Spatial Variation of PM in Motueka: Winter 2019

Prepared for Tasman District Council

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Executive summary

Motueka is the second largest township in Tasman District, with a population of approximately 8000 residents in 2018. Many Motueka residents use wood burners during winter to heat their homes. Rural Motueka and neighbouring Riwaka are a hub for horticultural activities and traditionally outdoor fires have been used as a low cost and efficient means to dispose of vegetation waste.

Tasman District Council (TDC) is responsible for the management of ambient air pollutants in Motueka. There has been little previous monitoring in the town but there are believed to be three key sources of pollutants; traffic in summer, woodburning for domestic heating in winter and agricultural burning. This report focusses on winter-time burning.

TDC have previously installed a temporary PM monitor (Partisol) in late winter of 2018 at a site in the west of Motueka.

This report covers a monitoring campaign that was conducted during the winter of 2019 to measure concentrations of $PM_{2.5}$ and PM_{10} across Motueka using a distributed network of 22 "ODIN" monitoring instruments.

Results indicate that $PM_{2.5}$ concentrations at sites in Motueka regularly exceed the WHO guideline for $PM_{2.5}$ (25 µg/m^3, 24-hour average value), with 24-hour average values nearly four times as high having been recorded. PM_{10} concentrations were also elevated with double the NES limit value being recorded.

These measurements revealed a noticeable spatial gradient across Motueka, with higher values, on average, being recorded in the east of the town. Whether this is due to the transport of smoke from the town on prevailing SW winds or a strong local emission source in the east is not yet known.

The current, winter only, temporary TDC monitoring site does not appear to capture the highest concentrations in Motueka (as recommended by official guidance), possibly due to being on the western side of town where concentrations are generally lower.

In addition, there is evidence for rural burning in the surrounding countryside, particularly around Riwaka, which may require further investigation.

The findings of this monitoring campaign are;

1. Motueka does appear to have an air quality issue with some locations having measured PM concentrations in excess of current guidelines and anticipated future legislation.

2. There is evidence for rural burning in the surrounding countryside, particularly around Riwaka, making a short-term and localised but significant contribution to poor air quality which may require further investigation.

3. A permanent monitoring site may be suitable, although it may take more than one winter to establish whether this is a persistent problem. Investigating locations on the eastern side of the town for any permanent site would seem prudent.

There are several options for next steps;

- Further monitoring using a single central site (e.g. current Partisol, or a single ODIN) for another winter will indicate whether this winter was typical and whether high concentrations are a pervasive problem.
- Further monitoring next winter but a reduced scale will help to better understand the representativeness of any given monitoring site and whether spatial variation observed in this study is persistent or changes over time.
- Establishing a monitoring site (permanent or temporary) in the eastern part of the town. This might be informed by winter monitoring of potential sites using ODINs (or similar) for one winter before a permanent site is selected.
- Further exploration of the current dataset to investigate relationships to weather and home heating and agricultural burning behaviour.
- A separate study is recommended to focus exclusively on agricultural burning, which could combine monitoring, modelling, video surveillance and other remote sensing approaches.

Similar exploratory campaigns in other Tasman townships, such as Brightwater and Wakefield, would establish whether they have an air quality issue from wood burning that may require further investigation.

1 Introduction

1.1 Background

Tasman District Council (TDC) is responsible for the management of ambient air pollutants in Motueka. There has been little previous monitoring in the town but there are believed to be three key sources of pollutants; traffic in summer, woodburning for domestic heating in winter and agricultural burning.

Motueka is the second largest township in Tasman District, with a population of approximately 8000 residents in 2018. Many Motueka residents use wood burners during winter to heat their homes. Rural Motueka and neighbouring Riwaka are a hub for horticultural activities and traditionally outdoor fires have been used to dispose of vegetation waste.

1.1.1 Home Heating

TDC does not know the prevalence of wood burner use for home heating in Motueka township. It could determine how many consented wood burners there are from building consents, but it is unknown how many older appliances there are or the total number which do not meet the National Environmental Standards for Air Quality (NES). The Tasman Resource Management Plan (TRMP) requires that any new burners installed on any site up to two hectares since September 2005 must comply with the emissions and efficiency standards as per the NESAQ.

1.1.2 Outdoor Burning

The TRMP delineates a 'Fire Ban Area' in Motueka township where most outdoor burning is prohibited with some exceptions (small cooking fires, fireworks, outdoor fireplaces, etc.) A 'Fire Sensitive Area' on the outskirts of Motueka to the west and south of the township largely restricts outdoor fires during the months of June to August (inclusive). The burning of diseased[1] horticultural waste for biosecurity purposes is a permitted activity during these winter months. Most horticultural waste is diseased and burning may happen at any time of year.

Over recent winters TDC has received many complaints regarding outdoor burning from residents in the Motueka and Riwaka areas. TDC's compliance staff have often found that these fires meet the requirements of the TRMP's permitted activity standards (smoke is going straight up and contained within the property boundary). However, due to the geography of the district, a temperature inversion layer is often present, which keeps the smoke low, dispersing it horizontally only. Therefore, on cold and calm days, the presence of an inversion layer in conjunction with multiple fires in the area has led to a distinctive smoke haze sitting low in the atmosphere.

1.1.3 Monitoring

There is currently no permanent air quality monitoring station in Motueka and there is no gazetted airshed[2]. TDC has some monitoring data of wintertime PM_{10} for 2006, 2014, 2018 and 2019. A temporary (winter only) PM_{10} monitoring station (a Partisol 2025i instrument for sampling PM_{10}) was installed in the second half of winter 2018 and again in 2019 (located at Parklands School, 9 Pah Street). Results from the winter 2019 were supplied to us by TDC. A permanent weather station was

[1] European canker (a fungal disease caused by Neonectria ditissima) is present in the area and is listed in the Nelson Tasman Regional Pest Management Strategy.
[2] An Airshed is an area identified as an air quality management area and designated in the New Zealand Gazette under the Resource Management (National Environmental Standards for Air Quality) Regulations 2004 and amendment 2011

established at the sports park in Motueka in August 2017. Data from this weather station supplied by TDC indicates that during summer the wind is predominantly from the NE and SW with the strongest wind from the NE direction as a result of ex-tropical cyclones. In winter, the predominant mode is weaker, down-valley winds from the SW.

1.2 Project scope

This project was designed to improve the understanding of air quality in Motueka, including whether there is an air quality problem which may need to be addressed through further monitoring and/or the use of policy tools (regulatory or non-regulatory methods). This information will also be used to help inform broader air quality research to understand if there is a relationship between air 'catchments' in Tasman Bay.

Specific questions raised by TDC were:

1. Does Motueka have an air quality issue?
2. What are the sources of air quality contaminants? (e.g. home heating, rural burning)
3. Is there a need for a permanent monitoring site, and if so, what would be the preferred locations?

TDC also asked for any recommendations on how to expand survey work to other Tasman townships, such as Brightwater and Wakefield, to assess if they have an air quality issue from wood burning.

The priority focus is on understanding air quality issues associated with wood burning (home heating and outdoor horticultural burning).

2 Measurement campaign

2.1 Study approach

Monitoring was conducted in Motueka for particulate matter (PM_x) during winter 2019 using 22 of NIWA's ODIN monitors. The PM_x measurements included $PM_{2.5}$ as the most suitable metric for monitoring woodburning and PM_{10} for comparison to the NES.

The PM_x monitoring was conducted in autumn and winter in order to establish:

- whether there is an air quality problem caused by domestic woodburning that will require further investigation and possible management
- whether and how horticultural burn-off contributes to PM_x pollution in Motueka

2.2 Measurement methods

2.2.1 Particulate PM_x (ODINs)

Measurements of $PM_{2.5}$ and PM_{10} were made using ODIN PM_x monitors. The Outdoor Dust Information Node (ODIN) is a low-cost sensor package developed in-house by NIWA, for the purpose of researching the impacts of domestic heating, rural burning and traffic-related air pollution (Figure 1).

Figure 1: ODIN low cost sensor package in-situ.

The core of the package is the dust sensor that optically detects light scattering by particles in the atmosphere being sampled. This measurement is then translated into a quantification of the mass of particulate (µg m^{-3}) using algorithms pre-programmed by the manufacturer. The ODINs deployed in this study used the Plantower PMS3003, which uses three channels to measure different sizes of

particulate: PM_1, $PM_{2.5}$ and PM_{10}. Sampling can be done at varied rates. At the beginning of the campaign, we recorded every 1 minute but found that the battery drain was too high, so we changed the frequency to every 5 minutes for this campaign.

Where possible, data were telemetered to NIWA via the mobile phone network. Each ODIN has a 2G wireless connection. The data were also recorded on an SD card onboard the ODIN and downloaded at the end of the campaign.

Raw data have been averaged into ten-minute averages for quality assurance and analysis purposes. A file of QA'd PM_{10} and $PM_{2.5}$ results will be supplied to TDC separately to this report.

It should be noted that the ODIN uses a different measurement method from the NES reference (or certified equivalent) methods used to monitor PM for regulatory compliance. Therefore, results from ODINs should not be compared directly to compliance measurements or to regulatory standards or guidelines and should be treated as indicative only. For the purposes of this report, references and comparisons are made to NES and WHO regulations and guidelines in order to give an indication of the relative "importance" of a result and should not be considered a definitive statement of compliance or otherwise with regulations.

2.3 Site Information

Monitoring took place from mid-May to the end of August 2019. ODINs were installed on 28th April but due to a software fault, data were not collected until 20th May. ODINs were removed on 2nd September.

Sites were chosen in consultation with TDC and were designed to give approximately even geographic coverage in all parts of Motueka itself along with 2 sites up- and down-wind of the town to capture orchard burning. In addition, three extra sites were located in Brooklyn (one) and Riwaka (two) to investigate areas where there had been public complaints of high woodsmoke concentrations. The location of each site is shown in Figure 2 and listed in Table 1.

2.3.1 Missing Sites

Three sites (10, 13 and 28) were planned but never implemented and hence are missing from any tables and figures. Throughout the campaign, there were problems with the instrument telemetry due to either poor signal from the mobile phone network or lack of sunlight to power the monitors' batteries. Although each ODIN has an internal memory card, several cards were found to be corrupted at the end of the campaign. As a result, of 25 ODINs deployed, three returned no data at all (sites 5, 16, 17). We are investigating why so many memory cards failed.

The failed units were situated in the densest part of the network, in the north-west part of the town. As such, we believe that the overall results are not significantly affected, as other working units were in close proximity. The locations are shown in Figure 2 (where sites with no data are X'ed out) and Table 1 (where sites with no data are greyed out).

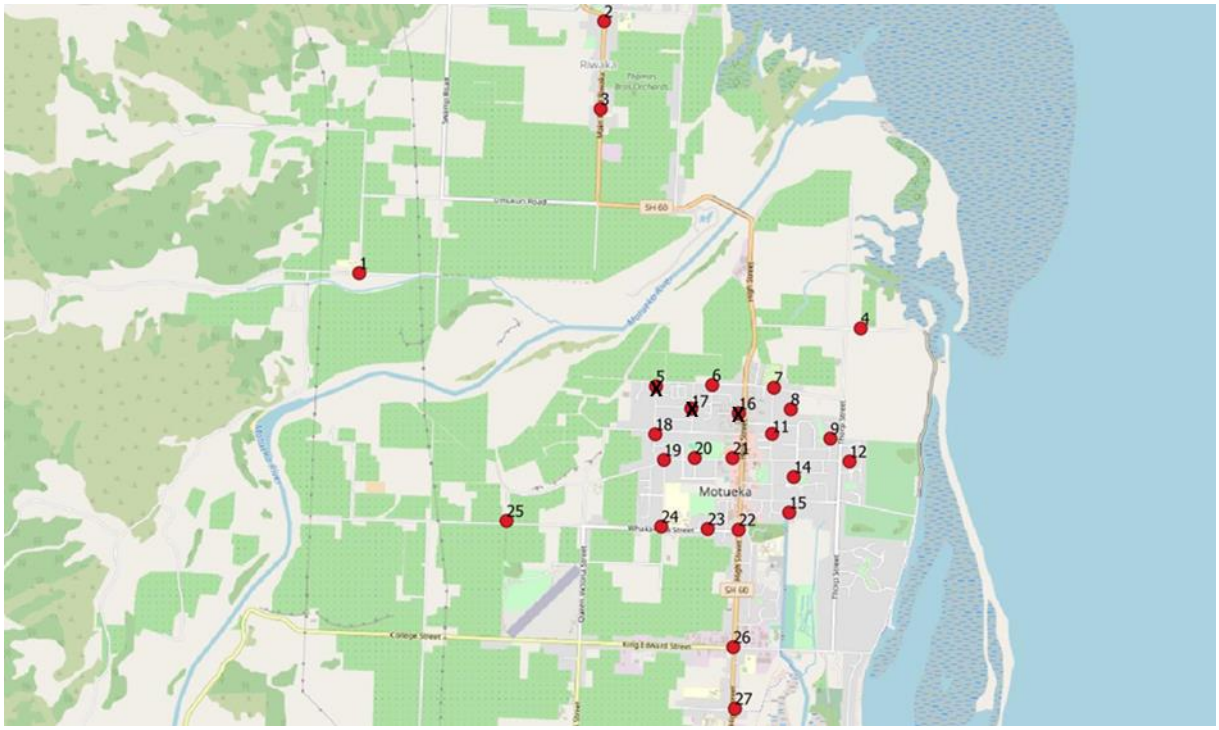

Figure 2: Locations of ODIN monitoring sites in Motueka and surroundings during winter 2019

Table 1: Locations of ODIN monitoring sites in Motueka and surroundings during winter 2019

SiteID	ODINSD	Mode	Street Address	NZTM_E	NZTM_N
1	165	OFFLINE	Old Mill Road Brooklyn	1597718	5450589
2	59	GSM	Main Road Riwaka	1599777	5452706
3	161	OFFLINE	Main Road Riwaka	1599747	5451968
4	37	OFFLINE	Staples Street Motueka	1601935	5450125
5	168	GSM	Aktins Street Motueka	1600213	5449638
6	64	GSM	Te Maatu Drive Motueka	1600686	5449649
7	157	GSM	Fearon Street Motueka	1601205	5449626
8	164	GSM	Tarrant Place Motueka	1601347	5449445
9	158	GSM	Pethybridge Street Motueka	1601680	5449199
11	61	GSM	Vosper Street Motueka	1601189	5449239
12	35	GSM	Blomfield Place Motueka	1601841	5449007
14	151	GSM	Goodman Drive Motueka	1601372	5448876
15	166	GSM	Taylor Avenue Motueka	1601333	5448577
16	70	OFFLINE	Eginton Street Motueka	1600909	5449410
17	162	GSM	Fry Street Motueka	1600510	5449451
18	153	GSM	Atkins Street Motueka	1600207	5449235
19	163	GSM	Pah Street Motueka	1600280	5449019

20	75	GSM	Pah Street Motueka	1600539	5449036
21	3	OFFLINE	Pah Street Motueka	1600857	5449035
22	149	GSM	High Street Motueka	1600908	5448432
23	169	GSM	Whakarewa Street Motueka	1600648	5448439
24	150	GSM	Whakarewa Street Motueka	1600258	5448460
25	159	GSM	Pamarika Street Motueka	1598957	5448508
26	152	GSM	High Street Motueka	1600863	5447447
27	154	GSM	Courtney Street East Motueka	1600877	5446930

Note: sites 10, 13 and 28 were planned but never used and hence missing from this table. Greyed out sites produced no data

2.4 Data handling and QA

The ODIN are designed to send data to the cloud as they are captured but they include an internal memory to serve as backup and to change default measurement parameters. Therefore, the primary source of ODIN data is NIWA's cloud IoT service. At the end of the campaign, the data were retrieved from NIWA's servers as well as the data from the memory cards when the instruments were returned to NIWA's lab.

Only for those periods when there was no telemetered data, the individual memory cards were reviewed and, where possible, data from the memory cards were used to fill gaps in the telemetered data.

The main reasons why there could be missing records in the telemetry dataset is because the units could not connect to NIWA's cloud in a timely manner or that due to poor cell phone coverage, they could not connect to the servers at all.

The patched data were homogenised to a timeseries starting on 20th May 2019 00:00:00 and with values as 10 minutes averages with no minimum number of measurements required for a valid 10 minutes average. Invalid data, reported by ODINs as –999, were removed while homogenising the dataset and before the hourly and daily timeseries were constructed. These hourly and daily average timeseries were also calculated with no minimum number of valid 10 minutes values required for an average. This was done to maximise the data captured.

2.4.1 Inter-instrument comparison

Using the homogenised 10 minutes interval timeseries, a test to evaluate the relative performance of the ODINs was implemented.

The theory behind this approach is that in a small geographical area during most 24 hours periods, all units will reach a common background level of PM_x concentrations and it is therefore meaningful to compare the first percentiles of daily values as if they were co-located.

Starting from the 10 minutes dataset:

1. calculate the 1st percentile daily data (the concentration that is lower than 99% of the readings for that day) for each sensor with more than 75% of data. This gives the "sensor baseline estimate" that is plotted in the y axis on Figure 3.

2. Calculate the "daily fleet average" for each day by averaging the 1st percentile data for all the sensors for that day. This is shown in the x axis on Figure 3 as PM $_{ref}$.

Sensors that systematically deviate from the rest of the fleet are easily identified with a scatter plot that shows significant deviations of the 1st percentile daily data from the fleet average.

Figure 3 shows that for this deployment, the ODINs showed deviations from the baseline that were less than 2 mg/m3 for more than 95% of the data for both PM_{10} and $PM_{2.5}$. This margin is comparable to the error expected from particle sensing instruments and therefore no correction is recommended for the data captured in this campaign.

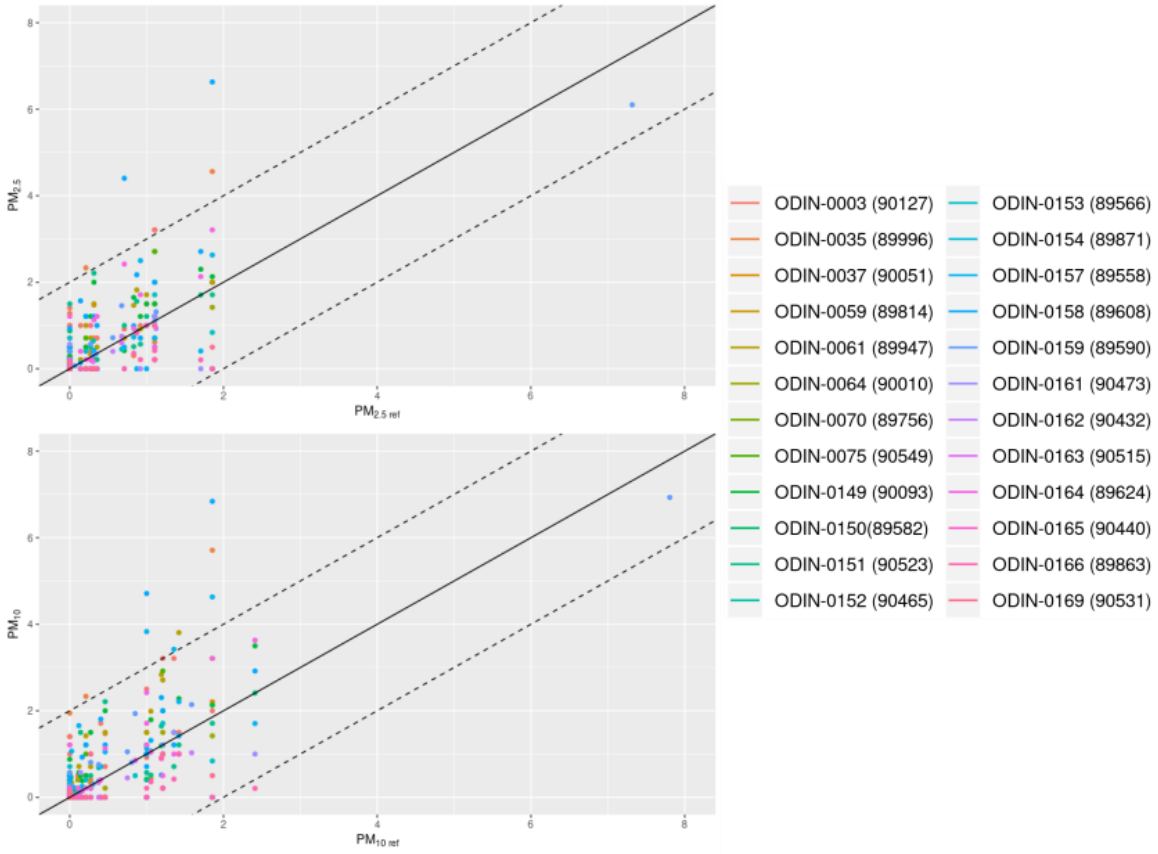

Figure 3: Scatter plot of the ODIN daily PM10 and PM2.5 baseline against the fleet average. The solid line indicates the 1:1 relationship and the dashed lines highlight the +/- 2mg/m3 envelope.

2.4.2 Missing data

Due to ODIN siting and variable telemetry, there were varying power demands on the units deployed across Motueka. This resulted in intermittent data loss throughout the campaign and a broad range of data capture rates. Table 2 gives the hour of the first and last data recorded by at each site, the number of hour's data captured and the percentage of total hours available that represents (based on a deployment period of 20th May to 1st September 2019). There are a few units with very little data but on the whole the fleet performed as well as expected in the stage of the network development, with an overall data capture rate of 58%.

Table 2: Data capture per ODIN site.

Site	First data record	Last data record	# Hour's data	% Hours' data capture
1	16/07/2019 15:00	4/08/2019 11:00	456	18.3
2	17/07/2019 9:00	12/08/2019 12:00	452	18.1
3	8/06/2019 3:00	31/08/2019 23:00	1906	76.4
4	16/07/2019 13:00	31/08/2019 23:00	1114	44.6
6	20/05/2019 13:00	31/08/2019 23:00	1755	70.3
7	20/05/2019 13:00	31/08/2019 23:00	2483	99.5
8	20/05/2019 13:00	31/08/2019 23:00	2456	98.4
9	20/05/2019 13:00	31/08/2019 23:00	2452	98.2
11	20/05/2019 14:00	31/08/2019 23:00	2346	94.0
12	20/05/2019 13:00	27/08/2019 6:00	1273	51.0
14	20/05/2019 14:00	31/08/2019 23:00	2482	99.4
15	20/05/2019 13:00	31/08/2019 23:00	2483	99.5
18	20/05/2019 13:00	31/08/2019 23:00	1772	71.0
19	20/05/2019 13:00	17/07/2019 13:00	215	8.6
20	12/06/2019 9:00	6/08/2019 23:00	704	28.2
21	10/06/2019 10:00	31/08/2019 23:00	1929	77.3
22	20/05/2019 12:00	31/08/2019 23:00	2482	99.4
23	20/05/2019 12:00	31/08/2019 23:00	1655	66.3
24	20/05/2019 12:00	17/07/2019 11:00	50	2.0
25	20/05/2019 13:00	31/08/2019 23:00	1225	49.1
26	20/05/2019 14:00	27/05/2019 16:00	171	6.9
27	20/05/2019 14:00	18/07/2019 15:00	78	3.1

3 Results

These results are based on the data from 22 working ODIN units for the campaign period of 20th May to 1st September 2019.

Where boxplots are used, the width of the box is an indication of the relative number of data points represented by that particular box and whisker. The whiskers extend out to no more than one and a half times the interquartile range from the box. Any data points beyond this range are represented as individual circles.

Wood-burning is best captured by $PM_{2.5}$ rather than PM_{10} which will be more influenced by natural sources of particulate matter, such as sea salt and dust. Most of the discussion about wood-burning sources will be based upon the $PM_{2.5}$ data. PM_{10} concentrations are also reported here, and are compared with Partisol PM_{10} data, however it is not expected that the different monitoring methods will produce matching concentrations.

3.1 Weather

Figure 4 summarises wind speeds and directions for the duration of the campaign (20th May to 1st Sept) at the Motueka sports ground. Windspeeds were generally low and typically from the prevailing wind direction of south-west.

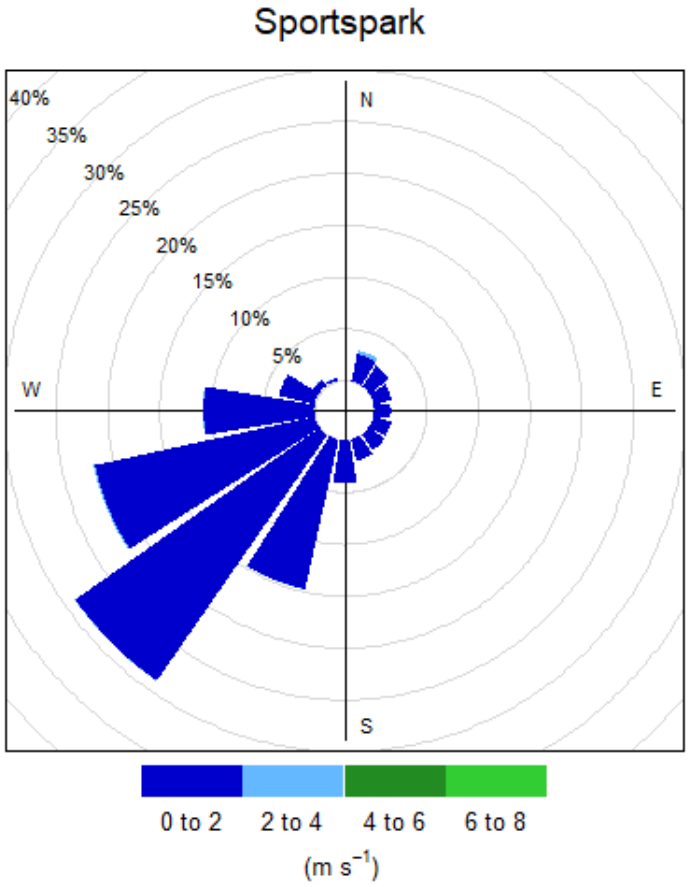

Figure 4: Wind speed and direction for the duration of the campaign (20th May to 1st Sept) at Motueka sports ground.

3.2 $PM_{2.5}$

3.2.1 Summary

Daily 24-hour averages across the monitored sites are shown in Figure 5, along with daily minimum temperature and daily 24-hour averaged windspeed There is a large variation in 24-hour average $PM_{2.5}$ values across the town for any given day, and a large variation between days, with very high values on some days, reaching a peak 24-hour average value for any individual site of 88.4 µg m^{-3} at site 9 (Pethybridge St) on 10th July. High values persisted across the town for four days from the 10th to 13th July, with the average value for all sites lying between 40 µg m^{-3} and 50 µg m^{-3}.

There is no observable relationship between concentrations and either average daily windspeed or minimum daily temperature. Although meteorological conditions do play a key role in how air pollution disperses, further analysis is required to illustrate connections between how air moves across Motueka and pollutant concentrations. In addition, during winter how much pollution is generated by the township is more dominated by habit and lifestyle than specific day-to-day weather conditions.

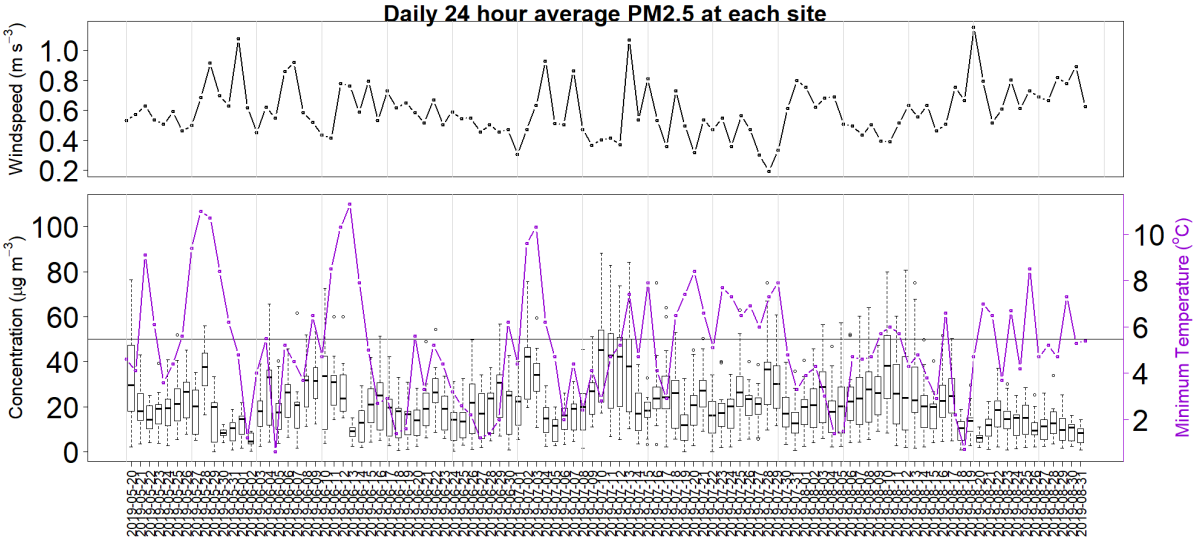

Figure 5: Range of daily 24-hour average $PM_{2.5}$ (µg m^{-3}) across Motueka during the winter 2019 monitoring campaign, with WHO guideline value.

Summary statistics for the campaign are shown in Table 3 and Figure 6. Campaign averages are mapped in Figure 7. They show considerable variation across the area with campaign-average values ranging from as low as 3.6 µg m^{-3}on the southern approaches to the town to as high as 43.3 µg m^{-3} on the eastern edge.

The map in Figure 7 appears to depict a a gradient in concentrations from west (low) to east (high). The high values to the east may be due to the prevailing south-west winds transporting smoke across the town, although at this stage we cannot rule out a strong local emissions source in the east. The highest ten-minute values (not shown) are spread around the town but not coincident, so probably due to local, short-term sources.

Table 3: Summary $PM_{2.5}$ (µg m^{-3}) statistics from hourly averaged values for the Motueka winter 2019 monitoring campaign.

Site	Minimum	25%	50%	Mean	75%	Maximum	# Hour's data
1	0.0	1.4	5.8	10.3	15.0	96.0	456
2	0.0	1.8	5.6	8.8	12.7	63.6	452
3	0.0	1.3	5.7	9.7	13.9	132.1	1906
4	0.0	1.0	6.1	12.5	16.9	114.4	1114
6	0.0	1.1	7.5	14.9	21.2	165.8	1755
7	0.0	2.8	13.1	23.8	35.6	194.2	2483
8	0.0	4.1	16.3	27.1	42.6	206.0	2456
9	0.0	6.2	24.5	43.4	64.0	330.6	2452
11	0.0	3.5	13.3	26.2	38.1	206.9	2346
12	0.0	4.5	20.4	39.4	57.4	290.2	1273
14	0.0	3.8	13.6	26.1	36.8	232.2	2482
15	0.0	0.9	5.1	11.7	16.6	145.0	2483
18	0.0	2.3	8.7	15.2	21.5	124.8	1772
19	0.0	1.8	9.5	19.5	31.8	109.6	215
20	0.0	3.0	11.5	22.9	31.5	165.9	704
21	0.0	4.2	13.3	22.6	33.1	141.6	1929
22	0.0	4.3	13.8	24.0	35.0	179.6	2482
23	0.0	1.4	7.5	15.7	22.4	147.8	1655
24	0.0	2.5	10.3	14.2	25.2	48.5	50
25	0.0	0.4	1.8	3.6	5.0	43.7	1225
26	0.0	1.7	5.4	11.2	15.2	84.0	171
27	0.0	1.2	4.6	15.2	21.4	80.5	78

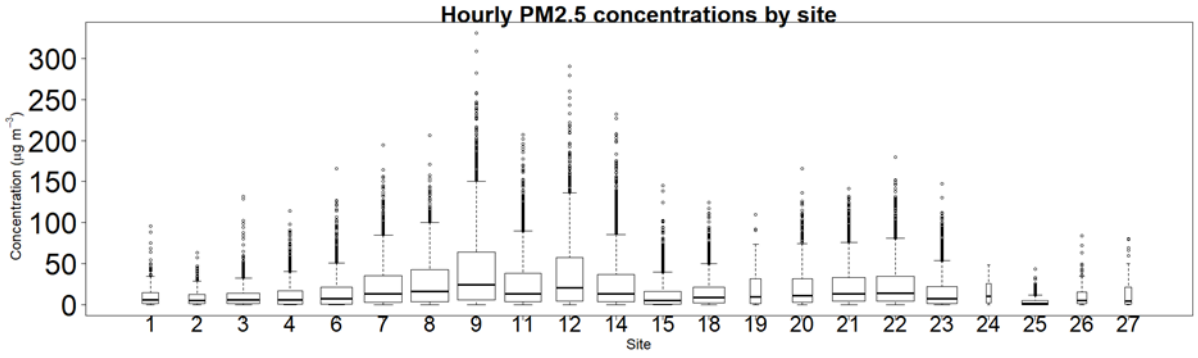

Figure 6: Hourly-average $PM_{2.5}$ (µg m^{-3}) across Motueka during the winter 2019 monitoring campaign.

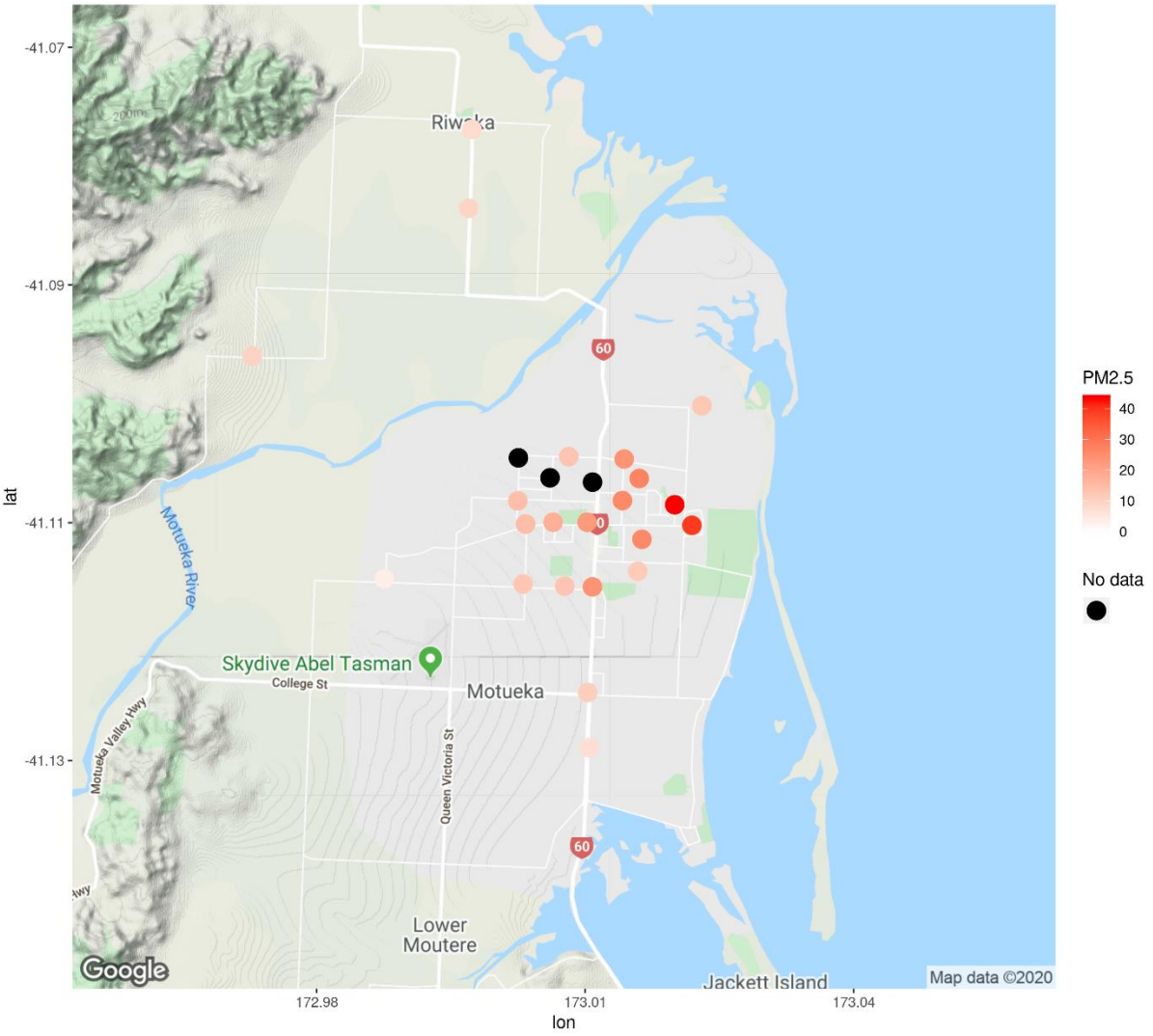

Figure 7: Campaign-average $PM_{2.5}$ (µg m^{-3}) across Motueka during the winter 2019 monitoring campaign.

3.2.2 Urban-Rural comparison

Tasman District Council requested a comparison of ODIN data from rural areas with data from Motueka township. It was hypothesised that daytime burning in rural areas might lead to different diurnal variations in concentration observed at more rural sites relative to urban sites. For this comparison results from Sites 1 (Brooklyn), 2 and 3 (Riwaka), and 25 (Whakarewa St) were designated as "rural". The daily cycle – i.e., the average hourly $PM_{2.5}$ concentration data from each site for each hour of the day are plotted in Figure 8 with the rural sites shown in green.

The rural sites followed the same diurnal pattern in concentrations as the Motueka sites, albeit with lower absolute concentrations, as would be expected from areas with similar but smaller source emissions. There is no evidence of a regular daytime source at any site, rural or urban. The lowest average concentrations are seen at Site 25 (Whakarewa St.) The two highest urban sites are Sites 9

(Pethybridge St.) and 12 (Blomfield Pl.), on the eastern edge of the town: These two sites have a large variation in concentrations through the day compared with other urban or rural sites.

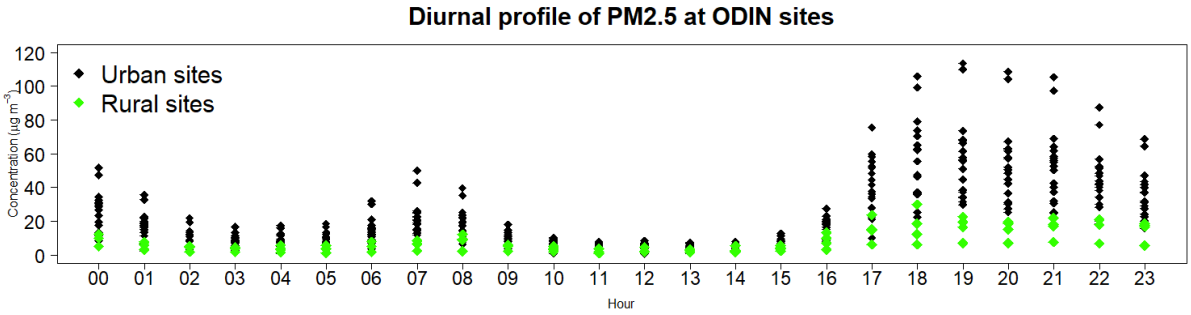

Figure 8: Diurnal Profile of hourly $PM_{2.5}$ concentrations at ODIN sites.

3.2.3 Rural burning events

Although there is no evidence for widespread or regular rural burning from the diurnal cycles seen at Sites 1 (Brooklyn), 2 and 3 (Riwaka), and 25 (Whakarewa St) (Figure 8), sporadic and short-lived high concentrations might indicate a 'plume strike' from a local woodsmoke source. To search for these, the 90th percentile of hourly average $PM_{2.5}$ concentrations for all 22 sites during the daytime hours of 6am to 3pm was calculated to be 16 µg m-3. Hours with concentrations above this threshold were identified for the four rural sites. Times when the threshold was exceeded are listed in Table 4. The frequency of events seen at Site 3 (Riwaka) suggests further investigation may be required. Figure 10 gives a visual indication of how frequently these events are occuring. TDC maintains cameras on the Richmond hills which can be used to observe weather conditions and rural burning in the wider area. Days when rural burning was observed are also shown on Figure 9 along with occasions when complaints to TDC were received from members of the public. These records can be found in Appendix A. Although there are days where complaints or observations of rural burning are coincident with spikes in $PM_{2.5}$ concentrations, it is not possible without further analysis to definitively link the events.

Table 4: Days and times when Hourly $PM_{2.5}$ concentrations were above the 90th percentile of all daytime hourly concentrations.

Site	Incidences when hourly $PM_{2.5}$ exceeded 16 µg m^{-3}	Dates when hours occured (hourly $PM_{2.5}$ concentrations recorded)
1	2	26/07/2019 15:00 (17.8 µg m^{-3})

		3/08/2019 10:00 (27.2 µg m^{-3})
2	3	19/07/2019 10:00 (17.0 µg m^{-3})
		21/07/2019 15:00 (18.4 µg m^{-3})
		10/08/2019 10:00 (21.0 µg m^{-3})
3	20	10/06/2019 10:00 (32.8 µg m^{-3})
		12/06/2019 14:00 (17.1 µg m^{-3})
		13/06/2019 13:00 (16.5 µg m^{-3})
		24/06/2019 14:00 (16.1 µg m^{-3})
		26/06/2019 15:00 (18.7 µg m^{-3})
		2/07/2019 10:00, 11:00, 14:00, 15:00 (19.5-60.1 µg m^{-3})
		3/07/2019 11:00 (32.3 µg m^{-3})
		10/07/2019 12:00, 14:00 (16.9 & 19.2 µg m^{-3})
		12/07/2019 12:00-15:00 (17.9-64.9 µg m^{-3})
		15/07/2019 12:00 & 14:00 (132.1 &40.8 µg m^{-3})
		19/07/2019 11:00 (35.9 µg m^{-3})
		20/07/2019 14:00 (33.4 µg m^{-3})
		26/07/2019 14:00 (44.8 µg m^{-3})
		1/08/2019 12:00 & 14:00 (17.2 & 21.1 µg m^{-3})
		4/08/2019 15:00 (16.9 µg m^{-3})
		10/08/2019 10:00 (16.6 µg m^{-3})
		14/08/2019 15:00 (18.6 µg m^{-3})
		16/08/2019 10:00 (27.5 µg m^{-3})
		17/08/2019 15:00 (21.7 µg m^{-3})
		25/08/2019 15:00 (21.8 µg m^{-3})
25	6	21/07/2019 14:00 & 15:00 (16.8 & 23.1 µg m^{-3})
		30/07/2019 15:00 (19.1 µg m^{-3})
		8/08/2019 11:00 (16.7) µg m^{-3}
		10/08/2019 10:00 (33.6 µg m^{-3})
		16/08/2019 13:00 (22.4 µg m^{-3})
		28/08/2019 12:00 (21.3 µg m^{-3})

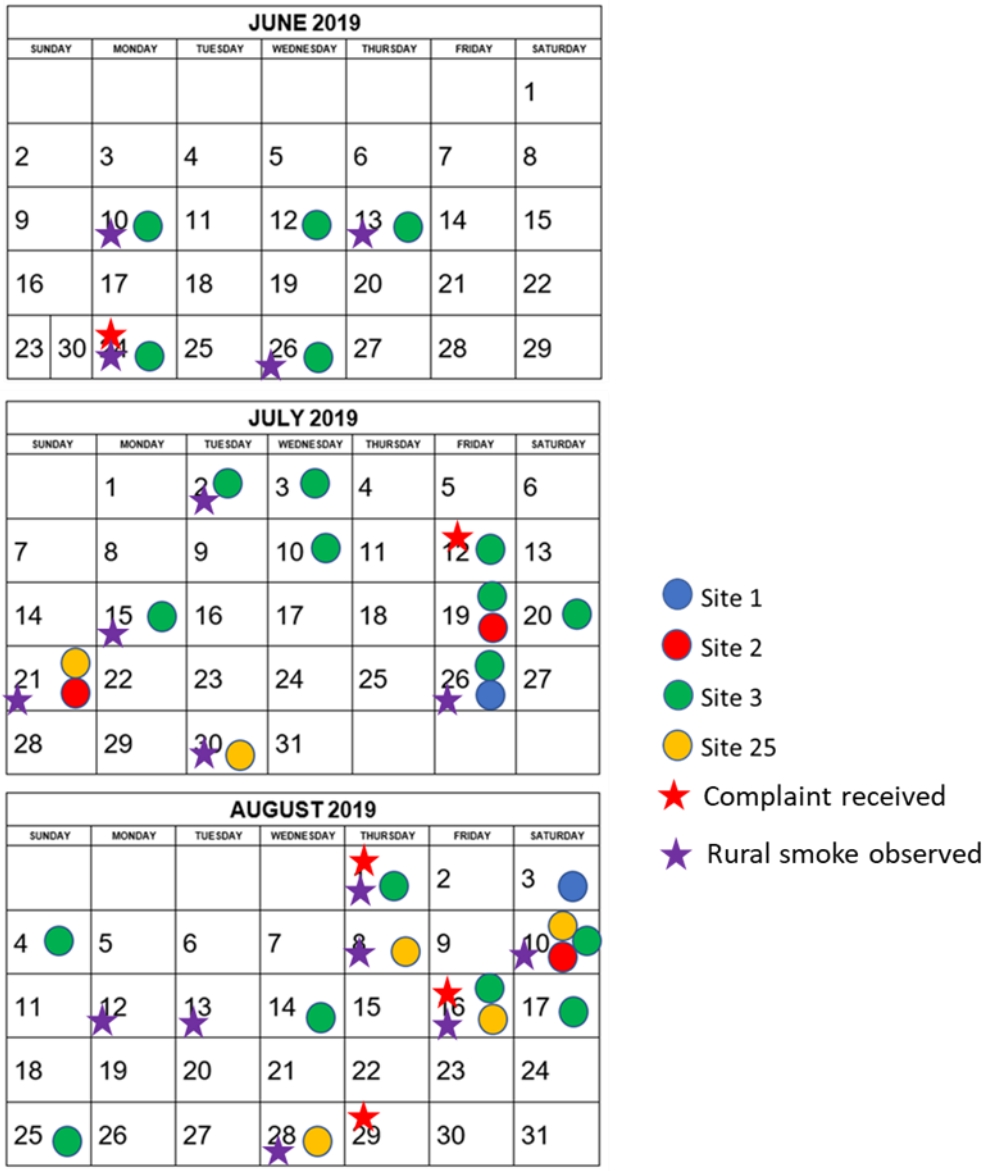

Figure 9: Calendar of potential 'Plume Strikes', when $PM_{2.5}$ concentrations were elevated at Rural Sites: Including occasions when complaints were received and burning observed using the TDC camera.

3.3 PM_{10}

Daily 24-hour averages across the monitored sites are shown in Figure 10, along with daily minimum temperature and daily 24-hour averaged windspeed. There is a large variation in 24-hour average $PM_{2.5}$ values across the town for any given day, and a large variation between days, with very high values on some days, reaching a peak 24-hour average value for any individual site of 109.5 µg m^{-3} at site 9 (Pethybridge St) on 10th July. High values persisted across the town for four days from the 10th to 13th July, with the average value for all sites lying between 40 µg m^{-3} and 60 µg m^{-3}.

As for $PM_{2.5}$, there is no observable relationship between concentrations and either average daily windspeed or minimum daily temperature. Although meteorological conditions do play a key role in how air pollution disperses, further analysis is required to illustrate connections between how air moves across Motueka and pollutant concentrations. In addition, during winter how much pollution is generated by the township is more dominated by habit and lifestyle than specific day-to-day weather conditions.

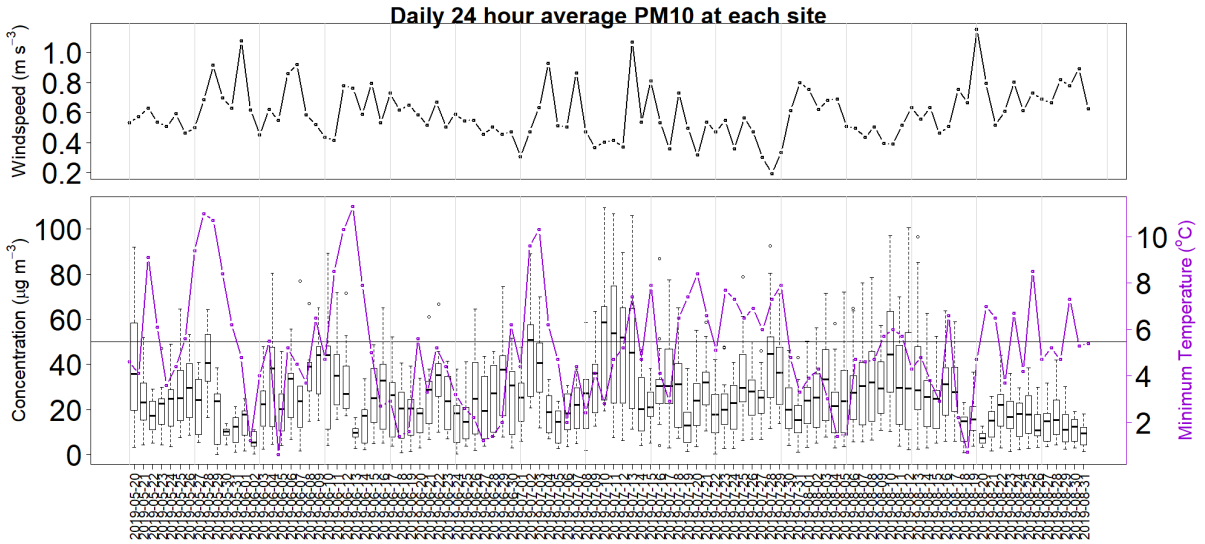

Figure 10: Range of daily 24-hour average PM_{10} (µg m^{-3}) across Motueka during the winter 2019 monitoring campaign, with NES limit value.

Summary statistics for the campaign are shown in Table 5 and Figure 11. Campaign averages are mapped in Figure 12. They show considerable variation across the area with campaign-average values ranging from as low as 4.6 µg m^{-3} on the southern approaches to the town to as high as 52.5 µg m^{-3} on the eastern edge.

The map in Figure 12 appears to depict a a gradient in concentrations from west (low) to east (high). The high values to the east may be due to the prevailing south-west winds transporting smoke across the town, although at this stage we cannot rule out a strong local emissions source in the east. The highest ten-minute values (not shown) are spread around the town but not coincident, so probably due to local, short-term sources.

Table 5: Summary PM_{10} (µg m^{-3}) statistics hourly averaged values for the Motueka winter 2019 monitoring campaign.

Site	Minimum	25%	50%	Mean	75%	Maximum	# Hours' data
1	0.0	1.9	6.8	12.6	17.8	132.3	456
2	0.0	2.0	6.2	9.8	13.8	71.0	452
3	0.0	1.7	6.4	11.2	15.8	143.5	1906
4	0.0	1.1	6.4	13.8	17.9	138.5	1114
6	0.0	1.2	7.8	16.6	22.7	192.5	1755
7	0.0	5.4	20.1	35.1	52.5	259.6	2483
8	0.0	4.7	19.1	33.9	52.5	275.1	2456
9	0.0	6.8	28.8	52.9	77.3	430.3	2452
11	0.0	5.4	18.1	35.1	50.2	286.4	2346
12	0.0	5.3	23.9	46.8	66.2	363.2	1273
14	0.0	3.9	14.6	29.8	41.1	301.7	2482
15	0.0	0.9	5.4	13.3	18.5	171.2	2483
18	0.0	2.5	9.2	17.0	23.6	143.4	1772
19	0.0	2.3	12.4	23.8	37.3	145.4	215
20	0.0	4.2	15.5	28.2	38.4	203.9	704
21	0.0	5.1	16.4	29.7	43.7	190.1	1929
22	0.0	4.9	15.2	27.1	39.3	195.5	2482
23	0.0	1.8	8.5	18.6	25.7	177.0	1655
24	0.0	2.7	11.2	15.5	26.8	54.8	50
25	0.0	0.8	2.5	4.6	6.6	53.5	1225
26	0.1	2.0	5.7	12.2	16.5	95.8	171
27	0.0	1.7	5.8	19.4	26.2	109.0	78

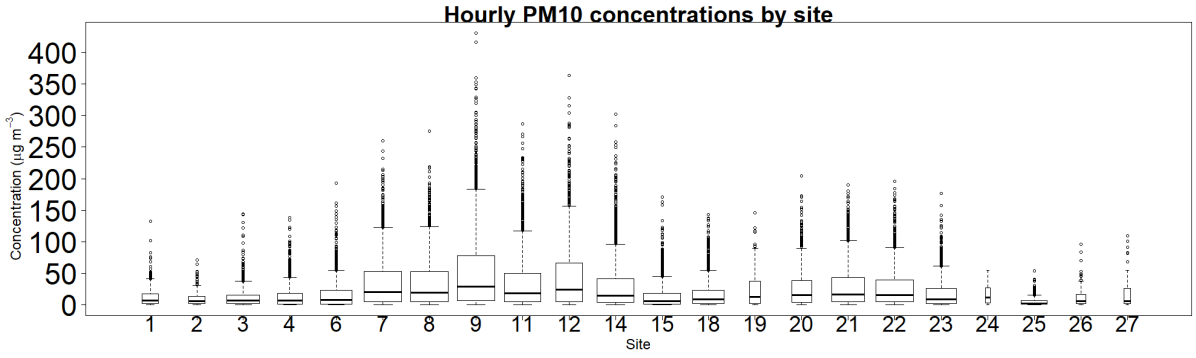

Figure 11: Hourly average PM_{10} (µg m^{-3}) across Motueka during the winter 2019 monitoring campaign.

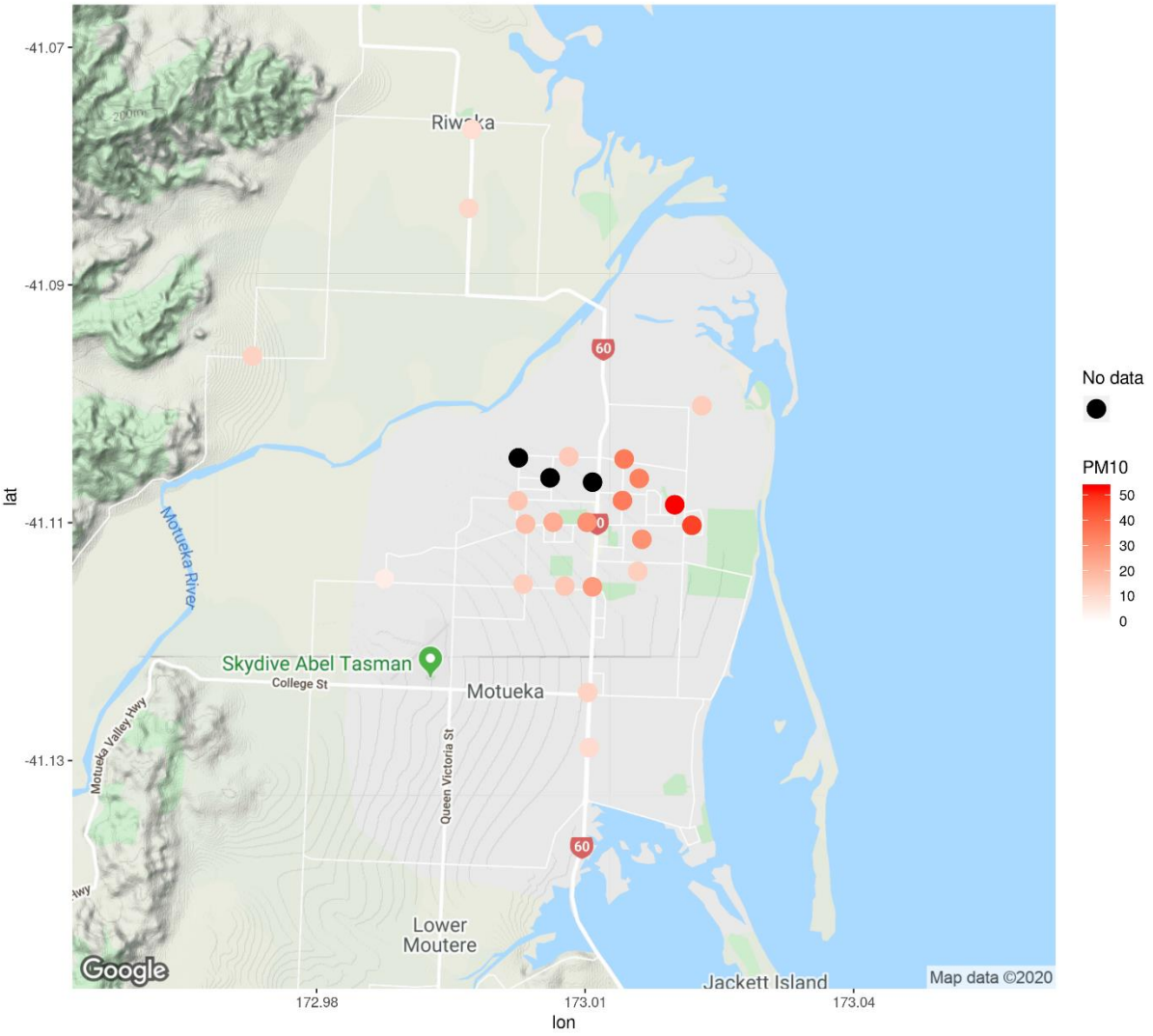

Figure 12: Campaign-average PM_{10} (µg m^{-3}) across Motueka during the winter 2019 monitoring campaign

3.3.1 Partisol

Tasman District Council measures PM_{10} at Parklands School, Motueka using a Thermo Fisher Partisol 2025 Sequential Air Sampler. Results, supplied by TDC, are shown in Appendix B. The maximum 24-hour PM_{10} value measured during the winter was 29 µg m^{-3}, with an average of 16 µg m^{-3}.

Figure 13 compares the time series of 24-hour averages from the Partisol with those from the nearest ODIN location (Site21 – Pah St.), approximately 100 m away. The PM_{10} results from both instruments generally follow the same temporal pattern. Concentrations from the ODIN are clearly higher. This is most likely due to differences in instrumental technology – it is common for partisol measurements to be lower than from other particulate measuring instruments – however, a genuine difference in concentrations between the two locations cannot be ruled out.

Figure 14 shows the range of daily PM_{10} concentrations across the ODIN network, with results from site 21 (Pah St.) and the Partisol highlighted. This shows that site 21 is consistently in the third quartile of concentrations measured across all sites. As a first approximation, therefore, it is reasonable to assume that the Parklands School site where the Partisol was located, is broadly representative of Motueka, but under-represents peak concentrations.

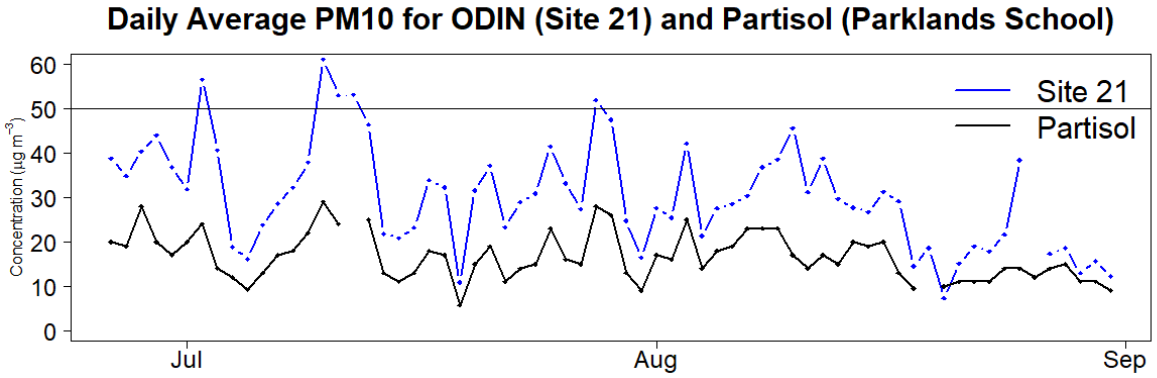

Figure 13: Comparison of Partisol with nearest ODIN (Site 21 – Pah St), with NES limit value.

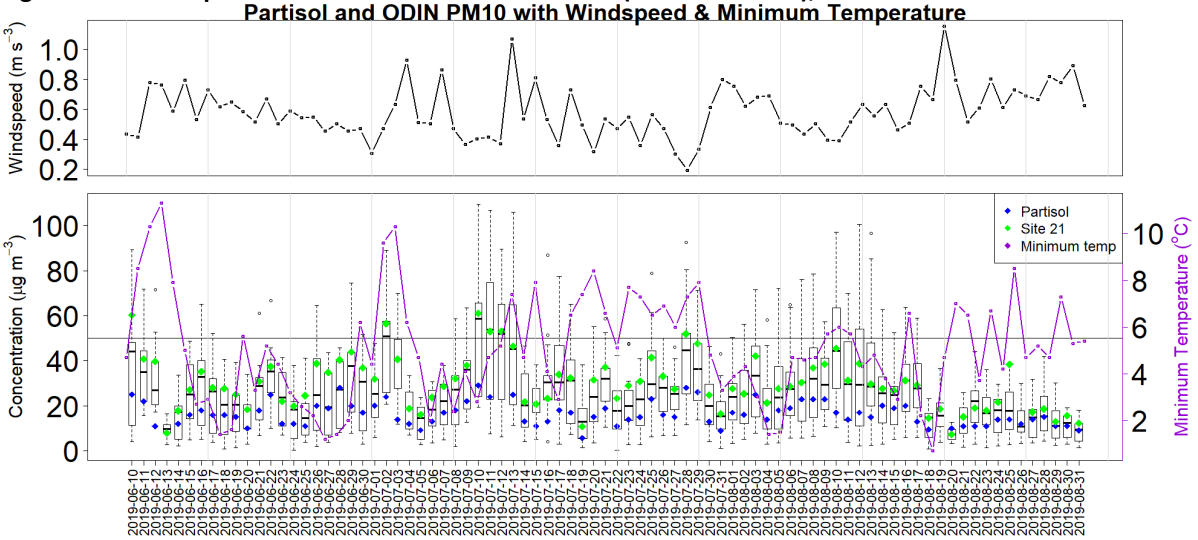

Figure 14: Partisol PM_{10} results from Motueka for winter 2019 (supplied by TDC) (blue dots) compared to PM_{10} measured across Motueka using an ODIN network, with NES limit value. The nearest ODIN (Site 21 – Pah St) to the Partisol is also shown (green dots).

4 Conclusions and Recommendations

4.1 Conclusions

The WHO guideline for $PM_{2.5}$ is 25 µg m^{-3}, as a 24-hour average. We understand the Ministry for the Environment plans to adopt the same limit as a National Environment Standard soon. Our study finds that sites in Motueka regularly exceed this value in winter, with 24-hour average values nearly four times as high having been recorded.

These measurements revealed a noticeable spatial gradient across Motueka, with higher values, on average, being recorded in the east of the town. Whether this is due to the transport of smoke from the town on prevailing SW winds or a strong local emission source in the east is not yet known.

The current TDC monitoring site does not appear to capture the highest concentrations in Motueka possibly due to being on the western side of town where concentrations are generally lower. Regulation 15 of the Resource Management Regulations 2004 state that Regional Councils must conduct air quality monitoring if the NES is breached in "that part of the airshed where… the standard is breached by the greatest margin or the standard is breached most frequently."

In general, rural agricultural burning does not appear to have made a significant contribution to air quality in the long-term. However, there is evidence for short-lived rural burning impacts in the surrounding countryside, particularly around Riwaka, which may require further investigation.

To answer the questions set out in the introduction (section 1.2);

1. Motueka does appear to have an air quality issue with some locations having measured $PM_{2.5}$ concentrations in excess of current guidelines and anticipated future legislation.

2. Potential short-term impacts of rural burning episodes on air quality have been identified, which require further investigation

3. A permanent monitoring site may be required, although it may take more than one winter to establish whether this is a persistent problem. Investigating locations on the eastern side of the town for any permanent site would seem prudent. We suggest a location in the area bounded by sites 8, 9, 12 and 14. For practical purposes either in Ledger-Goodman Reserve or at the northern end of Pethybridge St, where there are already installations where power might be available.

4.2 Outstanding questions

The following issues remain uncertain and deserve further investigation:

- Although rural burning was not found to be a major cause of poor air quality, we did find evidence of short-lived and localised impacts. Overall, the contribution, major source areas, and impacts of rural burning remain largely unknown.

- Whether the data recorded during this campaign, and the Partisol data from 2019, represent a typical or atypical range of conditions (from the point of view of meteorological variation and burning activity) is unknown at present.

- Whether the “hotspot” in concentrations to the east of the town is a permanent feature, or whether different weather conditions or other factors would lead to the highest concentrations being observed elsewhere is currently unknown.

4.3 Recommendations

There are several options for next steps;

- Further monitoring using a single central site (e.g. current Partisol, or a single ODIN) for another winter will indicate whether this winter was typical and whether high concentrations are a pervasive problem.
- Further monitoring next winter using ODINs or similar devices at a reduced scale (4 – 10 units) will help to better understand the representativeness of any given monitoring site and whether spatial variation observed in this study is persistent or changes over time.
- Establishing a monitoring site (permanent or temporary) in the eastern part of the town. This might be informed by winter monitoring of potential sites using ODINs (or similar) for one winter before a permanent site is selected.
- Further exploring the current dataset to investigate relationships to weather and burning behaviour.
- A separate study is recommended to focus exclusively on agricultural burning, which could combine monitoring, modelling, video surveillance and other remote sensing approaches.

Similar exploratory campaigns in other Tasman townships, such as Brightwater and Wakefield, would establish whether they have an air quality issue from wood burning that may require further investigation.

5 Acknowledgements

We gratefully acknowledge the help of Diana Worthy, Jane Stuart and Anna MacKenzie at Tasman District Council.

Appendix A Complaints Record and Visible Smoke

Outdoor rural burning complaint dates and details (applicable for rural sites 1, 2, 3 and 25):

Date	Description
24/06/19	Thick smoke between Lodders Lane, School Road and Main Road Riwaka (10am – 12 noon)
12/07/19	Large Orchard burn behind 84 Umukuri Road, Riwaka (between Swamp Road and Main Road Riwaka) Raining (12 noon – 3pm)
01/08/19	Orchard burn corner Umukuri Rd and Main Road Riwaka (12.15pm)
16/08/19	Orchard burn Peach Island (South of Brooklyn) 12noon
29/08/19	large orchard burn Chamberlain St, South of Motueka. 3.30pm

Webcam imagery – viewed on Richmond webcam showing inversion and smoke in Motueka:
Webcams can be viewed at: https://www.tasman.govt.nz/my-region/webcams/

Date	Description
28/05/19	Wet, low cloud
04/06/19	Smoke and smoke inversion visible most of day
10/06/19	Smoke low over Motueka with large rural fire visible Riwaka area
12/06/19	Wet, low cloud
13/06/19	Smoke inversion visible Riwaka area
24/06/19	Large orchard burn visible Riwaka
26/06/19	Smoke inversion visible Motueka and rural
02/07/19	Heavy smoke inversion visible Motueka out to Riwaka
03/07/19	Low cloud, Motueka not visible
10/07/19	Motueka appears smokey from 11am
11/07/19	Motueka appears smokey from midday
12/07/19	Low cloud, Motueka not visible
13/07/19	Richmond inversion impedes visibility
15/07/19	Smoke inversion visible late morning, large fire Riwaka from 12.30
19/07/19	Low cloud, nil visibility
20/07/19	Nil smoke visible

Date	Description
21/07/19	Low cloud early and poor visibility, low smoke inversion Motueka Riwaka visible from 2pm
26/07/19	Fire visible 9am Riwaka, smoke layers into late afternoon
28/07/19	Motueka appears smokey all day, visibility not great
29/07/19	Poor visibility
30/07/19	Heavy inversion from early morning, fire visible to south from 10.30am, smoke and inversion from this over Motueka Riwaka until late
01/08/19	Morning smoke inversion, number of fires visible Riwaka/Brooklyn
04/08/19	Hazy, poor visibility
08/08/19	Smoke inversion visible Motueka out to Brooklyn, Riwaka
10/08/19	Motueka/Riwaka appeared under smoke inversion early morning and late afternoon. Poor visibility in between
12/08/19	Smoke inversion early, then poor visibility
13/08/19	Smoke inversion visible early, looks clear after noon
14/08/19	Smoke not visible
16/08/19	Smoke visible mid-morning with plume visible Brooklyn (Peach Island?) from 11am. Motueka hazy with smoke all afternoon
17/08/19	Low cloud, poor visibility
25/08/19	Hazy with slight smoke afternoon. No inversion
28/08/19	Large fire visible Riwaka 11am, smoke drifting to South

Appendix B Partisol Record and ODIN concentrations for Site 21

Date	PM10 (24hr) (ug m-3) at AQ Motueka at Parklands School	PM10 (24hr) (ug m-3) Site 21 - Pah St	Date	PM10 (24hr) (ug m-3) at AQ Motueka at Parklands School	PM10 (24hr) (ug m-3) Site 21 - Pah St
2/05/2019	16	no data	26/05/2019	16	no data
3/05/2019	14	no data	27/05/2019	19	no data
4/05/2019	15	no data	28/05/2019	14	no data
5/05/2019	10	no data	29/05/2019	16	no data
6/05/2019	14	no data	30/05/2019	9	no data
7/05/2019	16	no data	31/05/2019	7	no data
8/05/2019	20	no data	1/06/2019	6	no data
9/05/2019	15	no data	2/06/2019	3	no data
10/05/2019	14	no data	3/06/2019	15	no data
11/05/2019	14	no data	4/06/2019	21	no data
12/05/2019	12	no data	5/06/2019	6	no data
13/05/2019	13	no data	6/06/2019	15	no data
14/05/2019	no data	no data	7/06/2019	15	no data
15/05/2019	10	no data	8/06/2019	26	no data
16/05/2019	11	no data	9/06/2019	25	no data
17/05/2019	14	no data	10/06/2019	25	60.4
18/05/2019	12	no data	11/06/2019	22	40.8
19/05/2019	13	no data	12/06/2019	11	39.7
20/05/2019	23	no data	13/06/2019	no data	8.0
21/05/2019	19	no data	14/06/2019	12	17.8
22/05/2019	14	no data	15/06/2019	16	27.1
23/05/2019	14	no data	16/06/2019	18	35.2
24/05/2019	17	no data	17/06/2019	16	28.1
25/05/2019	18	no data	18/06/2019	16	27.6

Date	PM10 (24hr) (ug m-3) at AQ Motueka at Parklands School	PM10 (24hr) (ug m-3) Site 21 - Pah St	Date	PM10 (24hr) (ug m-3) at AQ Motueka at Parklands School	PM10 (24hr) (ug m-3) Site 21 - Pah St
19/06/2019	15	25.0	13/07/2019	25	46.4
20/06/2019	10	18.4	14/07/2019	13	21.8
21/06/2019	18	30.9	15/07/2019	11	20.8
22/06/2019	25	37.5	16/07/2019	13	23.3
23/06/2019	12	21.9	17/07/2019	18	33.9
24/06/2019	12	19.8	18/07/2019	17	32.3
25/06/2019	11	24.5	19/07/2019	6	10.9
26/06/2019	20	38.8	20/07/2019	15	31.6
27/06/2019	19	34.8	21/07/2019	19	37.2
28/06/2019	28	40.4	22/07/2019	11	23.3
29/06/2019	20	44.0	23/07/2019	14	28.9
30/06/2019	17	36.8	24/07/2019	15	30.9
1/07/2019	20	31.9	25/07/2019	23	41.5
2/07/2019	24	56.5	26/07/2019	16	33.2
3/07/2019	14	40.6	27/07/2019	15	27.4
4/07/2019	12	18.8	28/07/2019	28	51.9
5/07/2019	9	16.1	29/07/2019	26	47.5
6/07/2019	13	23.7	30/07/2019	13	24.7
7/07/2019	17	28.6	31/07/2019	9	16.4
8/07/2019	18	32.2	1/08/2019	17	27.6
9/07/2019	22	37.8	2/08/2019	16	25.4
10/07/2019	29	61.0	3/08/2019	25	42.1
11/07/2019	24	53.0	4/08/2019	14	21.3
12/07/2019	no data	53.1	5/08/2019	18	27.6

Date	PM10 (24hr) (ug m-3) at AQ Motueka at Parklands School	PM10 (24hr) (ug m-3) Site 21 - Pah St	Date	PM10 (24hr) (ug m-3) at AQ Motueka at Parklands School	PM10 (24hr) (ug m-3) Site 21 - Pah St
6/08/2019	19	28.6	30/08/2019	11	15.7
7/08/2019	23	30.4	31/08/2019	9	12.3
8/08/2019	23	36.8			
9/08/2019	23	38.5			
10/08/2019	17	45.6			
11/08/2019	14	31.2			
12/08/2019	17	38.7			
13/08/2019	15	29.6			
14/08/2019	20	27.7			
15/08/2019	19	26.7			
16/08/2019	20	31.3			
17/08/2019	13	29.2			
18/08/2019	10	14.5			
19/08/2019	no data	18.6			
20/08/2019	10	7.3			
21/08/2019	11	15.1			
22/08/2019	11	19.0			
23/08/2019	11	17.9			
24/08/2019	14	21.6			
25/08/2019	14	38.4			
26/08/2019	12	NA			
27/08/2019	14	17.3			
28/08/2019	15	18.6			
29/08/2019	11	13.0			