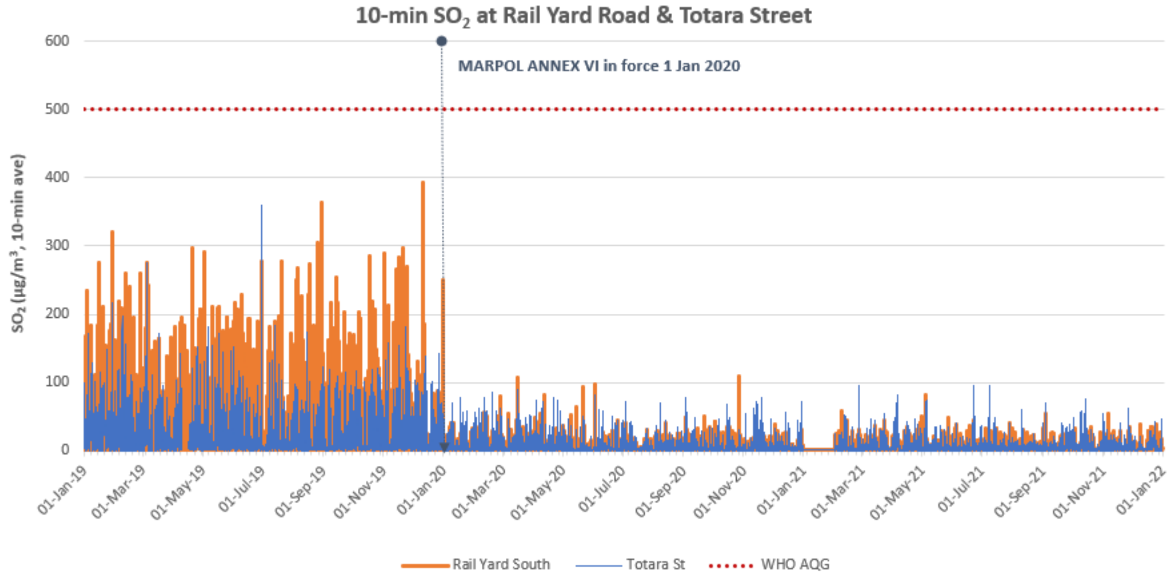

Figure A2: 10-minute SO_2 at Rail Yard South and Totara Street: 2019 – 2021

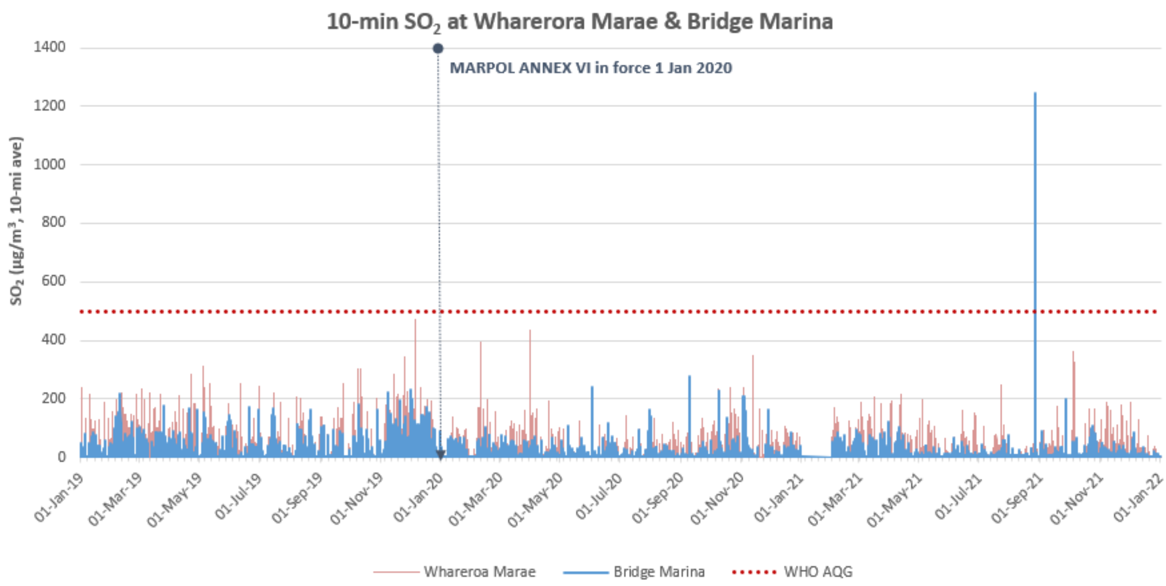

Figure A3: 10-minute SO_2 at Whareroa Marae and Tauranga Bridge Marina: 2019 – 2021

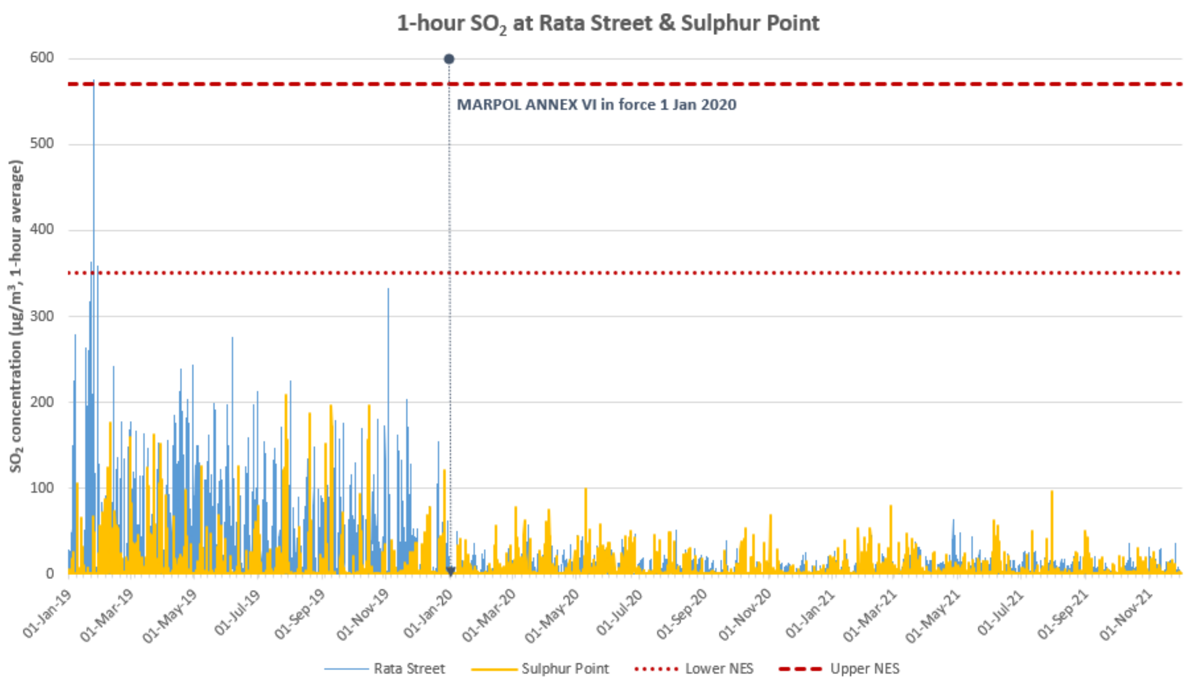

Figure A4: Hourly SO_2 at Rata Street and Sulphur Point: 2019 – 2021

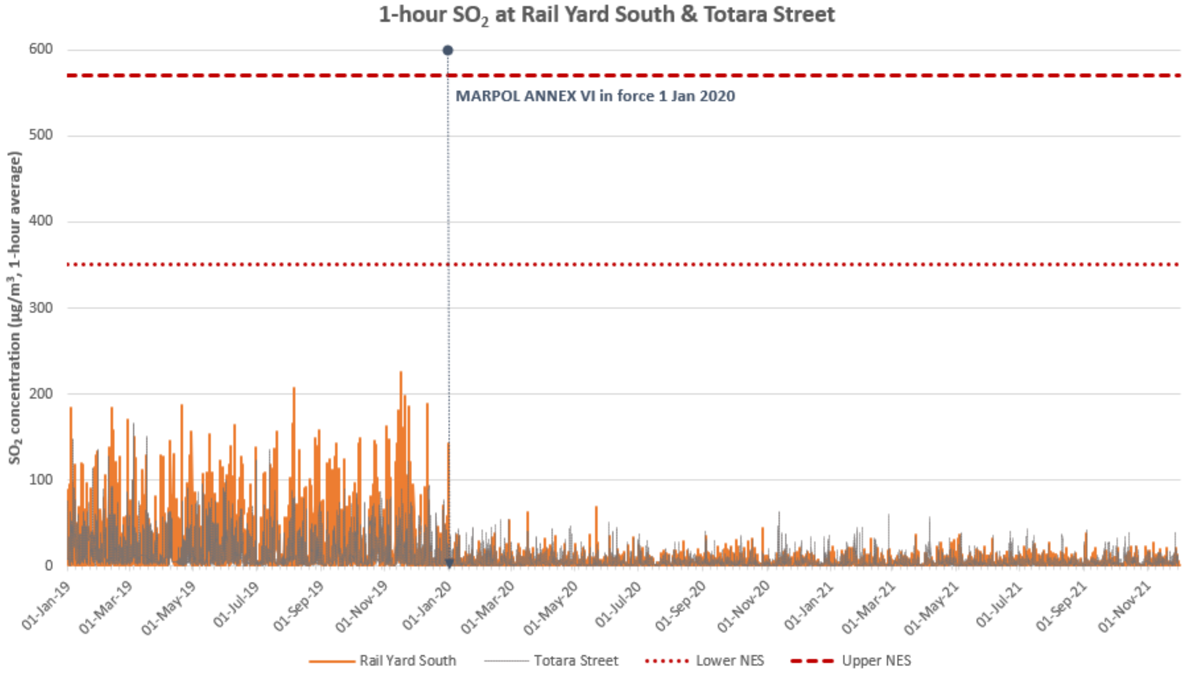

Figure A5: Hourly SO_2 at Rail Yard South and Totara Street: 2019 – 2021

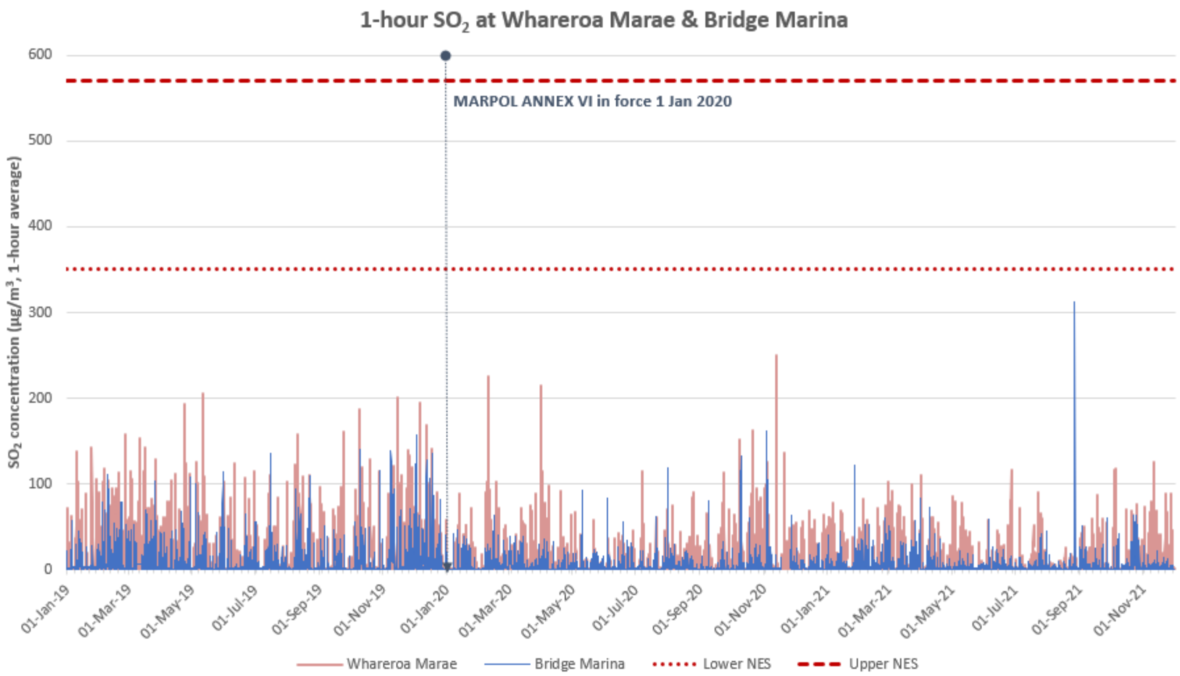

Figure A6: Hourly SO_2 at Whareroa Marae and Tauranga Bridge Marina: 2019 – 2021

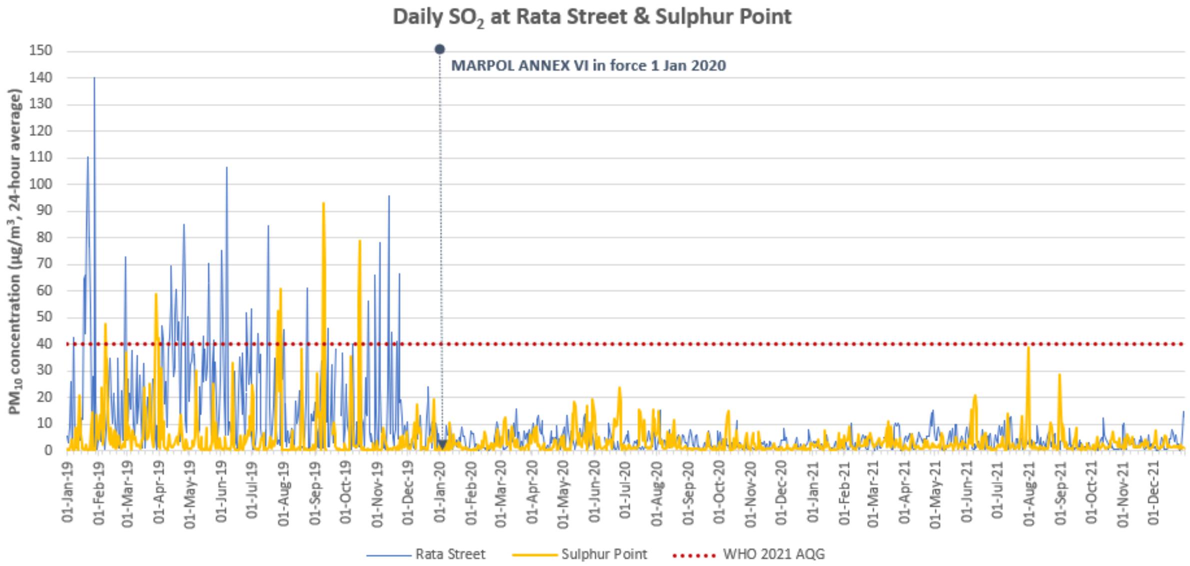

Figure A7: Daily SO_2 at Rata Street and Sulphur Point: 2019 – 2021

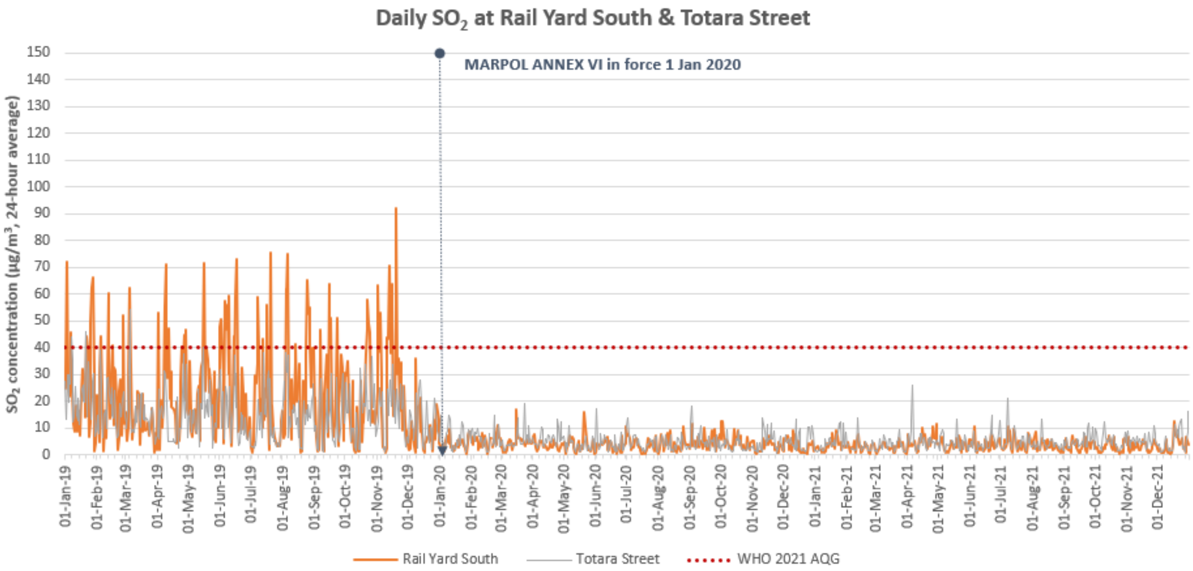

Figure A8: Daily SO_2 at Rail Yard South and Totara Street: 2019 and 2021

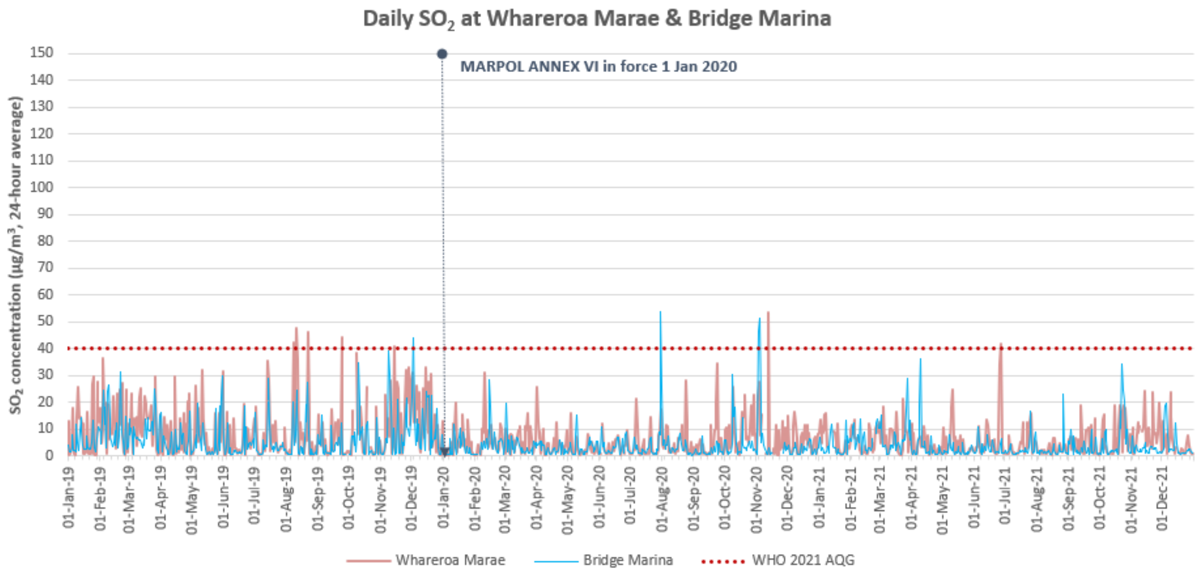

Figure A9: Daily SO_2 at Whareroa Marae and Tauranga Bridge Marina: 2019 – 2021

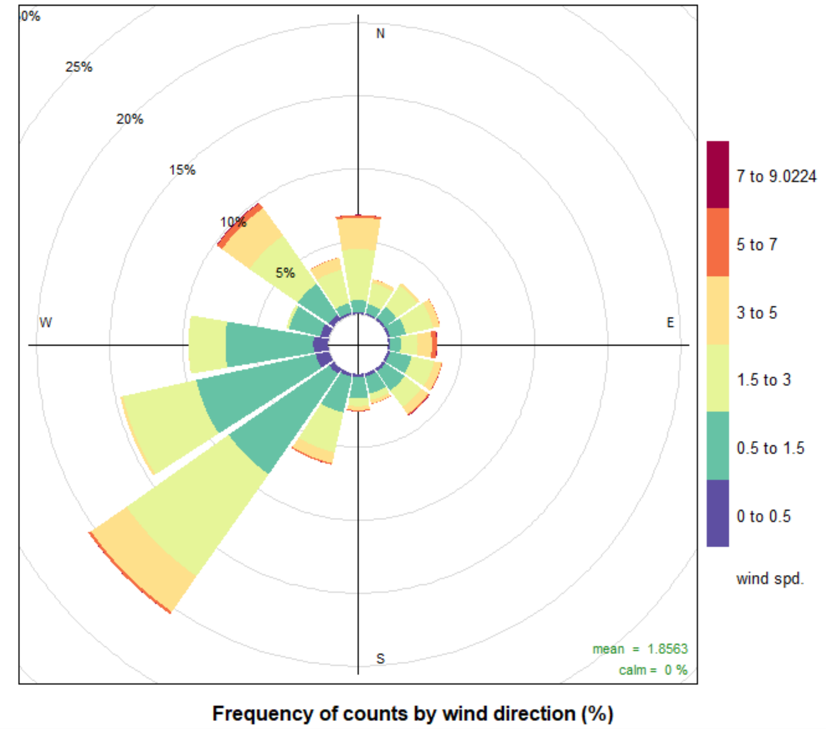

Figure A10: Frequency of (10-minute) wind direction (from) and wind speed measured at Whareroa Marae; 1 Jan – 31 Dec 2019

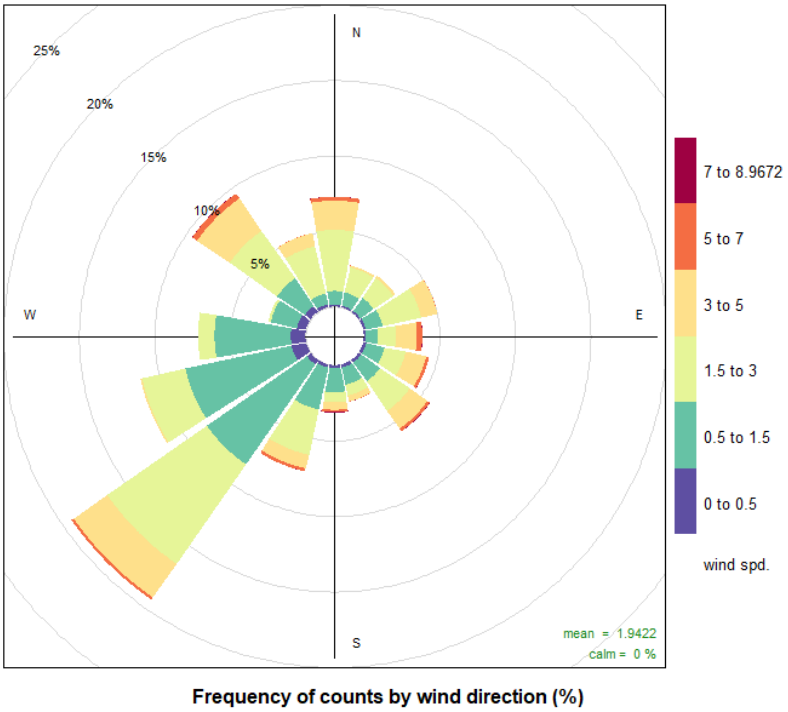

Figure A11: Frequency of (10-minute) wind direction (from) and wind speed measured at Whareroa Marae; 1 Jan – 31 Dec 2020

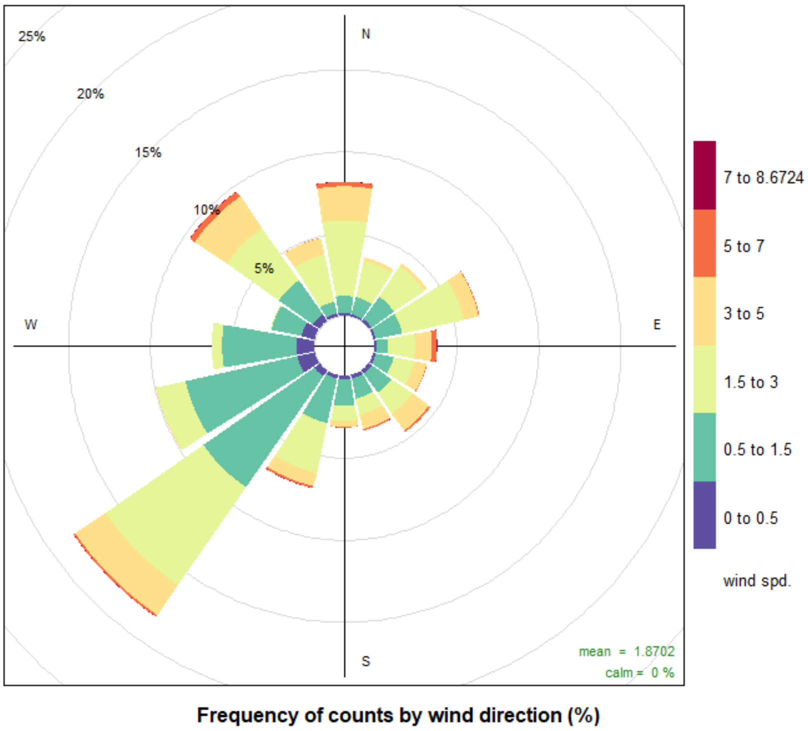

Figure A12: Frequency of (10-minute) wind direction (from) and wind speed measured at Whareroa Marae; 1 Jan – 31 Dec 2021

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