Reefton $PM_{2.5}$ monitoring network

June-October 2021

Final report for:

West Coast Regional Council

17 December 2021

40A George Steet, Mt Eden, Auckland
www.mote.io

Acknowledgements

Mote Limited would like to thank Emma Perrin-Smith and Millie Taylor for their assistance with identifying potential monitoring locations and the provision of air quality monitoring data.

Mote limited would also like to thank the residents and businesses in Reefton 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	11 Nov 2021	**Paul Baynham**	**Brett Wells**	V1 Draft report reviewed
2	17 Nov 2021	**Paul Baynham**		V1.2 Revised draft
3	17 Dec 2021	**Paul Baynham**		V1.3 Final version issued

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1.0 EXECUTIVE SUMMARY

15 air quality monitors were deployed in Reefton between 25 June and 6 October 2021 as part of a high resolution air quality monitoring network. The purpose of the network was to measure the concentration of particulate matter across Reefton and determine what the variation in concentration was across the town

Mote limited deployed a network of 15 monitors throughout Reefton between 25 June and 6 October 2021. The bulk of the instruments were operational as of 15 June and the study concluded on 6 October. Despite damage to one unit, the overall data capture rate for the network was acceptable at 94%.

The results of the monitoring identified a peak 24 hour $PM_{2.5}$ concentration of 37µg/m^3 and found that 9 of the 15 monitors recorded peak PM2.5 concentrations at or above the proposed draft 24 hour standard of 25 µg/m^3.

The study found that while there was day to day variation in particulate concentrations, overall concentrations of particulate matter were reasonably consistent throughout central Reefton. Higher concentrations were typically measured near the centre of town while concentrations decreased towards the town boundary.

2.0 PROJECT OUTLINE

Mote were contacted by Emma Perrin-Smith on 15 June 2021 to deploy multiple real-time ambient air quality monitoring units in order to establish an ambient monitoring network in Reefton over a two month period during the 2021 winter.

The focus of the investigation was to deploy a series of high resolution real time air quality monitors throughout the Reefton township in order to determine the spatial variation in particulate concentrations in Reefton. The network was intended to be deployed for a two month period intended to coincide with cold winter weather when emissions from home heating were expected to peak.

2.1 Project location

Reefton is a small town situated on the West Coast of the South Island and is home to a population of 924 residents with a total of 447 households[1].

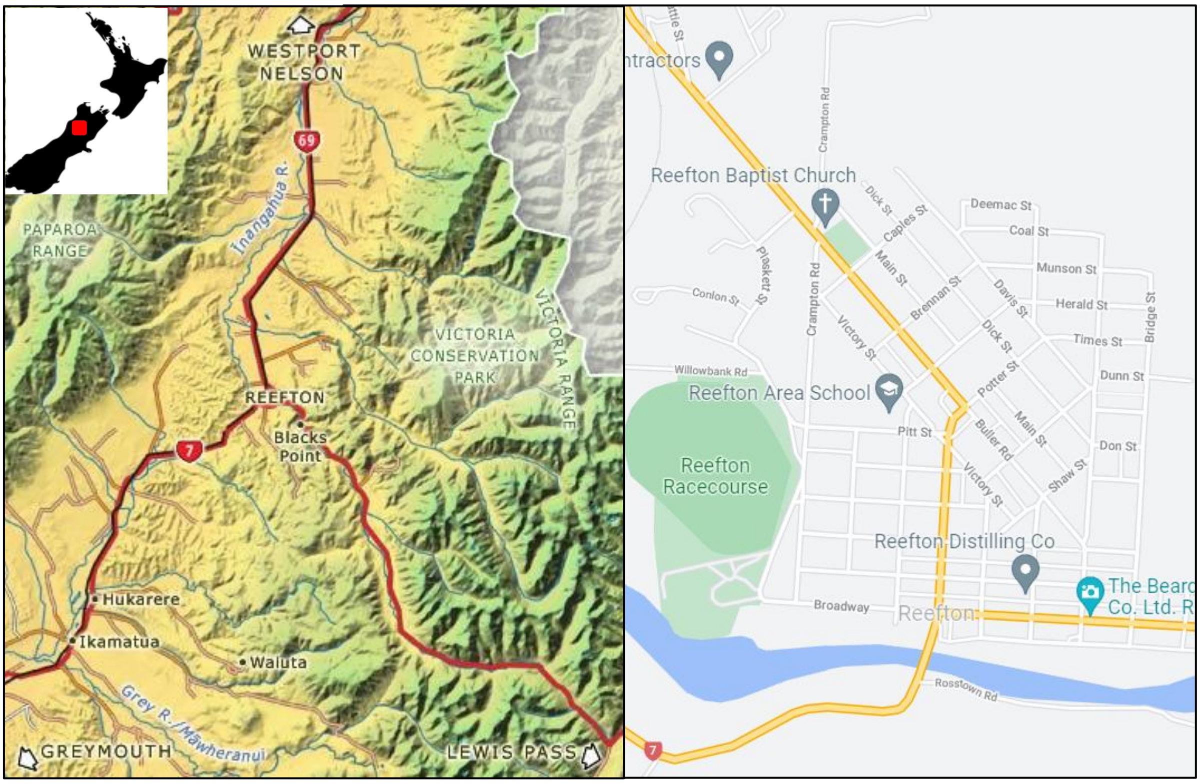


Figure 1: Location map of Reefton, West Coast, New Zealand (https://teara.govt.nz/en/map/20973/reefton)

The township of Reefton has several coal mines in the immediate vicinity and this is reflected in the higher proportion of households using coal for home heating (51.5%) than the rest of New Zealand (1.2%)[2] as shown in Figure 2 below.

[1] 2018 census data

[2] Data from the 2018 New Zealand Census

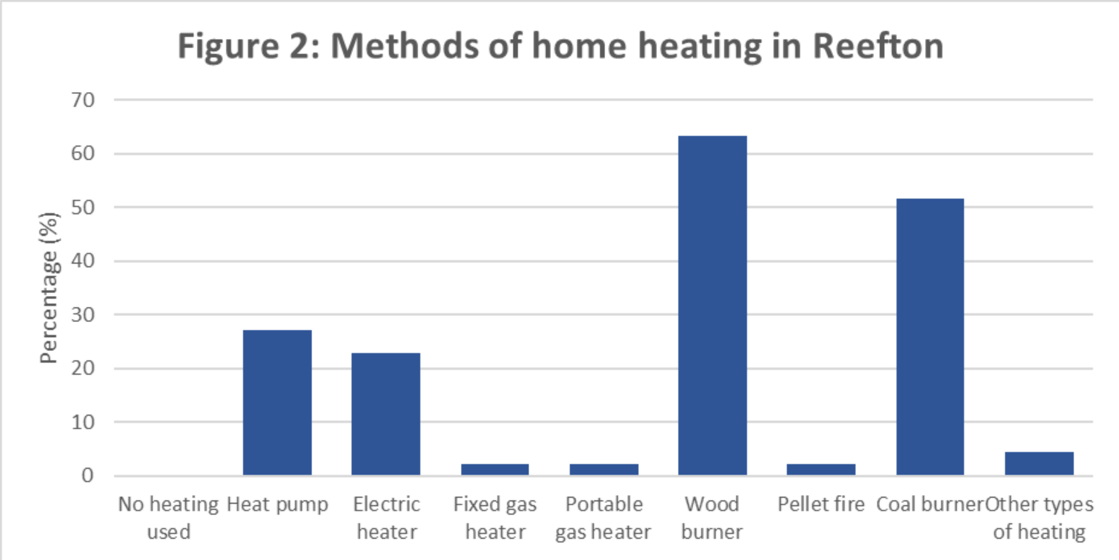


Figure 2: Graph displaying the proportion of different home heating methods in Reefton based upon the 2018 Census data. Note that the some households contain more than one heating type and/or mutifuel burners.

2.2 Instrument Selection

Two different types of instruments were selected – both optical nephelometers. The first 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 timestamp accuracy utilises the GPS satellite array and is typically accurate to within 0.1 seconds. Every 10 minutes, the collated data was transmitted via a privately provisioned cellular network to a secure cloud based server.

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.

Figure 3: Photograph of an ES642 unit collocated alongside the WCRC instruments at Reefton.

The second type of instrument used was a solar powered nephelometer referred to as a "minimote".

This unit consists of modified dual SDS011 side-scattering nephelometer units with heated inlets. The inlet fans were removed and a long life xavitech pump used to maintain a constant flow through the nephelometer units. Flow rates for each device were set following installation and were nominally 0.6 litres per minute (+/- 0.05 litres per minute). Flow rates were also checked following the deployment and confirmed to be within 5% of the initial flow flow rate for each instrument.

Both nephelometers produce 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. The minimote is powered using a monocrystalline solar panel which uses a small MPPT solar charge controller specifically designed to operate at the voltages required for the LiPo battery storage.

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.

The instruments were placed in a light smoke chamber and then co-located for a 7 day period prior to installation to verify that the instrumental concentrations were comparable (within +/-2% over a range of 1-500 μg/m^3. At the conclusion of the study, this process was repeated and all instruments were found to comply with the +/-2% threshold except for MM5 which had been vandalised. The data from this instrument after the vandalism was removed from the record during the data validation process.

Figure 4: Photograph of a minimote mounted on a lamp post in Reefton.

2.3 Site Selection

The West Coast Regional Council (WCRC) provided a list of preferred locations and attempts were made to position instruments as close to these sites as possible. It should be noted that to minimise health and safety risks, solar powered devices were mounted between 2.5 and 3 metres above ground level and secured firmly to a lamp post or similar.

Locations where powered instruments were installed involved contacting the landowner in advance and obtaining their prior agreement. All landowners/occupiers 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.

Part way through the deployment, the area experienced a period of unusually intense rainfall and surface flooding and two units needed to be repositioned approximately 1 metre above the original locations in order to avoid flooding. On both occasions, the land occupiers concerned were given additional vouchers to compensate for the inconvenience associated with instrument relocation.

A location map depicting the location of the instruments and their designation code is shown below in Figure 5 below. The location of the powered instruments is approximate. Units DM13 and DM14 were repositioned higher on 17 July to minimise the risk of water ingress into the instrument power supply.

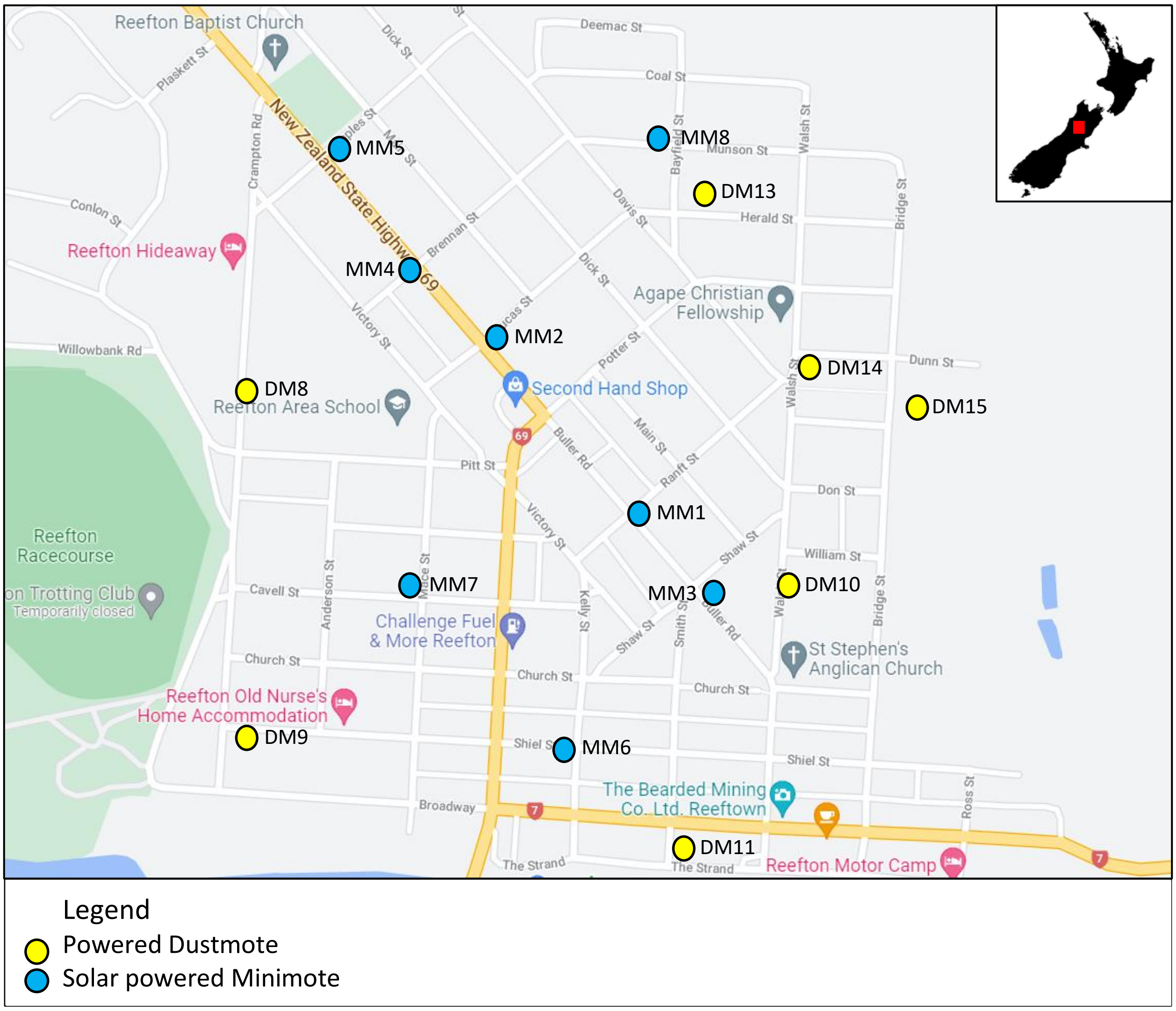


Figure 5: Device location map for Reefton, June – October 2021

3.0 RESULTS

3.1 Data capture rate

On 26 June, the first 4 initial mains powered units were installed.

Approximately 3 weeks later on 15 July an additional 3 powered units and another 8 solar powered units were deployed bringing the total number of installed devices to 15. These units operating from 15 July through until decommissioned on 7 October representing approximately 83 days of operation.

Unfortunately on 4 August, one solar powered monitor (MM5) was vandalised and ceased functioning. With the exception of this event, the remaining devices continued to function well and the total data capture rate for the period from 15 July through to 7 October was 94%.

Table 1: Instrument deployment details and data capture rate

Instrument	Type	Start date	End date	No. days	Data capture rate (%)	Comment
MM1	Minimote solar	16 jul	7 Oct	82	100	
MM2	Minimote solar	16 jul	7 Oct	78	95.1	
MM3	Minimote solar	15 jul	7 Oct	82	98.8	
MM4	Minimote solar	16 jul	7 Oct	82	100	
MM5	Minimote solar	16 jul	4 Aug	18	22.0	Vandalised 4 Aug
MM6	Minimote solar	16 jul	7 Oct	82	100	
MM7	Minimote solar	16 jul	7 Oct	79	96.3	
DM8	Dustmote mains	24 Jun	7 Oct	104	100	
DM9	Dustmote mains	24 Jun	7 Oct	104	100	
DM10	Dustmote mains	24 Jun	7 Oct	104	100	
DM11	Dustmote mains	25 Jun	7 Oct	103	100	
MM12	Minimote solar	15 jul	7 Oct	83	100	
DM13	Dustmote mains	16 jun	7 Oct	82	100	Raised by 1m 17 Jul
DM14	Dustmote mains	15 jun	7 Oct	83	100	Raised by 1m 17 Jul
DM15	Dustmote mains	15 jun	7 Oct	83	100	

A spreadsheet containing the 10 minute and 24 hour average $PM_{2.5}$ data from Reefton is available. The spreadsheet is named **Reefton_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. It should be noted that Dustmotes 8, 9, 10 and 11 were installed on 24/25 June so the data for these instruments covers an additional 21 days before the remaining instruments commenced operation.

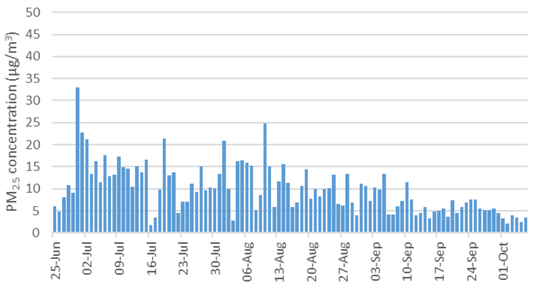


Fig 6. DM8 : 24 hour $PM_{2.5}$ concentration

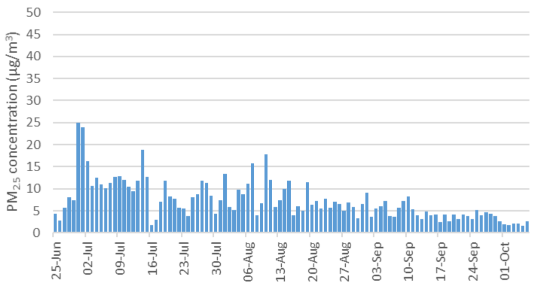


Fig 7. DM9 : 24 hour $PM_{2.5}$ concentration

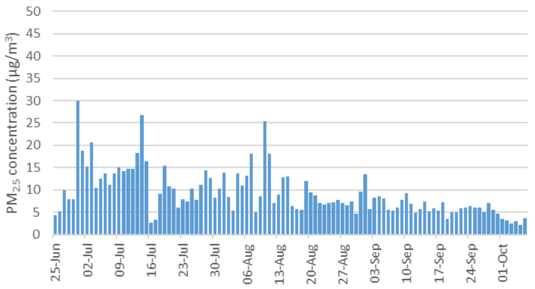


Fig 8. DM10 : 24 hour $PM_{2.5}$ concentration

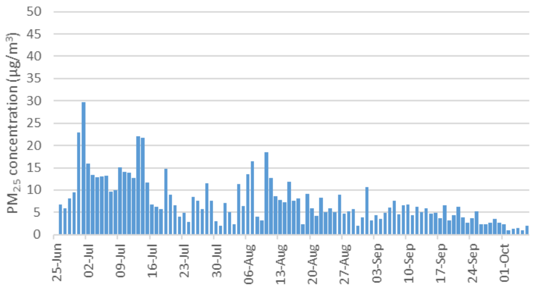


Fig 9. DM11 : 24 hour $PM_{2.5}$ concentration

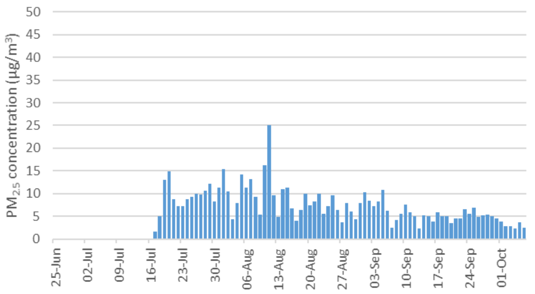


Fig 10. DM13 : 24 hour $PM_{2.5}$ concentration

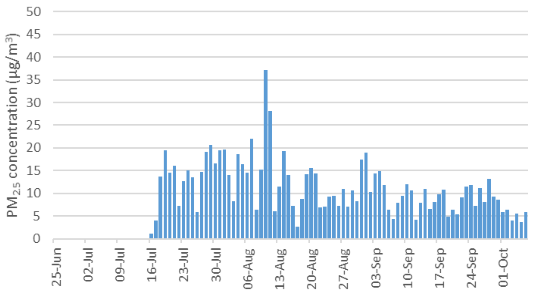


Fig 11. DM14 : 24 hour $PM_{2.5}$ concentration

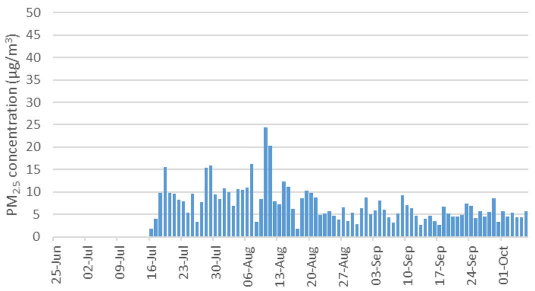


Fig 12. DM15 : 24 hour $PM_{2.5}$ concentration

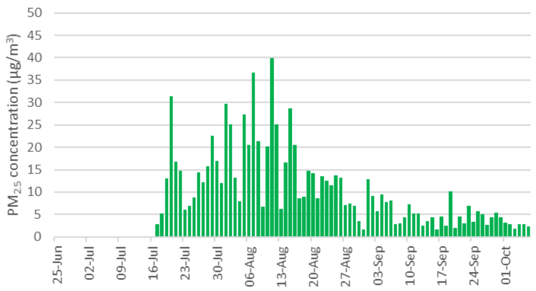


Fig 13. MM1 : 24 hour $PM_{2.5}$ concentration

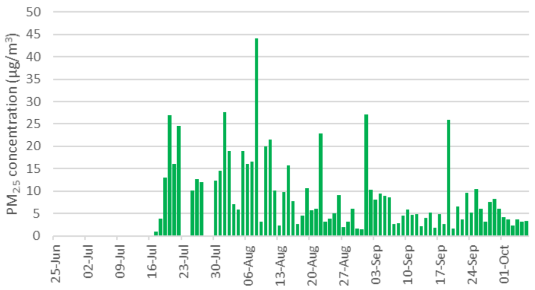


Fig 14. MM2 : 24 hour $PM_{2.5}$ concentration

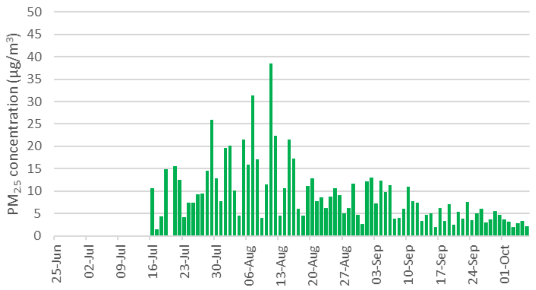
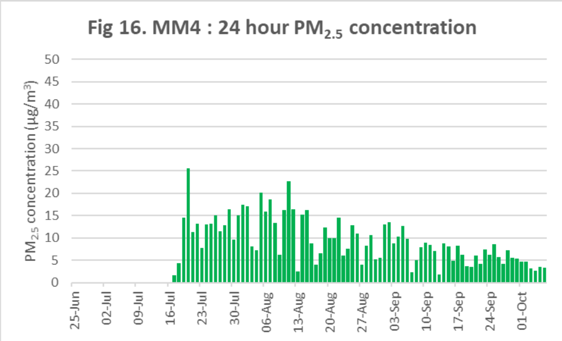
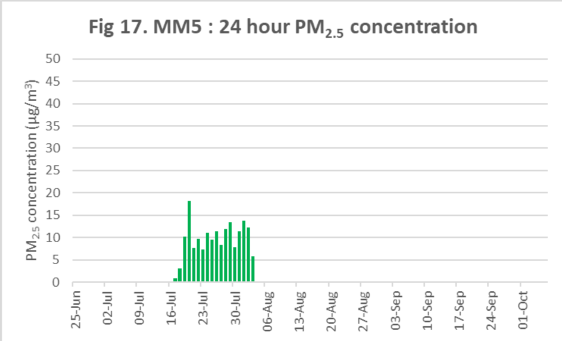
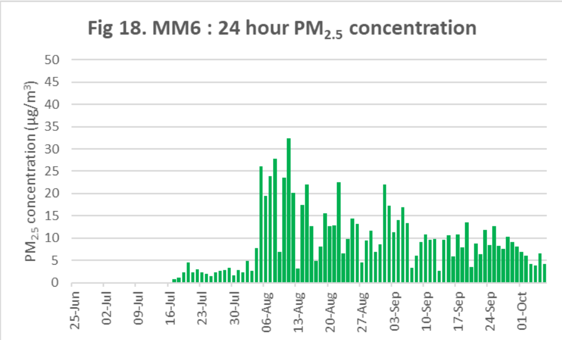
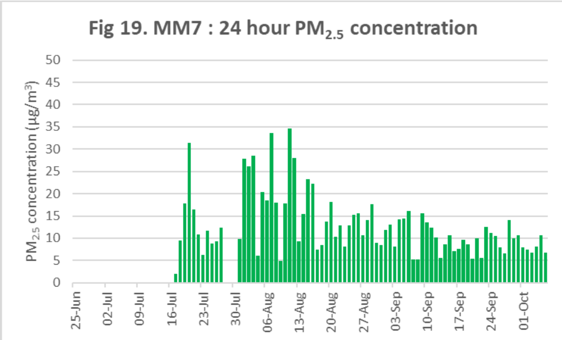


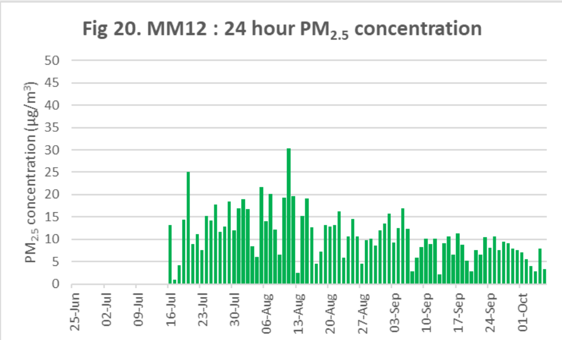
Fig 15. MM3 : 24 hour $PM_{2.5}$ concentration











Figures 6 through 20. Plots of 24 hour average $PM_{2.5}$ concentration for each instrument. Blue graphs denote Dustmote instruments, while green graphs represent Minimote instrumentation. Note periods where less than 75% of the valid data was present have been left blank.

The plots reveal generally similar variations between the instruments although the magnitude of the variation does change between instruments. Interestingly, the instruments mounted near the eastern town boundary (DM10, DM14, DM15 and MM3) while similar, display different variation in peak $PM_{2.5}$ concentrations to those near the center or western town boundary. Based upon the topography, it is possible that katabatic cold flow drainage may play a role in dispersing emissions during inversion conditions in this part of Reefton.

Aside from the eastern monitors previously identified, the remaining devices display generally similar patterns of behaviour indicating that the Reefton airshed is relatively homogenous.

Table 2 below displays the maximum 24 hour $PM_{2.5}$ concentration measured at each instrument during the study. Most of the instruments recorded similar elevated $PM_{2.5}$ concentrations during one of 3 dates during the study period being 30 Jun, 20 Jul or 10/11 August.

Table 2: Peak and average PM2.5 concentration measured at each site

Instrument	Type	Peak $PM_{2.5}$ concentration	Date measured	Average $PM_{2.5}$ concentration[3]
MM1	Minimote solar	39.96	11-Aug	10.5
MM2	Minimote solar	32.66	20-Jul	9.7
MM3	Minimote solar	38.42	11-Aug	9.1
MM4	Minimote solar	25.65	20-Jul	9.4
MM5	Minimote solar	25.91	20-Jul	13.2*
MM6	Minimote solar	32.29	11-Aug	9.4
MM7	Minimote solar	34.67	11-Aug	12.8
DM8	Dustmote mains	33.00	30-Jun	8.6
DM9	Dustmote mains	24.92	30-Jun	6.1
DM10	Dustmote mains	29.96	30-Jun	8.0
DM11	Dustmote mains	29.64	30-Jun	5.9
MM12	Minimote solar	30.28	11-Aug	10.8
DM13	Dustmote mains	25.04	11-Aug	9.8
DM14	Dustmote mains	37.18	10-Aug	11.3
DM15	Dustmote mains	24.39	10-Aug	7.2

*Note: Limited dataset available due to vandalism

Table 3 below displays the co-efficient of variation between each of the sites for the period between 15 July through to 7 October 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.

The table confirms the earlier observation that many of the sites are strongly correlated – particularly in the central and western parts of Reefton suggesting that the meteorological conditions are reasonably homogenous during inversion conditions.

Table 3: Co-efficient of variation between each of the 15 sites in Reefton

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		0.87	0.95	0.89	0.95	0.66	0.89	0.73	0.78	0.77	0.74	0.86	0.89	0.72	0.77
2	0.87		0.85	0.92	0.98	0.61	0.82	0.81	0.78	0.79	0.70	0.87	0.94	0.76	0.78
3	0.95	0.85		0.89	0.82	0.58	0.68	0.9	0.9	0.91	0.82	0.75	0.83	0.88	0.86
4	0.89	0.92	0.89		0.99	0.73	0.9	0.84	0.86	0.87	0.8	0.98	0.96	0.83	0.83
5	0.95	0.98	0.82	0.99		0.93	0.85	0.83	0.85	0.88	0.74	0.98	0.96	0.86	0.83
6	0.66	0.61	0.58	0.73	0.93		0.74	0.63	0.66	0.68		0.76	0.74	0.64	0.64
7	0.89	0.82	0.68	0.9	0.85	0.74		0.76	0.81	0.82	0.77	0.9	0.88	0.77	0.82
8	0.73	0.81	0.9	0.84	0.83	0.63	0.76		0.95	0.94	0.84	0.83	0.91	0.91	0.88
9	0.78	0.78	0.9	0.86	0.85	0.66	0.81	0.95		0.97	0.91	0.84	0.91	0.91	0.91
10	0.77	0.79	0.91	0.87	0.88	0.68	0.82	0.94	0.97		0.92	0.86	0.93	0.97	0.95
11	0.74	0.70	0.82	0.8	0.74	0.67	0.77	0.84	0.91	0.92		0.77	0.83	0.81	0.85
12	0.86	0.87	0.75	0.98	0.98	0.76	0.9	0.83	0.84	0.86	0.77		0.97	0.85	0.83
13	0.89	0.94	0.83	0.96	0.96	0.74	0.88	0.91	0.91	0.93	0.83	0.97		0.91	0.9
14	0.72	0.76	0.88	0.83	0.86	0.64	0.77	0.91	0.91	0.97	0.81	0.85	0.91		0.95
15	0.77	0.78	0.86	0.83	0.83	0.64	0.82	0.88	0.91	0.95	0.85	0.83	0.9	0.95	

[3] Covers the period from 15 July through to 6 October 2021

The following interpolation plots (**Figures 21-24**) have been included as indicative plots which provide a visual aid to distinguish $PM_{2.5}$ concentrations between sampling locations. There is insufficient data to definitely demonstrate a linear reduction in concentration from one node to the next and the interpolation used in these images does not account for convective turbulence of objects and structures or topography.

While the assumption of linear reduction is unlikely to hold over short timeframes of seconds to minutes due to the variable nature of emissions from nearby sources and the limited dispersion under specific meteorological conditions. As the sample period increases (hours to days), the nature of dispersion begins to approximate a more probabilistic process and while linear reductions between sample nodes cannot be assumed, it is not unreasonable to expect that the average gradation will follow patterns similar to the interpolation shown in the images below.

Figure 21 displays the maximum 24 hour $PM_{2.5}$ concentration recorded at each site during the study period. As such the image is a composite of the maximum concentration observed throughout the study rather than that of a single day. These peak concentrations have been mapped across Reefton to produce a contour map depicting the variation peak $PM_{2.5}$ concentration across Reefton during the study period.

Figure 21 identifies that higher concentrations occur towards the geographic centre of Reefton, while peak $PM_{2.5}$ concentrations reduce towards the town boundaries. Similar patterns of emissions have been observed in a number of communities around New Zealand and reflects the concentration of emission sources closer to the center of communities.

By way of comparison, **Figures 22 and 23** compare the peak concentration observed at each site on two days when the average 24 hour $PM_{2.5}$ concentration was the highest. These figures cover 20 July and 11 August respectively. Plots for other dates during the study period are available upon request.

Figures 22 and 23 illustrate the subtle differences in the pattern of emissions on days when $PM_{2.5}$ concentrations are elevated. Although the general pattern of emissions is similar in the two Figures, it is clear that on 11 August, the elevated $PM_{2.5}$ concentrations were focussed more towards the south eastern part of the town than the 20 July event. This probably reflects differences in the meteorology and also potential differences in emission sources on these two days. These images serve to illustrate some of the complexities in managing multiple emission sources in a community.

The last contour plot – **Figure 24** is the average $PM_{2.5}$ concentration measured at each site for the period between 15 July – 6 October 2021. This useful plot demonstrates that although there may be differences on individual days, overall concentrations are broadly consistent throughout the central Reefton community. Please note that the concentration scale used in **Figure 24** is different to that used in **Figures 21-23**.

Figure 21: Plot of maximum 24 hour $PM_{2.5}$ concentrations measured at each site

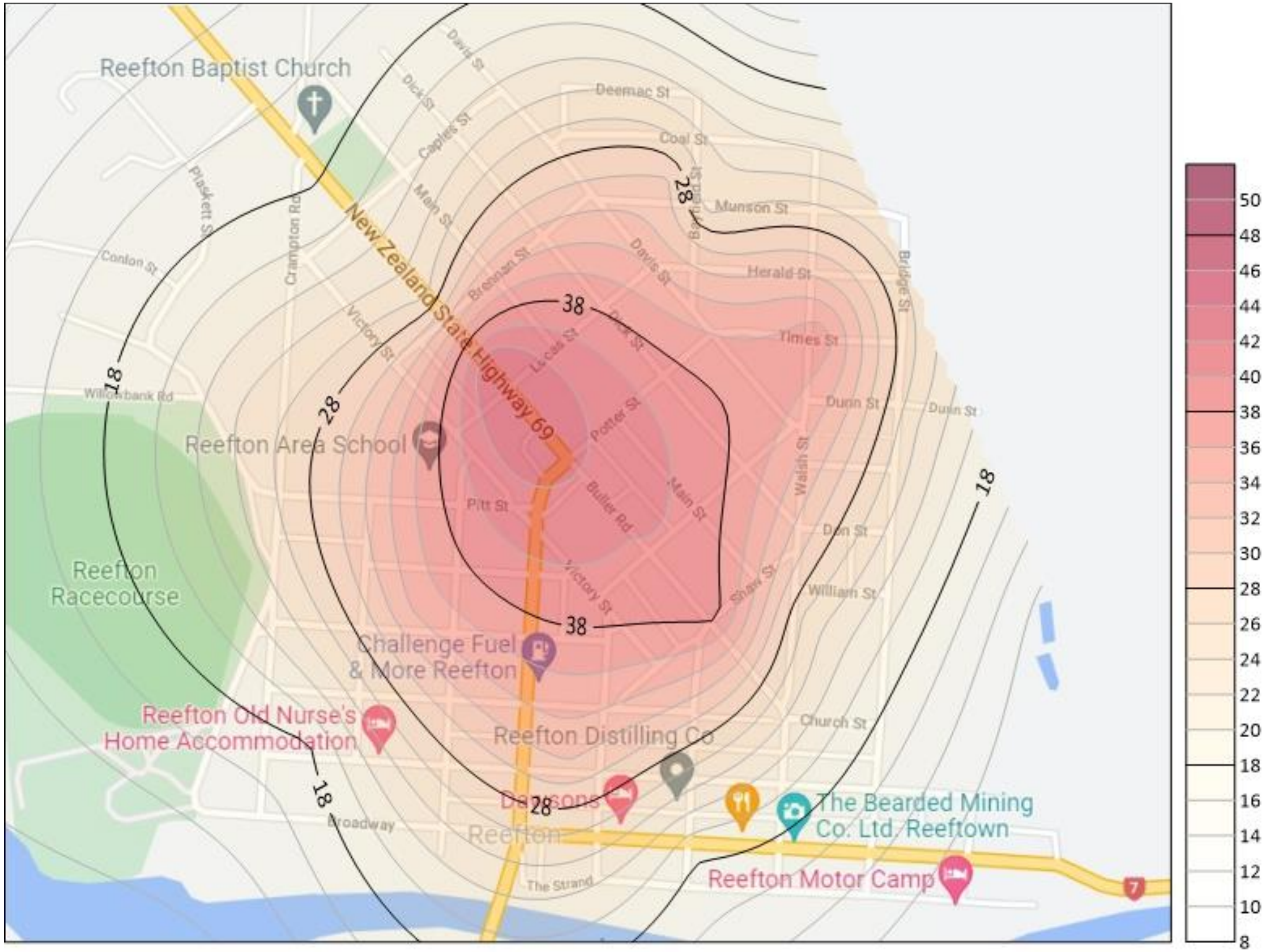


Figure 22: Plot of maximum 24 hour $PM_{2.5}$ concentrations for 20 Jul 2021

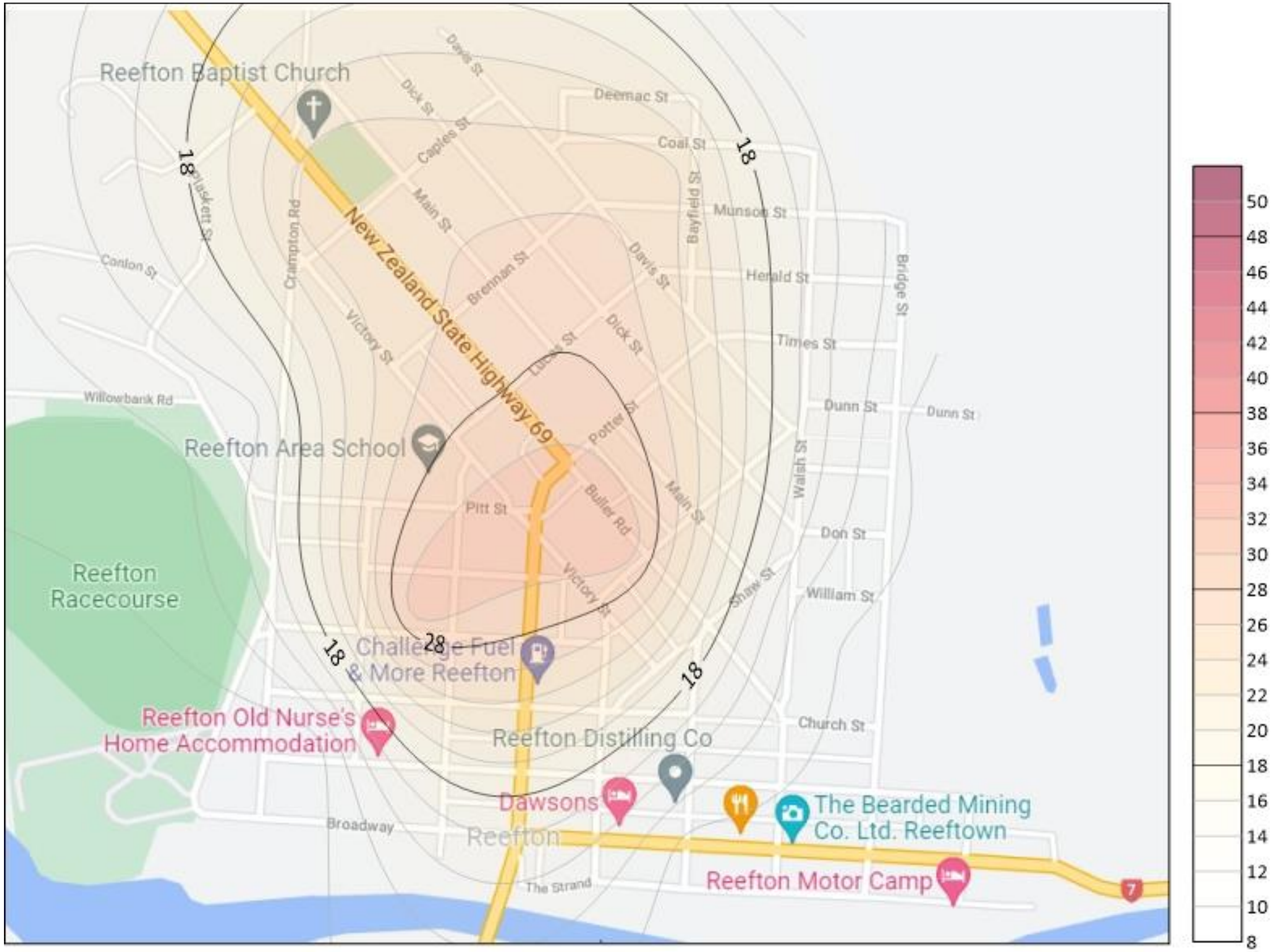


Figure 23: Plot of maximum 24 hour $PM_{2.5}$ concentrations for 11 Aug 2021

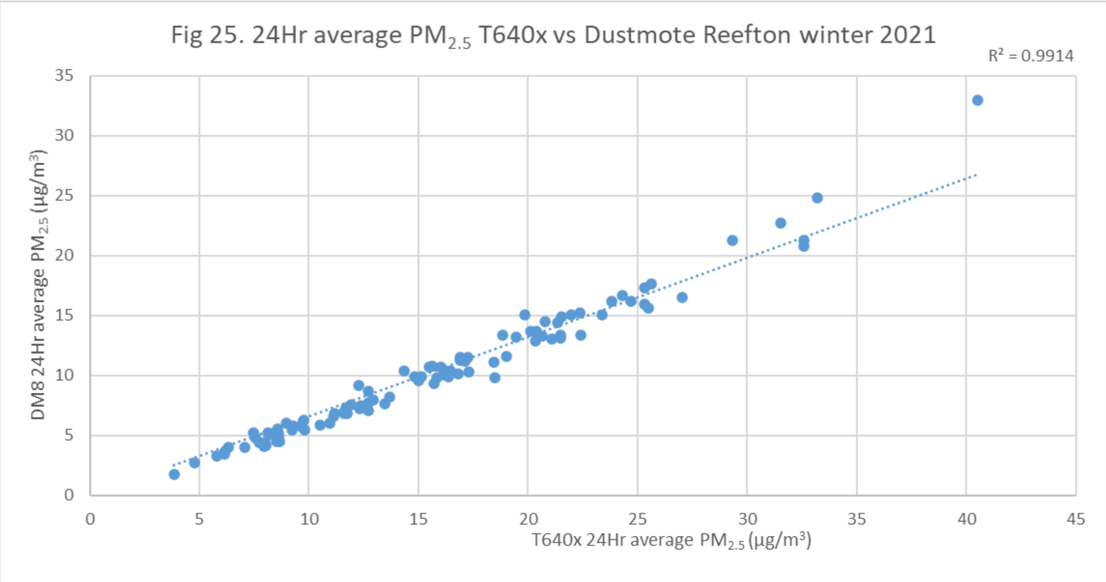
Figure 24: Plot of average 24 hour PM2.5 concentrations between 15 Jul – 6 October 2021

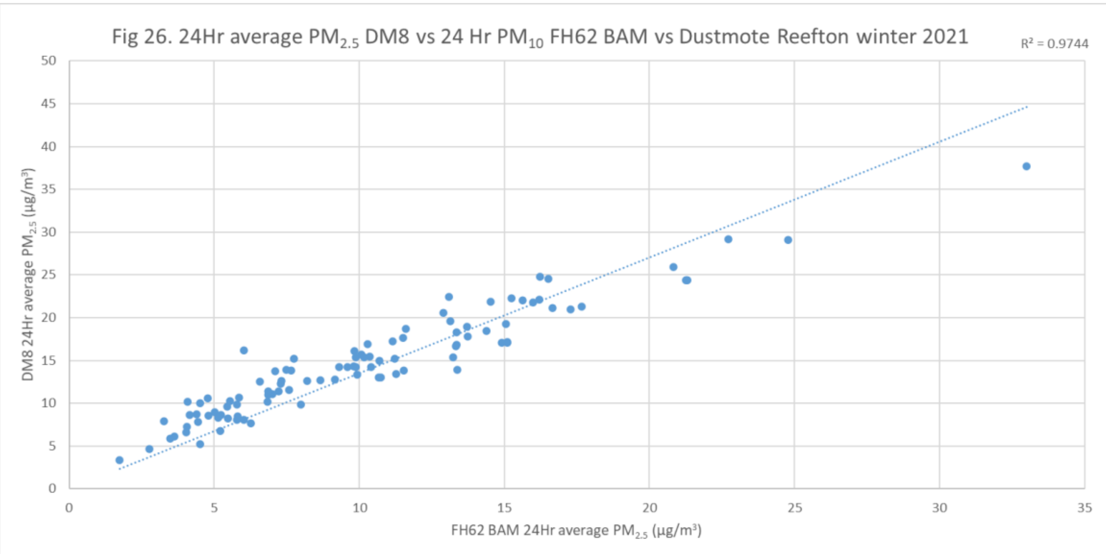
3.3 Agreement with Reference instruments

One of the instruments (DM8) was located at the WCRC Reefton monitoring station during the deployment. This enabled a comparison of this instrument with both a Teledyne T640x and a Thermo FH62 Beta attenuation monitor.

The DM8 instrument had reasonable agreement with both instruments, but the relationship was slightly better for the T640x than for the FH62 BAM. This is primary due to the different instrumentation methods Nephelometers vs Beta attenuation monitor. Another key factor will be that the FH62 BAM is measuring PM_{10}, while the DM8 is measuring $PM_{2.5}$ – the variability in the proportion of PM10-PM2.5 will also be resulting in some differences in results.

Plots comparing the 24 hour average concentrations of both instruments are shown below in Figures 25 and 26.





Figures 25 and 26: Plot of 24 hour average $PM_{2.5}$ concentration from collocated Dustmote against T640x ($PM_{2.5}$) and FH62 BAM (PM_{10})

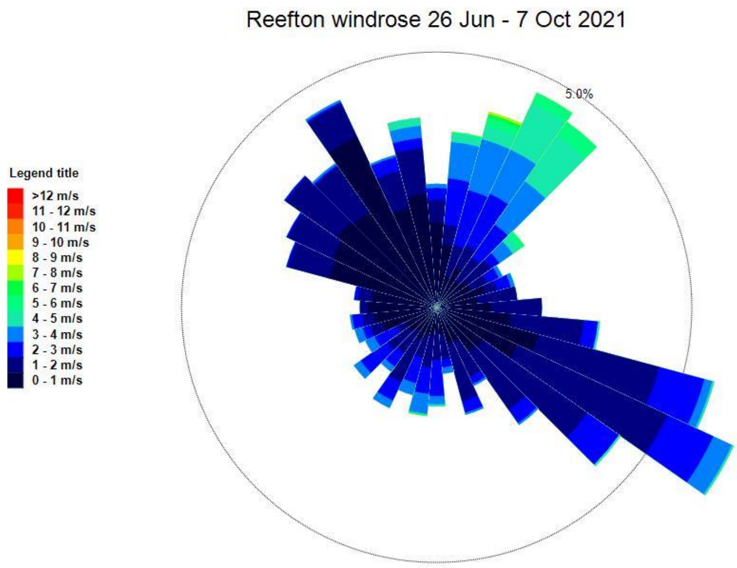
Table 3: Differences between instruments at WCRC Reefton (25 Jun – 30 Sep)

Instrument	Max concentration (µg/m3)	Average concentration (µg/m3)
DM8 Nephelometer ($PM_{2.5}$)	33.0	10.18
T640x Nephelometer ($PM_{2.5}$)	40.53	15.78
FH62 BAM (PM_{10})	37.67	14.58

The Dustmote nephelometer (DM8) 24 hour average $PM_{2.5}$ readings were approximately 65% of the T640x 24 hour average $PM_{2.5}$ concentrations (+/- 11.9% at 2σ) while the DM8 instrument were approximately 67% of the equivalent FH62 BAM PM_{10} concentrations (+/-24% at 2σ). The percentage difference between DM8 and the FH62 BAM decreased when the average concentration increased which is consistent with combustion sources being the primary source of particulate material during periods of heightened particulate concentrations during winter conditions.

3.4 Meteorological conditions

Figure 27 below is a windrose covering the study period (26 Jun – 7 October 2021). The windrose depicts low wind speeds throughout much of the study period, with the occasional moderate winds from the northeast.



Meteorological conditions during the 2021 study period can be compared to previous years in Table 4 below.

A comparison of meteorological conditions during the 2021 study period (25 June – 6 October) reveals that the 2021 period reveals that meteorological conditions were generally similar to that of previous years (not unusually warm or cold) and that the study period is generally representative of typical winter in Reefton.

Table 4: Comparison of meteorological conditions during the 2021 study period with previous years.

Year	Average wind speed (m/s)	Average ground temperature (degC)
2021	1.19	1.98
2020	0.76	1.2
2019	1.02	1.71
2018	1.06	1.28
2017	1.11	1.88
2016	1.12	1.11

4.0 RECOMMENDATIONS

Following on from the investigation into the ambient air quality in Reefton, this report makes the following recommendations:

1. Consider installing meteorological monitoring equipment (wind speed, wind direction, air temperature, relative humidity and rainfall) at the Reefton monitoring station. The addition of this monitoring information will assist with interpretation of ambient air quality monitoring data.

2. Consider the implications of the 2021 World Health Organisation air quality guidelines – in particular the recommendation to limit the 24 hour average $PM_{2.5}$ concentration to 15 micrograms per cubic metre.

3. Given the notable differences between the Teledyne T640x and the Beta Attenuation Monitor at Reefton, consider operating a high-volume sampler on a 1 day in 3 or 1 day in 6 schedule during the winter months (May, June, July, August) to both quantify the extent of the differences and to verify the accuracy of the existing suite of instrumentation.

4. Consider repeating an ambient $PM_{2.5}$ monitoring network assessment in Reefton within the next 10 years to verify that the findings in this report remain relevant. Alternatively, the reassessment could be linked to population growth or housing in Reefton.

5.0 CONCLUSION

Mote limited deployed a network of 15 monitors throughout Reefton between 25 June and 6 October 2021. The bulk of the instruments were operational as of 15 June and the study concluded on 6 October. Despite damage to one unit, the overall data capture rate for the network was acceptable at 94%.

A maximum 24 hour PM2.5 concentration of 37 micrograms per cubic metre was measured on 10 August at one locality and 9 of the 15 monitoring locations registered 24 hour averages above the proposed draft 24 hour PM2.5 standard of 25 micrograms per cubic metre.

The results demonstrated that the central portion of the Reefton airshed is reasonably homogenous when averaged over several months, but displays day to day variation during periods when particulate concentrations are elevated. This is similar to many other small communities in New Zealand and likely reflects differences in meteorological conditions and emission rates at different times.

There was evidence to suggest that under strong inversion conditions, there is katabatic cold flow drainage on the eastern boundary of the town.

6.0 REFERENCES

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