Spatial Variation of $PM_{2.5}$ in Reefton during winter 2020

Prepared for West Coast Regional Council

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Climate, Freshwater & Ocean Science

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Executive summary

The WCRC have commissioned NIWA to investigate whether the council has been underestimating the concentrations of air-borne particulate matter (PM) in Reefton due to the location of its air quality monitoring site (Reefton Area School) and a lack of information about spatial patterns in the distribution of particulate matter across the town. The monitoring site was relocated about 300m from its former site in 2016 and there are concerns that changes in measured PM are due to this move rather than changes in air quality.

The aim of this work is to:

- Compare air quality data from a number of locations across the town to assess whether there is significant spatial variation in air-borne particulates within the Reefton urban area.
- If there is spatial variation, identify any spatial patterns in air-borne particulates across the Reefton air shed.
- Advise WCRC on future methods for assessing particulates in Reefton that take into account any identified spatial variability.

An air quality measurement campaign was conducted by WCRC in Reefton during winter 2020 using 18 NIWA-built ODIN monitors to measure the mass concentration of $PM_{2.5}$ (PM with an aerodynamic diameter of 2.5 micrometres or less). Data collection was sporadic as there was not enough sunlight during the daytime to keep the solar-powered ODINs fully charged, leading to intermittent failures of the instruments. However, enough data were captured to give an initial description of the spatial variation of $PM_{2.5}$ in Reefton and of how representative of air quality in the town the current monitoring site at the Reefton Area School is.

There is clearly considerable variation in $PM_{2.5}$ across Reefton, with the pattern changing depending on conditions. The mean daily concentration in Reefton during July was 36 $\mu g/m^3$. Even as late as early September, there were still days with many locations recording high values, only falling to consistently lower levels by the middle of September.

On some days at the height of winter, the difference in the daily average between the most and least polluted locations in Reefton can be in the region of 40 – 60 µg/m3 if outliers are discounted. Throughout the winter and into September, the difference tended to be in the region of 20 µg/m3 until all values dropped later in September.

The results show that the highest concentrations tend to be in the central and northern parts of town. However, care should be taken in interpreting results as sparse data at the southern end of town can increase the uncertainties in that area. There is a particular lack of data in the area roughly between Potter St and Church St, although the ODIN monitor towards the southern end of Buller Rd recorded a mean of concentration of 44 µg/m3 during July, which was one of the highest measured in that period, indicating that there were high concentrations in this area during that time.

The current regulatory monitoring site at Reefton Area School consistently underrepresents concentrations across the town. In fact, the original monitoring site at the corner of Lucas Street and Buller Road was probably more generally representative. For regulatory compliance, monitoring should be conducted where pollutant concentrations are known or expected to be highest.

The highest concentrations measured during the campaign were at the site on Bridge St. However, this location is clearly impacted by a local source and not representative of the town in general. A site in the area bounded by Buller Rd (SH69), Davis St, Caples St and Ranft St will be more generally representative of air quality across the town.

Since not all the instruments were operating concurrently the dataset is incomplete, this means that there is some uncertainty in the results of the monitoring. That is, it was difficult to compare different sets of instruments on different days with no consistent pattern in the data loss. While we are confident that the current dataset is sufficient to give a general picture of the magnitude and type of variation across Reefton, uncertainty remains, particularly in the southern part of town. Further work should consider completing the dataset that this work set out to capture to fill in some of the gaps.

1 Introduction

The West Coast Regional Council (WCRC) is required to evaluate air quality in the Reefton airshed as stipulated by the National Environmental Standards for Air Quality (NES)[1]. The WCRC currently monitors particulate matter (PM) in Reefton at the Reefton Area School[2] using two instruments – a Teledyne T640x sensor and a Thermo Fisher beta attenuation mass monitor (BAM). Both instruments measure the concentration of air-borne particulate matter (PM), albeit with respect to different size classes[3]; the first is able to measure both $PM_{2.5}$ and PM_{10} while the latter measures only PM_{10}.

The Reefton air quality monitoring site was re-located in September 2016 from the corner of Lucas Street and Buller Road to the Reefton Area School, a distance of approximately 300m. The school site is close to the edge of town with open spaces nearby while the former site was closer to the town centre and next to the main State Highway running through the town.

The 2017-2019 period had lower PM_{10} results than those recorded at the previous site, as shown in Figure 1. This raises significant uncertainties around the scale of the air quality issue, the representativeness of the current monitoring site and compliance with national environmental standards.

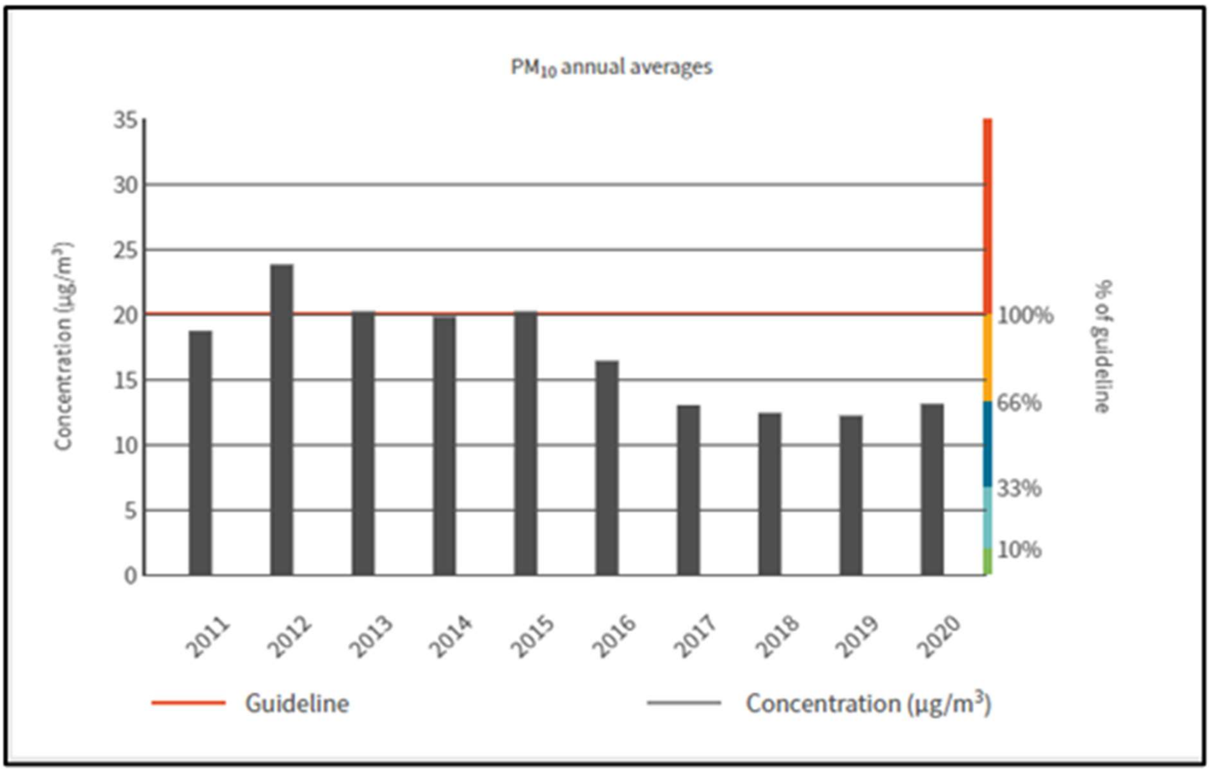

Figure 1: PM_{10} annual average (µg/m³) in Reefton: the monitoring site was relocated in late 2016. (Chart from www.lawa.org.nz)

[1] https://environment.govt.nz/assets/Publications/Files/2011-user-guide-nes-air-quality.pdf
[2] https://www.lawa.org.nz/explore-data/west-coast-region/air-quality/reefton/reefton-aq-at-school-pool/
[3] $PM_{2.5}$ refers to particles that have an aerodynamic diameter of 2.5 microns or less and PM_{10} refers to particles that have a diameter of 10 microns or less.

The WCRC have commissioned NIWA to investigate whether the council has been underestimating the concentrations of particulate matter due to the location of the air quality monitoring and a lack of information about spatial patterns in particulate distribution.

The aim of the work is to:

- Compare air quality data from a number of locations across the town to assess whether there is significant spatial variation in air-borne particulates within the Reefton urban area.
- If there is spatial variation, identify any spatial patterns in air-borne particulates across the Reefton air shed.
- Advise WCRC on future methods for assessing particulates in Reefton that take into account any identified spatial variability.

A measurement campaign was conducted in Reefton during winter 2020 using 18 NIWA-built Outdoor Dust Information Node (ODIN) monitors. It should be noted that the ODIN monitors use 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.

According to the latest Reefton emissions inventory (Wilton 2019), the total PM discharged to air in Reefton on an average winter's day in 2019 was estimated to be 141 kilograms PM_{10} and 131kg $PM_{2.5}$. Domestic home heating was estimated to be the main source of PM emissions contributing 98% of the daily wintertime emissions, which was further broken down into approximately 60% coal and 40% wood burning for both the PM_{10} and $PM_{2.5}$ particulate fractions. The emissions inventory was based on the entire Reefton airshed and does not comment on spatial variation. There was also no attempt to translate emissions into concentrations.

2 Methods

2.1 Measurement methods

Measurements of $PM_{2.5}$ and PM_{10} were made using ODIN PM_x monitors. An ODIN monitor 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.

The core of the ODIN package is a Plantower PMS3003 dust sensor[4] that optically detects light scattering by particles in the atmosphere being sampled. This measurement is then translated into a quantification of the mass per unit volume of particulate (µg/m^3) using algorithms pre-programmed by the manufacturer. the Plantower PMS3003 dust sensor, reports three different sizes of particulate: PM_1, $PM_{2.5}$ and PM_{10}. This work reports only the $PM_{2.5}$ fraction.

Eighteen ODIN monitors were deployed for this study. Each ODIN has a 2G connection and data are telemetered to NIWA via the mobile phone network. Rather than measure continuously, the ODIN takes a single reading at set intervals. Initially the ODINs were set to take a measurement every minute but were reset on the 15th July to record every 10 minutes in order to conserve power.

[4] http://www.plantower.com/en/

Initially the ODINs were set up alongside the current reference monitoring station at Reefton Area School for a period of co-location in order to calibrate the ODINs to the local conditions. This occurred in two batches. The first batch of ten ODINs was co-located on 1st July and deployed on 7th July. The second batch of eight was co-located on 31st July and deployed on 3rd August. Results showed that the units all gave consistent measurements within the limits of error of the sensors. The precision of each data point is 1 $\mu g\ m^{-3}$.

The data from each ODIN were corrected to the results from the WCRC Teledyne T640x reference instrument co-located at the Reefton Area School. The correction was conducted to ensure internal consistency amongst the ODINs, so that they could be compared to one another to investigate the variation in $PM_{2.5}$ concentrations in Reefton.

The units were then set out on lampposts at 17 locations around Reefton, with one remaining at the School reference site, in a pre-determined pattern, to provide coverage of the entire town (Figure 2). Monitoring took place from 7th July to 30th September 2020

Data have been averaged into hourly averages where at least one data point was recorded every 10 minutes during that hour. A file of quality assured $PM_{2.5}$ results was supplied to WCRC separately to this report.

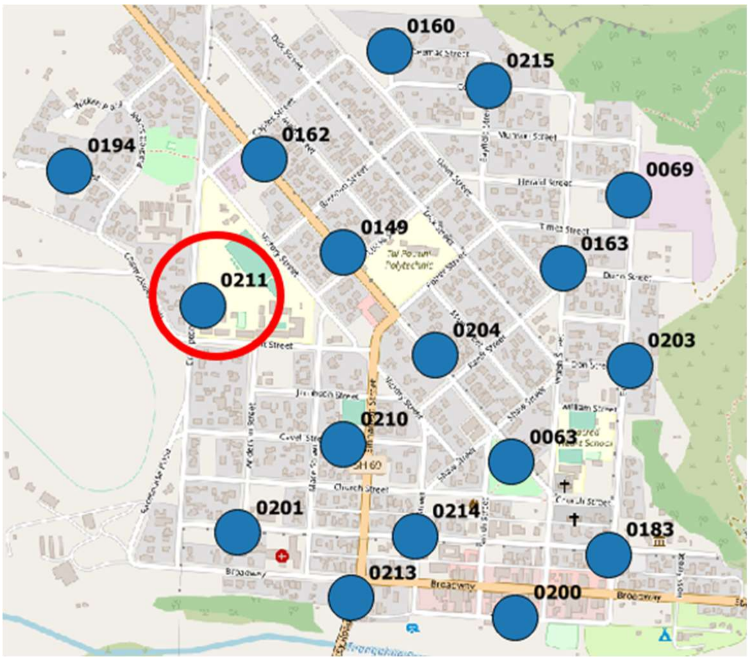

Figure 2: ODIN monitoring locations around Reefton during the winter 2020 monitoring campaign. The WCRC site at Reefton Area School is circled.

3 Results and discussion

3.1 Challenges with Data Coverage

Throughout the campaign, a problem with power led to most of the ODIN units failing intermittently to varying degrees. The units are solar-powered and it is thought that there was insufficient sunlight to keep the units working during the winter.

Data coverage was not as good as anticipated due to:

- the power requirements exceeding the capacity of the solar panel to recharge the battery, due to a combination of the solar energy available and the initial measurement frequency of the ODINs (one measurement per minute). This was later changed to one measurement per 10-minutes, which provided better reporting reliability.
- Some units malfunctioning and not recording data at all, or for most of the deployment period.

Across the entire campaign, the data recovery was 58%. This was strongly affected by three units that recorded very little or no data at all. If they are discounted the remaining units returned 64% data, which while below our expected data capture rate of greater than 75% is enough to give an indication of the spatial and temporal variation of $PM_{2.5}$ in Reefton. A table of data capture rates is given in Appendix A.

3.2 Generating unbiased data

The result of intermittent data loss is that a complete picture of the spatial and temporal variation cannot be created due to biases in the dataset caused by different periods relying on a different number and arrangement of monitors leading to uncertainties in the results.

In the initial data processing, the following analysis steps determined which periods had enough data to provide a less biased picture of $PM_{2.5}$ across Reefton, both spatially and temporally:

1. For each unit, a ten-minute mean time-series was generated. This allowed the amalgamation of the early period dataset, when ODINs were measuring every minute, with the later data.
2. Each ODIN was assessed to see how many 10-minute datapoints were available in every measurement hour. The hour was given a score from 0 to 6.
3. Only hours that had six 10-minute datapoints were used to generate a 1-hour mean time series.
4. For each unit, the 1-hour time series was then assessed to see how many hours were available for each 24-hour period.

No threshold number of hours was set to determine if a day had enough hours present to generate a 24-hour mean. This is because air pollution in Reefton is not uniform throughout the day; some hours matter more than others in capturing the distribution of air pollution across the town. Instead, expert opinion was used to determine which days had an adequate number of ODIN units measuring for an adequate number of hours to gain a representative ‘picture’ of Reefton’s air quality. In this case, the suitable days chosen clustered into three periods.

We have chosen to call the three periods when the ODINs were providing a representative picture of Reefton's air quality, case-studies. Figure 3 shows the range of 24-hour mean concentrations for the whole deployment period, with case-studies A, B and C highlighted in blue.

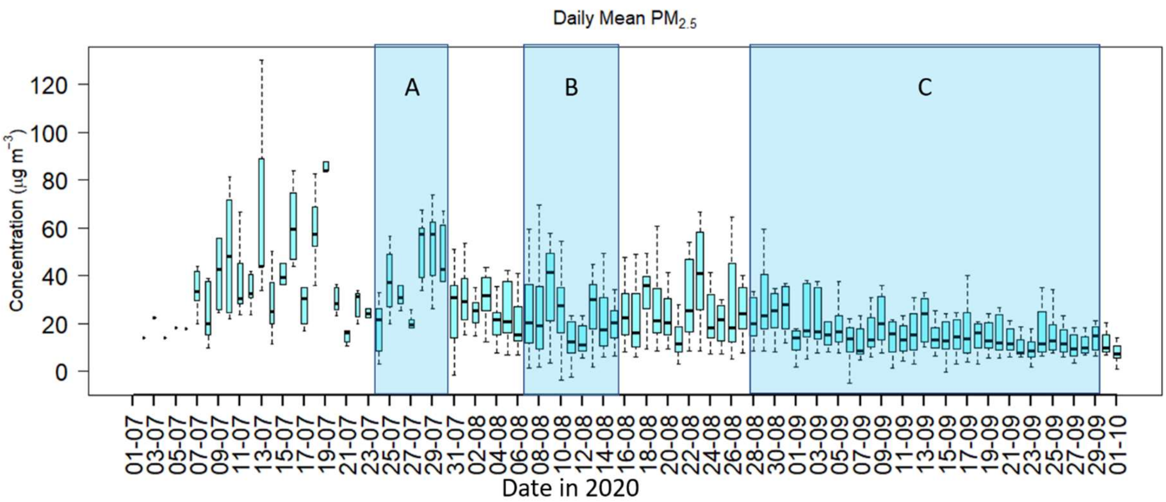

Figure 3: 24-hour mean concentrations with the three case studies highlighted.

The case studies have slightly different characteristics. During case study A there were only ten ODINs adequately measuring $PM_{2.5}$ but they were evenly distributed around the town. This period experienced higher concentrations than the later case studies. Case study B had the most ODINs recording but this was a relatively clean air period and 24-hour mean concentrations dropped. The final case study, C, was the longest period and had lower 24-hour mean concentrations. Table 1 gives details of each case study.

The ODIN located at the corner of Herald and Bridge Streets (Unit 0069) gave consistently higher concentrations than any other unit in the campaign, with hourly concentrations strongly uncorrelated with all other units – results from this location peak during the day rather than in the evening. The unit is considered an outlier (**Error! Reference source not found.**) but at this stage we are not able to positively identify a cause for the unusual results. The overall 24-hour mean is calculated with and without this unit as shown in Table 1.

Table 1: Three case study periods identified for further analysis during the winter 2020 monitoring campaign in Reefton.

Case Study	First day	Last day	Total number of days	Number of ODINS recording	24-hour mean $PM_{2.5}$ concentration (µg m^{-3})	
					All sites	Unit 0069 removed)
A	24/07/20	30/07/20	7	10	36	36
B	07/08/20	15/08/20	9	14	31	22
C	28/08/20	29/09/20	32	13	30	20

Figure 4 shows the range of 24-hour mean concentrations measured by each ODIN during the case studies. It's apparent that unit 0069 (present in case studies B and C) is a significant outlier and is responding to a local source. This was clear not just from the high concentrations but also from the temporal pattern of the measurements, which were high during the day, as well as night.

Figure 5 shows maps of the average $PM_{2.5}$ concentrations reported by each contributing ODIN during each of the study periods.

Figure 6 shows the time series of 24-hour concentrations with the 24-hour mean concentrations measured by the reference ODIN unit, 0211, located at the Reefton Area School AQ site, shown as orange points. It is clear that the concentrations measured at this site are generally in the lower quartile of concentrations measured around the town. This suggests the site is under-representing air quality across Reefton.

From the results in Figure 5, interpolated maps of concentrations across the town can be derived for case study periods B and C using spline interpolation in ArcMap, as shown in Figure 7. It is not possible to interpolate period A because the number of locations is too small. ODIN 069 is not included in the interpolation as it is an outlier (see above) and ODIN 160 (Corner of Curle and Deemac St.) is also not included as its higher values distort the interpolation across the rest of the town.

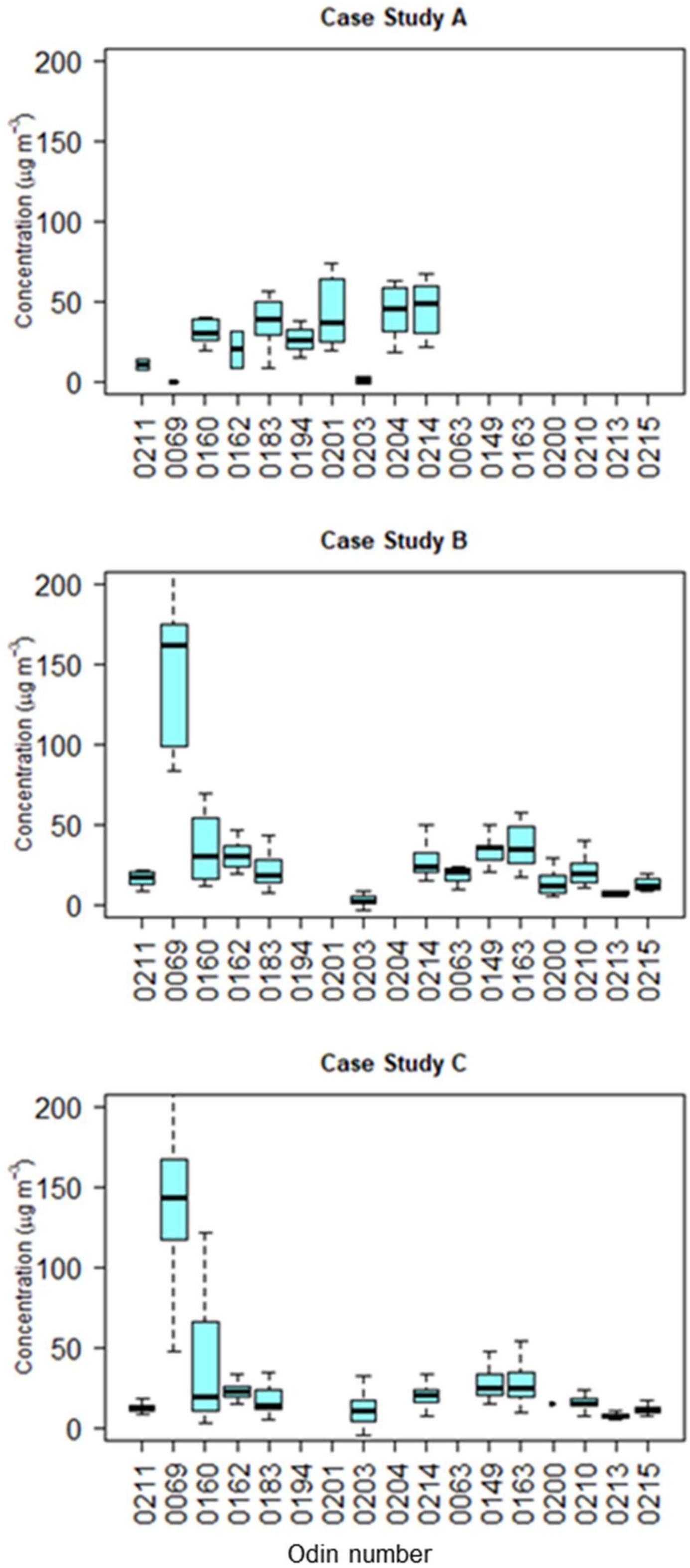

Figure 4: **Range of 24-hour mean concentrations measured by each unit over the three case study periods.**

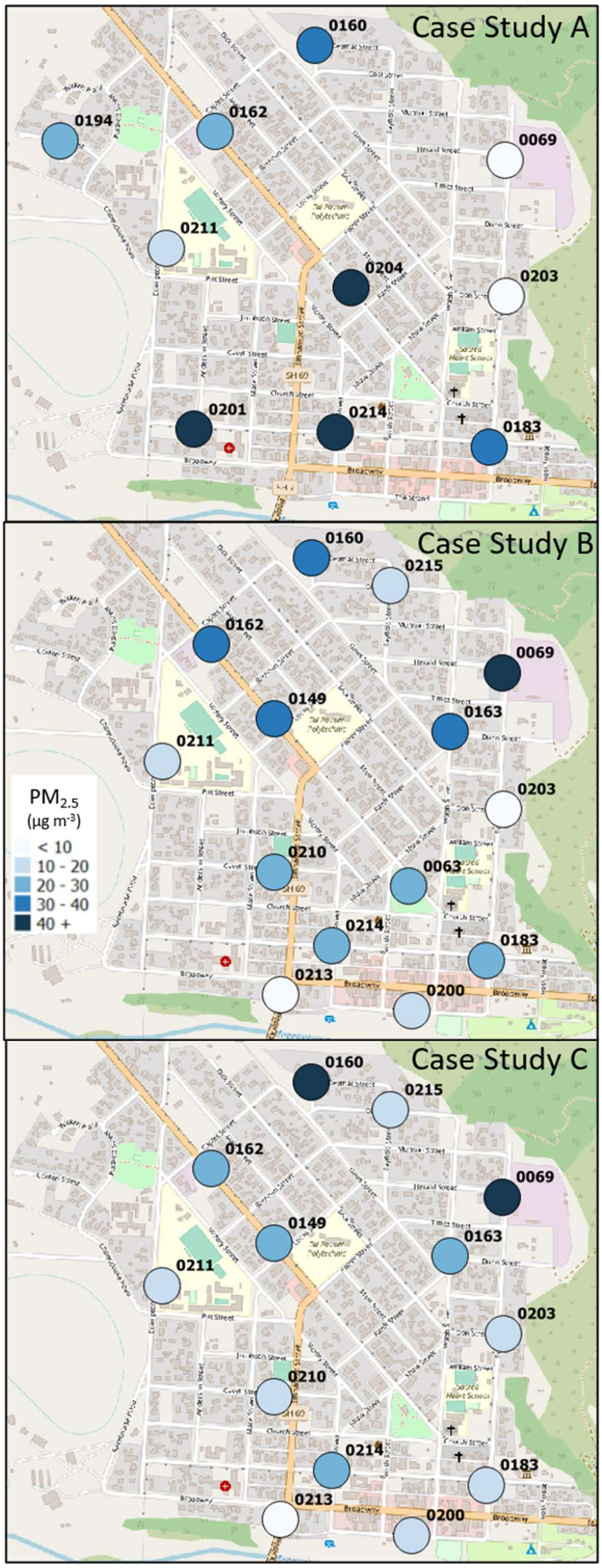

Figure 5: Average concentrations of $PM_{2.5}$ (µg/m³) during each case study period in Reefton during winter 2020.

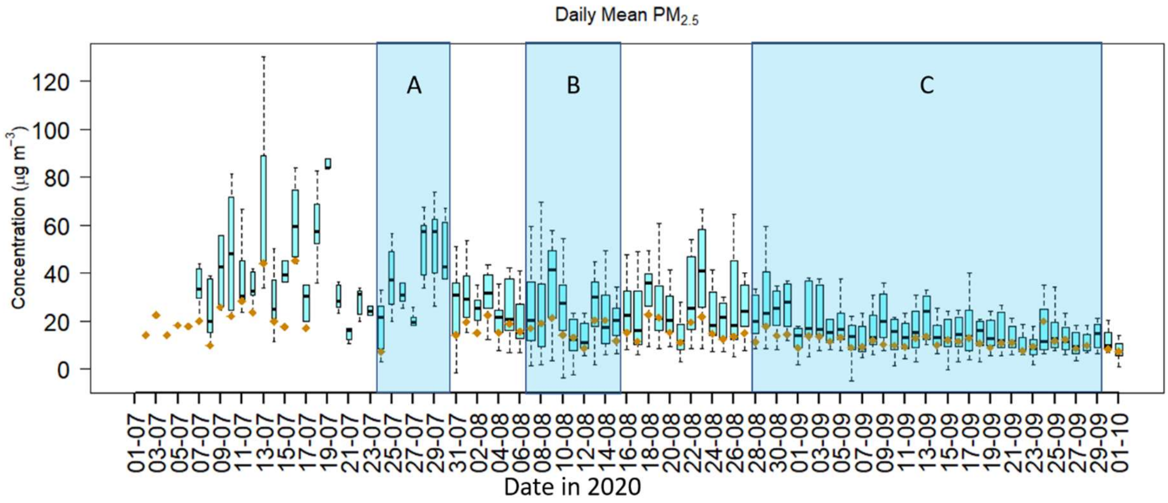

Figure 6: **24-hour mean concentrations with the three case studies highlighted. Orange points are ODIN unit 0211.**

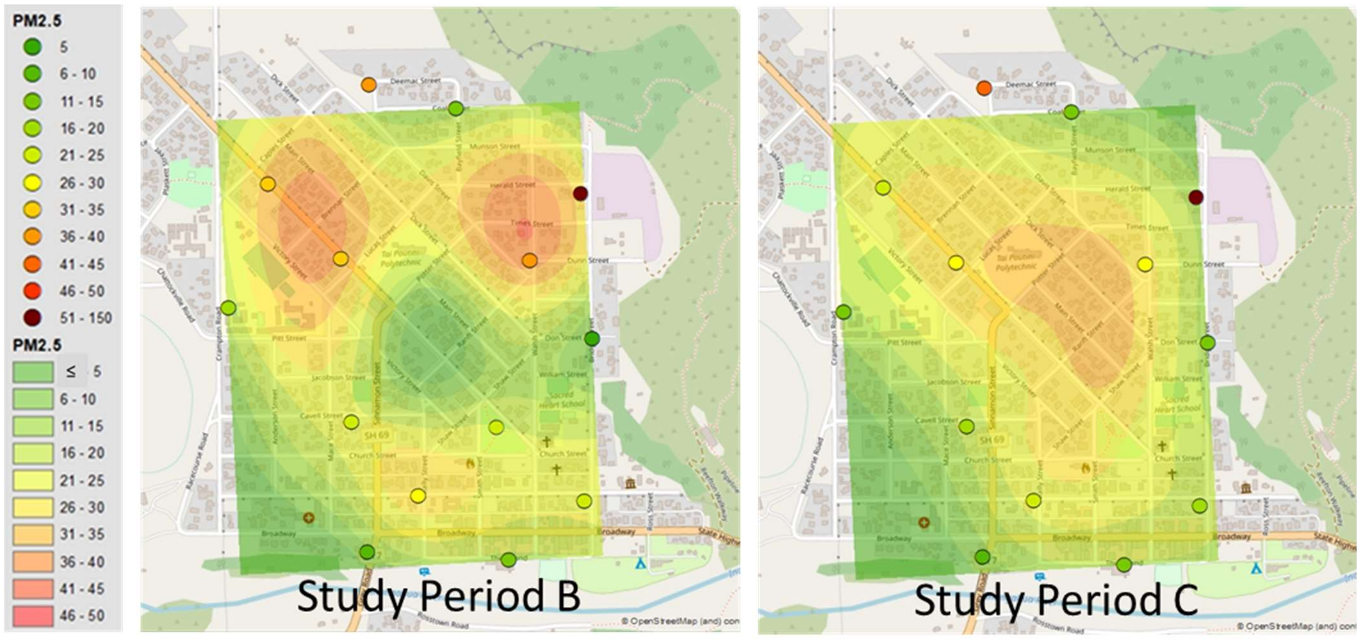

Figure 7: **Interpolated maps of average $PM_{2.5}$ concentrations (µg/m^3) in Reefton during study periods B and C**

4 Conclusions

There is clearly considerable variation in PM across Reefton, with the pattern changing depending on conditions. During Case Study A, which is in July, measured concentrations were at their highest, with a majority of locations having high concentrations for the majority of the time (Figure 3). The mean daily value in Reefton during Case Study A was 36 µg/m^3. Even as late as early September, there are still days with higher values, only falling consistently to lower values by the middle of September.

On some days at the height of winter, the difference in the daily average between the most and least polluted locations in Reefton can be in the region of 40 – 60 µg/m^3 if outliers are discounted. Throughout the winter and into September, the difference tends to be in the region of 20 µg/m^3 until all values drop in late September.

The results show that the highest concentrations tend to be in the central and northern parts of town. However, care should be taken in interpreting results as sparse data at the southern end of town can increase the uncertainties in that area. There is a particular lack of data in the area roughly between Potter St and Church St, although ODIN 204 towards the southern end of Buller Rd recorded a mean of 44 µg/m^3 during July, despite operating sporadically, one of the highest measured in that period, indicating that there were high concentrations in this area during that time.

The current regulatory monitoring site at Reefton Area School consistently under-represents concentrations across the town. In fact, the original monitoring site at the corner of Lucas Street and Buller Road was probably more generally representative. For regulatory compliance, monitoring should be conducted where pollutant concentrations are known or expected to be highest. The highest concentrations measured during the campaign were at the site on Bridge St. However, results from this location show a different diurnal pattern from other locations, suggesting it is impacted by an, as yet unidentified, local source and not representative of the town in general. A site in the area bounded by Buller Rd (SH69), Davis St, Caples St and Ranft St will be more generally representative of air quality across the town.

Because this dataset is incomplete, there is some uncertainty in the results, as not all instruments were measuring at the same time. This leads to trying to compare different sets of instruments on different days with no consistent pattern in the data loss. While we are confident that the current dataset is sufficient to give a general picture of the magnitude and type of variation across Reefton, uncertainty remains, particularly in the southern part of town. Further work should consider completing the dataset that this work set out to capture to fill in some of the gaps. We also recommend investigating the source of the high values recorded at Bridge St.

5 Acknowledgements

Our thanks to West Coast Regional Council for setting up the project, doing all the legwork, making the measurements and providing the data.

This work was funded by Envirolink grant number 2065-WCRC194 and supported by NIWA as part of the Impacts of Air Pollution research programme.

Appendix A Data Capture percentages

The following tables show the percentage of data capture for each of the ODIN units both for all the ODIN monitoring units and with low-performing units removed.

Table A-1: Data capture rates for all 17 ODINs deployed in Reefton during winter 2020 - hourly data. Figures for Low performing units are shaded in blue and total in brackets is the percentage data capture with these units removed

Data capture	ODIN unit																	
	203	194	204	162	214	160	69	183	201	211	210	149	152	215	213	63	200	163	Total
July only																			
Number of data counts	22	651	370	285	632	226	27	380	513	241									
% data capture	3	93	53	41	90	32	4	54	73	34									48 (59)
Aug-Sept																			
Number of data counts	969	113	38	1405	1249	1403	1022	1298	115	1303	1034	1351	54	1339	1292	519	427	1104	
% data capture	65	8	3	95	84	94	69	87	8	88	70	91	4	90	87	35	29	74	60 (71)
Entire period																			
Number of data counts	991	763	408	1690	1880	1628	1049	1677	627	1543	1034	1351	58	1339	1292	519	427	1104	
% data capture	45	35	19	77	86	75	48	77	29	71	70	91	4	90	87	35	29	74	58 (64)