Riwaka, Brooklyn and Motueka $PM_{2.5}$ monitoring network

May-September 2021

Report for:

Tasman District Council

18 January 2022

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Acknowledgements

Mote Limited would like to thank Anna MacKenzie, Diana Worthy and Jane Stuart for their assistance with locating monitoring locations and the provision of air quality monitoring data.

Mote Limited would also like to thank the land owners/occupiers in Riwaka and Brooklyn who kindly agreed to host an air quality monitoring during this monitoring campaign. Their assistance and patience during the installation and instrument removal is gratefully acknowledged.

Revision History

No.	Date	Author(s)	Reviewer(s)	Details
1	14 Nov 2021	**Paul Baynham**	**Dr. Brett Wells**	V1.0 Draft report completed
2	17 Nov 2021	**Paul Baynham**		V1.2 Revised draft sent to client
3	06 Dec 2021	**Paul Baynham**		V2.0 Draft revised following feedback from TDC
4	16 Dec 2021	**Paul Baynham**		V2.1 Draft revised following feedback from TDC
5	18 Jan 2021	**Paul Baynham**		V2.2 Final version issued

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1.0 EXECUTIVE SUMMARY

7 air quality monitors and 4 meterological monitors were deployed around Riwaka, Brooklyn, and Motueka between 28 April and 18 October as part of a high resolution air quality monitoring network evaluating the effect and source of $PM_{2.5}$ concentrations in the Riwaka/Brooklyn area.

The investigation found that the winter air quality in the Riwaka/Brooklyn area during the study period was good or excellent for between 89 and 99% of the time.

The lowest 24-hour average $PM_{2.5}$ concentrations were measured along the western boundary of the study area, while the highest 24-hour average $PM_{2.5}$ concentration of 14.8 $\mu g/m^3$ was measured just to the North of Riwaka. The peak concentrations at all sites within the Riwaka/Brooklyn area remained just below the World Health Organisation guideline of 15 $\mu g/m^3$ and well below the 2019 Ministry for the Environment's proposed 24-hour average National Environmental Standard for $PM_{2.5}$ of 25 $\mu g/m^3$.

An analysis of the data reveals that $PM_{2.5}$ concentrations in the Riwaka area during the study period were sourced primarily from domestic home heating.

The co-located monitor at Motueka recorded a peak 24-hour average $PM_{2.5}$ concentration of 27 $\mu g/m^3$ which is just above the proposed 24-hour average National Environmental Standard for $PM_{2.5}$ of 25 $\mu g/m^3$.

Wind speeds during the study remained relatively low and were typically south-westerly, although nearby topographical features appeared to have a significant effect on both wind direction and wind speed. Most sites displayed clear evidence of cold flow drainage under light winds which appeared to be the dominant dispersive mechanism at night.

2.0 PROJECT OUTLINE

Mote were contacted by Anna MacKenzie (Resource Scientist – Contaminants) from Tasman District Council on 16 June 2020 regarding a potential ambient air quality monitoring network for 2021. The focus of this investigation was to undertake particulate monitoring in Riwaka and Brooklyn to investigate whether there is an air quality issue – primarily associated with outdoor rural burning. Discussions continued in February 2021 and in April the monitoring proposal was formalised and scheduled to commence in May 2021.

The focus of the investigation was on the concentration of airborne particulate matter (the term for a mixture of solid particles and liquid droplets found in the air). The particular size fractions of interest were primarily particles with an aerodynamic diameter of 10 microns or less (PM_{10}) and those with an aerodynamic diameter of 2.5 microns or less ($PM_{2.5}$).

On 28 April, 7 continuous monitoring instruments (6 x $PM_{2.5}$ and 1 x PM_{10}) were co-located with a Partisol at Goodman Park in Motueka for a period of 14 days. This was to establish the relationship between the nephelometers and the National Environmental Standard compliant monitoring device (Thermo Scientific Partisol) operated by the Tasman District Council. On 12 May 2021 five of the instruments were transferred to various locations in and around Riwaka and Brooklyn, some 5 kilometres to the North of Motueka while two instruments remained with the Partisol in Motueka.

The monitors which remained at Motueka were used to monitor the relationship between the nephelometers and the Partisol to allow the accuracy of the distributed monitoring network to be quantified.

The network was intended to be deployed for a three month period to coincide with cooler winter weather when temperature inversions reduce the amount of atmospheric dispersion which can result in an increase in particulate concentrations. Unfortunately, on 17 August a national lockdown was imposed due to the detection of COVID19 within the Auckland community. The imposition of the lockdown and the subsequent travel restrictions delayed the scheduled decommissioning of the ambient monitoring network until 18 October. Some instruments were powered off prior to this date in consultation with the land owners/occupiers.

2.1 Project location

Riwaka is a small settlement in the Tasman District of New Zealand's South Island. It lies beside Tasman Bay / Te Tai-o-Aorere, five kilometres north of Motueka and is home to a population of 1341 residents with a total of 627 households[1]. The project area also included the neighbouring area around Brooklyn School, at the foot of the Brooklyn Valley.

[1] 2018 census data

The wider Riwaka area is internationally recognised as having an ideal climate for the growing of various crops – particularly apples, pears, hops and kiwifruit and there are numerous plantations in the area.

The topography consists of a generally flat river valley bounded to the west by the foothills at the base of the Takaka Hill. The valley comprises the northern section of the Motueka catchment but also drains a number of smaller tributaries into Tasman Bay.

A location map identifying the area can be seen in **Figure 1** below.

Riwaka and Brooklyn study area location map

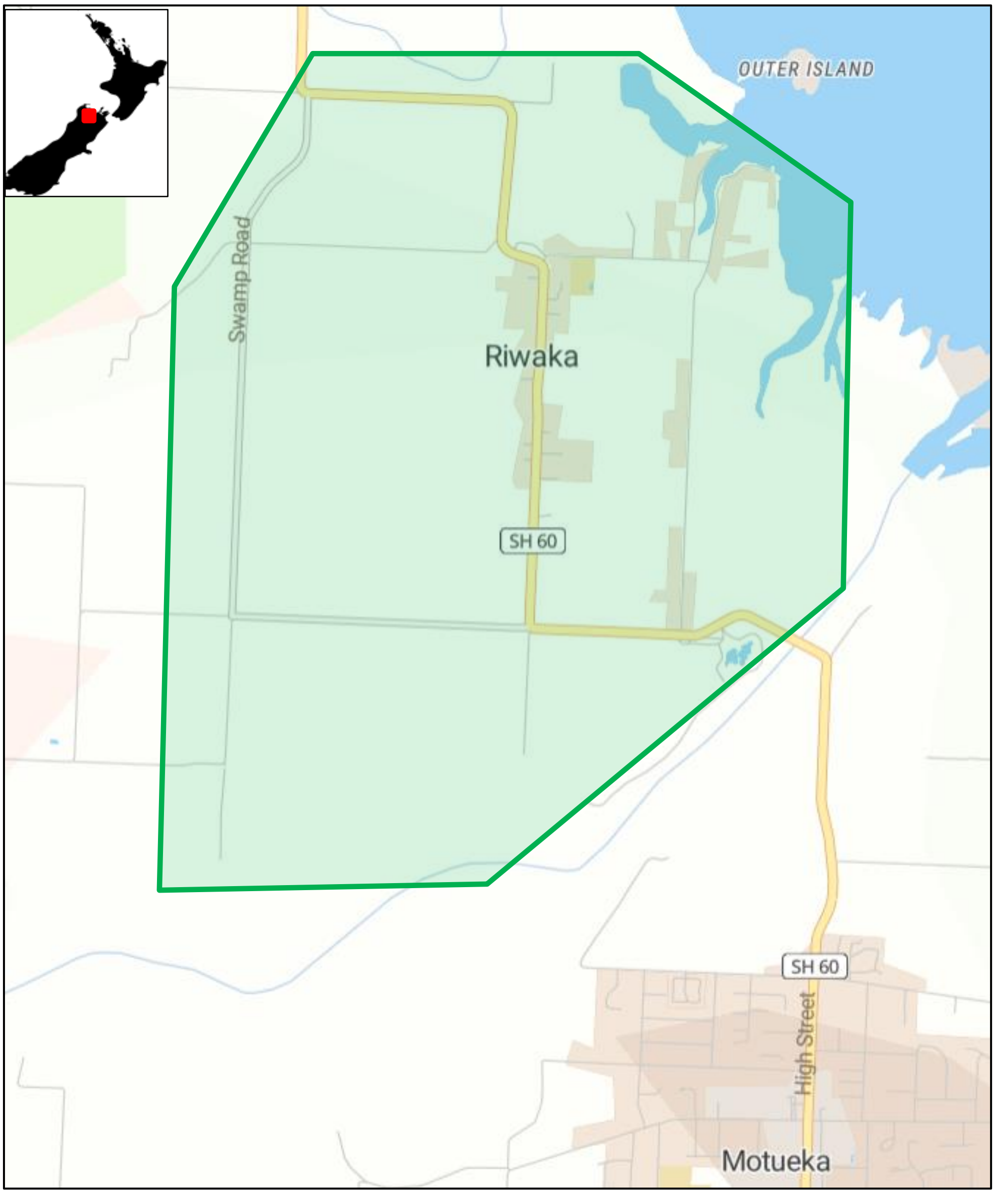


Figure 1: Location map of the study area (highlighted green), Tasman District, New Zealand

The Riwaka community has a higher proportion of wood fires (67.7%) than the New Zealand average (32.3%) as shown in **Figure 2** below.

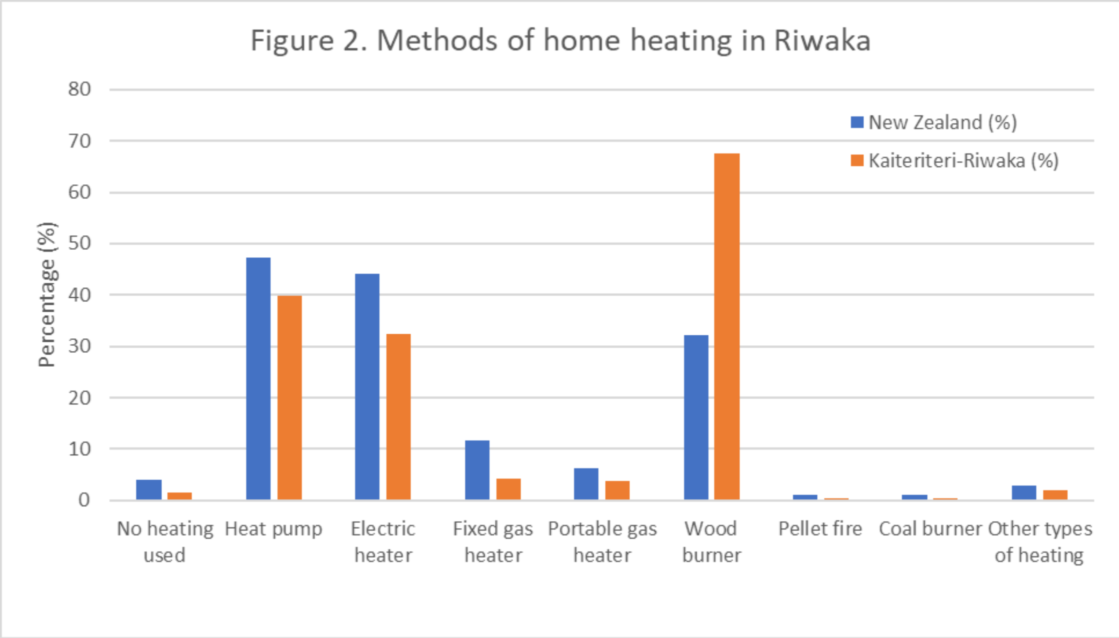


Figure 2: Graph displaying the proportion of different home heating methods in Kaiteriteri-Riwaka compared with the New Zealand average based upon the 2018 Census data. Note that some households contain more than one heating type and/or mutifuel burners.

2.2.1 Particle Instrument Selection

One primary instrument was selected - an optical nephelometers. The instrument is a Met One ES642 near-forward nephelometer which was coupled with a programmable modem.

The ES642 produces 1 second data which was collated to produce 1 minute averaged data. The ES642 unit contains an inlet heater which was controlled using a set point of 35% relative humidity. Sample flow rates of 2 litres per minute were calibrated using a DryCal defender following installation of the instrumentation and confirmed again at the conclusion of the project.

Temperature, pressure and relative humidity sensors were also calibrated using Vaisala HMT330 and HM70 meters following installation in order to ensure accurate flow measurement.

The instruments store data locally in the event that cellular transmission is disrupted. When cellular connectivity is restored, then data transmission will recommence with older data transmitted first.

Figure 3: Photograph of the ES642 units co-located alongside the TDC Partisol at Goodman Ledger Park, Motueka.

All instruments were co-located at Motueka alongside the TDC partisol for a 14 day period. The purpose of this co-location was firstly, to ensure that the optical nephelometers are producing consistent data prior to their respective field deployment locations (degree of precision). The second purpose is to enable the optical concentration data to be corrected to gravimetric equivalent (degree of accuracy).

Following the 14 day co-location, the data from each of the units was adjusted using a linear correction factor to ensure consistent measurements during the monitoring campaign and to verify that the instrumental concentrations were comparable during the initial 14 day deployment. This was performed by calculating an average concentration during the co-location and comparing this with combined average value of all instruments over the same period.
The gain on each instrument was then adjusted and the instrumental data checked to verify that the values where within +/-2 μg/m^3. For five of the nephelometers this adjustment was relatively minor (+/-5%), however two of the nephelometers had values that were lower than their neighbouring devices (>25%). Further inspection found that this was due to an incorrect internal correction factor for these instruments. Once this was corrected, the raw data from the instruments was found to be similar to that of the other 5 nephelometers.

Standard practice is to replace any instruments which fail to meet this requirement, however following gain adjustments, all optical nephelometers met the required degree of precision (24-hour average +/-2 μg/m^3)

Figure 4 displays the corrected instrumental concentrations for each of the monitors used during the deployment.

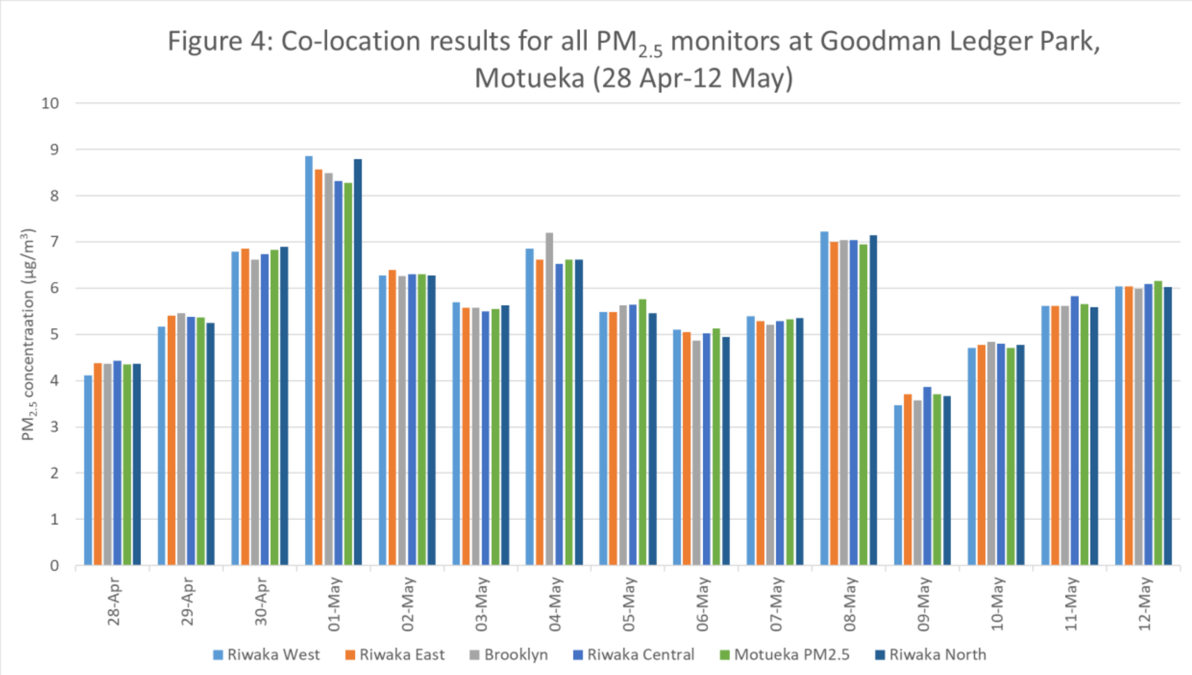


Figure 4: comparison of 24-hour average concentrations for the 6 PM2.5 instruments co-located in Motueka (28 April – 12 May 2021).

The second part of the co-location process involves applying a linear correction factor or a site specific correction factor to correct the optical concentrations to gravimetric equivalent. This is normally achieved by either sampling the optical particles onto a filter (e.g MetOne ESampler), calculating the optical correction factor and applying linearly across the sampling period or as in this case, using filter based results from a co-located instrument.

The correction factor recognises that two different instrumental techniques are used by the instruments (Gravimetric vs Optical). Essentially, the optical devices measure the number of particles during a given period of time and then convert this to a concentration by making an assumption around particle density(ρ). Investigations in other parts of New Zealand have established that $PM_{2.5}$ particle density assumptions can vary (0.8>ρ>2.2) between sites.

As the particle size decreases, there is generally better agreement between optical nephelometers and gravimetric instruments. There are several reasons, for this, however if one considers the formulae to calculate the volume of a sphere:

$$V = \frac{4}{3}\pi r^3$$

It is apparent that the cubic radius has a significant effect on particle volume. Therefore it follows that as the particle size decreases, the particle volume and the effect of particle density becomes less significant.

A site specific correction factor was devloped by comparing the co-location 24-hour average data from the PM_{10} nephelometer for the period from 28 April through to 12 May with the 24-hour average TDC partisol data over the same period and deriving a linear correction factor that enables the correction of the optical data to a gravimetric equivalent. The colocation of the PM_{10} and $PM_{2.5}$ monitors at Motueka confirmed that there is a very strong relationship between the two particle sizes (R^2 was 0.995) and on this basis the relationship between the PM_{10} gravimetric and optical instruments was also applied to the $PM_{2.5}$ optical monitors.

The nephelometer produces 1 second data that are averaged using a programmable modem to produce 1 minute average data. The minimotes use GPS to ensure the accuracy of timestamped data is within 0.1 seconds.

The collated data is transmitted via a privately provisioned cellular network to a secure web-based server every 15 minutes.

Both sets of instruments store data locally in the event that cellular transmission is disrupted. If cellular connectivity is restored, then data transmission will recommence with older data transmitted first.

At the conclusion of a deployment, instruments are normally co-located at a nearby site to confirm that the initial correction factors adjustments remain valid. However due to the National COVID19 lockdown and restrictions on non-essential travel, it was instead decided to retrieve the instruments and place the instruments in a controlled atmosphere smoke chamber to verify the instrumental readings.

All ES642 units were retrieved and placed in the calibration chamber and the decrease in PM2.5 concentration for all instruments are shown in **Figure 5**. This post-location analysis confirmed that the 24-hour equivalent concentrations remained within +/-2 $\mu g/m^3$ at the conclusion of the study.

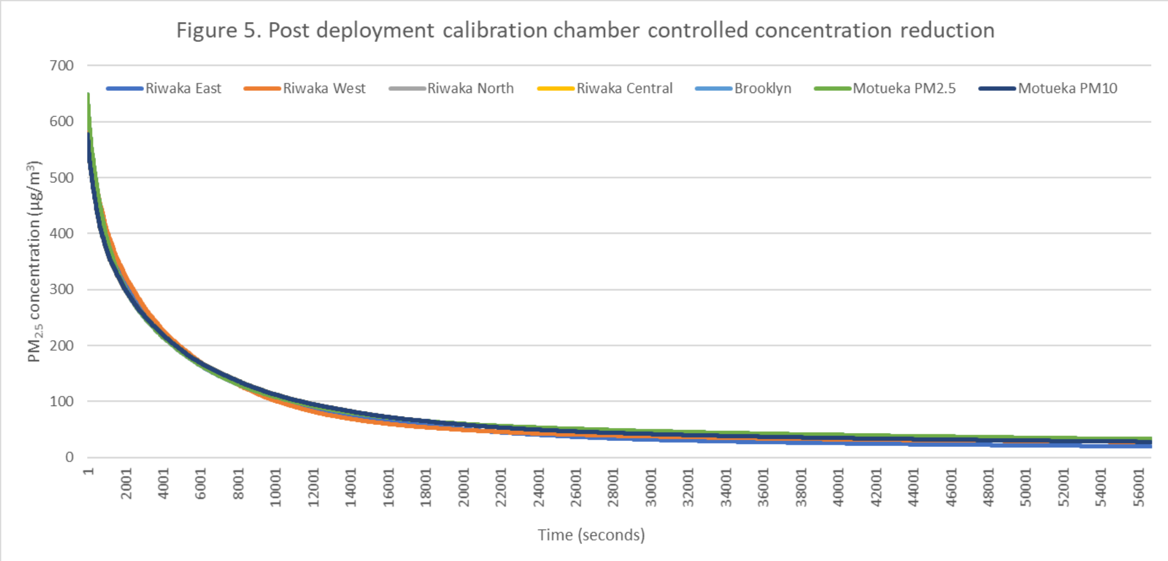
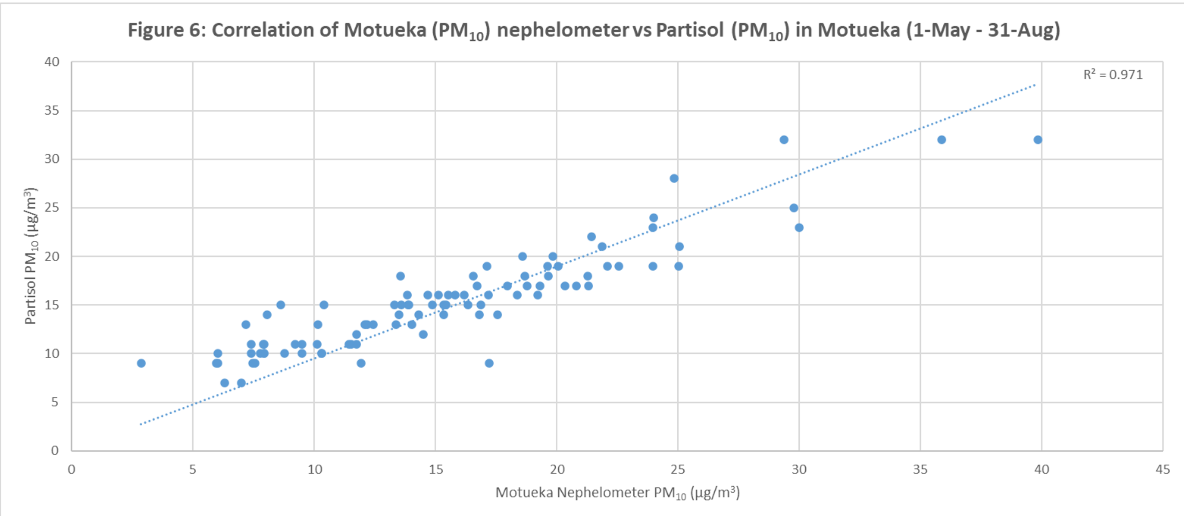
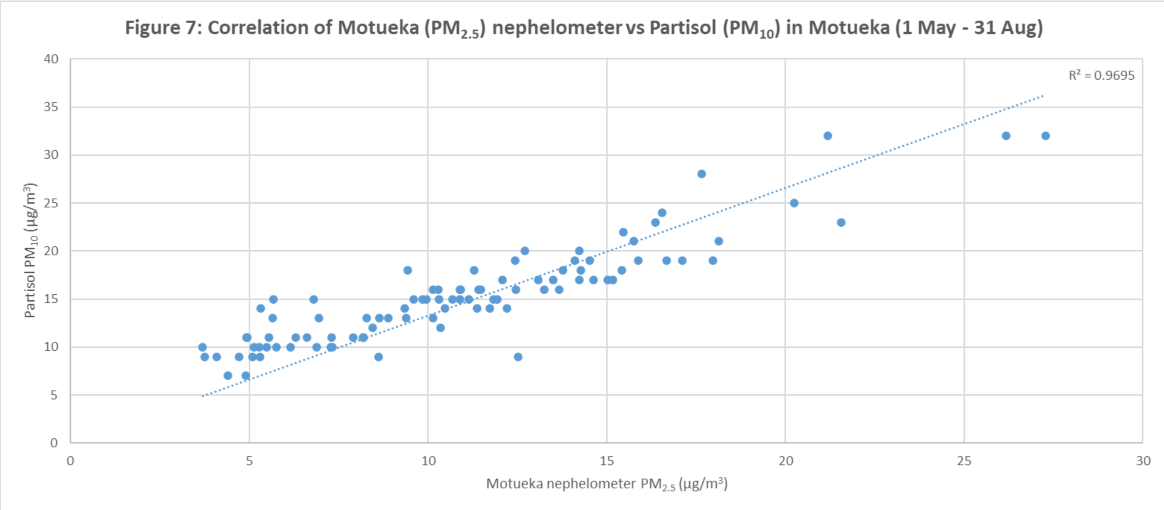


Figure 5: Comparative plot of deployed instruments post-deployment

Figures 6 and 7 below display the comparison between the 24-hour partisol results with the equivalent 24-hour nephelometer results for Motueka PM_{10} and Motueka $PM_{2.5}$ monitors which were co-located from 1 May through to 31 August.

The R^2 relationship for the PM_{10} intercomparison is 0.97 while the R^2 relationship for the $PM_{2.5}$:PM_{10} intercomparison is 0.96.





Figures 6 and 7: Comparative plot of the 24-hour average PM_{10} Partisol results with the co-located nephelometers PM_{10}(Figure 6) and $PM_{2.5}$ (Figure7)

relationship between the two types of instruments is acceptable given the different techniques (gravimetric vs nephelometric) methods used to quantify particle concentration.

2.2.2 Meteorological Instrument Selection

Four of the ES642 units were co-located with Gill Windsonic 60 ultrasonic wind speed and direction sensors which were mounted on poles which extended 900mm above the ES642 inlet height. The devices were aligned to true north during installation. The instruments were factory calibrated prior to deployment with the reported accuracy of the wind speed and wind direction being +/- 2% and +/-2º respectively.

The ultrasonic anemometers collect data at 1 second intervals (u & v vectors). The meridional and zonal components are then converted to 1 minute average data using vector averaging. The 1 minute average data has the same timestamp as the associated ES642 data to enable direct comparison.

2.3 Site Selection

The Tasman District Council identified their preferred locations during the pre-planning phase of the deployment in conjunction with Mote limited. Apart from the monitor at Riwaka North which was solar powered, all remaining instruments were mains powered with RCD trip devices in the event of any fault developing.

Instruments were generally positioned between 2 and 3 metres above ground level where possible and associated wind speed and direction monitors were positioned approximately 1 metre above the nephelometers.

A location map depicting the location of the instruments is shown in **Figure 8**.

Figure 8: Location map of monitors in the Riwaka, Brooklyn and Motueka areas during the monitoring network deployment.

3.0 RESULTS

Locations where powered instruments were installed involved contacting the landowner in advance and obtaining their prior agreement.
Landowners/occupiers provided approval to house the instrument and were given a food voucher for a local supermarket upon the initial installation along with a second food voucher when the instrument was removed.

These vouchers were provided to compensate the landowners and occupiers for the inconvenience of having an instrument on their property and also in recognition of the small amount of electricity consumed by the device while it was operational.

3.1 Data capture rate

On 28 April, the 7 Dustmotes were installed at the TDC monitoring site in Motueka. These devices operated continuously until 12 May when 5 of the units were removed and relocated to the monitoring sites identified in Figure 8 above. The installations were completed by 15 May and data was collected from the devices up until their eventual decommissioning in September.

Part way through the deployment on 16/17 July, the area experienced a period of unusually intense rainfall and surface flooding which resulted in widespread power outages across the Region. Moisture in the powersupply impacted on the co-located nephelometers at Motueka and also the unit at Riwaka West and approximately 18 days of data was lost until repairs were able to be made. Total data capture rates are shown in **Table 1** below.

Table 1: Instrument deployment details and data capture rate

Instrument	Target days[1]	Actual Days[1]	Data capture rate (%)	Total days[2]	Comment
RIWAKA WEST	123	102	83	118	Power trips resulted in data loss
RIWAKA EAST	123	121	98.4	172	
BROOKLYN	123	120	97.6	171	
MOTUEKA PM10	123	99	80.5	150	Moisture in plug caused data loss
RIWAKA CENTRAL	123	122	99.2	145	
MOTUEKA PM2.5	123	99	80.5	150	Moisture in plug caused data loss
RIWAKA NORTH	123	123	100	174	

[1] Number of days between 1 May and 31 August 2021
[2] Total days of data collected (28 April – 18 October)
Yellow refers to units which experienced data loss during the study period

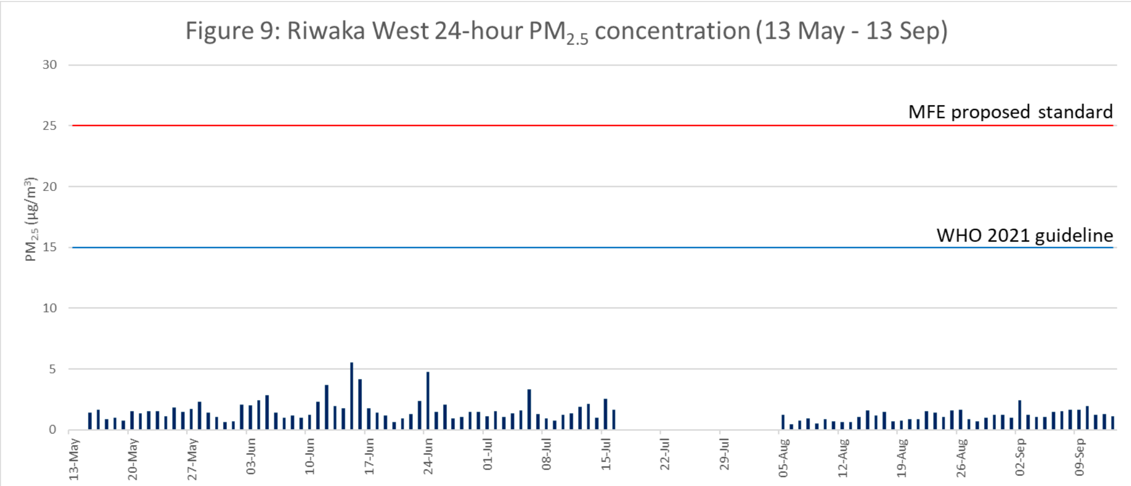
Overall data capture rates for the period between 1 May and 31 August were 91.3%. If we exclude the co-located instruments at Motueka which were impacted by moisture in the plugs following heavy rain during 16/17 July, the data capture rate for field deployed instruments in Riwaka/Brooklyn rises to 95.6%.

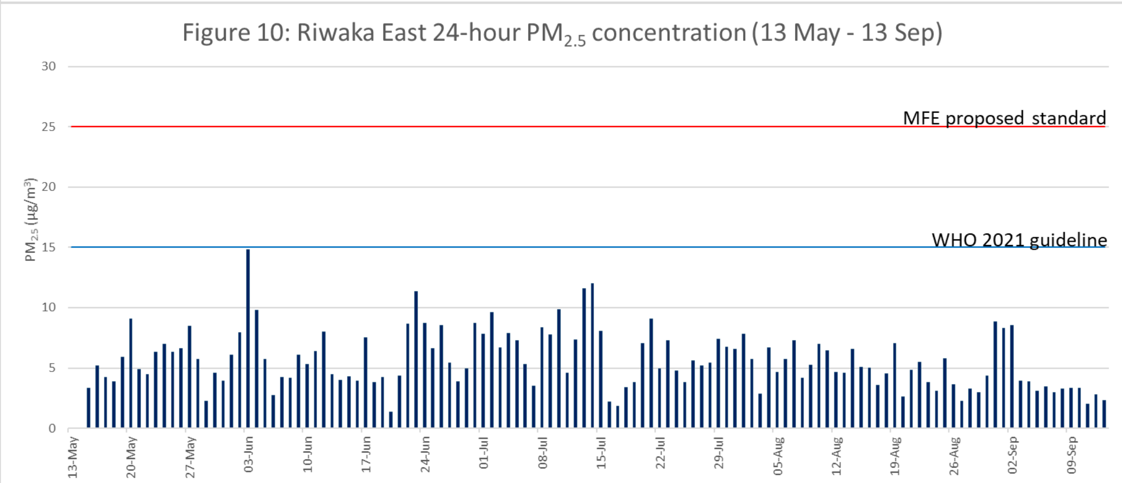
As mentioned previously, due to COVID19 travel restrictions, the network continued to operate through September with some instruments continuing to operate until 18 October and the data has been included and validated at no additional cost to Tasman District Council.

A validated spreadsheet containing the 1 minute and 24-hour average data from Riwaka accompanies this report. The spreadsheet is named **Riwaka_Data_V1.1.xlsx.**

3.2 $PM_{2.5}$ results

The following series of graphs reveal the daily maximum 24-hour $PM_{2.5}$ concentration for each of the monitoring stations. Comparisons are made against the proposed 2020 National Environmental Standard for $PM_{2.5}$ of 25µg/m3 (24-hour)[2], and the more recent 2021 World Health Organisation guideline of 15µg/m3 (24-hour).





[2] Ministry for the Environment. 2020. Proposed amendments to the National Environmental Standards for Air Quality: particulate matter and mercury emissions – consultation document. Wellington: Ministry for the Environment.

Figure 11: Brooklyn 24-hour $PM_{2.5}$ concentration (13 May - 13 Sep)

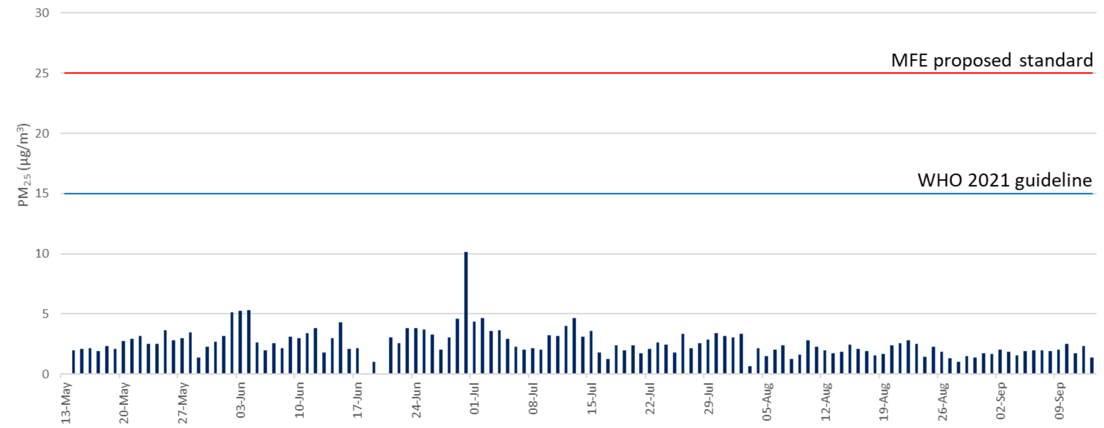


Figure 12: Riwaka Central 24-hour $PM_{2.5}$ concentration (13 May - 13 Sep)

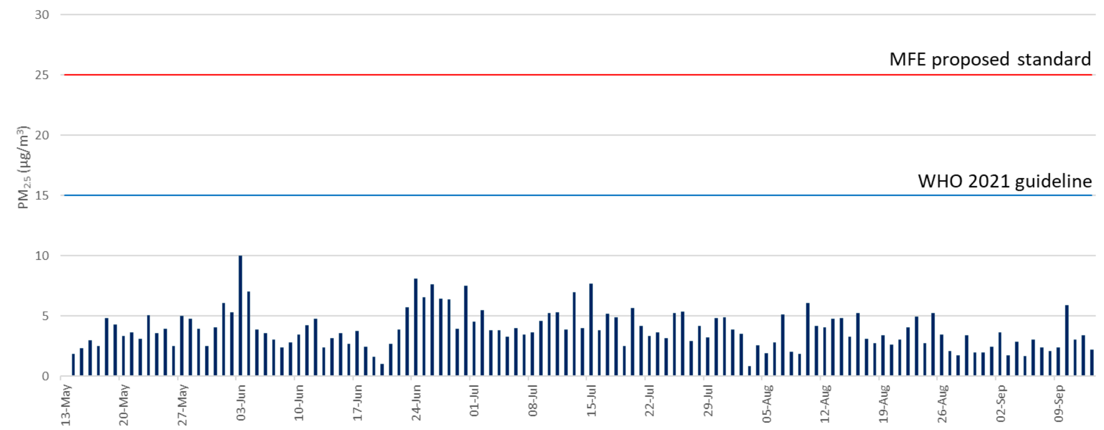
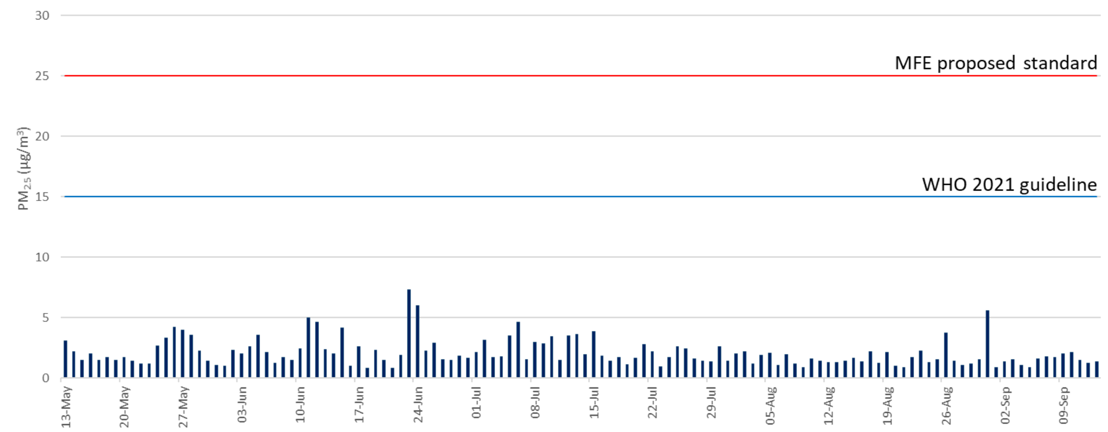
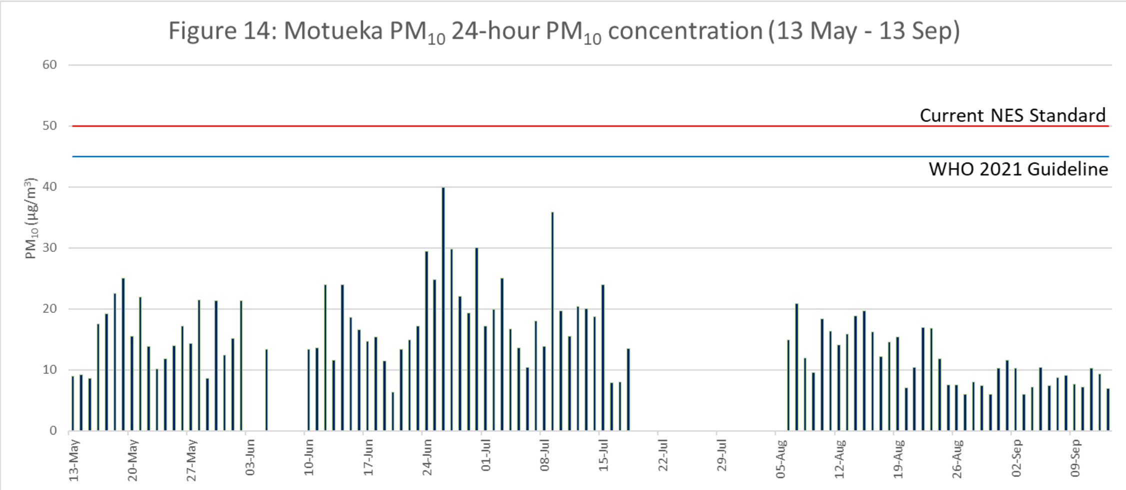
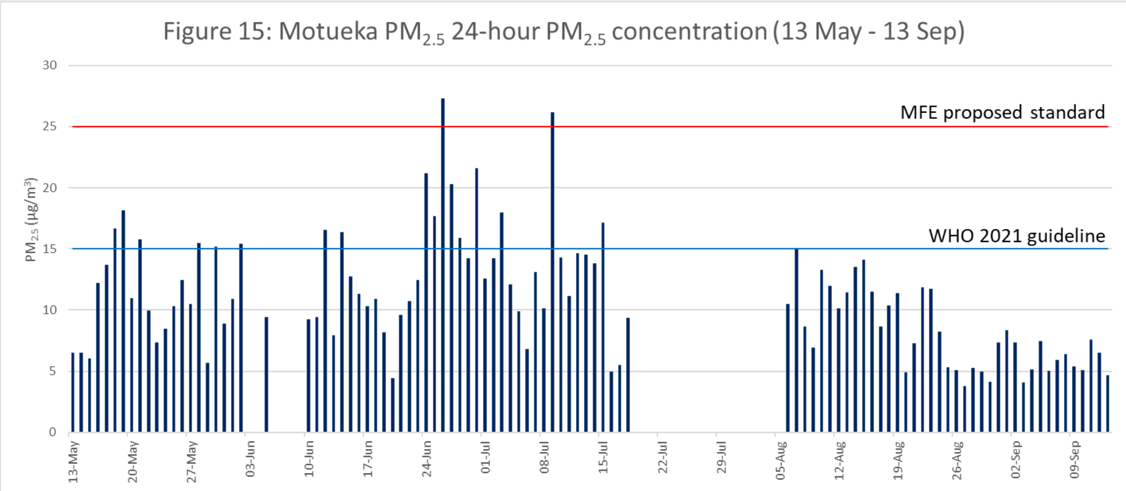


Figure 13: Riwaka North 24-hour $PM_{2.5}$ concentration (13 May - 13 Sep)



Figures 9 through 13. Plots of 24-hour average $PM_{2.5}$ concentration for each instrument. Note periods where less than 75% of the valid data was present have been left blank. The red line indicates the proposed 24-hour National Environmental Standard for $PM_{2.5}$ (25 µg/m³) while the blue line indicates the World Health Organisation 2021 guideline (15 µg/m³).





Figures 14&15: Plot of 24-hour average PM_{10} and $PM_{2.5}$ concentration for each instrument at Motueka. Note periods where less than 75% of the valid data was present have been left blank. The red line indicates the present 24-hour National Environmental Standard for PM_{10} (50 µg/m^3) and the blue line indicates the World Health Organisation 2021 guideline (45 µg/m^3).

Figures 9 to 15 reveal that aside from the co-located instrument in Motueka, all field instruments in the Riwaka/Brooklyn area complied with the proposed 24-hour National Environmental Standard for $PM_{2.5}$ and the 2021 World Health Organisation 2021 24-hour guideline for $PM_{2.5}$.

The highest 24-hour average $PM_{2.5}$ concentration of any monitor in the Riwaka/Brooklyn area during the study period was 14.8 µg/m^3 measured at Riwaka East on 3 June which was well below the proposed National Environmental Standard for $PM_{2.5}$ of 25µg/m^3.

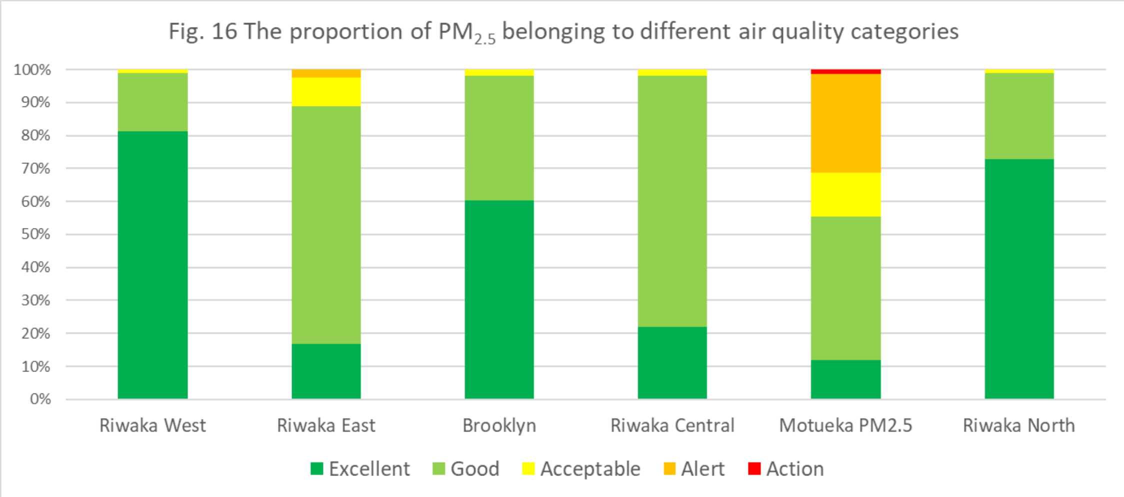


Figure 16: The proportion of time each site spent in each air quality category for the proposed 2019 MfE $PM_{2.5}$ Standard (MfE Environmental Performance Indicator (EPI) programme air quality indicators (2002).

The air quality in the Riwaka/Brooklyn area was either good or excellent for between 89 and 99% of the duration of the field sampling campaign.

Figure 16 above demonstrates that the site with the lowest average $PM_{2.5}$ concentration for the duration of the study was the Riwaka West site, which as will be covered later, experienced katabatic cold flow drainage that transported clean air from higher altitudes down the sides of the valley and maintained a very good level of air quality during the study period.

Table 2 below displays the co-efficient of variation between each of the sites for the period between 15 May through to 13 September 2021. The values provided are based on the 24-hour average data and provide an indication of the degree of similarity between sites during the investigation.

Table 2: Co-efficient of variation between each of the 7 sites

	RIWAKA WEST	RIWAKA EAST	BROOKLYN	RIWAKA CENTRAL	RIWAKA NORTH	MOTUEKA PM2.5	MOTUEKA PM10
RIWAKA WEST		0.71	0.74	0.74	0.81	0.69	0.70
RIWAKA EAST	0.71		0.87	0.88	0.8	0.86	0.86
BROOKLYN	0.74	0.87		0.89	0.74	0.85	0.85
RIWAKA CENTRAL	0.74	0.88	0.89		0.76	0.89	0.89
RIWAKA NORTH	0.81	0.8	0.74	0.76		0.72	0.72
MOTUEKA PM2.5	0.69	0.86	0.85	0.89	0.72		0.99
MOTUEKA PM10	0.70	0.86	0.85	0.89	0.72	0.99	

The coefficient of variation describes the extent to which one site agrees with another or put another way the proportion of variation at one site (dependant) that can be explained by the variation at another (independent) site.

A value of “1” means that two sites completely agree with each other while a value of “0” means that two sites behave completely independently.

The values have been shaded with darker colouration indicating a stronger relationship than a lighter colouration to assist with visual interpretation of the data. Green shading has been used to highlight variation in the Riwaka/Brooklyn area while blue shading has been used to highlight the variation between the monitors in Motueka and Riwaka/Brooklyn.

In an air quality context, these tables can be used to identify whether parts of an airshed or even different airsheds behave in the same way and whether one or more monitoring sites could be representative of the entire airshed or even other airsheds in the region.

By examining the strength of the relationship between instruments and also the change in relationships between sites, it is possible to deduce information about the sources of particulate impacting a given location.

If, for example we were exploring whether open burning was the primary source of the particulate then it follows that we might expect to observe the following:

- Open burning typically commences during the day
- Particulate emissions tend to be higher during the day when compared with domestic home heating where emission are typically higher in the morning and evening.
- Open burning generally has a local effect. That means that if open burning was occurring on a frequent basis, then there would be a poor relationship (<0.5) between monitors in Riwaka/Brooklyn and those in Motueka.
- With open burning there is often a strong relationship between wind speed and direction and very high particulate concentration whereas emissions from domestic home heating tend to become more evident during very light winds and cool/cold weather.

Conversely if domestic home heating was the primary source of particulate then we might expect to observe the following:

- Unlike open burning, there is usually a moderate relationship between air temperature and 24-hour average particulate concentrations.
- There will be reasonably high levels of agreement (>0.7) between monitoring sites even some distance from one another provided the primary emission source consists of domestic home heating.
- Domestic fires typically exhibit more minute to minute variation in particulate concentration than open burning. This is often a function of distance to the source – so adding fuel to a domestic fire may result in a short term increase in emissions which is characterised by short duration spikes in the one minute data recorded by the nearby monitor. Open burning tends to occur some distance from residential dwellings and so changes in particulate concentrations tend to occur more gradually under consistent meteorological conditions.

Table 2 confirms that that a moderate relationship exists between many of the sites and when consideration is given to previous observations suggests:

1. That the emission sources are linked. Given the geographic spread of the monitoring stations, this suggests that most of the variation at the monitoring sites probably relates to home heating rather than that of other sources.

2. That the monitoring station at Motueka has reasonable agreement with monitors in Riwaka Central – however the magnitude of the variation differs between the sites. This suggests that both sites experience increased emissions during strong inversion conditions, although the magnitude of this increase is much higher in Motueka than in Riwaka. This also suggests that home heating is the primary source of particulate in these two locations.

3. In general, the Riwaka West and Riwaka North sites which are both situated near the base of the Takaka Hilll had slightly weaker relationships overall with other sites (R^2 0.69-0.81) compared to the Brooklyn, Riwaka East and Riwaka Central sites (R^2 0.85-0.89). It is also noted that the Riwaka West and Riwaka North sites generally measured lower levels of particulate than other sites during the study period. An analysis of the meteorological data from Section 3.3 below identified different meteorological conditions occurred at Riwaka West and Riwaka North under inversion conditions suggesting slightly different dispersive mechanisms may apply at these sites.

3.3 Effect of meteorology

Four of the instruments used in this study were fitted with ultrasonic wind speed and direction sensors. This type of sensor is much more sensitive at lower wind speed than traditional cup and vane anemometers and recorded wind speed and direction at 1 second intervals during the study. This one second data was converted to 1 minute (vector) averaged wind speed and direction to enable comparison with the one minute data collected by the $PM_{2.5}$ nephelometers.

Windrose plots for each of the 4 monitoring stations are shown in Figures 19 to 22.

Figure 19: Riwaka West meteorological sensor

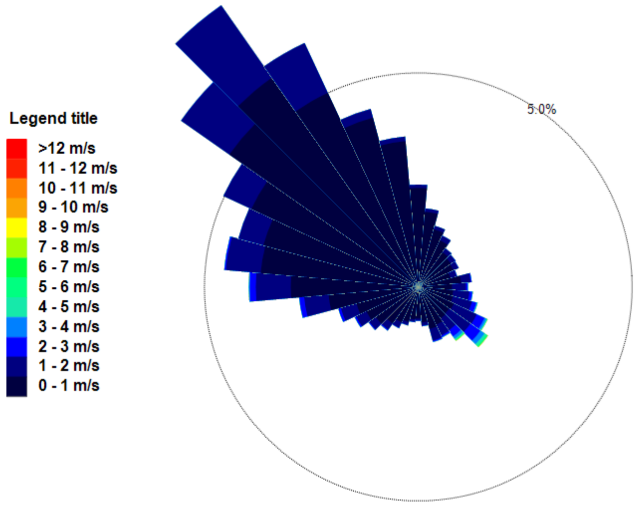


Figure 20: Riwaka East meteorological sensor

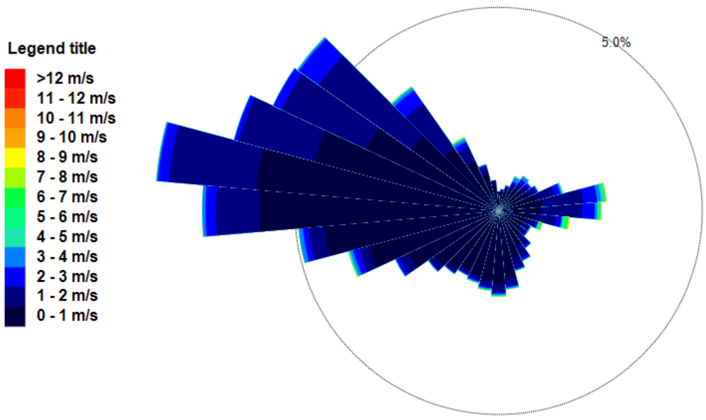


Figure 21: Brooklyn meteorological sensor

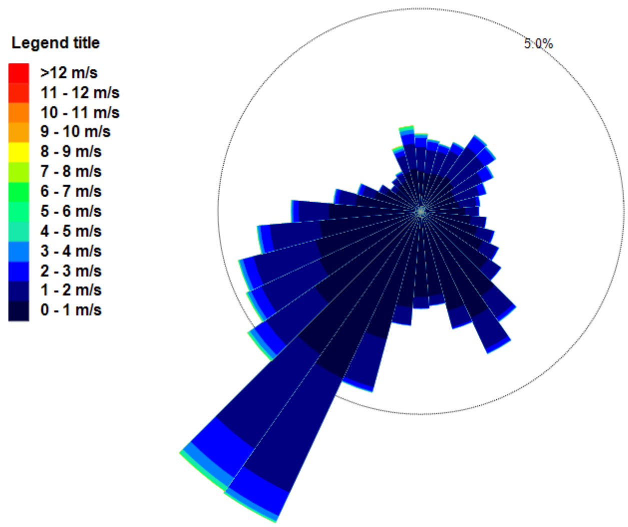
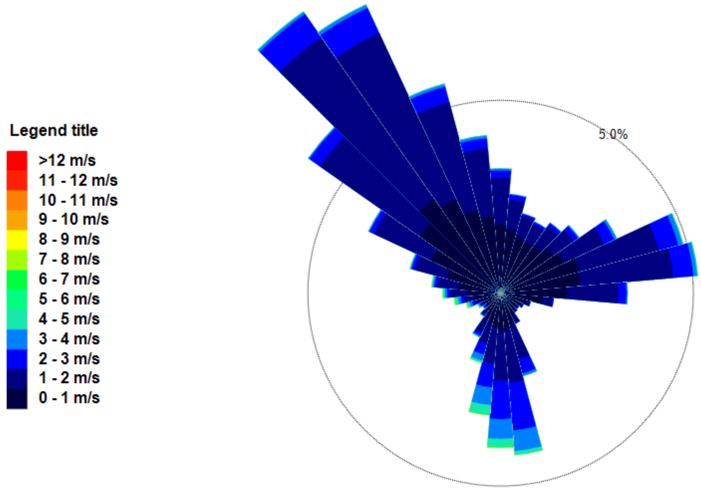


Figure 22: Riwaka North meteorological sensor



Figures 19 – 22: Windrose plots at each of the four monitoring sites which included anemometers covering the period from 28 April through to 18 October 2021. Note that the anemometer height was typically 3 metres above ground level at each site.

Figure 23: Brooklyn Electronic Weather Station

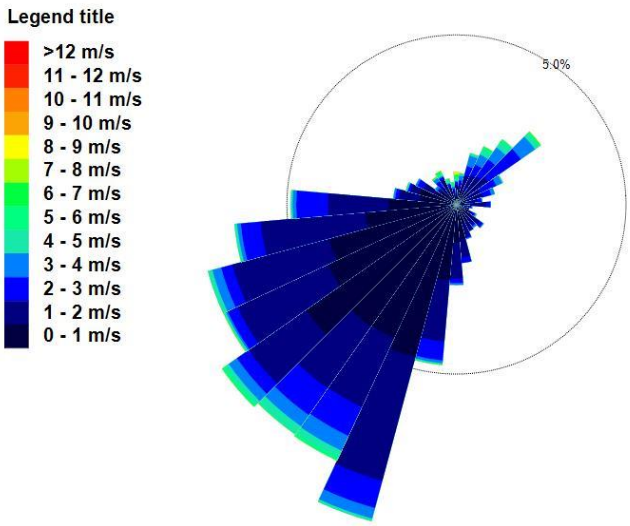


Figure 23 is a wind rose for the Electronic weather station at Riwaka which has a height of 8 metres.

The Brooklyn electronic weather station (EWS) is closest to wind monitor Brooklyn and the differences between the two sites is probably a combination of the difference in meteorological sensor height as well as the impact of structures and trees surrounding the site at Brooklyn. Nevertheless, the wind speed and direction are sufficiently similar to provide confidence that the meteorological measurements are broadly representative of each of the site locations.

The windrose plots confirm that the Riwaka/Brooklyn area was dominated by relatively low winds speeds during the study period. The variation in wind direction at different monitoring points in the study area suggests that the low wind speeds are strongly influenced by topography within the study area.

Figures 24 and 25 depict the hourly average wind speed and direction on 3 June – the date when the highest 24-hour average $PM_{2.5}$ concentrations were detected across the study area. Interestingly, this is also the date of an exceedance in the Richmond airshed. This suggests that similar meteorological conditions are driving most of the variation in $PM_{2.5}$ concentration between the sites. In this case, temperature inversion during sub-tropical high pressure systems.

The two graphs reveal the prevalence of katabatic cold flow drainage at night when downslope flows from the hills to the west dominate. The direction of this drainage is strongly influenced by proximity to local topographical features. Following sunrise the heating of the land gives rise to convective turbulence which in turn generates an onshore (easterly) breeze. Following sunset, the situation reverts.

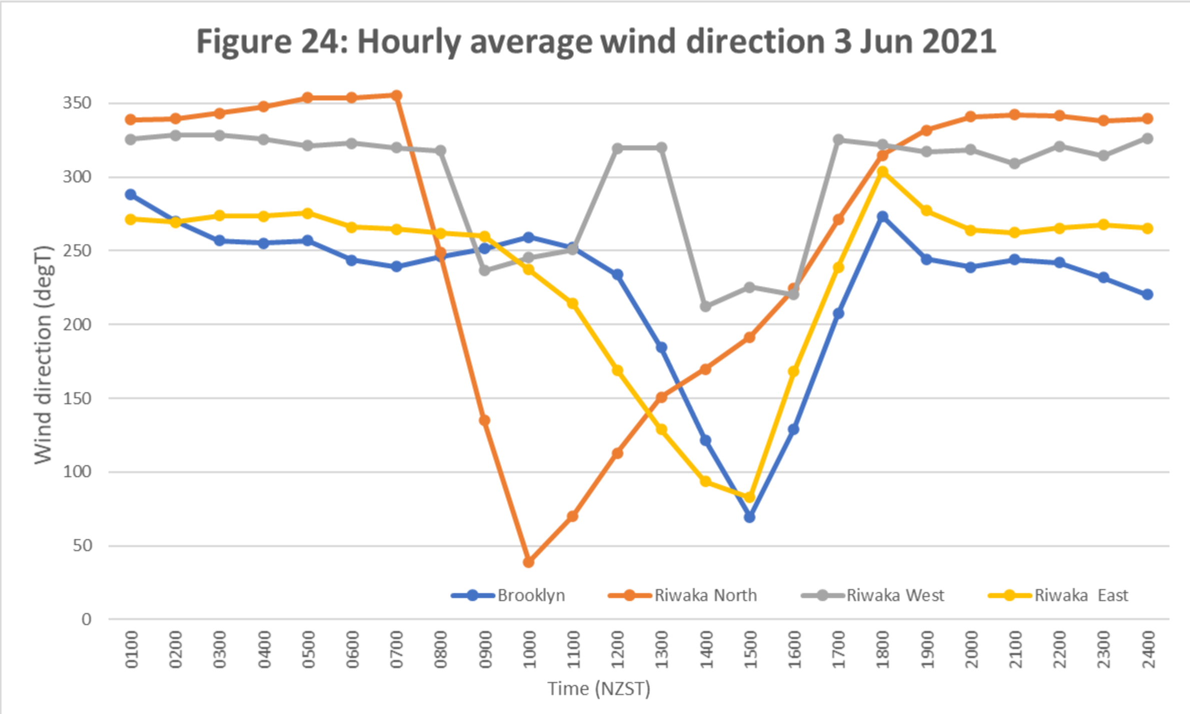


Figure 24: Plot of hourly average wind direction at each of the 4 meterological stations on 3 June 2021

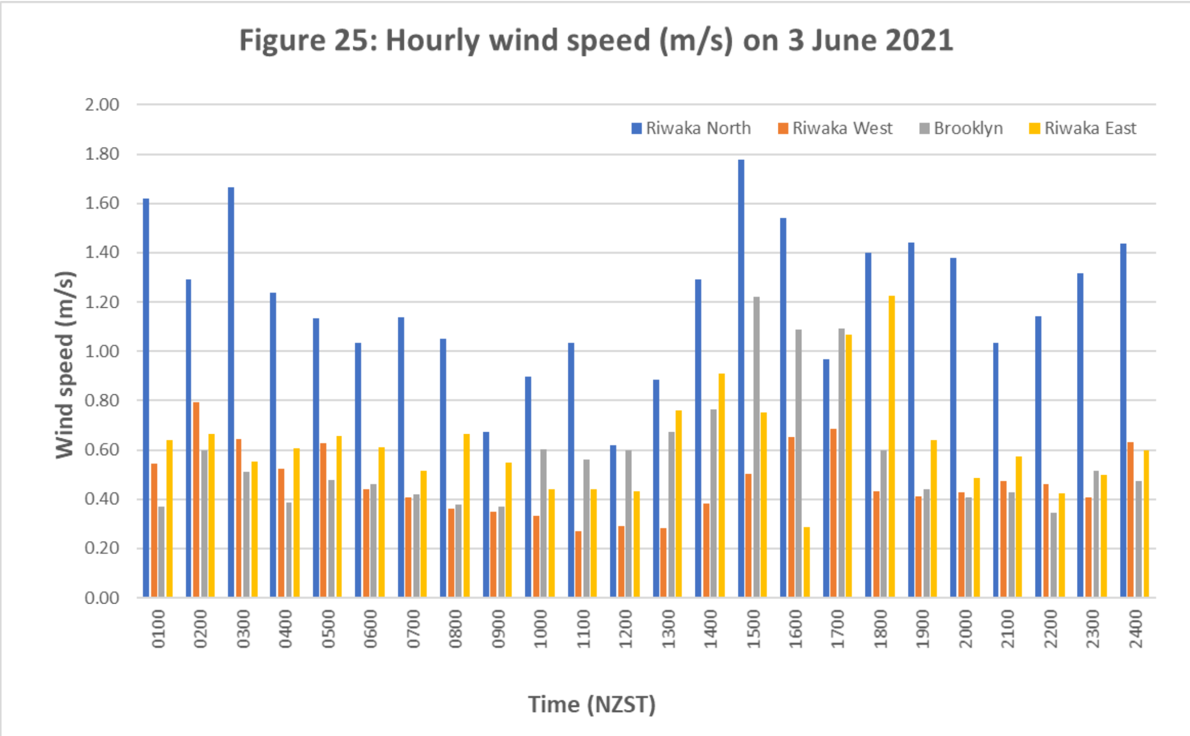


Figure 25: Plot of hourly average wind speed at each of the 4 meterological stations on 3 June 2021

A comparison of average 24-hour $PM_{2.5}$ concentration with average air temperature at Riwaka East reveals a weak relationship which is shown in **Figure 26** below.

Despite a relatively low co-efficient of determination (R^2 = 0.47), **Figure 26** suggests that the primary source of the $PM_{2.5}$ concentration in Riwaka is domestic home heating rather than outdoor burning due to the fairly consistent relationship during the study period.

If outdoor burning were the primary source of $PM_{2.5}$, we would expect to see a much weaker relationship (if at all) and multiple outliers on days when open burning was prevalent.

The time series plot shown in **Figure 27** confirms this observation. The peak $PM_{2.5}$ concentrations from domestic fires are typically observed in the early evening when families return home and light their fires. Emissions usually increase following this period until immediately prior to midnight when emissions reduce until the early hours of the morning when fires are again refuelled. The increase and decrease in emissions during this period is again characteristic of near-source domestic home heating. The pattern of emissions from outdoor burning tends to have less variability (peak to mean ratio) over these timeframes.

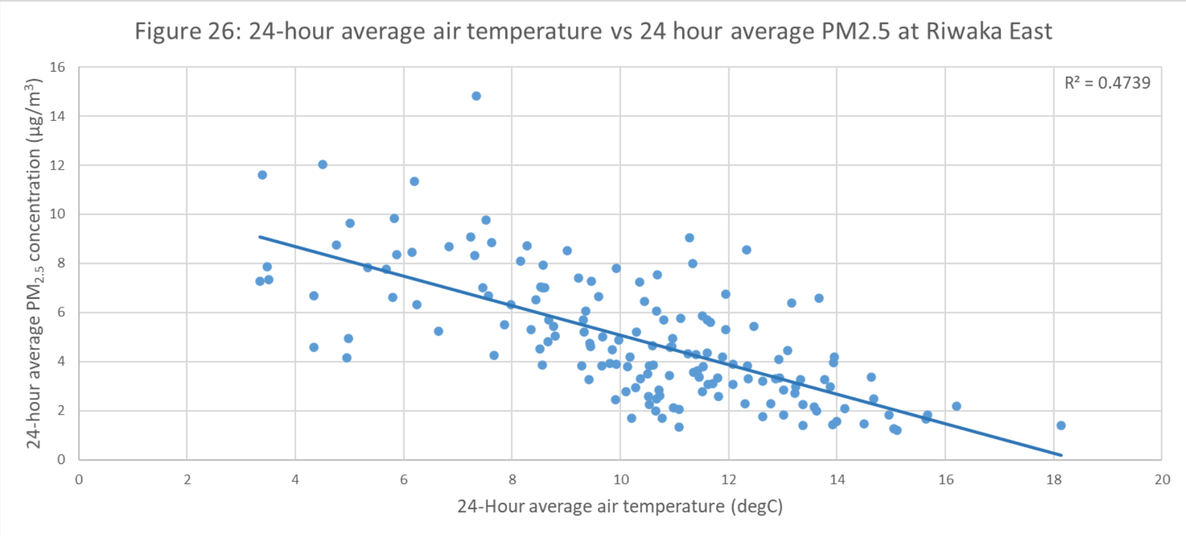


Figure 26: comparison of 24-hour $PM_{2.5}$ against 24-hour average air temperature (degC) for the period 15 May – 13 September 2021

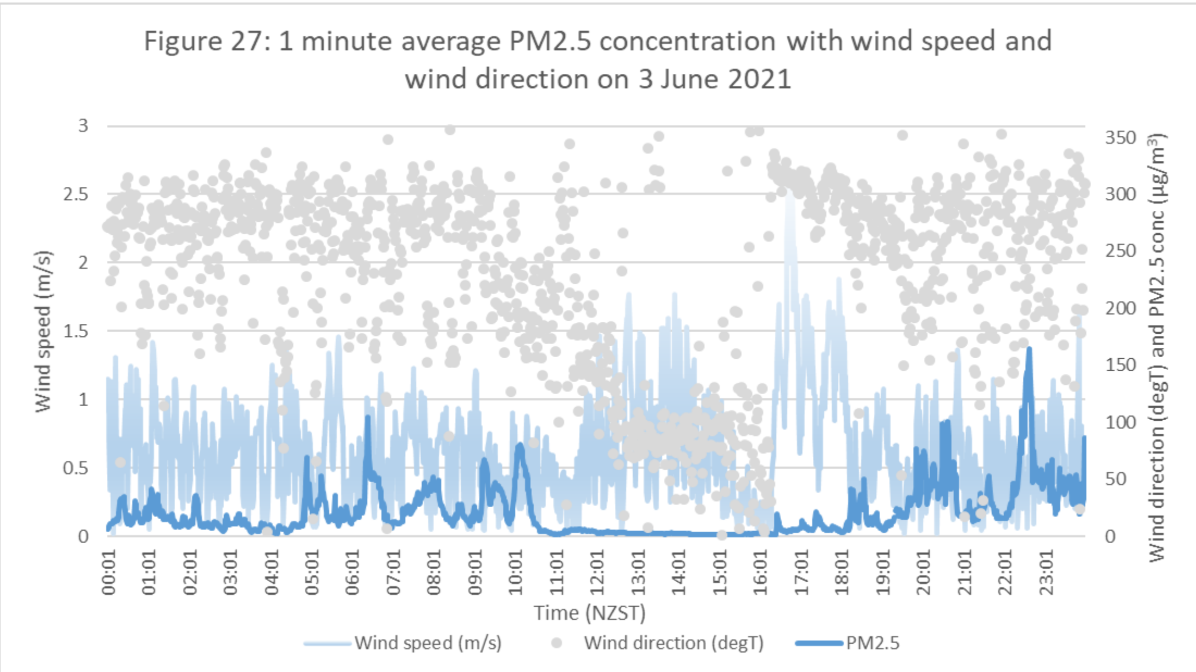


Figure 27 Plot of the 1 minute average PM2.5 concentration at Riwaka East during 3 June 2021.

Figure 28 compares the average ground temperature during the study period (15 May – 13 September) in 2021 with the previous 5 years to provide an indication as to how representative the 2021 study period was.

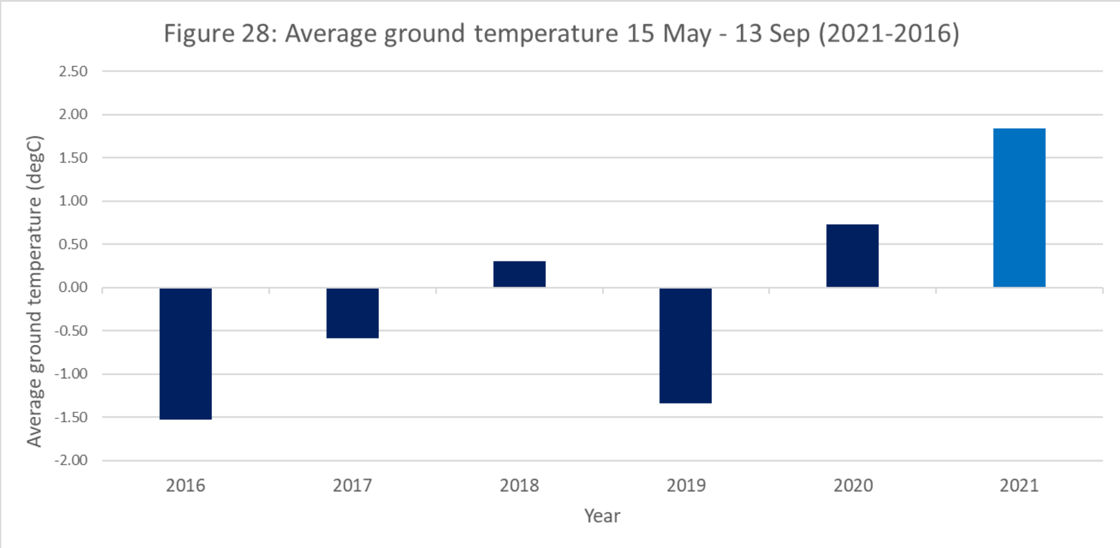


Figure 28: Comparison of the average ground temperature during the study period (15 May – 13 September) with the same period in previous years.

Figure 28 reveals that the ground temperature during the 2021 study period was 1.1 degrees warmer than the same period in 2020. A comparison of air temperature during the same period displays similar results as shown in Table 3 below.

Table 3: Comparison of average temperature measurements (15 May – 13 Sep) at Brooklyn EWS for the period 2016-2021.

Year	$Temp_{(ground)}$ average	$Temp_{(air)}$ Max	$Temp_{(air)}$ Min
2021	**1.84**	**15.44**	**3.96**
2020	0.73	14.79	3.08
2019	-1.34	13.93	2.64
2018	0.3	14.02	2.91
2017	-0.59	14.03	2.77
2016	-1.53	14.29	2.15

The magnitude of the difference is relatively minor and it is not possible to quantify with any certainty what effect the warmer 2021 temperatures may have had on 24-hour average $PM_{2.5}$ concentrations. However on the basis of the (admittedly weak) relationship between temperature and 24-hour average $PM_{2.5}$ concentration shown in Figure 26, the effect would probably have been a small reduction in average concentrations but within the margin of error for the instruments (+/- 1 $\mu g/m^3$).

One of the residents who agreed to host one of the instruments observed that the smoke concentrations were much lower this year than they had been during 2020. This is consistent with the complaints data from the Tasman District Council[3]. During the six month period

[3] Data taken from the Tasman District Council 2020 and 2021 Annual Air Quality Reports'

from 1 April 2020 through to 30 September 2020 there were 85 cross-boundary smoke nuisance complaints in the Motueka/Lower Moutere and Riwaka area. The number of complaints in the same areas during the 2021 period was on 35 representing an almost 60% reduction in the number of complaints on the same period one year earlier.

It was noted in Section 5.2.2 of the Tasman District Council 2021 Annual Air Quality Reports that:

> *"Compliance staff were advised in April 2021 that orchardists were struggling to source replacement apple tree stock. The flow on effect of this situation was that less orchard trees were removed for replacement and therefore less outdoor burns were undertaken. Anecdotal evidence from Council staff was that it 'felt' like there were less rural fires during winter particularly on the Waimea Plains and Riwaka."*

On this basis, it is concluded that the study period most likely coincided with a reduction in the amount of open burning relative to that of previous years. Furthermore, while the conclusions from this study are that the primary source of emissions in the Riwaka/Brooklyn area was domestic home heating – it is possible that the contribution of open burning to particulate concentration in the Riwaka/Brooklyn area could be much higher during a "normal" year.

For these reasons, it is considered prudent to perform some additional monitoring during the 2022 winter period. Mote have agreed to supply Tasman District Council with a $PM_{2.5}$ monitor for the duration of the 2022 winter at no cost to Tasman District Council. Mote will summarise any collected data and will provide an addendum to this report based on the ambient air quality data collected during the 2022 winter season.

4.0 CONCLUSION

Mote limited deployed a network of 7 continous nephelometers and 4 continous meteorological instruments throughout the Motueka, Riwaka and Brooklyn areas during the winter of 2021.

The data capture rate for the field deployed instruments between 15 May to 13 September 2021 was 95%, despite heavy rain and flooding on 16/17 July which resulted in some widespread power outages and subsequent data loss. Pre and post deployment collocation data confirmed all instruments were comparable (+/- 2 $\mu g/m^3$). The instruments also displayed reasonable agreement with the National Environmental Standard compliant equipment operated in Motueka.

Maximum 24-hour $PM_{2.5}$ concentrations of between 6 and 15 $\mu g/m^3$ were measured at each of the 5 instruments located in the Riwaka and Brooklyn areas during the study period. These values are all well below the proposed 24-hour National Environmental Standard of 25 $\mu g/m^3$ and just met the World Health Organisation 2021 guideline value of 15 $\mu g/m^3$.

An evaluation of the data recorded during the study found that the air quality was either good or excellent at all sites for between 89 and 99% of the time. In terms of sites, Riwaka East recorded the highest 24-hour average $PM_{2.5}$ concentration of 14.8 $\mu g/m^3$ while the instrument situated at Riwaka West recorded the best air quality with a maximum 24-hour average $PM_{2.5}$ concentration of 5.5 $\mu g/m^3$.

Wind speeds during the study remained relatively low and were typically south-westerly, although nearby topographical features appeared to have a significant effect on both wind direction and wind speed. Most sites displayed clear evidence of cold flow drainage under light winds which appeared to be the dominant dispersive mechanism at night.

The co-located PM2.5 monitor at Motueka recorded the highest 24-hour PM2.5 concentration of 27 $\mu g/m^3$ which is just above the proposed 24-hour $PM_{2.5}$ National Environmental Standard of 25 $\mu g/m^3$.

5.0 REFERENCES

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