NIWA
Taihoro Nukurangi

Air quality in Picton

An analysis of data collected between July 2019 and August 2020

Prepared for Marlborough District Council

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Cover photo: Temporary 'Harbour View' meteorological site, Picton. [Tony Bromley]

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Executive summary

Picton is unique in its mixture of housing, industry and being a major port, all of which can contribute to impacts on air quality. While domestic heating sources dominate fine particulate matter (PM10) levels during the winter no monitoring had been carried out during other times of the year to assess other PM_{10} sources and their significance on Picton's air quality. In late 2018 Marlborough District Council (MDC) approached NIWA to assist with an air quality campaign spanning a longer period of time, with the aim of establishing with more confidence if Picton complies with PM_{10} levels set by the National Environment Standards for Air Quality (NESAQ). Previous air quality monitoring in Picton had shown that the town may possibly exceed the NESAQ for PM_{10}, however the data collected were not continuous and previous winter-time monitoring was not conclusive on this matter. The source(s) of pollutants affecting the town was also of interest to MDC, in particular emissions from shipping given Picton's location as a port for the inter-island ferries, log vessels and for a continually increasing number of cruise ship stopovers.

A continuous air quality and meteorological monitoring program was developed in early 2019. The equipment was jointly installed and maintained by NIWA and MDC, with data available from late June 2019 to early September 2020. MDC engaged NIWA, through an MBIE Envirolink advice grant, to analyse the data collected. This report documents the air quality and meteorological monitoring that was carried out and the results obtained.

Vaisala AQT420 air quality sensors were installed at three sites (Queen Charlotte College, Foreshore and Wairau Rd) to measure carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (O_3) using reactive electrochemical cells, and a laser particle counter to measure PM_{10} and the finer $PM_{2.5}$. Meteorological data (wind speed and direction, air temperature, relative humidity and solar radiation) were also collected from ten sites to support interpretation of the air quality data. Weather and topography influence the movement of air contaminants via local wind flows and may create areas where contaminants remain for significant periods or become concentrated.

The meteorological data were used in a high resolution wind-flow model of the Picton region and showed that there were generally differences between morning and afternoon wind patterns; mornings were dominated by drainage flows from adjacent hills, and afternoons showed winds generally flowing north to south along the two major valleys that run into Picton town.

The three gases measured by the AQT instruments (CO, NO_2, SO_2) are known to be emitted from a range of potential sources: these are primarily from combustion sources which include the burning of hydrocarbon fuels; diesel used in heavy-duty vehicles, rail locomotives and larger recreational boats; heavy fuels used in larger shipping including the inter-island ferries, cruise ships and other bulk cargo vessels, petrol from light vehicles and the combustion of coal and wood for domestic home heating. O_3 results from photochemical reaction of nitrogen oxides and volatile organic compounds, with the primary pollutants being produced from motor vehicle emission, combustion and the use of some solvents and coatings. Particulate matter is known to be the result of incomplete combustion but can also include natural sources of sea salt, pollen and dust. The gas and particulate data from the AQT instruments were analysed using the R Openair software package, and graphics of the data are displayed along with comment. Selected individual pollution events have been highlighted and commented on.

The PM_{10} data indicates that an exceedance of the NESAQ could occur anywhere in the Picton area under the right combinations of meteorological conditions (e.g., low wind speeds, cold air

temperatures allowing strong temperature inversions to form and trap particulates, cold air drainage flow moving particles from higher elevations into lower lying areas of the town). The Wairau Road area recorded higher PM_{10} peaks during the day, which may be an indication of the higher traffic flows. Higher PM_{10} concentrations measured through September to November are likely to result from a combination of drier weather causing more ambient dust in the air, coupled with pollen from trees and grass.

CO concentrations were overall found to be low, with the highest concentrations recorded during the winter months. A general pattern was observed of a short morning peak and a longer evening peak, this pattern is indicative of a CO emission source dominated by home heating using wood and/or coal.

SO_2 concentrations recorded at the Wairau Road and Foreshore sites are suggestive of a correlation with ferry arrival/departure times, and when ships are visiting Picton. However, further information on actual ship arrival/departure times and engine usage when in port, combined with a detailed understanding of the meteorological conditions for each ship movement would be needed to make more definitive comments. Overall, SO_2 was within acceptable levels for over 80% of the time. A tracer study focusing on the ship emissions alone may be necessary to fully understand the emission concentrations and contaminant movement from this source.

The study period included the COVID-19 lockdown and Picton's air quality followed the national trend observed in many air quality data sets throughout New Zealand. There was a marked drop in NO_2 and CO concentrations, especially during the Level 4 and Level 3 lockdown periods. Levels returned to "normal" again once the country was back at Level 1.

1 Introduction

The township of Picton comprises a mix of housing and industry in close proximity to a major port. While previous winter time monitoring of particulate matter (PM_{10}) levels had showed domestic heating sources influenced the concentrations, no air quality monitoring had been carried out during other times of the year, to assess particulate matter or other pollutants and their significance on Picton's air quality. In late 2018 Marlborough District Council (MDC), supported by MBIE Envirolink advice grant MLDC148, approached NIWA to assist with an air quality campaign spanning a longer period of time, with the aim of establishing with more confidence if Picton complies with PM_{10} levels set by the National Environment Standards for Air Quality (NESAQ). Previous air quality monitoring in Picton had shown that the town may possibly exceed the NESAQ for PM_{10}, however the data collected were not continuous and previous winter-time monitoring was not conclusive on this matter. The source(s) of pollutants affecting the town was also of interest to MDC, in particular emissions from shipping given Picton's location as a port for the inter-island ferries and for a continually increasing number of cruise ship stopovers.

The continuous air quality campaign was set up by NIWA and operated by MDC staff from late June 2019 to early September 2020. The measurements covered of a range of pollutants, including PM_{10} and the finer $PM_{2.5}$, carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (O_3), alongside key meteorological measurements needed to assist with data interpretation and modelling. In spring 2020 MDC engaged NIWA, through a second MBIE Envirolink medium advice grant MLDC159, to analyse the data collected. This report documents the air quality monitoring that was carried out and the results obtained.

1.1 Report outline

This report comprises five sections:

- Section 2 overviews the monitoring methods and sites used to collect meteorological and air quality measurements between June 2019 and September 2020.
- Section 3 presents the results of the monitoring campaign, including a comparison of pollutant concentrations present at three main sites; Queen Charlotte College, Foreshore and Wairau Rd.
- Section 4 presents the output of modelling carried out of different pollution sources and an overview of the general weather conditions over New Zealand for each of the seasons during the measurement campaign. Picton's measurements are also compared to data collected over the same period at other locations in New Zealand.
- Section 5 presents selected 'case studies' investigating the impact of ship emissions, transport, winter-time domestic sourced PM_{10} concentrations from home heating and the impact of COVID-19.

This report looks at the air quality in Picton as an entire area, and the resulting data set will allow for more in-depth analyses to be undertaken into specific areas of interest.

2 Methodology

2.1 Measurement sites

Ten measurement sites were selected in Picton, from Queen Charlotte College in the north to the upper Wairau Road leading out of town to the south as shown in Table 2-1. The site areas were identified by NIWA and then MDC contacted the property owners / tenants to gain their approval for the installations.

The sites were selected to cover the town area and a range of the terrain features that are expected to influence wind flows (especially in lighter wind conditions), and where concentrations of pollutants were suspected to build up in those conditions.

Additional meteorological data was available from the Picton Automatic Weather Station (AWS) site and three sites operated by Port Marlborough.

The selected sites are listed in the summary table (Table 2-1) and are marked on Figure 2-1, where the new meteorological stations are in yellow, the Picton AWS in red and the air quality sites are in orange (note the 30 Wairau Rd and Queen Charlotte College sites also include meteorological sensors).

Table 2-1: Summary information on each site used during the monitoring.

Site name	Ground height (m AMSL)	Meteorological station	Sensor height (m AGL)	Air quality station	Sensor height (m AGL)
Queen Charlotte College (QCC)	22	Yes	4.1	Yes	3.9
Milton/Sussex	33	Yes	2.5	No	
Water Reservoir	91	Yes	5.0	No	
Surrey St	3	Yes	2.5	No	
Queen Charlotte Drive Lookout	30	Yes	2.5	No	
Foreshore	2	No		Yes	6.95
Picton AWS	2	Yes	6.0	No	
Broadway	15	Yes	2.5	No	
Harbour View Heights	61	Yes	2.5	No	
30 Wairau Rd	8	Yes	3.75	Yes	2.5
68 Wairau Rd	61	Yes	2.5	No	

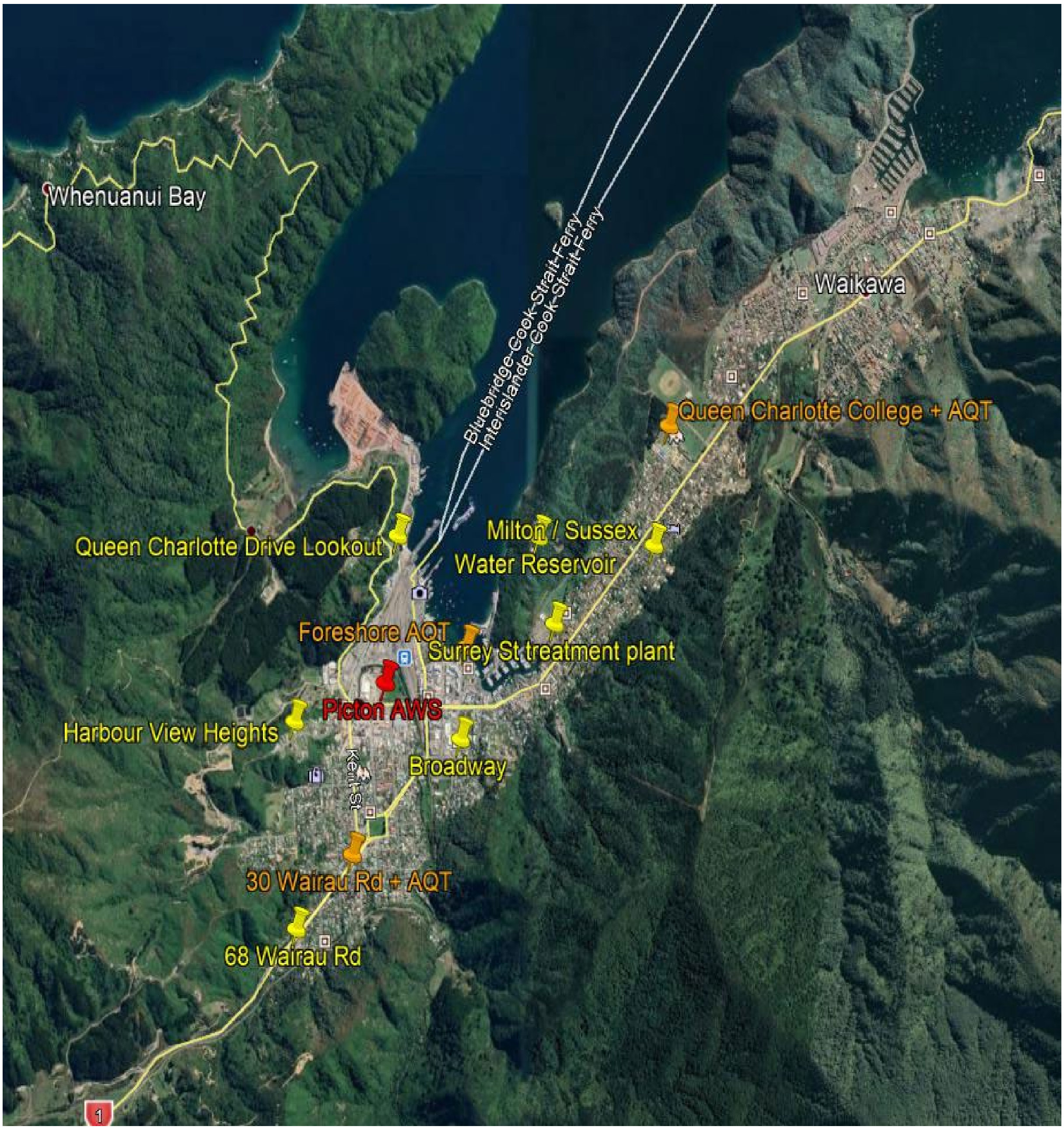


Figure 2-1: Location of the sites used during this study.

2.2 Meteorological monitoring stations

As the terrain in the Picton area is complex (hills, valleys and marine sounds), it was decided to gather general meteorological information, in particular wind speed and direction from temporary meteorological stations in conjunction with the air quality data. Weather and topography influence air pollution by affecting the concentration, movement and dispersal of air pollutants. High-resolution modelling of the wind data would therefore enable a fuller understanding of the local wind flows within the Picton area and enables investigation of how these flows affect the local transport of various atmospheric contaminants.

Temporary meteorological stations were installed on the 25th and 26th June 2019 at nine sites. The main parameters which needed to be monitored included:

- Wind speed and direction
- Air temperature
- Solar radiation.

With the exception of the Queen Charlotte College site, the instrumentation used were Vector A101 and WP200 wind speed and direction sensors, LM34 air temperature probes, and Licor pyranometers for solar radiation. Queen Charlotte College had a Vaisala WXT520 combined sensor which uses a sonic anemometer to measure the wind speed and direction and includes a relative humidity sensor. The images in Figure 2-2 show the Vaisala and Vector wind systems. The instrumentation was at the top of light aluminium poles, which were fastened to existing fencing posts and generally at 2.5m above ground level.

Figure 2-2: The two types of weather stations used in the study. Left is a Vaisala system and right is a Vector system.

All the stations recorded air temperature, wind speed and direction, with solar radiation at five of the stations, and relative humidity available from the Queen Charlotte College site. The data were measured at 3-second intervals and logged as 10-minute means. The station data were downloaded approximately weekly at which time the logger battery was also replaced.

Additional meteorological data were obtained from the Picton AWS operated by MDC. This site recorded wind speed and direction, air temperature and relative humidity and uses the same type of sensor that was used at Queen Charlotte College. For the first few months of this study the data were logged as 15-minute means, but it was changed to 10-minute means in November 2019.

Images of all the sites are included as Appendix A.

2.3 Air quality monitoring

Three locations were selected for monitoring the air pollution, namely Queen Charlotte College, Foreshore and 30 Wairau Road. The sites at Queen Charlotte College and Wairau Rd were co-located with the meteorological station to assist with understanding the data collected in more detail

The air quality parameters which were measured in Picton for this study were:

- carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and ozone (O_3)
- particulate matter less than 10 µm (PM_{10}) and less than 2.5 µm ($PM_{2.5}$).

They were measured using a Vaisala AQT-420 sensor, located at the top of lightweight aluminium poles, with the logger housing lower down the mast, as shown in Figure 2-3.

Figure 2-3: Air quality system at the Picton foreshore site.

The gas measuring technology in the Vaisala AQT420 is based on electrochemical cell technology, where the sampled air causes a reaction in the electrochemical cell resulting in a change in the electrical current. The current is directly dependent on the volume of the measured gas. This technology is used to measure the CO, NO_2, SO_2 and O_3 concentrations. Most electrochemical cells are highly susceptible to ambient conditions (temperature and humidity in particular) but a proprietary adjustment and compensation system is designed to give accurate measurements (Vaisala 2017).

The particle sensor technology uses a laser particle counter where light is scattered as particles pass through the light beam. Optical and photosensitive sensors assist the particle counter to measure the angular scattering intensity and they use this to determine both the $PM_{2.5}$ and PM_{10} size fractions.

A sampling pump controlled by the central processing unit transfers the outside ambient air into the gas analysis module so the analyses can take place.

It should be noted that this Vaisala model (along with a number of other lower cost sensors) are not on the Ministry for the Environment's (MfE) list of approved instruments for NES-AQ monitoring. They may not give the same concentration as that obtained from co-located NESAQ approved instrument, with differences up to 20% being reasonably common in some of the earlier lower cost sensors. Despite this limitation, these sensors are useful in giving an indication of the possible levels and variability of gas pollutants in a location and can guide councils when deciding where to locate full NESAQ stations.

The specifications from the instrument manual for the AQT420 are shown in Table 2.2.

Table 2-2: Specifications of the AQT420.

Parameter	SO2	NO2	CO	O3	PM2.5	PM10
Range	0 - 2 ppm	0 - 2 ppm	0 - 10 ppm	0 – 2 ppm	0 – 2000 µg/m^3	0 – 5000 µg/m^3
Minimum Detection Limit	0.005 ppm	0.005 ppm	0.1 ppm	0.005 ppm		
Resolution	± 0.001 ppm	± 0.001 ppm	± 0.01 ppm	± 0.01 ppm	0.1 µg/m^3	0.1 µg/m^3
Precision	<± 1% FS	<± 1% FS	<± 2% FS	<± 3% FS		
Linearity	<± 1% FS	<± 1% FS	<± 2% FS	<± 2% FS		

These sensors were not co-located with reference equipment before or after this study in Picton. In California, the South Coast AQMD has an air quality sensor performance evaluation center which carries out testing of lower cost sensors against reference instrumentation. Vaisala submitted the AQT410 analyser for evaluation and this model uses the same electrochemical sensors as the AQT420. Three units were supplied. The evaluation, undertaken in ambient conditions for two months in 2018, reported R^2 values for the CO sensor between 0.80 – 0.83, NO_2 between 0.43 – 0.61, and O_3 between 0.66 – 0.82, (SO_2 was not evaluated as the concentrations were too low to be detected on the reference instrument). An R^2 value of 1 reflects near perfect correlation with a value of 0 indicating no correlation. The report noted that the NO_2 concentration was overestimated compared to the reference analyser but tracked the trend well, whereas CO tracked the trend and the concentrations well (South Coast AQMD 2018). No independent evaluation of the particulate matter sensor is available.

Data from the electrochemical cells were logged as a 10-minute mean, whereas the particulate data were only for the last minute of each 10-minute period.

2.4 Terrain data

LIDAR (light detecting and ranging) terrain data were collected in 2018 by MDC which enabled 3D modelling of the geographical features in the Picton area. One of the products from this data set is a contour file with elevations at a one metre resolution and this was used as an input into the modelling undertaken by NIWA.

3 Results

3.1 Meteorological data

The data from all the meteorological stations were used in a wind flow model of the region.

The first investigation was to review whether there were any differences in the wind patterns during the early morning (0500 – 0650 NZST) in Figure 3-1 and during the afternoon (1400 – 1550 NZST) in Figure 3-2. This analysis showed that during the morning the winds were dominated by drainage downflow from the adjacent hills whereas the afternoon winds were generally flowing along the two main valleys from north to south. The wind roses are located at the position of each of the meteorological sites.

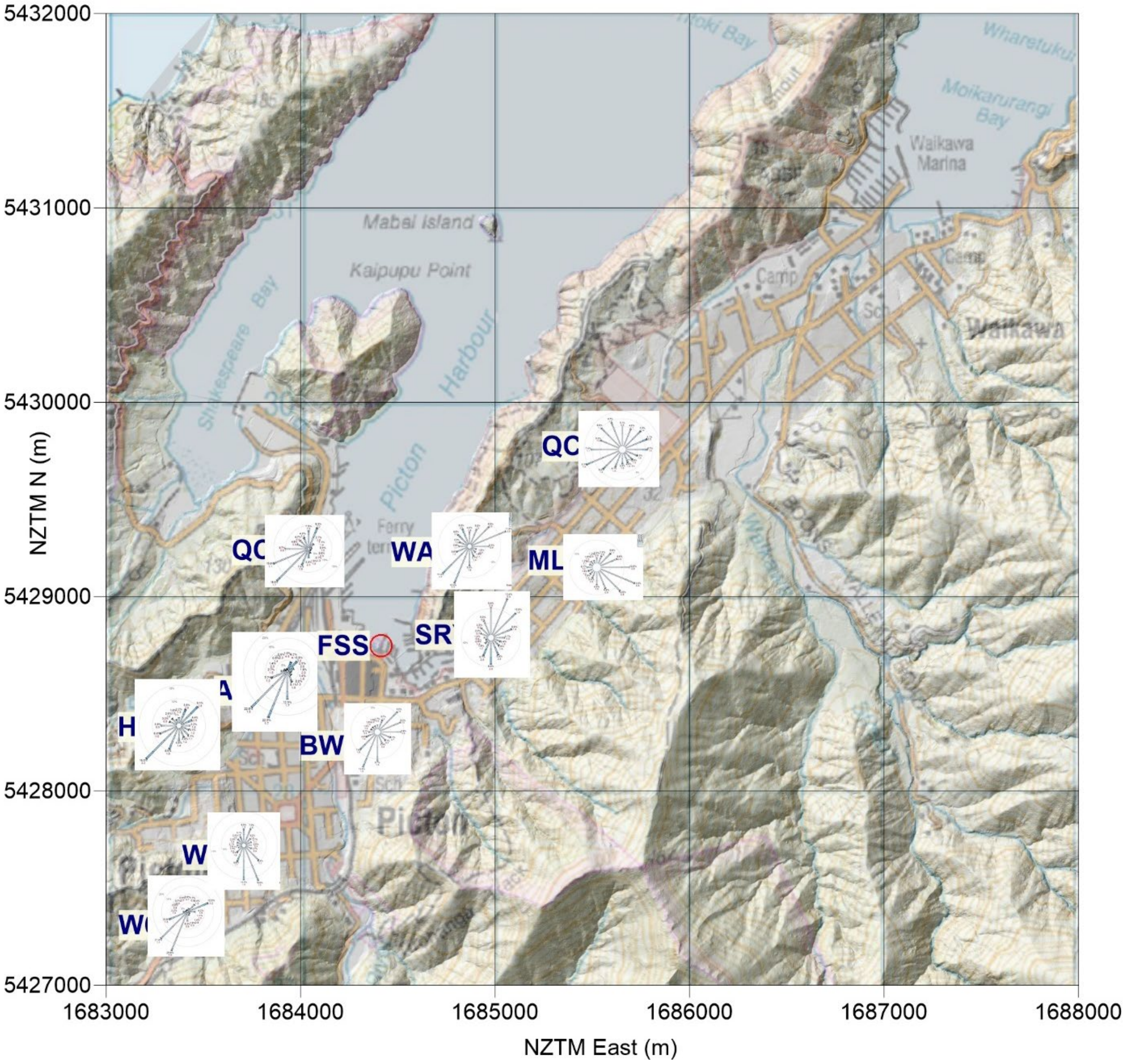


Figure 3-1: Wind roses for the ten sites from 0500 to 0650 NZST each day.

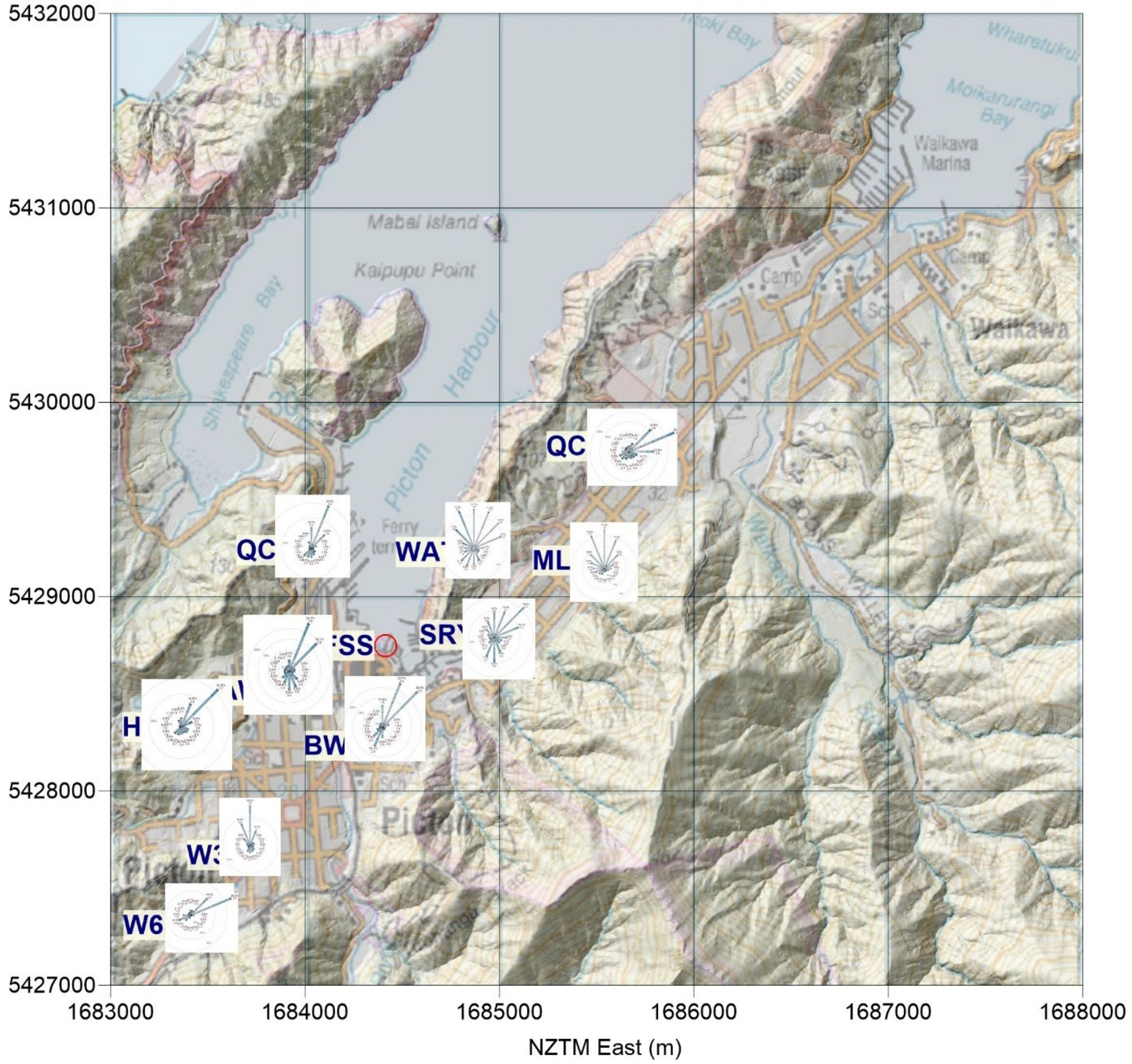


Figure 3-2: Wind roses for the 10 sites from 1400 to 1550 NZST each day.

The wind change seen in the figures above are common in the Picton area, so even though the wind may be southerly and blowing the pollution plumes out to sea through Queen Charlotte Sound, in the early morning, it can easily be brought back over the town if the wind direction changes to a more northerly or northeasterly flow (sea breeze as a result of the land heating up during the day). Not only are the surface winds an issue, but the upper level winds such as those along the hilltops can easily alter the direction of movement of any airmass.

This effect is more likely to occur during relatively calmer conditions when cold air drainage from the southern part of town can carry gases and particulates caused by winter home-heating fires, as well as ferry and road traffic pollution, out into Queen Charlotte Sound. As the land heats up during the day, the sea breeze then brings the pollution brought back into the town area later in the day. This makes it difficult to apportion pollution to a particular source without the use of high density meteorological stations and modelling of the data.

3.2 Gas data

There are four standard gas parameters (NO_2, SO_2, CO and O_3) available on the Vaisala AQT 420. These parameters cover a range of potential emission sources. NO_2 is used as an indicator of diesel sources such as heavy duty vehicles (HDV) and rail locomotives but is also used by many of the larger recreational boats; SO_2 is mainly associated with shipping sources but is also a by-product of burning coal and using diesel; CO comes from incomplete combustion sources such as petrol vehicle emissions or home heating and diesel use, and O_3 which is formed through photochemical reactions of nitrogen and volatile organic compounds. For this particular study, NO_2, SO_2, and CO are the significant pollutants of concern.

The gas data measured at the three AQT stations have been quality assured. From the checks carried out, it has been decided that the ozone data do not appear to be realistic (when compared to ozone data measured at Baring Head near Wellington, and shown in Appendix F) and further investigation will need to be undertaken if these data are to be used in the future.

The data quality assurance involved checking the 10-minute data and removing any invalid data. Apart from a day when communication failed (March 2020 at all sites) and when the battery voltage became too low due to lack of solar charging (Queen Charlotte College and Wairau Rd sites in June / July 2020), the only other data that was invalidated was for the Foreshore site where all the gas data for a 10 hour period was the same (September 2019). Following this, the data were converted from ppb into µg/m^3 (NO_2 and SO_2) or mg/m^3 (CO) as these are the regulatory units used in New Zealand. The data were then averaged into hourly concentrations, and then into either 8-hour rolling averages (CO) or 24-hour fixed averages (NO_2 and SO_2). This allows the data to be compared with NESAQ standards and MfE (2002) ambient air quality guidelines.

The data were analysed using the R Openair software package. This allows a large amount of data to be easily compared to other sites or pollutants. The concentration data are normalised (individual data points are divided by the mean of the full data set for that pollutant and site, and then the mean is set at 1.0), because this makes it easier to compare pollutants and sites which have different concentration ranges.

In the following sections, only data with an associated NESAQ standard have been included, the data relating to MfE guidelines being shown in Appendix B.

3.2.1 CO data

The factor used to convert the data from ppb to mg/m^3 was 0.001249. The MfE guideline for CO is 30 mg/m^3 as a 1-hour fixed average and the NESAQ standard is 10 mg/m^3 as an 8-hour rolling average.

Figure 3-3 shows the 8-hour rolling average data from each of the three sites. This shows that the concentration of CO in Picton is very low and that the higher concentrations are during the winter months. The winter of 2019 is at a similar level to the 2020 period.

From the concentrations seen during this study period, it is unlikely that there would be any exceedances of the NESAQ value, or that the MfE guideline value would be reached.

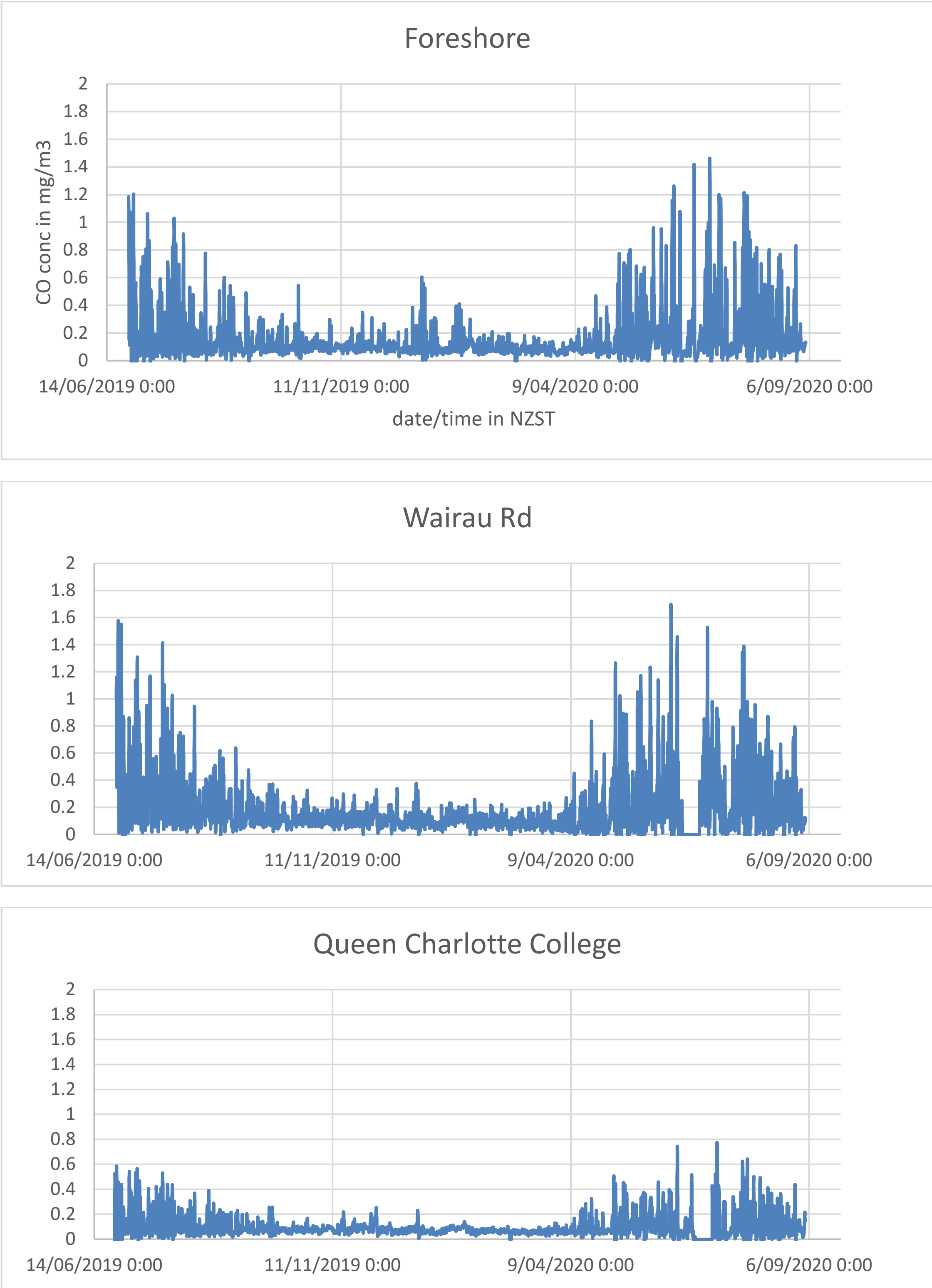


Figure 3-3: CO data – 8-hour rolling mean in mg/m^3.

Figure 3-4 shows the normalised data and is useful as an overview of CO in the Picton area. The most significant point to take from these images is the similarity at each site and within each plot.

It shows that the CO concentrations have a small morning peak around 0700 NZST and a longer evening peak (around 1900-2200 NZST). The concentrations are higher during the cooler months

(May – August). It is only in the days of the week plot where Wairau Rd shows a different trend on Friday and Saturday.

This information is indicative of a CO emission source dominated by home heating using wood and/or coal fires.

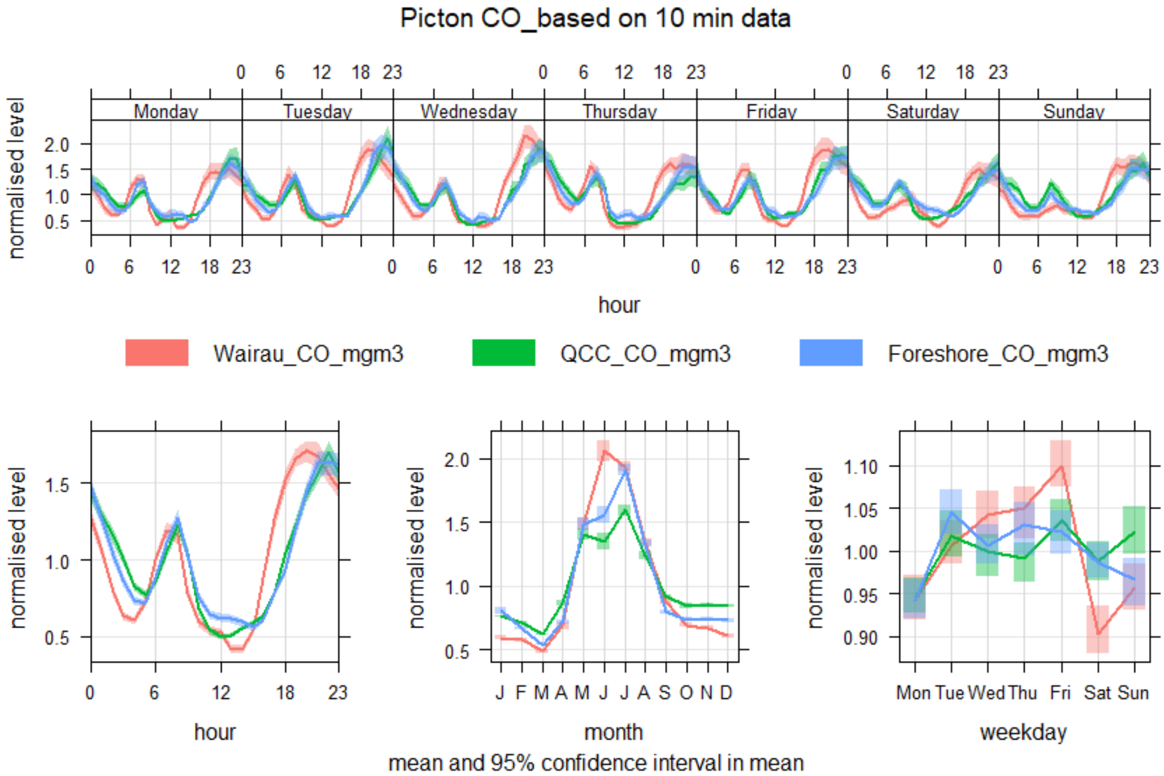


Figure 3-4: CO analysis for Picton.

3.2.2 SO_2 data

The factor used to convert the data from ppb to µg/m^3 was 2.85. The MfE guideline for SO_2 is 120 µg/m^3 as a 24-hour fixed average and the NESAQ standards are 350 µg/m^3 and 570 µg/m^3 as 1-hour fixed averages. The two standards for one-hour averages are due to the number of allowable exceedances, with nine being allowed at the lower concentration and none being allowed at the higher concentration.

Figure 3-5 shows the 1-hour average data from each of the three sites with the NESAQ standard at 350 µg/m^3. This shows that there are periods of higher SO_2 concentrations throughout the year especially at the Wairau Rd and Foreshore sites, when the NESAQ standard was exceeded. The concentration of SO_2 is slightly higher in the winter period of 2019 before becoming lower and steady over the summer / autumn period. It increases again from May 2020 and appears to be decreasing at the end of the sampling in August.

It is possible that SO_2 in Picton peaks in the May-June period and that we did not see this in 2019 as sampling only began at the end of June. As this trend is seen at all three sites, it is less likely that the cause is an instrument fault, but it is still possible these electrochemical cells did not last as long as expected, they have at least a 12-month serviceability period.

The hourly SO_2 data and the 24-hour data included in Appendix B, show for the period up until May 2020 there were only a few exceedences of the guideline values, notably July 2019 at the Wairau Rd and Foreshore sites and February 2020 at Queen Charlotte College. In May 2020 there is an obvious step increase in concentration at the Wairau Road and Foreshore sites, but not at the Queen Charlotte College Site, resulting in more exceedences at all the sites. It is unclear what is causing this step increase.

Caution should be taken before conclusions can be drawn that these exceedances of the standards are a true reflection of levels which may be the result of instrumentation error margin and life span of the electrochemical components in the sensors.

It would be interesting to investigate the SO_2 data recorded between 2019 to 2020 at other sites within New Zealand (such as the port areas of Wellington, Lyttelton, Tauranga or Auckland). It should be noted however that these ports have significantly greater shipping traffic than Picton and comparison of data between sites is limited due to variables such as the type of monitor, location of monitor and the overall difference is shipping volumes, frequencies and size of vessels. Data was obtained from the Port of Tauranga and this is detailed in section 4.3.2.

Other possible causes for the increase from May 2020 onwards, are changes in the amount of coal being used for domestic heating or diesel vehicle use, but these have not been investigated.

Along with looking at the peaks or exceedences in a data set, it is very important to look at the frequency of these events. The impact of air pollution on a human is a balance between short term high concentration exposure and long term low concentration exposure. This is discussed further in the next paragraph.

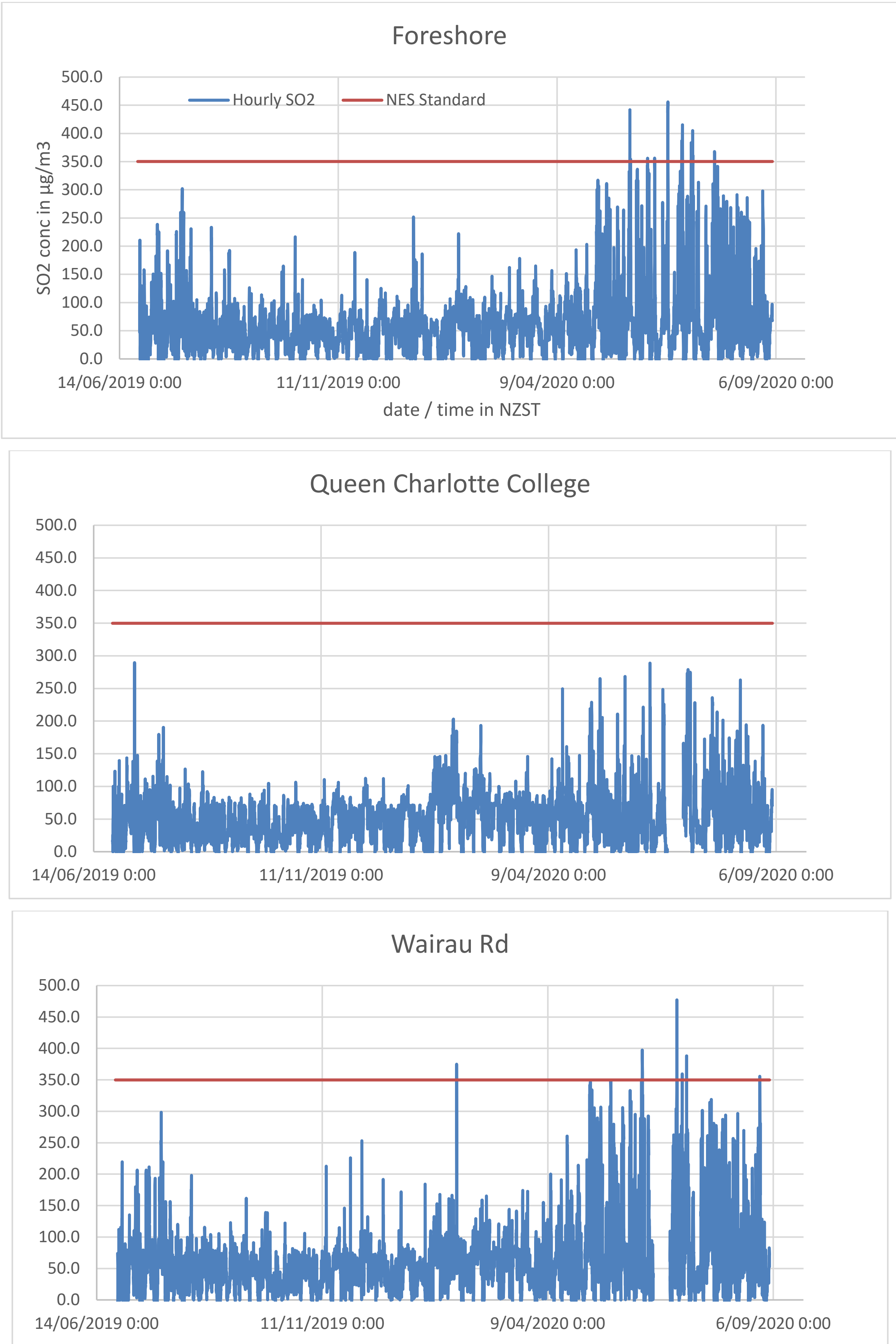


Figure 3-5: SO_2 data – one hour average in µg/m³. The NESAQ standard (350 µg/m³) is the red line.

The SO_2 data were then sorted according to the Ministry for the Environment's environmental performance indicator statistics for air quality. These are based on the guideline values for each pollutant and in this instance the hourly data and 350µg/m^3 NESAQ standard has been used. Table 3.1 describes the categories for reporting air quality data, and figure 3.6 shows the results for each of the three sites.

Table 3-1: Environmental Performance Indicators for Air Quality.

Category	Measured value	SO_2 value range in µg/m^3	Comment
Excellent	Less than % of the guideline value	<34.9	Of little concern: if maximum values are less than a tenth of the guideline, average values are likely to be much less
Good	Between 10% and 33% of the guideline value	35.0 – 115.5	Peak measurements in this range are unlikely to affect air quality
Acceptable	Between 33% and 66% of the guideline value	115.6 – 230.9	A broad category, where maximum values might be of concern in some sensitive locations but generally they are at a level which does not warrant urgent action
Alert	Between 66% and 100% of the guideline value	231 - 350	This is a warning level, which can lead to exceedences if trends are not curbed
Action	More than 100% of the guideline value	>350.1	Exceedences of the guideline are a cause for concern and warrants action, particularly if they occur on a regular basis

This analysis shows that SO_2 at all the sites is in either the excellent, good or acceptable categories for over 80% of the time that was monitored and in most months was greater than 90% of the time. It also illustrates the increase in concentrations seen from May 2020 onwards. The data for Wairau Rd in June 2020 and for Queen Charlotte College for June and July 2020 should be treated with caution as this included a period when no data was recorded due to the battery voltage being too low.

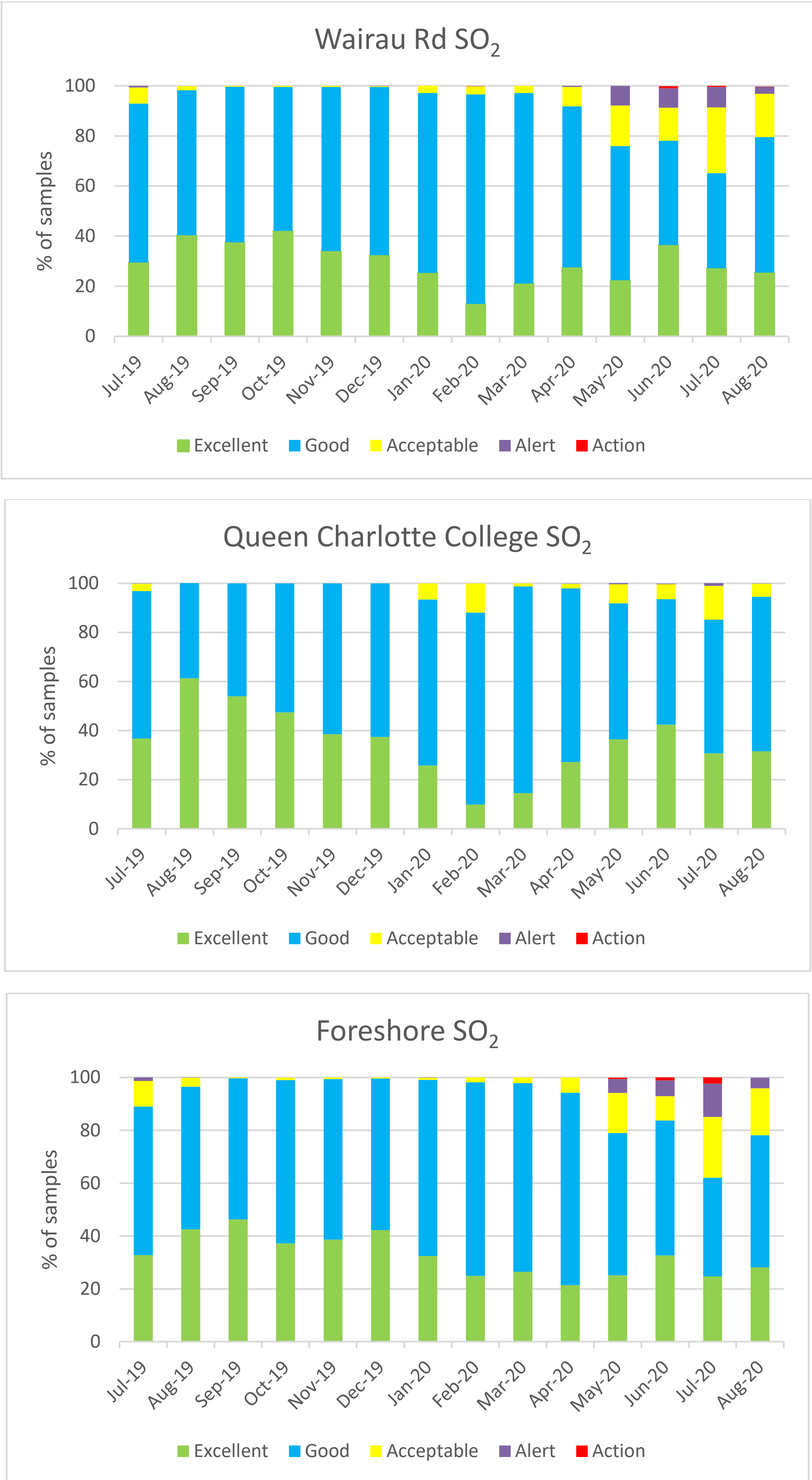


Figure 3-6: EPI statisics for each month using hourly SO_2 data.

The hourly plot in Figure 3-7 shows a SO_2 minimum in the early afternoon with an increase later in the day which remains all night and into the early hours of the morning. It is likely that this is associated with the strength of the winds, which are usually higher during daylight hours than night hours. The appearance of the early morning peak (at the Wairau Rd and Foreshore sites) is also seen in other pollutants related to home heating as discussed in the previous section.

A couple of features in the monthly plot are the reduction in SO_2 throughout the town during September – December, and the monthly trends are more similar at the Foreshore and Wairau Rd sites than at Queen Charlotte College which is higher in late summer whereas the other two sites are higher in winter. This SO_2 reduction indicates that either there is a meteorological effect (such as stronger winds) at this time of the year, or the sources of SO_2 in the Picton area change during the year. As SO_2 is a by-product of coal burning, it is possible that parts of Picton have a higher number of properties using coal as a heating source.

The weekday plot in Figure 3-7 shows more SO_2 on Tuesday to Friday, so investigating the relationship of this with regards to the ferry timetable would be interesting.

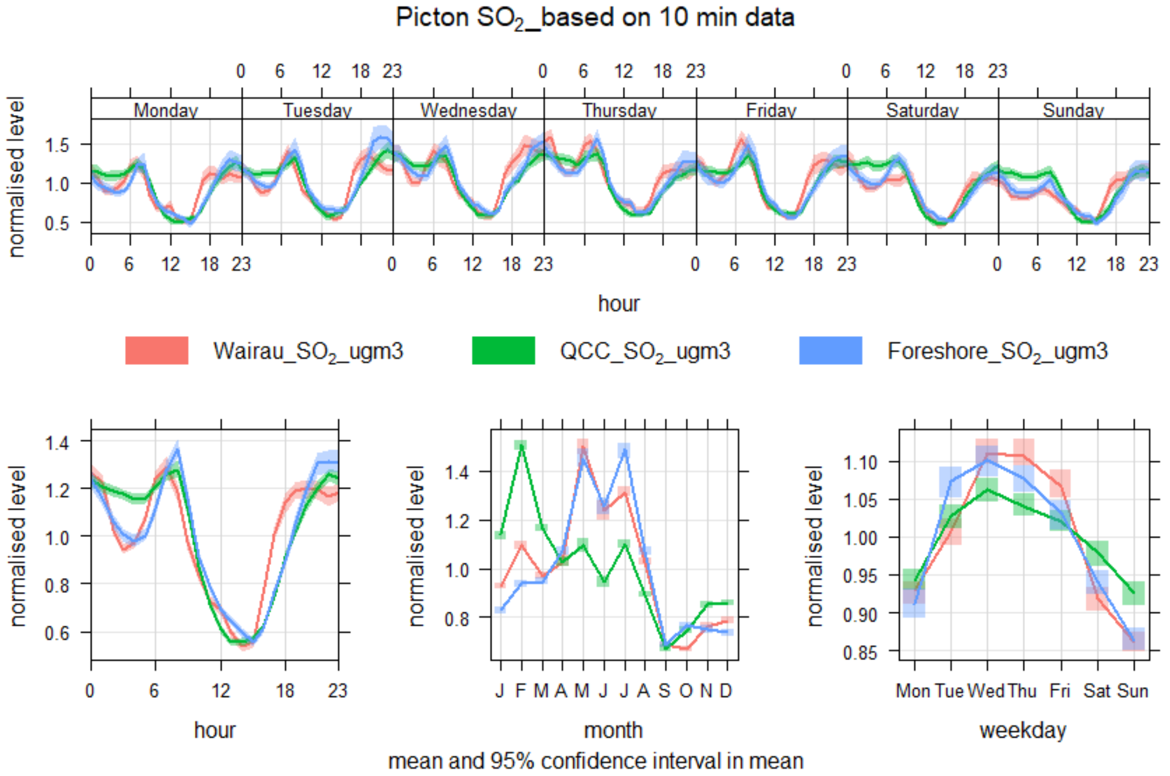


Figure 3-7: SO_2 analysis for Picton.

3.2.3 NO_2 data

The factor used to convert the data from ppb to µg/m^3 was 2.053. The MfE guideline for NO_2 is 100 µg/m^3 as a 24-hour fixed average and the NESAQ standard is 200 µg/mg^3 as a 1-hour fixed average.

Figure 3-8 shows the hourly data from each of the three sites and the NESAQ standard. Unlike the CO and SO_2 data, the NO_2 concentrations across each of the sites over the course of the year does not follow a consistent pattern between sites. The Wairau Road site has the lowest levels despite this being a roadside location and exposed to the highest road traffic volumes of all three sites. It also does not show the typical trend seen at traffic sites around the country where the higher concentrations are in winter, usually a consequence of traffic volume changes. These lower levels were an unexpected result. The Foreshore site had the highest concentrations and also increased over the summer period. Again, this also was not expected. A possible explanation for the summer increase is the increase in use of local boats powered by diesel fuel in the harbour immediately adjacent to the foreshore site, and there is a fuel wharf in the area. However further investigation would be required to confirm this hypothesis and its correlation with photochemical reactions between NO and O_3.

The hourly NO_2 data, and the 24-hour data included in Appendix B, for the Foreshore site in particular, indicate that exceedances of the NESAQ value and more frequent exceedances the MfE guideline could occur. However, this is less likely at the other two sites.

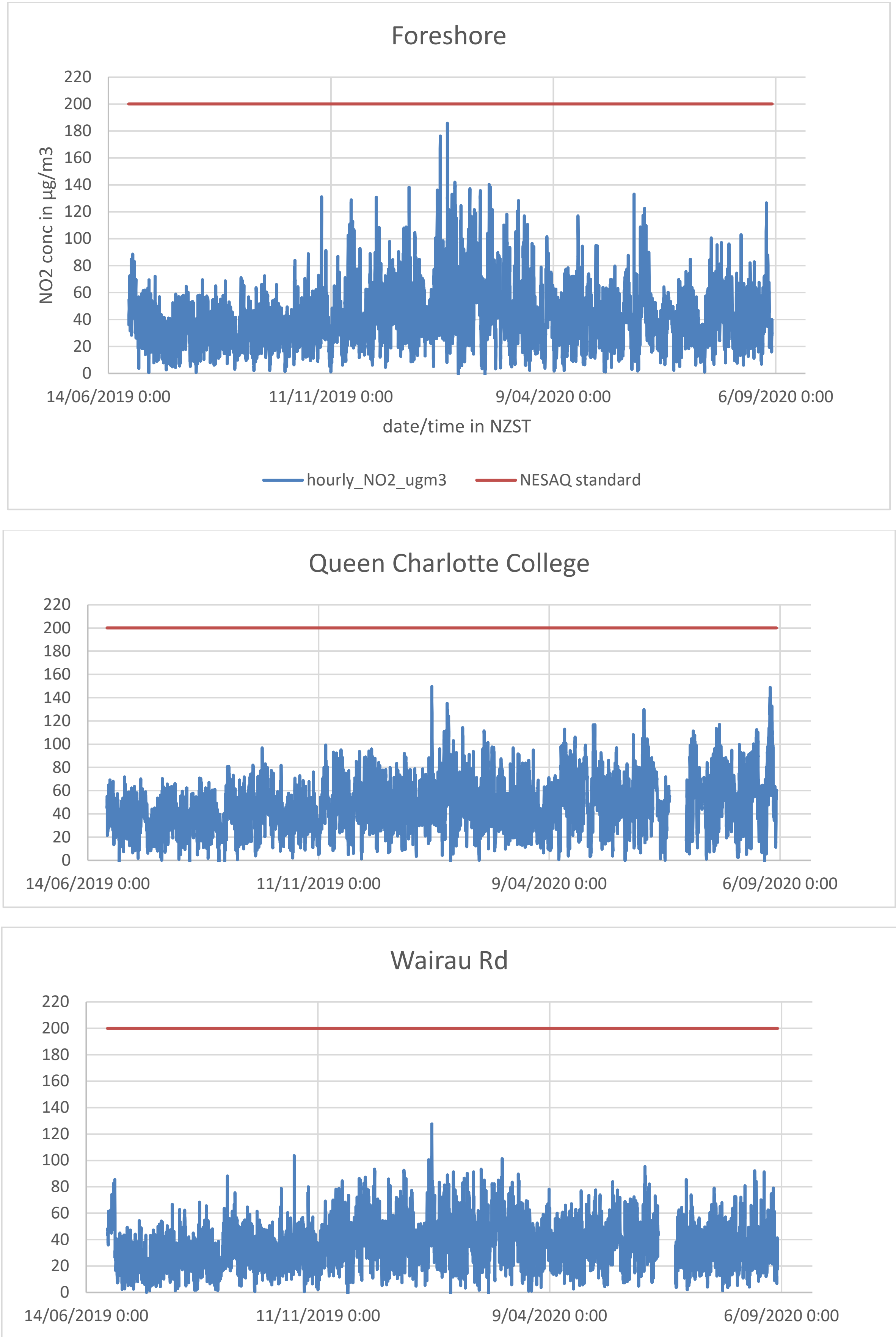


Figure 3-8: NO_2 data – one hour average in µg/m³. The NESAQ Standard (200 µg/m³) is the red line.

The hourly plot in Figure 3-9, shows the consistency of NO_2 over the entire town with the main peak being in the afternoon, with a small morning peak at the Wairau Rd and Foreshore sites. The afternoon increase in NO_2 is not unexpected as NO_2 is formed as a result of photochemical reactions of NO emissions (primarily from vehicles) and ozone. The higher summer concentration at the Foreshore sites as mentioned above is clearly visible on the monthly plots (blue line. The lower concentrations of NO_2 is seen during the late winter / spring period in the monthly plots for all the sites. The weekday plot is especially interesting for the Wairau Rd site where there is very little NO_2 at the weekends indicating that the emissions may be a more Monday-Friday workday source.

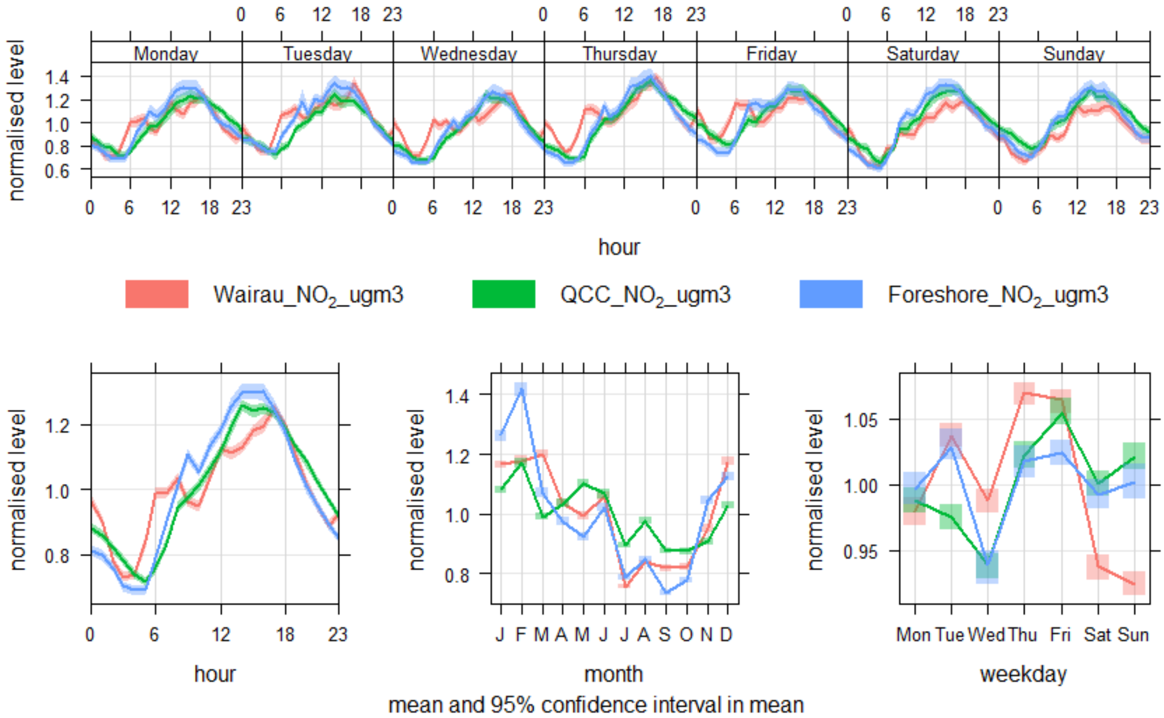
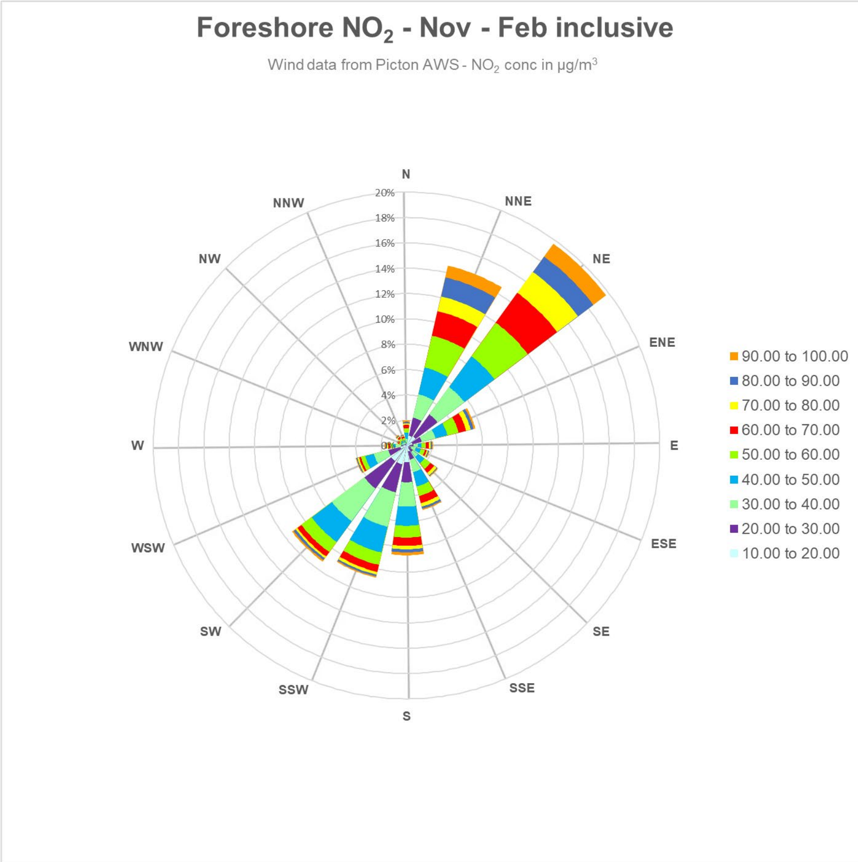


Figure 3-9: NO_2 analysis for Picton.

Pollution roses of the NO_2 data from the Foreshore site were prepared to investigate if there was a significant difference between the winds during summer (November 2019 to February 2020 inclusive) and the rest of the period and are shown in Figure 3-10. The summer plot has a dominance of NNE-NE winds and thus the potential for an NO_2 source in the vicinity of the wharves around the western end of the marina is quite possible, as the concentrations are also very high indicating there has not been much dispersion from the emission source.



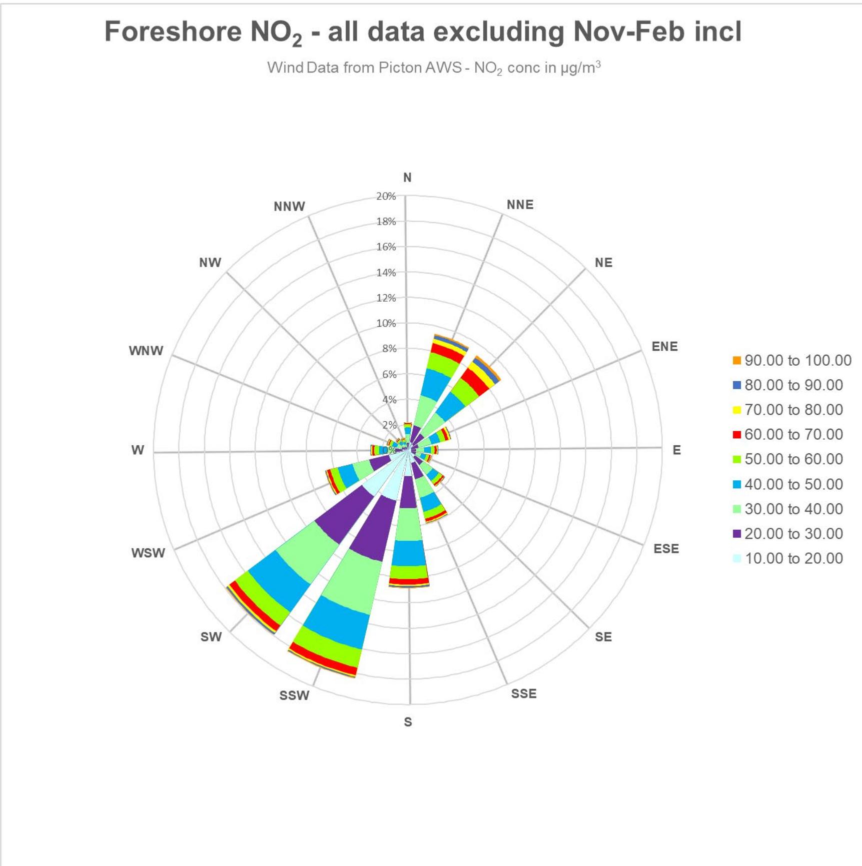


Figure 3-10: Foreshore NO_2 - pollution roses for summer (top) and the rest of the year (bottom).

3.3 Particulate data

PM_{10} is a standard particulate matter size used in New Zealand for ambient air quality reporting, although interest in $PM_{2.5}$ (a subset of PM_{10}) has increased recently, due to the more significant health impacts from $PM_{2.5}$. $PM_{2.5}$ is more likely to come from home heating whereas PM_{10} can also include salt, pollen and dust particles.

It should be noted that concentration data from lower cost sensors is not considered to be the equivalent to that obtained from co-located NESAQ approved instruments, with differences up to 20% being common. Despite this limitation, these sensors are useful in giving an indication of the possible concentrations and variability of particulates in a location and can guide councils when deciding where to locate full NESAQ stations.

The data quality assurance involved checking the 10-minute data and removing any invalid data. Invalid data included one day when communication failed (March 2020 at all sites), a period of 10 hours when all the particulate data was the same (Foreshore site - September 2019) and when the battery voltage became too low due to lack of solar charging (Queen Charlotte College and Foreshore sites), which required invalidating.

The particulate data measured with the Vaisala AQ420 have been more affected by high humidity than is normally encountered with NESAQ regulated instruments due to the sample not being heated before analysis. The consequence is that when fog occurs, the sensor records the moist fog particles as well as any dry emission particles, and thus we recorded extremely high concentrations which were not realistic. These high concentrations resulted in a large amount of data needing to be invalidated from the data set. Queen Charlotte College was the most affected site of the three, with Wairau Rd being the least affected.

Following the removal of the invalid data, the remaining data were averaged into hourly data, and then into 24-hour fixed averages. This allows the data to be compared with NESAQ standards and MfE guidelines. The data were analysed using the same R Openair software package used for the gaseous pollutants.

3.3.1 PM_{10}

The NESAQ standard for PM_{10} is 50 $\mu g/m^3$ as a 24-hour fixed average and the MfE guideline is 20 $\mu g/m^3$ for an annual average.

Figure 3-11 shows the 24-hour averaged data from each of the three sites. Similar to the SO_2 data, there is an increase in concentration at the Foreshore site since May 2020 which was also observed to a lesser degree in the Wairau Rd data.

The PM_{10} data indicates that an exceedance of the NESAQ standard is more likely in the Queen Charlotte College area and potentially around Wairau Road. However as noted above, the Queen Charlotte College results were heavily affected by fog affecting the sensor response and therefore may not be a complete reflection of PM concentrations.

Although the MfE annual average guideline period is over a calendar year, we can calculate an average for the period 1 July 2019 to 30 June 2020 as an indicative annual average. The calculated annual averages are 8.5 $\mu g/m^3$ at the Foreshore site, 29.6 $\mu g/m^3$ at the Queen Charlotte College site and 12.2 $\mu g/m^3$ at the Wairau Rd site. The equivalent average for the Blenheim site at Redwoodtown would have been 18.1 $\mu g/m^3$ (the calendar 2019 annual average was 17.8 $\mu g/m^3$ and 2020 was 18.1 $\mu g/m^3$) so the use of the July to June period did not have a big impact compared to doing the standard calendar year calculation. The inclusion of the Blenheim data gives more confidence that the Queen Charlotte College average may be elevated by the impact of fog.

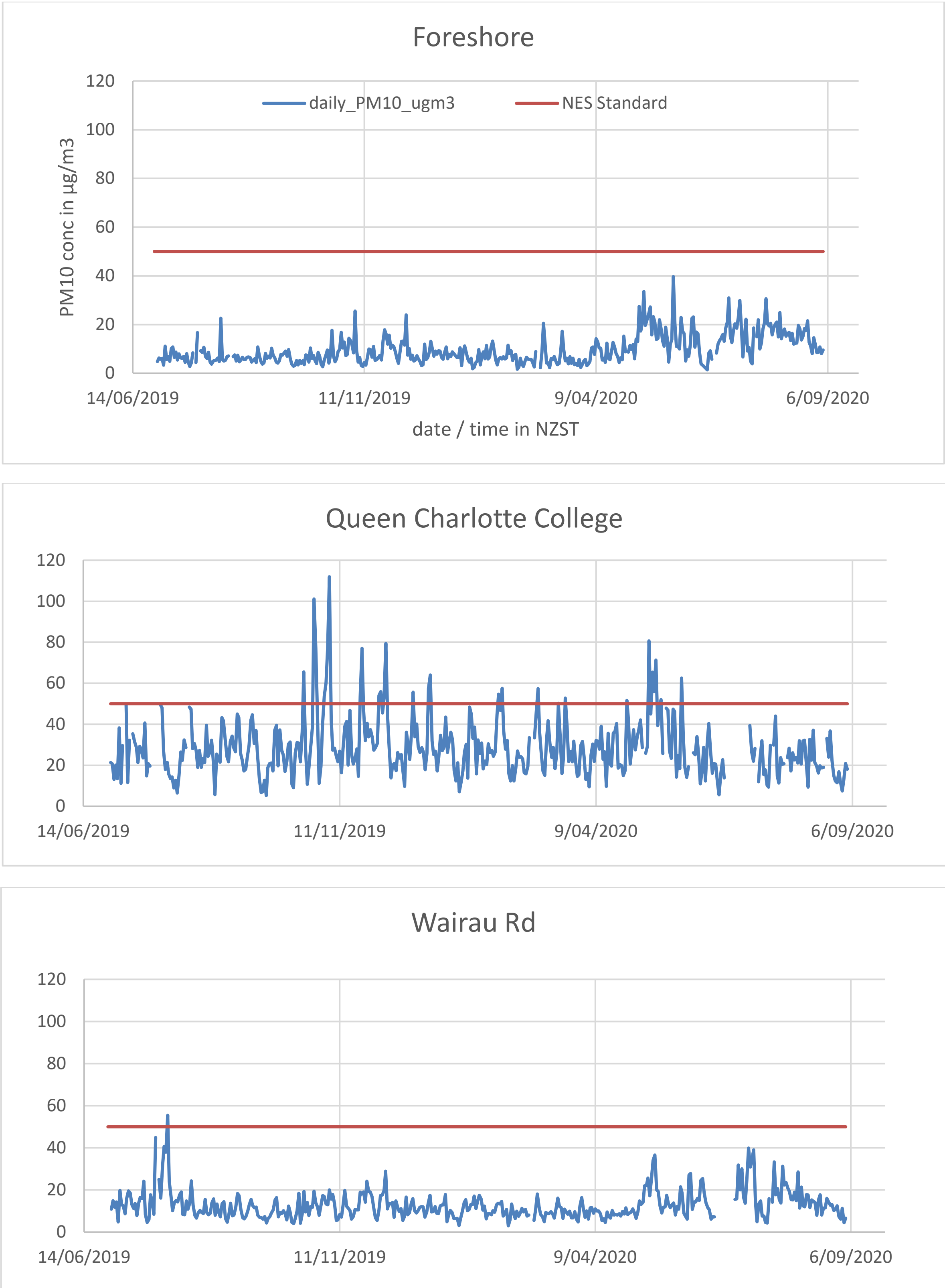


Figure 3-11: PM$_{10}$ data - 24 hour average in µg/m^3. The NESAQ standard (50 µg/m^3) is the red line.

Figure 3-12 shows that there is no consistent pattern around the town, with Wairau Rd having higher PM_{10} during the day and less at night, while the Foreshore and Queen Charlotte College have more evening peaks. The higher peak during the day would indicate the source is different and is likely to be related to road movements. Winter has more PM_{10} but there is a secondary peak in November at all sites. This secondary increase between September and November, may be associated with drier weather conditions causing more ambient dust in the air and is also around the time when tree and grass pollens become more prolific.

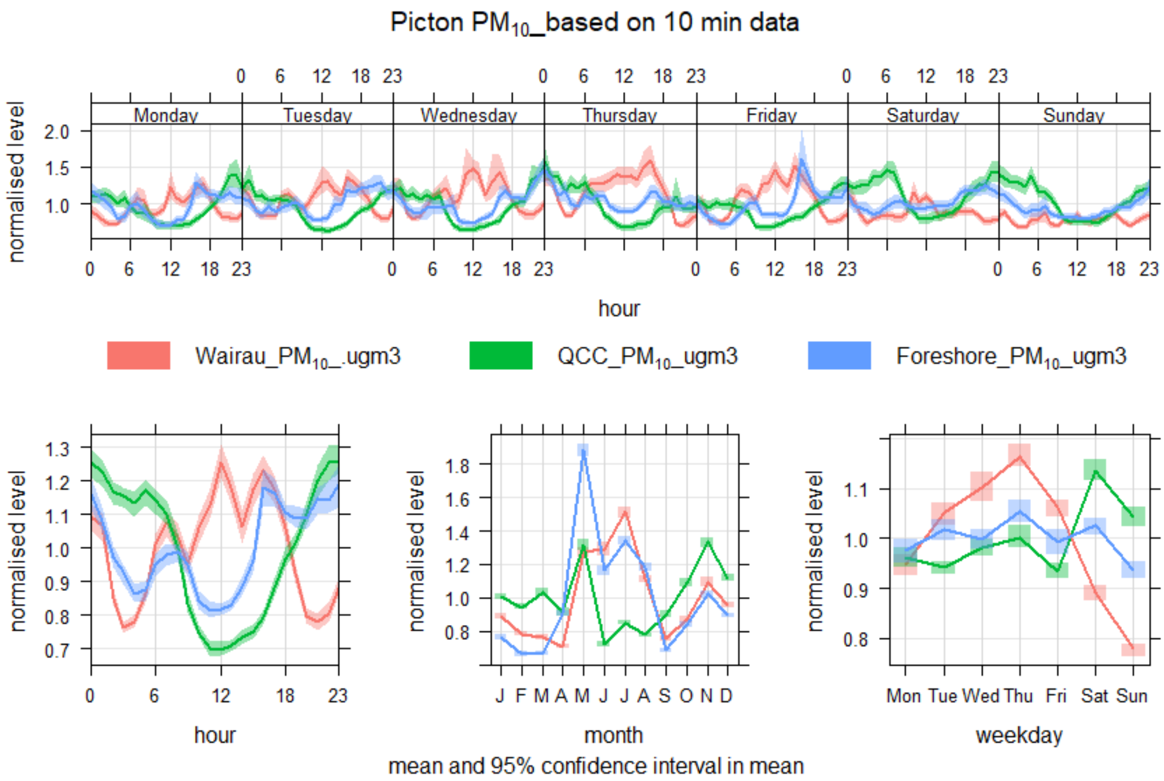


Figure 3-12: PM_{10} analysis for Picton.

3.3.2 $PM_{2.5}$

There are currently no standards for $PM_{2.5}$ but it is proposed by MfE to introduce them in the coming year. The proposed values are: 25 µg/m^3 as a 24-hour fixed average and 10 µg/m^3 as an annual average.

Figure 3-13 shows the daily data from each of the three sites. As with the PM_{10} data, there were a number of periods when fog influenced the concentrations and this needs to be taken into consideration when reviewing these data.

The Wairau Rd site shows a change to very low concentrations since April 2020 which is not observed in the PM_{10} data where the concentrations increased. The Foreshore site shows a very significant increase at the same time while the PM_{10} data is more consistent with earlier data. Queen Charlotte College for both $PM_{2.5}$ and PM_{10} is consistent throughout the sampling period. This variation in patterns may indicate an instrument sensor issue, but it could also be a result of emission source changes near the site or a localised meteorological effect. Further investigation would be needed to come to a definitive answer.

Although the proposed annual average guideline period will be over a calendar year, we can calculate an average for the period 1 July 2019 to 30 June 2020. The averages are 4.2 µg/m^3 at the

Foreshore site, 1.4 µg/m³ at the Queen Charlotte College site and 1.8 µg/m³ at the Wairau Rd site. For comparison, the 2019 annual average at the Redwoodtown site in Blenheim was 11.5 µg/m³ and the 2020 average was 11.9 µg/m³.

With respect to the proposed $PM_{2.5}$ standard and guideline, if the step increase at the Foreshore site is not an instrumentation issue, then it is possible that the proposed 24-hour standard could be exceeded at this location, but the data indicates that it would be unlikely for the annual guideline to be reached.

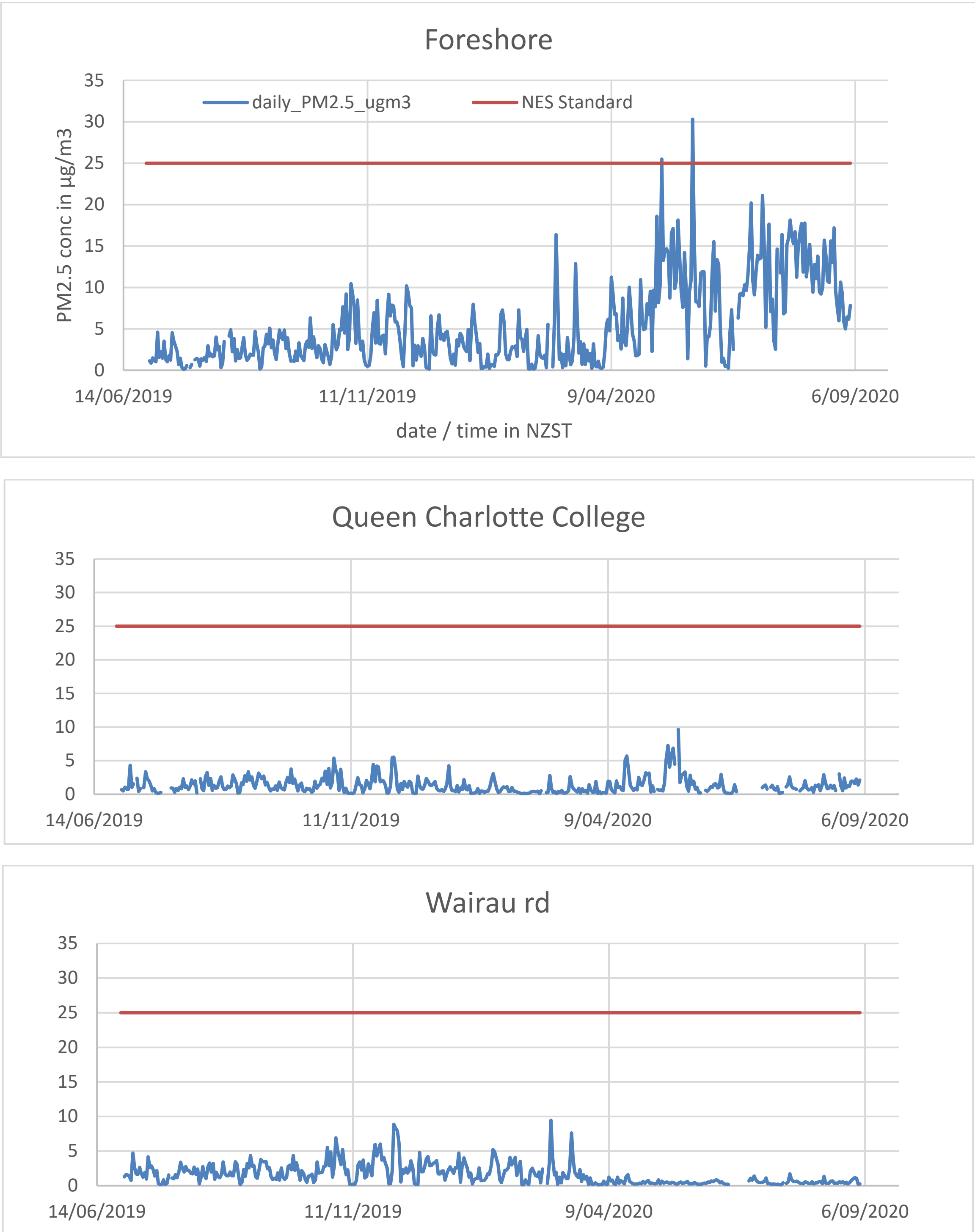


Figure 3-13: $PM_{2.5}$ - 24 hour average in µg/m³. Proposed standard (25 µg/m³) is the red line.

Figure 3-14 shows a different set of patterns to the PM_{10} data. The cause of this difference is unknown without deeper analysis of the data. On the hourly plot, Queen Charlotte College and Wairau Rd are similar with the main peak being late morning to early afternoon, and the Foreshore being more consistent throughout the day. The monthly plot shows that Queen Charlotte College and Foreshore have the highest concentration in early winter whereas Wairau Rd is in summer. The weekday plot shows a high peak on Thursday at Wairau Rd.

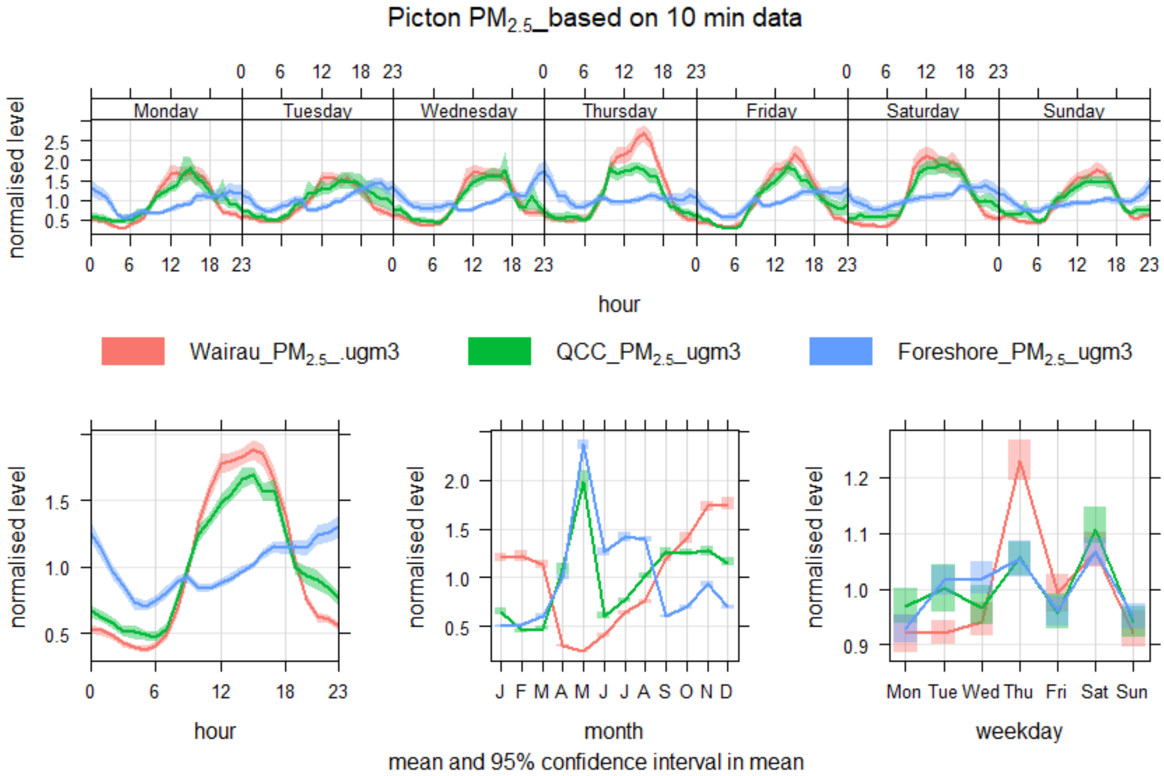


Figure 3-14: $PM_{2.5}$ analysis for Picton.

3.4 Pollutant comparison at each site

This section looks at the relationship between the pollutants at each site to help in determining possible emission sources. An example of a commonly used relationship is where both CO and PM_{10} are higher in the winter period and during the evening hours, indicating home heating as the likely source.

3.4.1 Queen Charlotte College

The Queen Charlotte College site (Figure 3-15) was primarily selected as a background site, in an area where there should not be much impact from road traffic. Residential housing is close-by to the south (~100 m away) but further away to the northeast (~330 m) and southeast (~220 m). To the west-northwest is bush and trees. The school grounds surround the site but there is also a diesel fired heating boiler to the southeast of the site in the school grounds. Communication from the caretaker indicates that this is only used during term time, primarily in the mornings.

Figure 3-15: Queen Charlotte College site map.

Figure 3-16 shows the relationship between the three gases. This indicates in the hourly plot that the trend in NO_2 is not the same as the trend for CO and SO_2. The afternoon increase in NO_2 is not unexpected as NO_2 is formed by the photochemical reactions of NO and O_3. The lack of a variation in the hourly or monthly timescales is typical of a background site. As there is no reduction in NO_2 at the weekends, it is unlikely that the boiler is the only source of NO_2 being measured at this site. The correlation of SO_2 with CO, especially in the hourly plot, indicates that the source of sulphur dioxide may also include incomplete combustion particles.

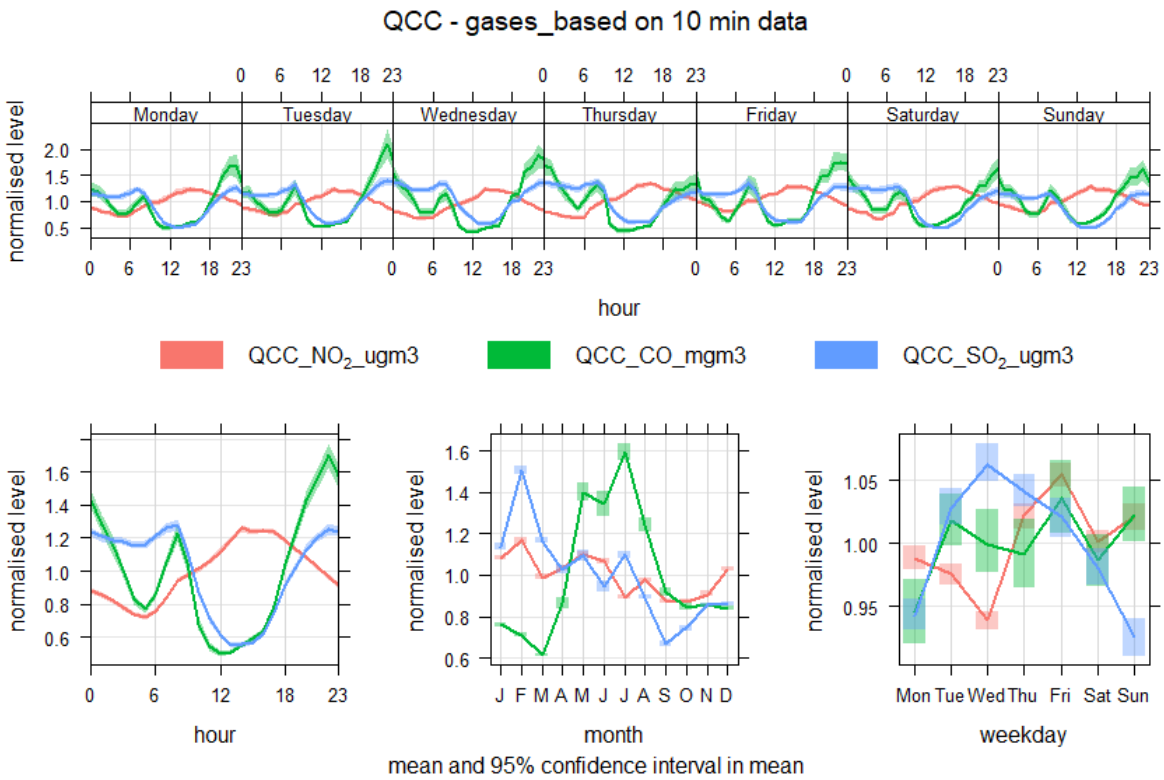


Figure 3-16: QCC - gas data comparison.

In Figure 3-17 we compare the CO and SO_2 with the PM_{10} data. We observe a similar trend in the hourly data for all three pollutants, this indicates that PM_{10} is also associated with these two gases. The variation in the monthly plot of these three pollutants makes it more difficult to assign them to the same emissions source, such as home heating where the dominant winter CO peak is typical of this source. Summer peaks of PM_{10} have been seen in other coastal areas as a result of sea spray, and this along with pollen from the nearby trees may account for these peaks. A high peak of PM_{10} on Saturday and Sunday is also indicative of a home heating signal when more people are at home than during weekdays.

A review of the data on a seasonal basis was undertaken and this showed that during all the seasons except winter, the hourly data at each site was very similar but in winter the CO showed a night-time increase (1700 – 0300) and a second morning peak around 0700-0800, while the SO_2 and PM_{10} remained similar to each other and to the other seasons. The weekday plot showed higher values for PM_{10} than CO or SO_2 during the spring season, especially on the weekends and had the lowest values every day during winter. CO values were higher on every day of the week compared to SO_2 and PM_{10} during winter and lowest in summer on every day. SO_2 values were the highest in summer on all days and during the working week during autumn, and lowest on all days in spring. This confirms the difficulty discussed above in assigning pollutants to emission sources.

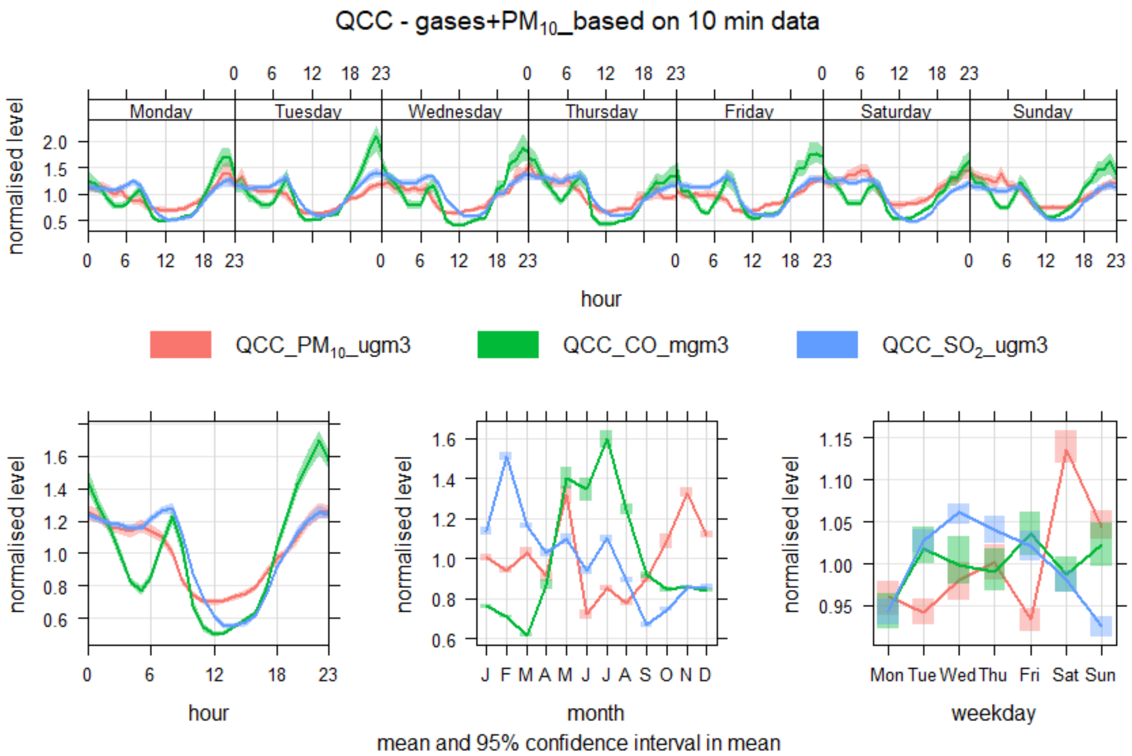


Figure 3-17: QCC - PM_{10} comparison with CO and SO_2.

In Figure 3-18 we compare NO_2 and PM_{10}, where we find there is no correlation between these two parameters. This helps to validate the notion that NO_2 is from a different source to the PM_{10} source.

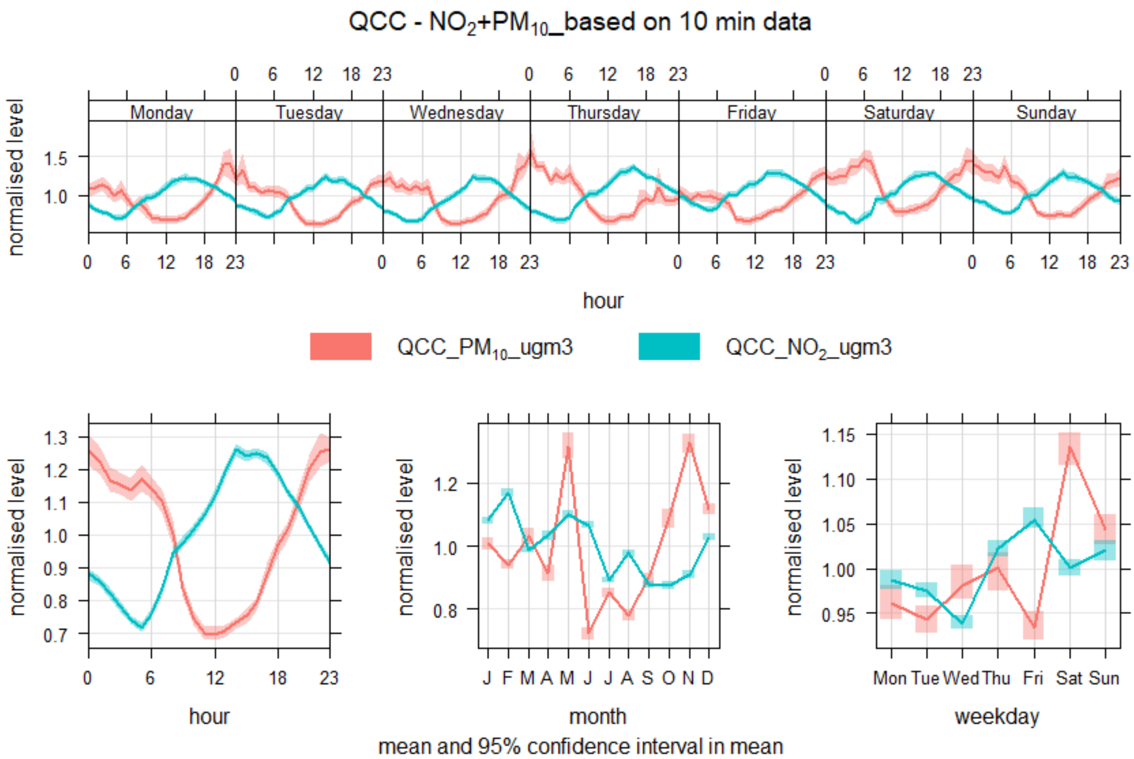


Figure 3-18: QCC - PM_{10} comparison with NO_2.

To investigate the higher concentrations of particulate measured at this site, a pollution rose was prepared investigate which direction most of the particulate came from. This is based on 10-minute data and it is the trend in the data, and not the actual values, which is important. Figure 3-19 shows that NE, ENE and E are the dominant wind directions with a lesser amount from the WSW. When these data are then separated into just the night-time hours (1800 – 0600 NZST), Figure 3-20 shows a different trend with similar amounts of pollution coming from all direction except SSW through S to ESE. This helps confirm that the strong NE signal seen in Figure 3-19 is the result of overnight pollution drifting down the valley in the dominant NE daytime flow. The higher particulate concentrations can also come from any of the directions.

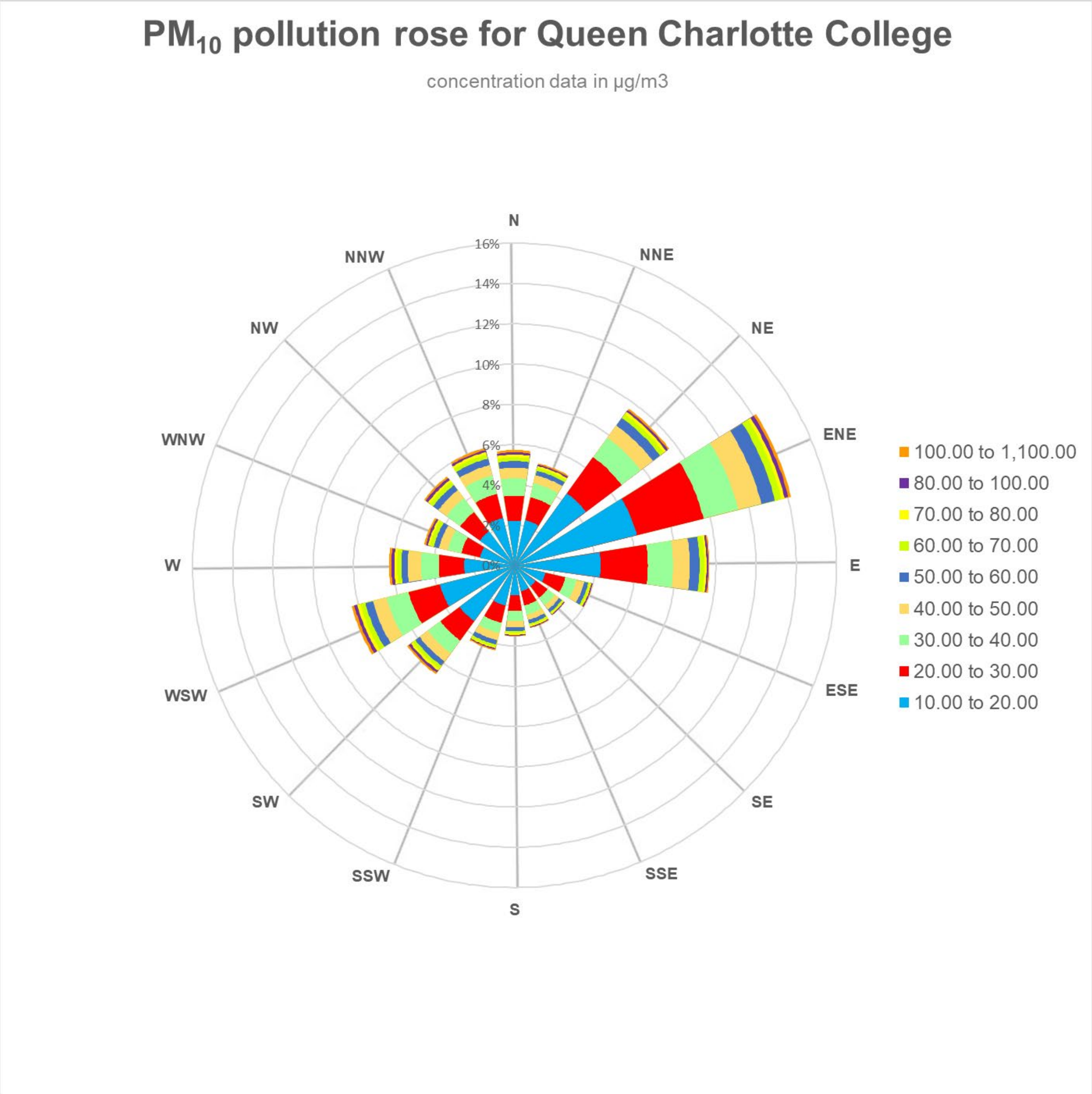


Figure 3-19: QCC - pollution rose of PM_{10} data – all hours.

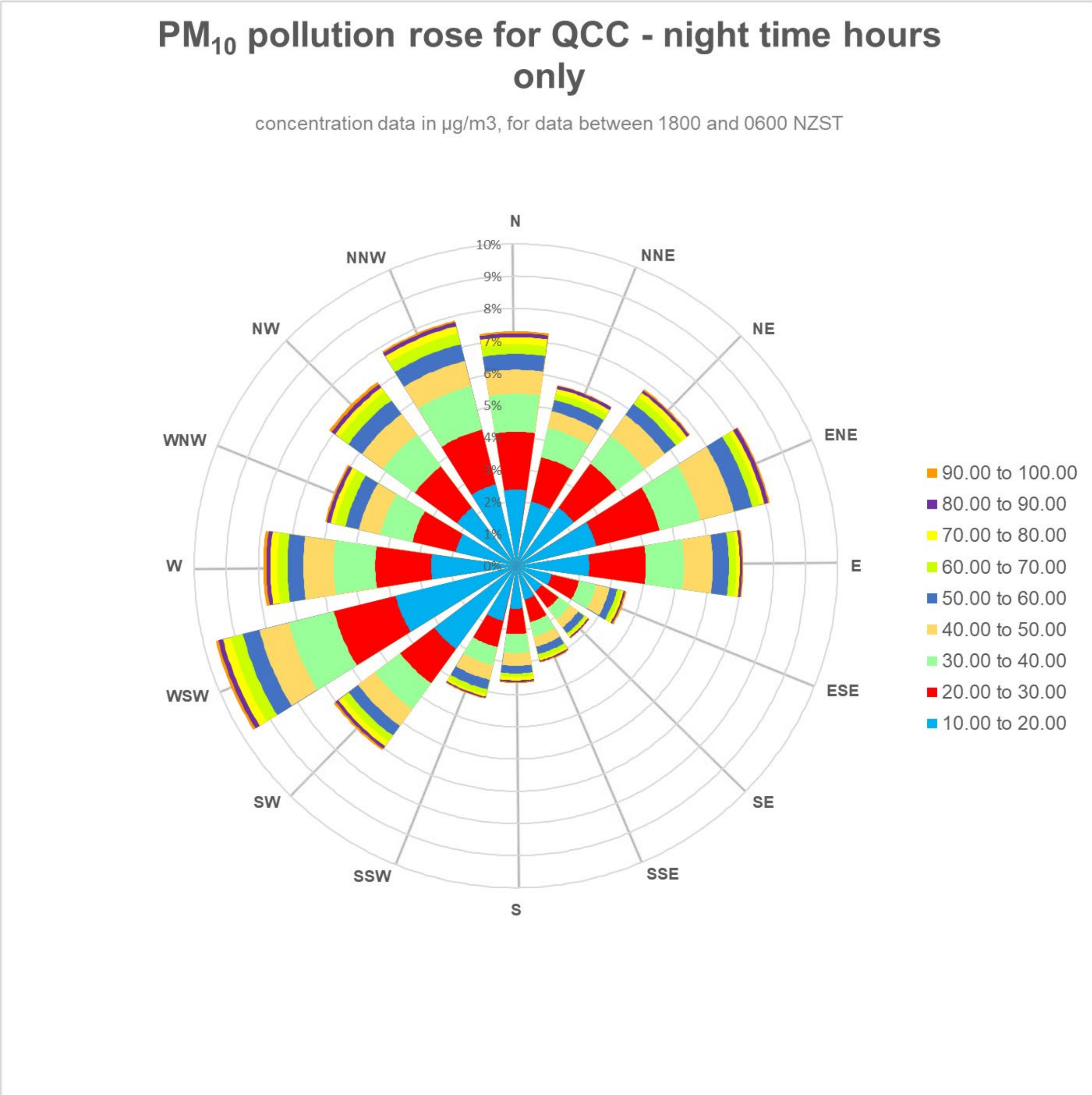


Figure 3-20: QCC - Pollution rose of PM_{10} data - night time hours.

3.4.2 Foreshore

The Foreshore site at E-Ko tours, (Figure 3-21) was primarily selected to assist in determining the impact of shipping. The inter-island ferry terminal is 470 m to the NW and the closest of the Queen Charlotte Sound tourist vessel wharves is 30 m to the north, with the remainder of Picton marina to the east. The fuel wharf is 120m to the ENE. The closest roadway (London Quay) is 15 m to the SW.

Figure 3-21: Foreshore site map.

As with the Queen Charlotte site, we see in the hourly plot in Figure 3-22 that CO and SO_2 are closely correlated but NO_2 is not, with a maximum during the early afternoon matching with the photochemical reactions of NO and O_3 being the strongest during this period. The CO and SO_2 are both showing higher concentrations during the evening with the smaller peak in the early morning. The other difference we see is in the monthly data where CO and SO_2 are now both showing maximum winter concentrations, and the NO_2 remaining with the higher peak from spring into summer. There is less SO_2 over the weekends which is an interesting finding, and this would need to be investigated to determine if there are fewer shipping movements at this time.

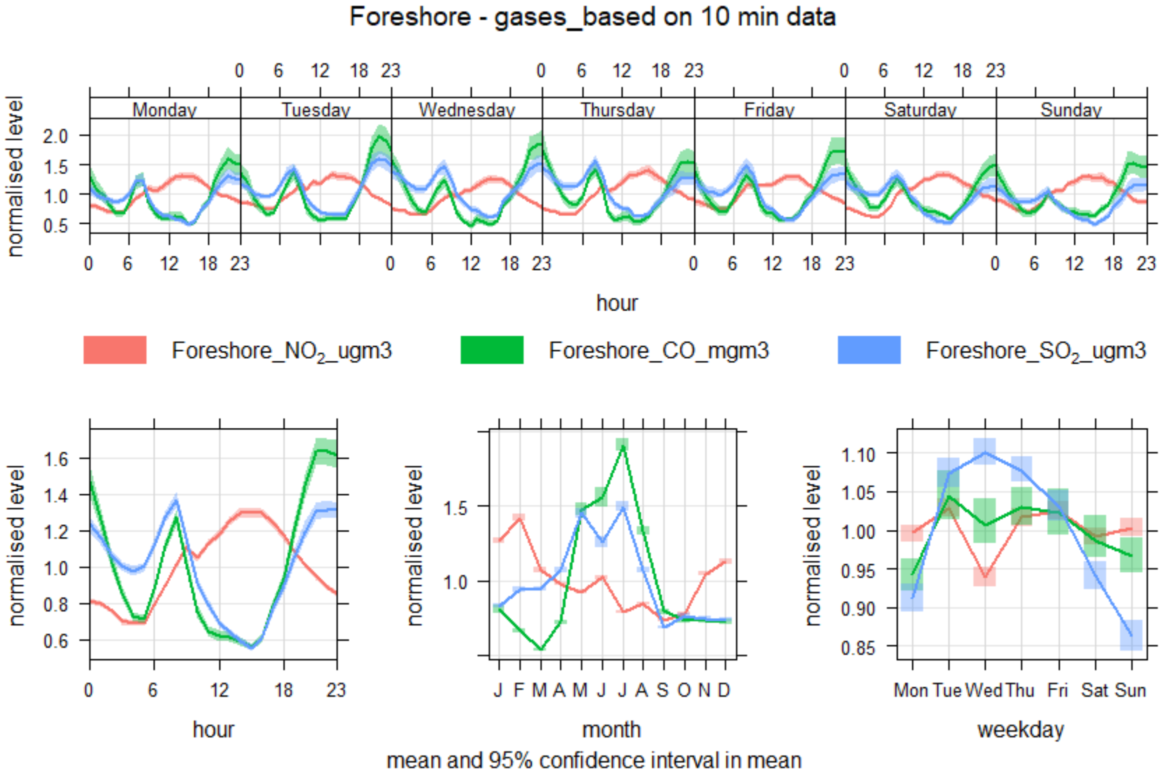


Figure 3-22: Foreshore – gas data comparison.

When we compare the PM_{10} data with CO and SO_2 in Figure 3-23, we see the monthly plot correlates very well for all three pollutants. The hourly plot shows similar trends except for a slight PM_{10} peak around 1600 hours which remains steady during the evening hours. The weekday plot shows the similarity between CO and PM_{10} which higher SO_2 concentrations on Tuesday to Thursday and less over the weekend as discussed above. The three pollutants correlating together suggests that incomplete combustion is influencing these results.

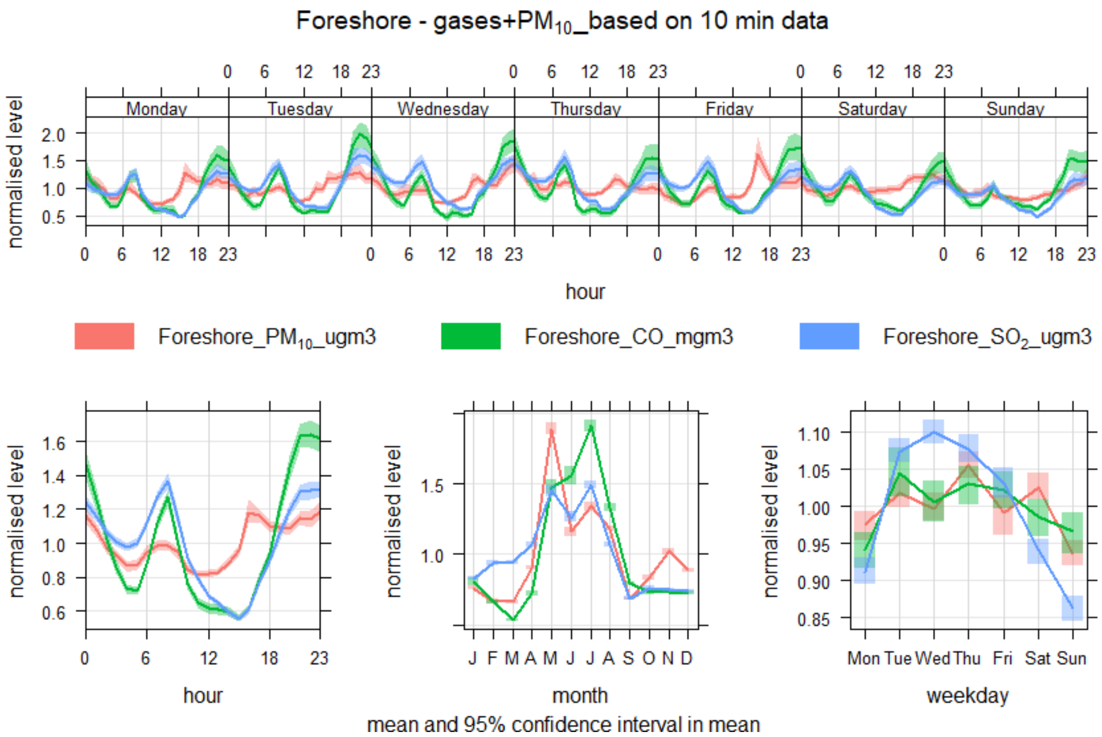


Figure 3-23: Foreshore - PM₁₀ comparison with CO and SO₂.

Looking at PM_{10} with NO_2 in Figure 3-24, we again see no obvious correlation, so it is unlikely that these two pollutants are coming from the same emission source.

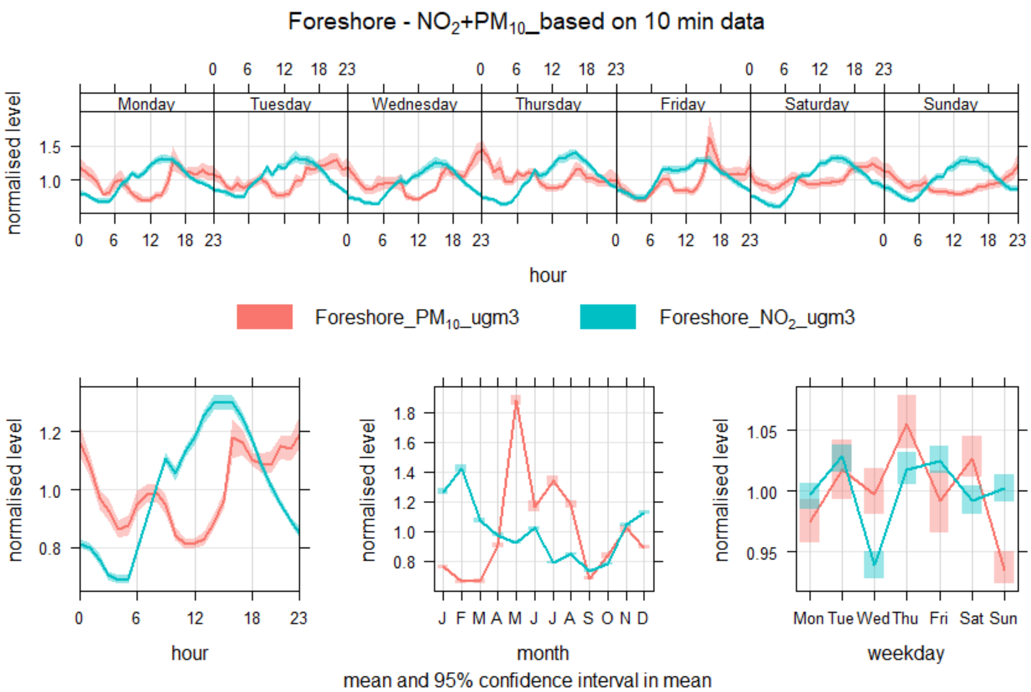


Figure 3-24: Foreshore - PM_{10} comparison with CO and SO_2.

3.4.3 Wairau Rd

The Wairau Rd site (Figure 3-25) was primarily selected to assist in determining the impact of traffic, as it is on a property adjacent to SH1, some 120 m south of the intersection used by heavy duty vehicles (HDV) to go to the ferries and the port. There is an NZTA traffic counter at the Waitohi Bridge which for 2020 had an annual average daily traffic (AADT) count of 5660 vehicles of which 6.8% were HDV and a second counter at Koromiko had a count of 6150 and 12.3% HDV, so this gives an indication of the volume of traffic that could be using Wairau Rd in the vicinity of this site. The train track is 245 m to the SE at its closest point. These two features are shown in Figure 3-25 where the HDV route is in red and the train track in orange.

Figure 3-25: Wairau Rd map showing the HDV and train routes.

Similar to observations from the other sites, Figure 3-26 shows a relationship between CO and SO_2 but not with NO_2. There is also a dominant winter peak in SO_2 and CO concentrations as was seen at the Foreshore site. There is a difference in the weekday plot where we see a marked variation between Monday to Friday and the weekends for all pollutants. This suggests that the emission source area is dominated by more traditional work day activities, as opposed to seven day a week activities.

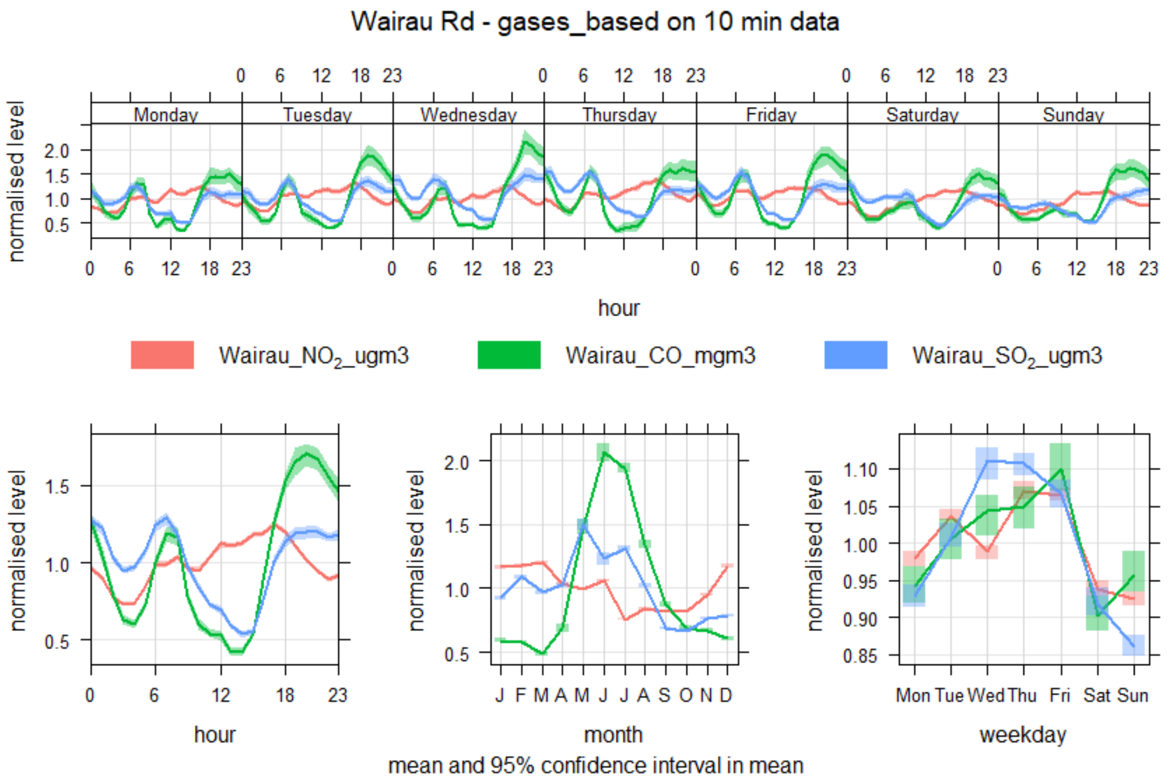


Figure 3-26: Wairau Rd - gas data comparison.

The addition of PM_{10} to the CO and SO_2 data in Figure 3-27, shows they still appear to be correlated on the monthly and day of the week timeframes but the PM_{10} hourly data show a different pattern with more particulate matter during the day.

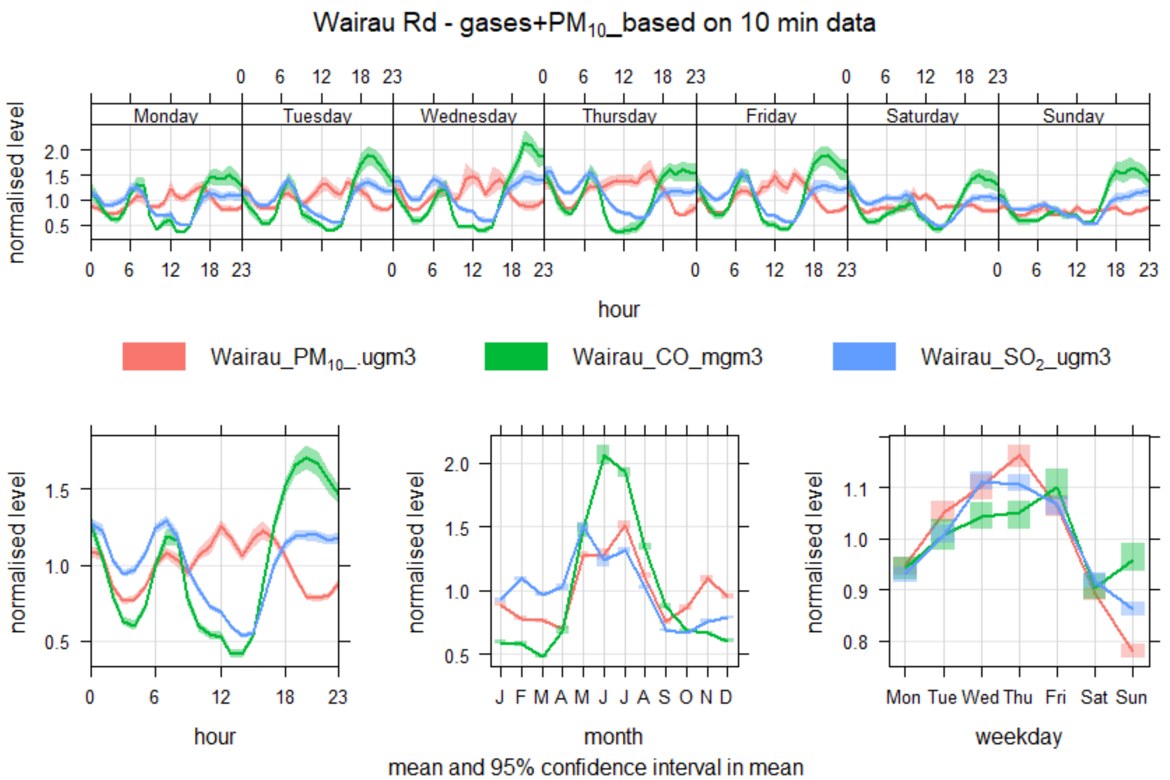


Figure 3-27: Wairau Rd - PM_{10} comparison with CO and SO_2.

It is when we look at PM_{10} with NO_2 in Figure 3-28, that we see a difference compared to the other two sites. Here we see a strong correlation at the hourly and weekday scale. This suggests that road traffic (and maybe rail traffic) will be influencing the PM_{10} concentrations recorded at this site, through such factors as dust generation off the road surface. The lower concentrations of NO_2 in the winter months may be associated with less potential for photochemical reactions as a consequence of the shape of the valley at this site reducing the number of hours of sunlight. It could also be related to changes in traffic movements with less tourist traffic going to the ferries. Further investigation into traffic volumes and types may help to understand the concentration data measured at this site.

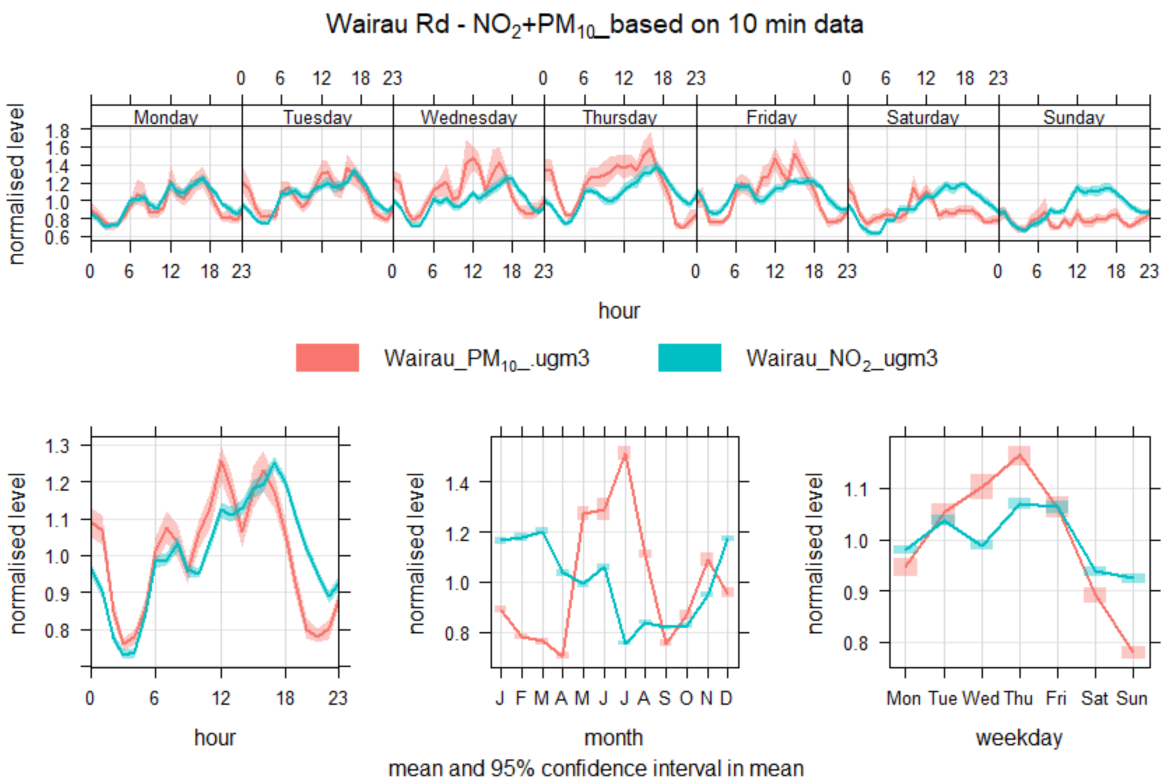


Figure 3-28: Wairau Rd - PM_{10} comparison with NO_2.

4 Discussion

4.1 Model data output

Figures 4.1 and 4.2 are examples of the output that can be created with the model.

In this example based on data for 4th August 2019 (when there were high concentrations of PM_{10} measured at several sites), the model used the measured meteorological data (top part of Figure 4-2), and the ferry terminal area as a point source of PM_{10} with pollutants being injected at three intervals during the day. The receptor position was taken to be the Foreshore site. The bottom part of Figure 4-2 shows the injection (red lines) and the modelled PM_{10} in blue.

The output in Figure 4-1, is a plume map showing the 24-hour average concentration of PM_{10}.

The regional wind situation was a south-westerly which slowly moved through west and then ended up as a light NW. The local surface sites were generally SW with some have a light northerly for a period, before becoming more southerly in the evening. Strong cooling started in the late afternoon and continued into the evening. Figure 4-1 shows the spread of particulate matter around the Picton area as the wind patterns changed.

The modelling can be used in selected 'case studies' to help in determining where some of the high concentrations of pollutants may have come from and how they move around the town.

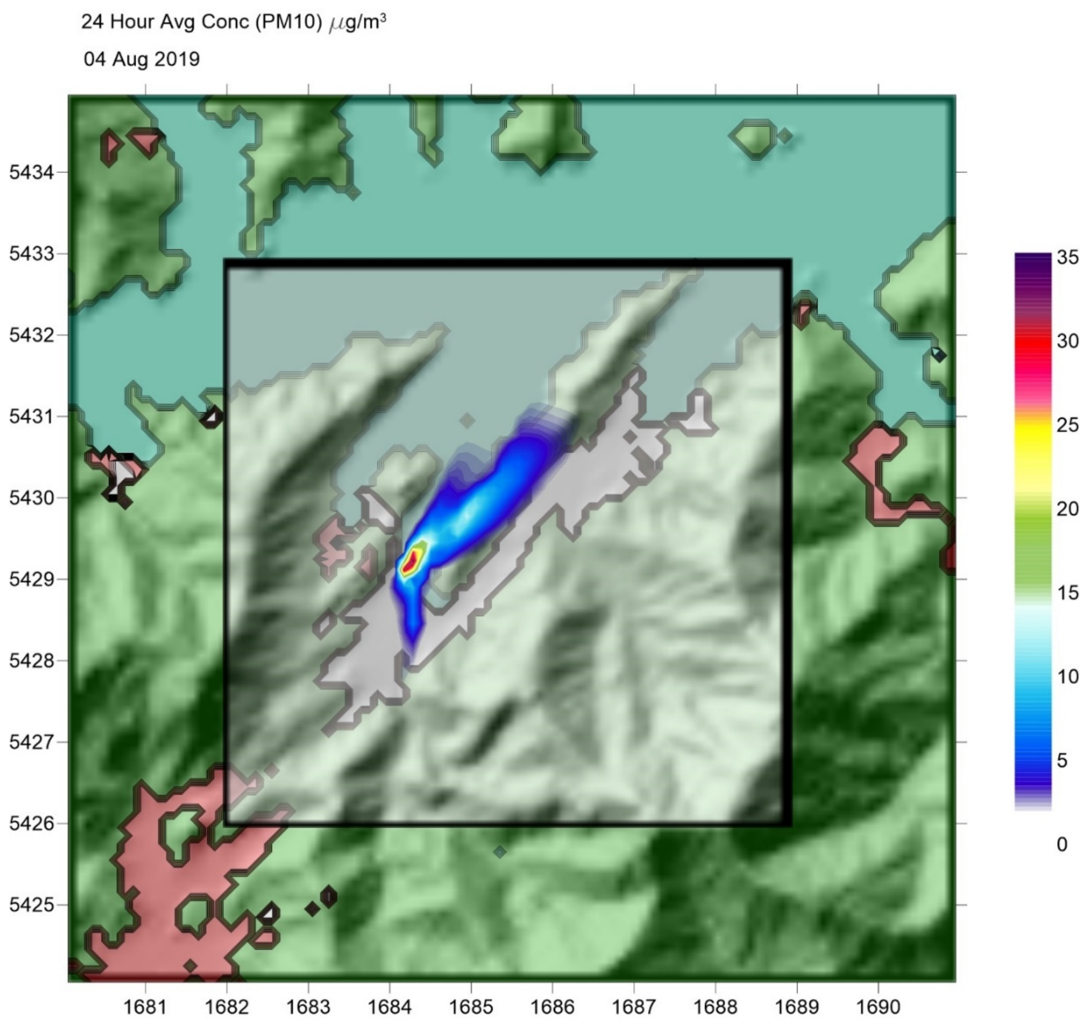


Figure 4-1: Wind modelling for 4th August 2019, output as a map.

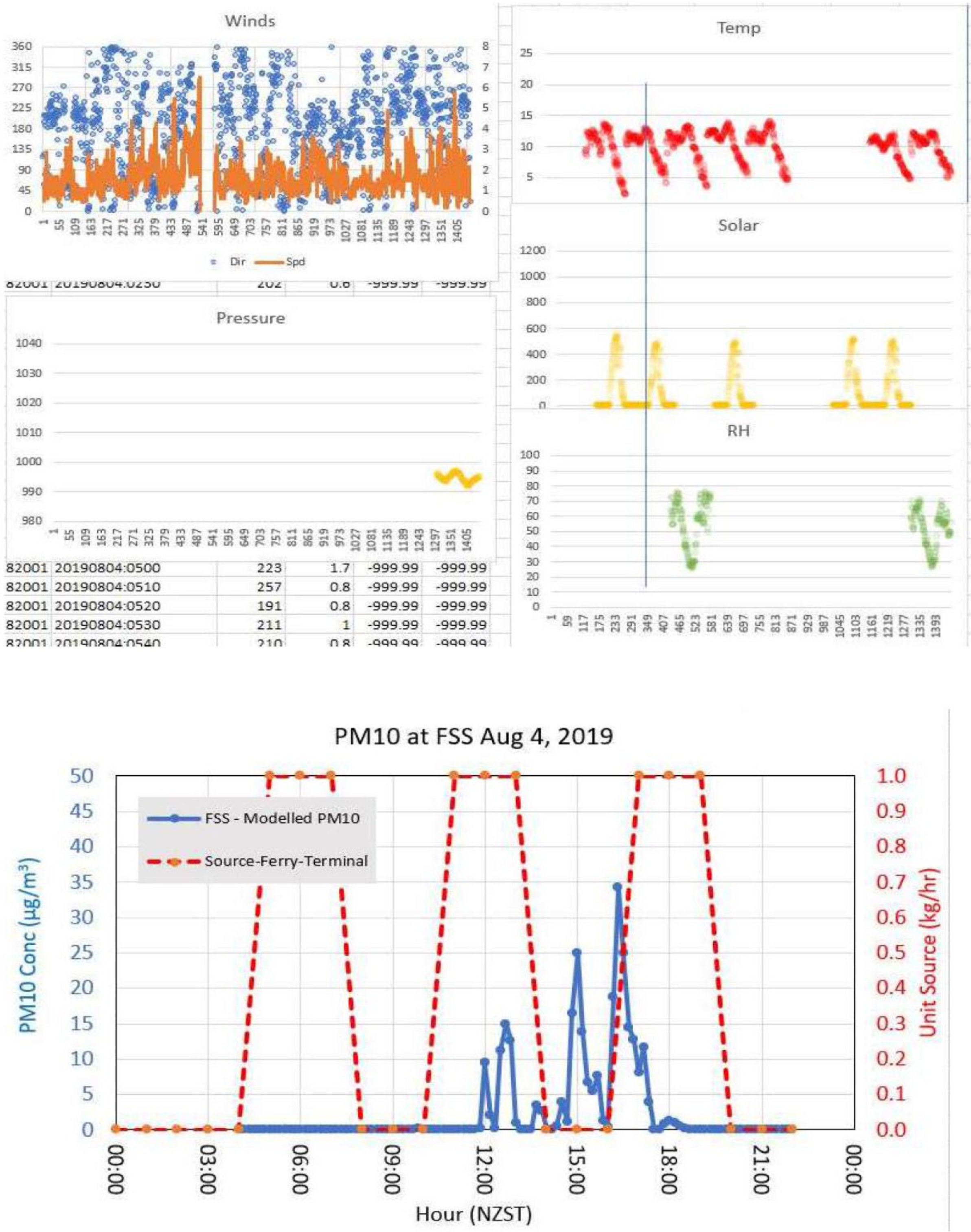


Figure 4-2: Model input and receptor output for 4th August 2019.

4.2 Comparison of this period to long term climate patterns

4.2.1 Overview

2019 was the 4th warmest year on record for New Zealand based on NIWA's seven-station series which began in 1909. The annual temperatures were above average (+0.51°C to +1.20°C above the annual average) across the majority of New Zealand but for Marlborough, temperatures were near average (within -0.50°C to +0.50°C of average). Rainfall was below normal (50-79% of normal) across much of the North Island and also in Marlborough. A dry and warm January led to the rapid depletion of soil moisture levels, which continued throughout February and into autumn. Winter rain improved the situation so soil moisture levels were near normal for most of the country by the end of the period. By the end of spring 2019, soil moisture levels were again below normal for much of the North Island and parts of Tasman, Marlborough and Canterbury. Late rain resulted in soil moisture levels being wetter than normal conditions by the end of December in parts of Southland, Otago, Nelson, Marlborough Sounds and Wellington.

2020 continued the warm temperatures, resulting in the 7th warmest year on record. The annual temperatures were above average across much of the North Island, and parts of every South Island region with Marlborough having near average temperatures. The hottest spell of the year took hold over New Zealand from late-January to early-February. This period of warmth coincided with the latter stages of an extended dry spell for many areas of the country. Most notably, a 64-day dry spell was recorded in Blenheim. It lasted from 20 December 2019 to 21 February 2020, making it the longest dry spell on record for the town. From late-March to late-April, high pressure prevailed over the country, delivering mild and very dry conditions for many areas. Coastal Marlborough recorded less than 5 mm of rain during April. These dry conditions resulted in the annual rainfall being below normal across many parts of the North Island, and also in Marlborough, Canterbury and eastern Otago. The dry conditions caused a severe meteorological drought to be in place by the end of February across Northland, Auckland, much of Waikato, western Bay of Plenty, East Cape, and southern Marlborough. Soil moisture levels returned to near normal for many areas during the middle of the year and by the end of December, soils were wetter than normal for coastal areas from Taranaki through to Wellington, the Nelson-Tasman region and northern Otago.

By the end of 2019 there had been 35 months since New Zealand had a month with below average temperatures, (January 2017 was the last month with a below average temperature) and by the end of 2020 this had increased to 47 months. The increase in the number of red above average temperature squares is clearly visible in Figure 4-3.

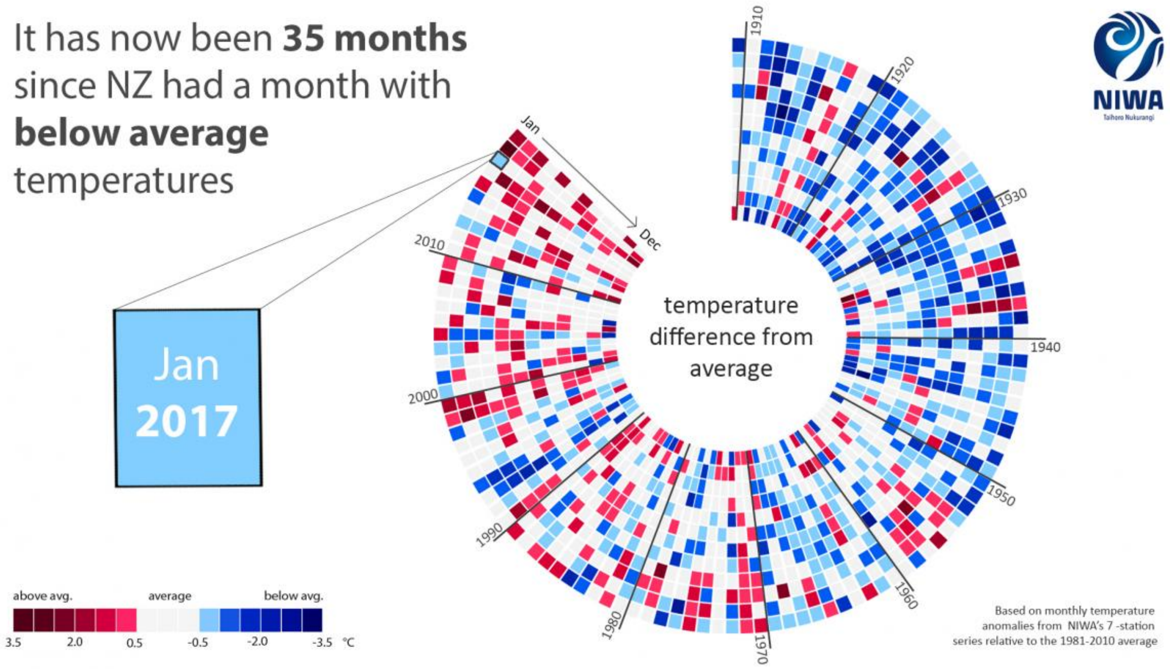


Figure 4-3: National temperature difference from average as at end of 2019.

Further detailed information on the climate during the 2019 and 2020 period is included in Appendix E.

Temperature, rainfall and soil moisture are significant parameters in air quality, especially for particle formation. Dry conditions allow surface dust to rise into the air and mix with urban pollution sources and increase the concentrations of particle matter, predominantly in the summer months. The warming temperatures should reduce the need to use heating to keep houses warm.

4.2.2 Seasonal climate summaries

Winter (June – August) 2019 began on a chilly note, with snow falling in the South Island and the Central Plateau on 1 June but this was not indicative of the whole season. June was the driest winter month with below or well below normal rainfall for the majority of New Zealand. While July wasn't as dry as June, a distinct lack of southerlies and frequent periods of high pressure led to unseasonably warm temperatures and New Zealand's second-warmest July on record. August was unsettled, characterised by frequent low-pressure systems and a strong southwesterly flow. Frequent fog events occurred during winter.

The winter climate pattern was influenced by a polar jet stream that remained south of New Zealand during June, was weaker than normal in July, but occasionally passed over the country during August while interacting with the sub-tropical jet stream. This contributed to an unsettled end to the winter season. New Zealand coastal sea surface temperatures were above average for the season. These two factors tipped the odds toward a warmer than average winter season. Winter as a whole saw average to above average temperatures across the country. The nationwide average temperature for winter 2019 was 9.0°C (0.6°C warmer than the 1981-2010 winter average, making it the seventh-warmest winter on record.

Spring (September – November) 2019 was characterised by lower than normal mean sea level pressure over, south and east of New Zealand. This pressure setup resulted in more southwesterly winds than normal).

Variable temperatures started the spring season in September with warm subtropical winds mixed with chilly southerlies. September temperatures were near average in September and October, before prevailing north-westerlies in November brought unseasonably warm temperatures and New Zealand's warmest November on record. Spring as a whole, had near average temperatures across the country with an average temperature of 12.5°C (0.4°C warmer than the 1981-2010 spring average, making it the 12th-warmest spring on record.

Summer (December – February) 2019-20 was characterised by lower than normal mean sea level pressure over the South Island and higher than normal atmospheric pressure to the northwest of the country. This pressure set up was associated with more westerly-quarter winds than normal. Drought conditions were present in several northern South Island locations, including parts of Tasman, northern Canterbury, and much of Marlborough.

The summer season had temperatures that were near average for much of the South Island with parts of Canterbury, Otago and Tasman observing above average temperatures. The nationwide average temperature was near average at 17.1˚C (0.4°C warmer than the 1981-2010 summer average).

Autumn (March – May) 2020 was associated with slightly more westerly airflows than normal over the country. Autumn temperatures were near average for most New Zealand locations. This was reflected by the nationwide average temperature of 13.4°C (0.1°C above the 1981-2010 average). The season got off to a hot start, with record or near-record high autumn temperatures recorded during the early days of March.

Winter (June-August) 2020 was a season characterised by more frequent warm northeasterly winds, associated with a developing La Niña event in the equatorial Pacific. Sea surface temperatures surrounding New Zealand were also warmer than average during winter, most notably during August, and this exerted a further warming influence on the country's air temperatures.

The nationwide average temperature was 9.6°C (1.1°C above the 1981-2010 average), making it New Zealand's warmest winter on record and included the fifth-warmest June, and fourth-warmest August on record.

4.3 Comparison of Picton data to other locations

It is useful, when doing a short period of monitoring to compare the collected data with other locations to see if the trends are similar. It is the trends and not the actual concentrations that give more certainty that the data collected, are realistic and representative. By using trend patterns, it allows comparisons to be made when other factors, (for example, daily meteorological conditions, volumes of traffic and emission sources) are not the same in each location.

4.3.1 Particulate data

The PM_{10} data, as discussed in section 3.3.1, showed higher concentrations from May 2020 onwards, than during the July – August period in 2019. To investigate this further, the daily PM_{10} data collected by MDC at the Bowling Club site in Blenheim were obtained and a comparison undertaken. The Foreshore and Wairau Rd sites were used in the figure to make it easier to see the patterns.

Figure 4-4 shows that the trends are similar in both locations with higher values during the winters of 2019 and 2020, and that 2020 is higher than 2019. The increase in the 2020 data in Blenheim has been attributed to the change from COVID-19 level 3 back to level 2 and will be discussed further in section 5.4.

The similarity in the trends between Picton and Blenheim is very reassuring and gives confidence in the data collected at Picton during the study period.

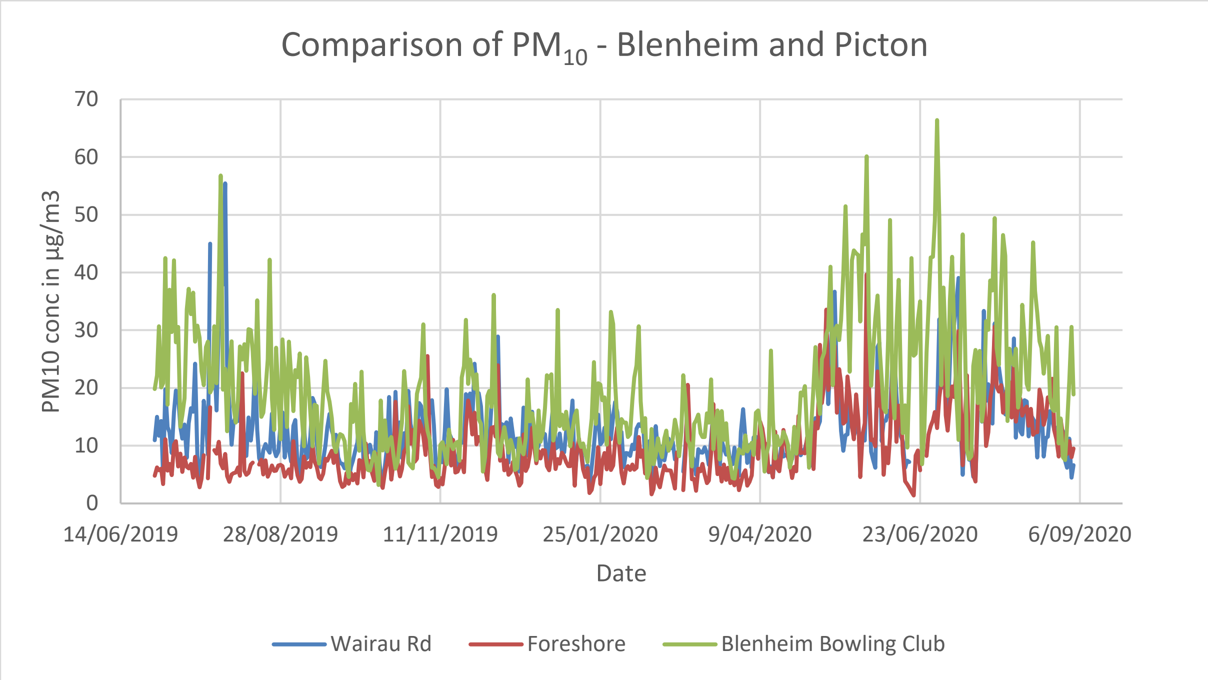


Figure 4-4: PM_{10} comparison between Picton and Blenheim.

Comparing the $PM_{2.5}$ data over the same period, the data in Figure 4-5 shows the trend is not the same between the two sites. During the winter of 2019 while Blenheim had elevated levels of $PM_{2.5}$, Picton had very low levels. During Spring they become more similar, then Blenheim has an increase in summer not replicated in the Picton trend. The Foreshore site was the only site to show the increased trend from May 2020 onwards.

This lack of trend similarity, when we had close similarity in PM_{10} trend, is unexpected. It is most likely due to different sources being responsible for the $PM_{2.5}$ signal in each town, especially since the trend variation was evident since the monitoring began in 2019. There are still the underlying concerns about the sensor response and impact of fog discussed in section 3.3.2, especially for the Wairau Rd and Queen Charlotte College sites.

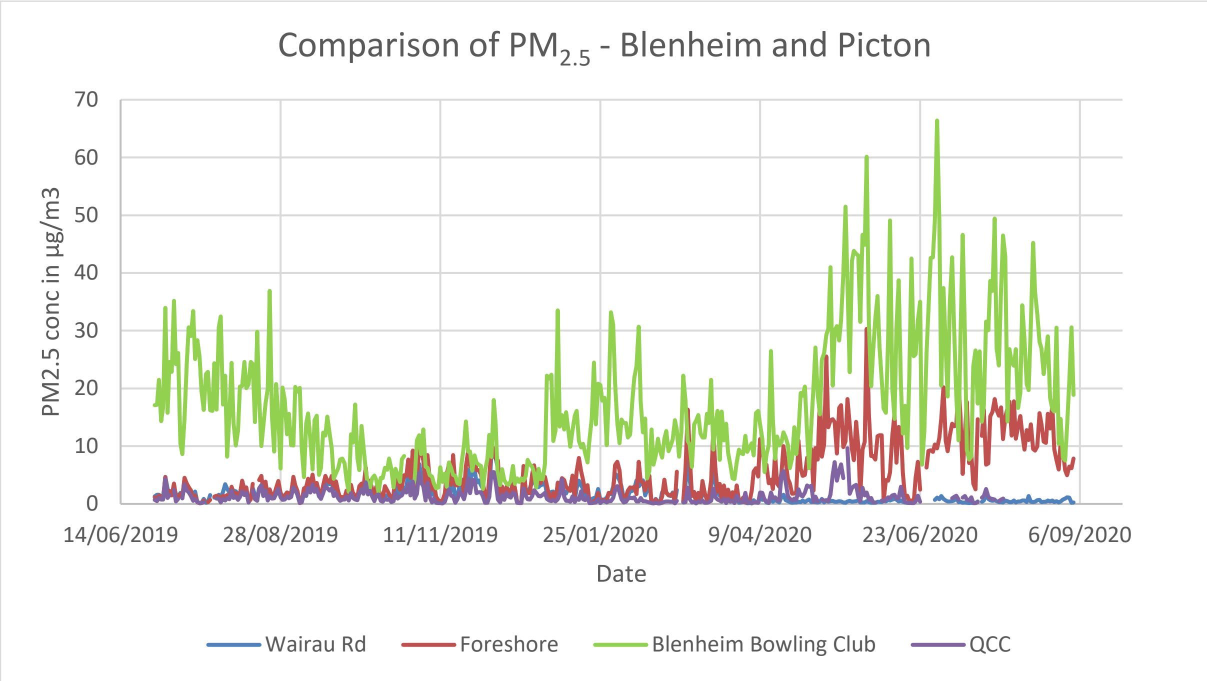


Figure 4-5: **$PM_{2.5}$ comparison between Picton and Blenheim.**

4.3.2 SO_2 data

SO_2 is only monitored in a few locations in New Zealand such as Whangarei around the oil refinery and a few port areas, namely Auckland, Tauranga and Timaru. Hourly data were obtained from the Tauranga site operated by Bay of Plenty Regional Council, as this measurement site is close to the port operational area in Mount Maunganui.

Figure 4-6 shows the comparison of data between these two sites. The Tauranga site uses an MFE approved instrument and thus the accuracy of the data will be of a higher quality than that measured by the AQT420. As Tauranga ship volumes changed as a consequence of COVID-19, only the data up to the end of 2019 have been reviewed. This shows that the values being recorded at the Foreshore site are in a similar range to those measured at Tauranga. The consistently higher base line in the Foreshore data is most likely associated with the regular ferry movements as opposed to freight vessels which remain alongside for longer periods.

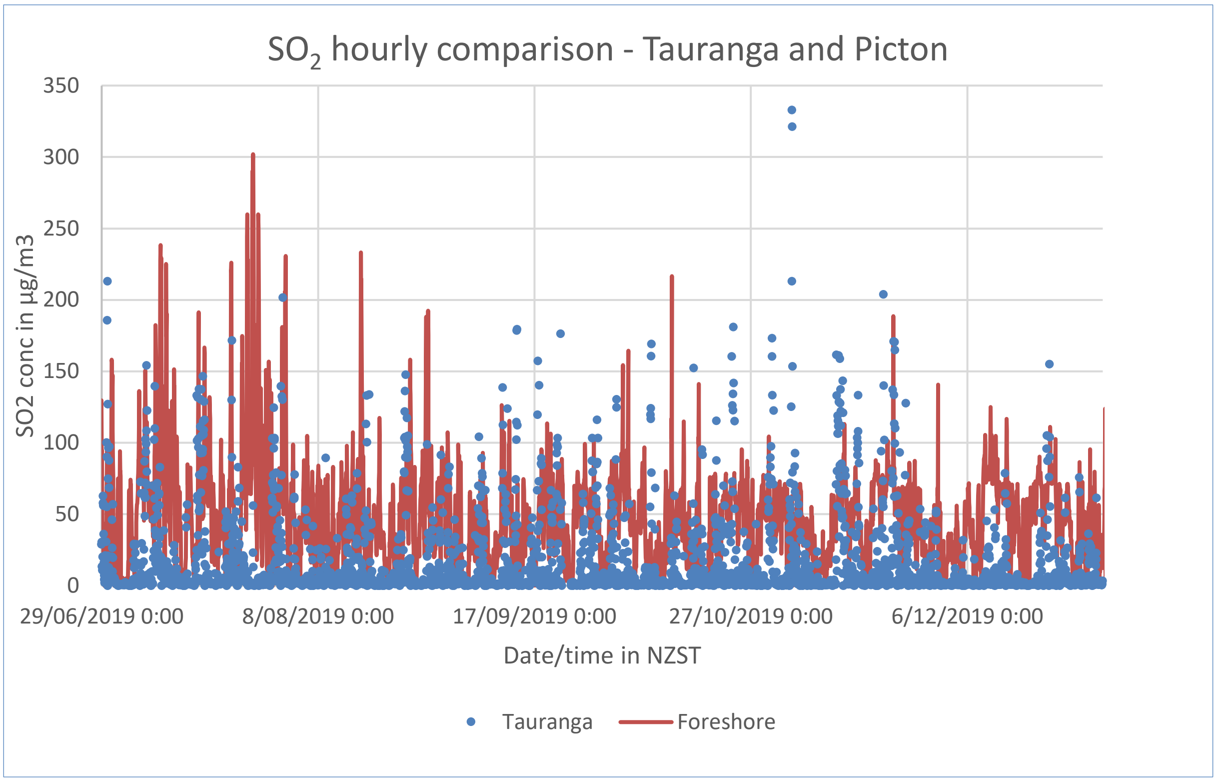


Figure 4-6: SO_2 comparison between Picton and Tauranga.

This 6 month period of data from the Port of Tauranga, shows that SO_2 concentrations were characterized by relatively regular peaks in concentrations above a more consistent base concentration below 20µg/m^3. Peaks are generally below 250 µg/m^3 although on some occasions reaching above 300 µg/m^3. Similarly, Picton's trend also shows a pattern of a general "base" level of SO_2 interspersed with peaks, although the base level is higher than at Tauranga.

However, there are several reasons why a direct comparison of concentrations should be treated with a lot of caution. Firstly, the data are measured with different instruments which are affected by different accuracies/error margins. Secondly, the Port of Tauranga has a greater level of industrial activity in the Port area and a different mix of vessels (size, fuel source, frequency of movements, periods alongside) to that at Picton. Thirdly, is there would be different wind patterns on the same day.

To investigate the data in a bit more detail, a sample month (October 2019) has been selected. Figure 4-7 shows, that at this scale, the episodic events at the Port of Tauranga, and the higher baseline at Picton are more evident. The SO_2 concentration peak for Picton was between 0700 and 1000 NZST on 12th October, with the winds switching from a light southerly (<1 m/s) to a stronger NE (>1.7m/s) after 0900 hours.

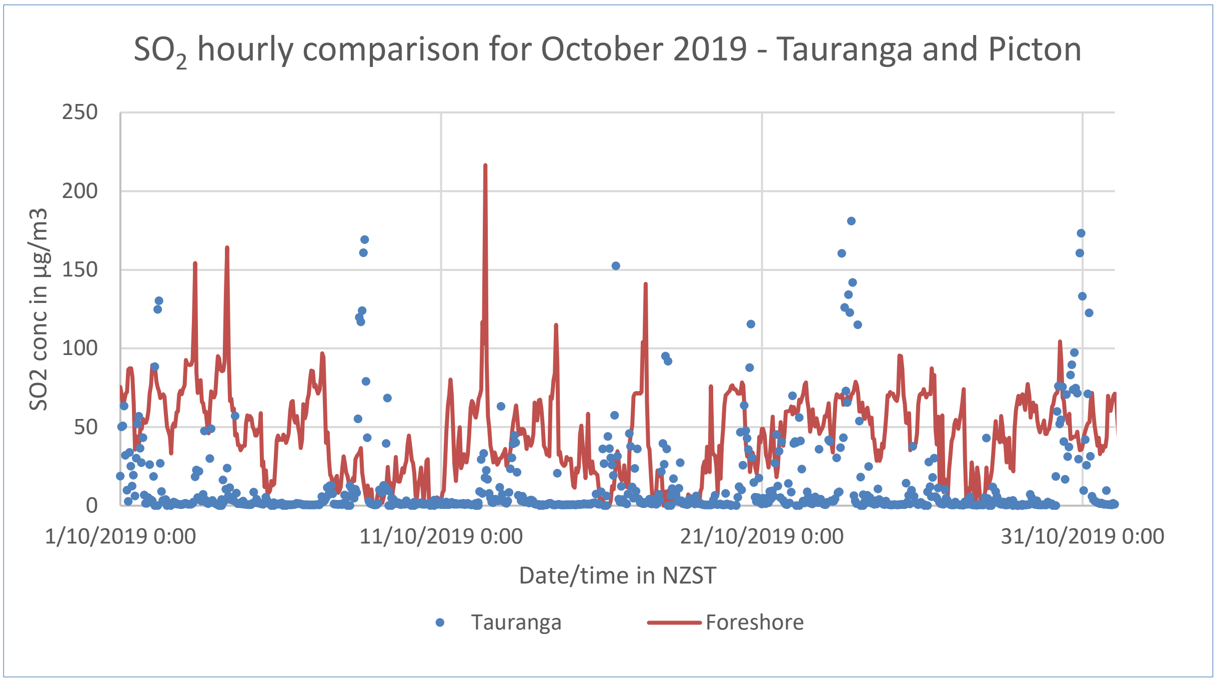
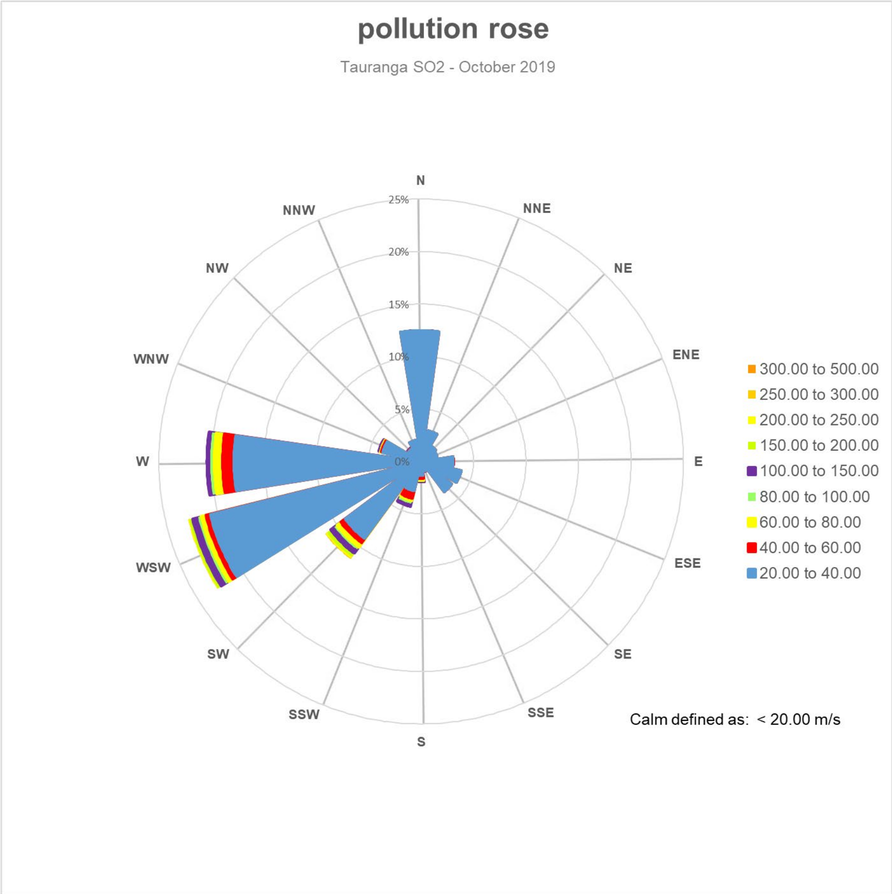


Figure 4-7: SO_2 comparison for October .

Pollution roses for these two sites shows the dominance of the WSW and W winds at Tauranga and how variable the winds are at Picton (Figure 4-8). For the Picton data, we have used Foreshore SO_2 data and Picton AWS wind direction data and this shows how much of the SO_2 moves around the valley with the most dominant direction being from the SSW.



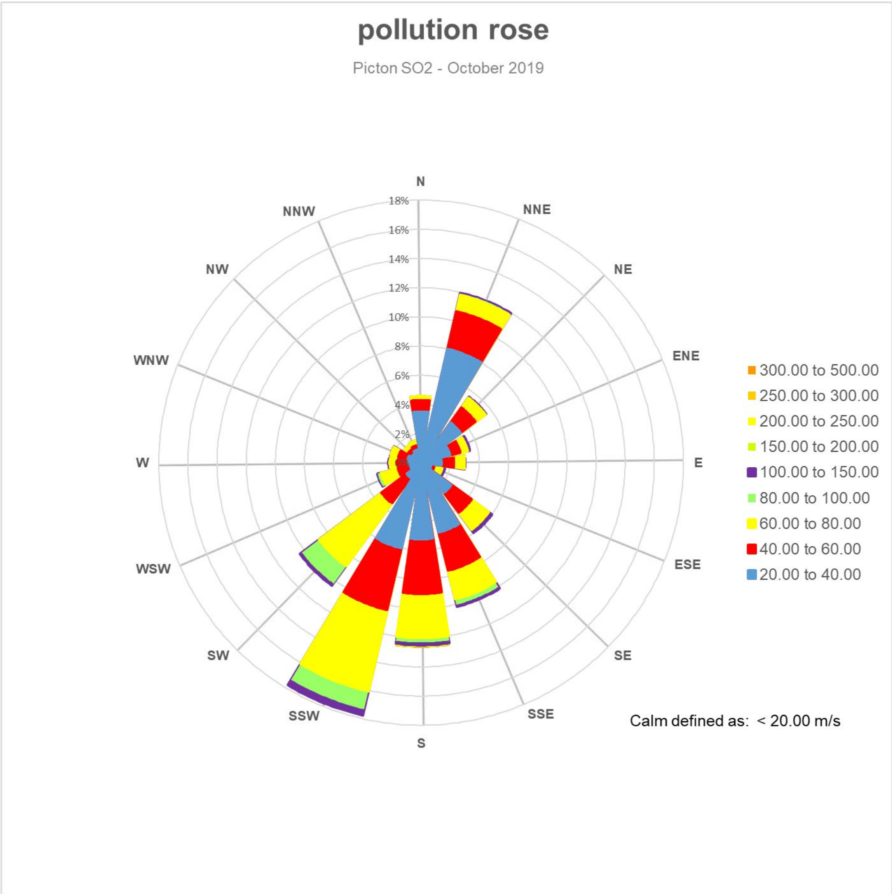


Figure 4-8: SO_2 pollution roses for Tauranga (top) and Picton (bottom).

4.3.3 CO data

CO data are measured in a number of cities and towns by the local regional councils. One of the sites at Timaru operated by Environment Canterbury (ECAN) has been selected, as it is a port town with shipping, traffic and home heating as sources of emissions so should have a similar profile to Picton.

The 8-hour rolling average data are used for the comparison. Figure 4-9 shows the same trend during the sampling period, with concentrations that are comparable. This helps confirm that the data collected in Picton are representative of these sources. The Wairau Rd was selected for the comparison as it had the highest concentration of CO of the three Picton locations.

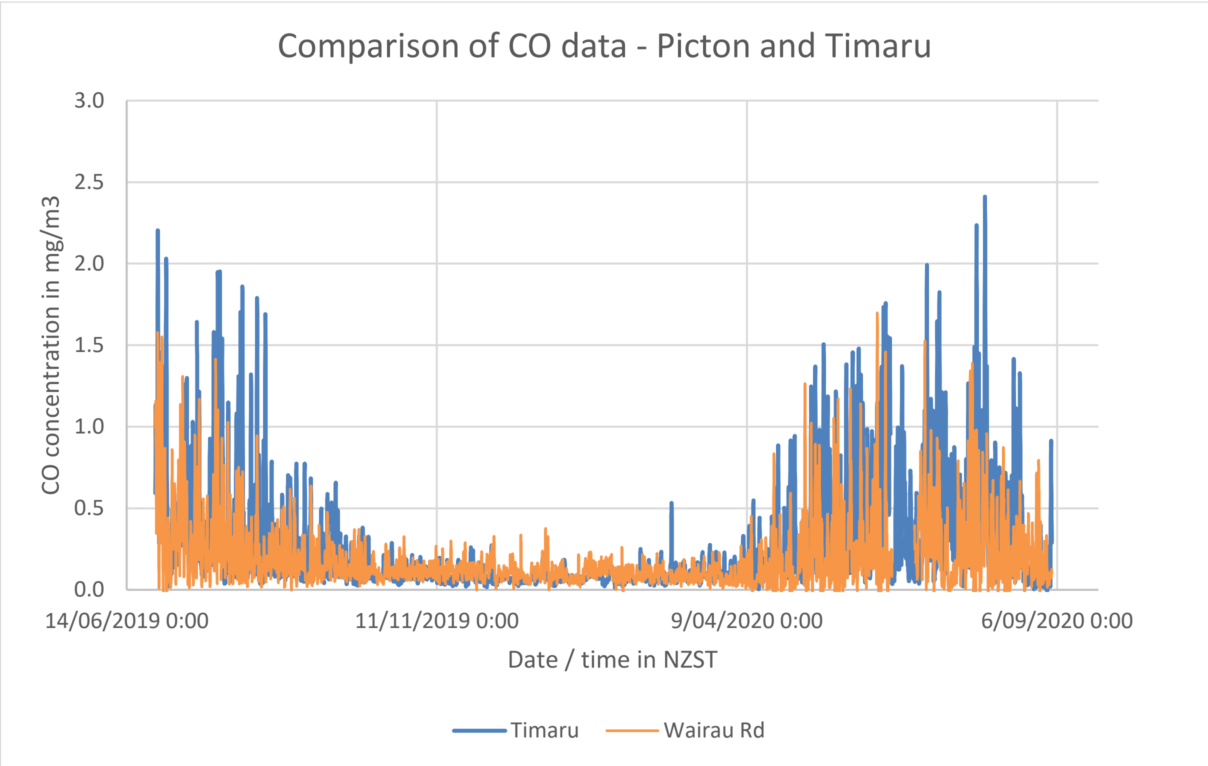


Figure 4-9: CO comparison between Picton and Timaru.

4.3.4 NO_2 data

Hourly averaged data from the ECAN site on Riccarton Road site in Christchurch have been used as a comparison with Picton as there are only a limited number of locations which measure this pollutant. The Wairau Road site has been selected as this should be the most traffic dominated site.

Figure 4-10 shows that the concentrations in Picton are similar to those at Riccarton Road but the trend is not the same with more NO_2 being observed during the summer period.

Figure 4-11 shows the data for July 2020 to give more detail of the relationship.

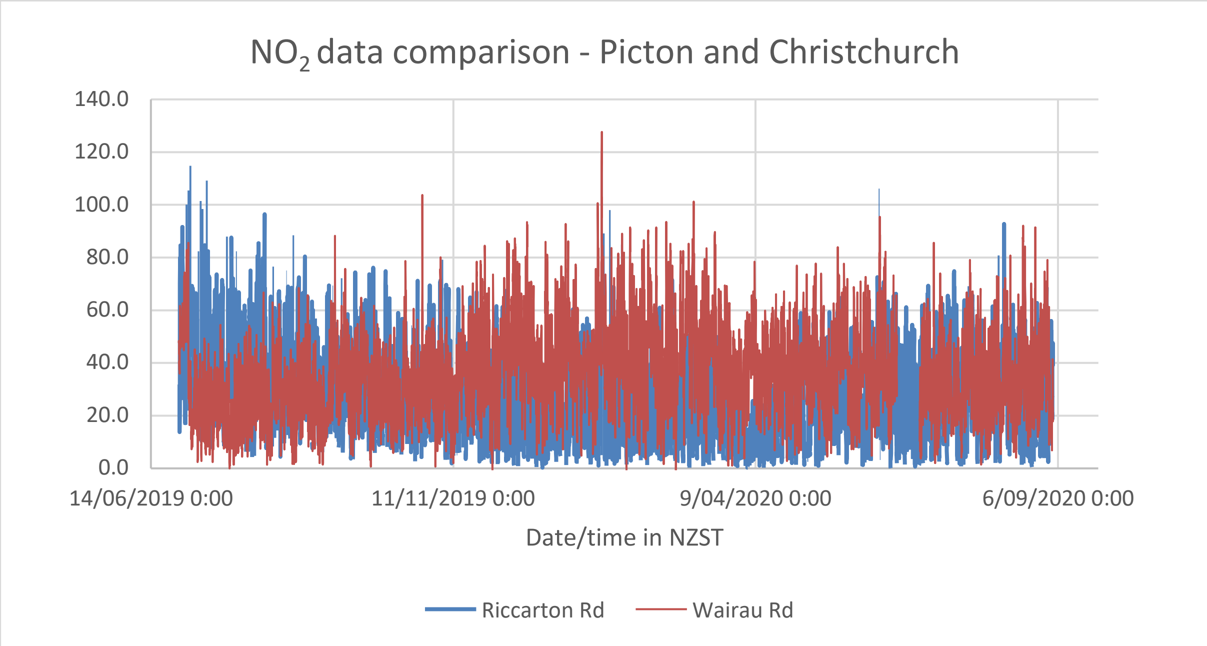


Figure 4-10: NO_2 comparison between Picton and Christchurch - full period.

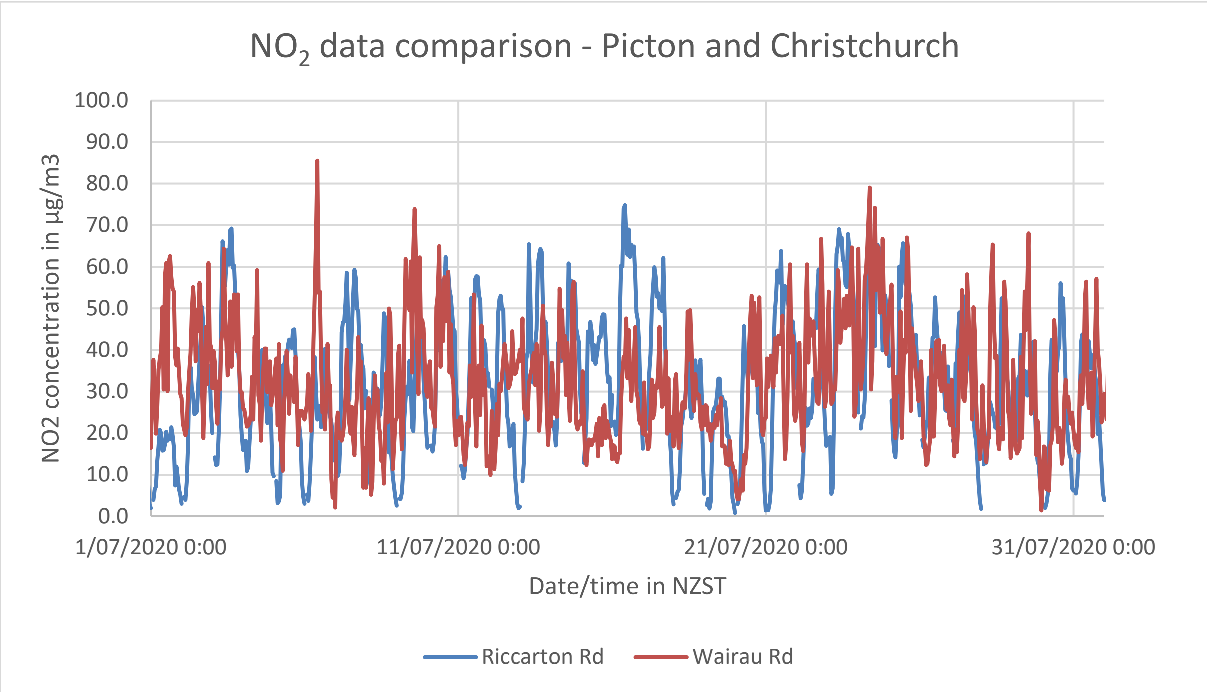


Figure 4-11: NO_2 comparison between Picton and Christchurch - July 2020.

5 Case studies

5.1 Shipping

One of the aims of this project was to investigate the impact of shipping, in particular the inter-island ferries operated by Bluebridge and KiwiRail. Another aim was to investigate if emissions from cruise ships visiting the port could be observed, although this part was somewhat curtailed in March 2020 when COVID-19 reached the country and cruise ships stopped operating.

World-wide studies have shown that shipping emissions impact the air quality of adjacent coastal areas adversely affecting the local environment and human health. Ships emit a far greater concentration of hazardous air pollutants compared to land-based transport. This is attributed to the use of poorer quality fuel, especially the concentration of sulphur. Globally shipping emissions are estimated to contribute 10-25% of NOx, 10-25% for SO_2 and 15-25% for $PM_{2.5}$ (AQEG 2017). A 2016 study at the Shanghai Port found 36.4% of the SO_2, 5.1% of NO_2 and 5.9% of $PM_{2.5}$ could be attributed to shipping emissions and this was 40-70% greater that the NO_2 and SO_2 concentrations in Shanghai city (Wang et al 2019). In this paper Wang et al also reported that pervious shipping studies had put direct emissions of $PM_{2.5}$ to be between 1% and 14% in other European areas. The AQEG report also found that emissions in the shipping lanes could be seen in the data for between 10 and 30 minutes after the vessel had passed depending on the weather conditions, which was also noted in the Auckland data (Talbot & Reid 2017).

5.1.1 Inter-island ferries

The ferries operated by both KiwiRail and Bluebridge operate in the Picton Harbour area and regularly both ferries will be in port at the same time. Figure 5-1 is a sample of a number of photographs of emissions coming from their engine stacks. Such photographs are regularly taken by residents and many people also raise concerns about the effect on the air quality in the town.

This investigation has not looked into the individual ferries and the following images are indicative of what can be seen at various times. It is not only while the ferry is at its berth that emissions occur but also while it is arriving and leaving. Exhaust emissions can be clearly visible along Queen Charlotte Sound for some considerable time after a ferry has left its berth and is travelling towards Wellington, similarly when ferries arrive into the sounds from Wellington.

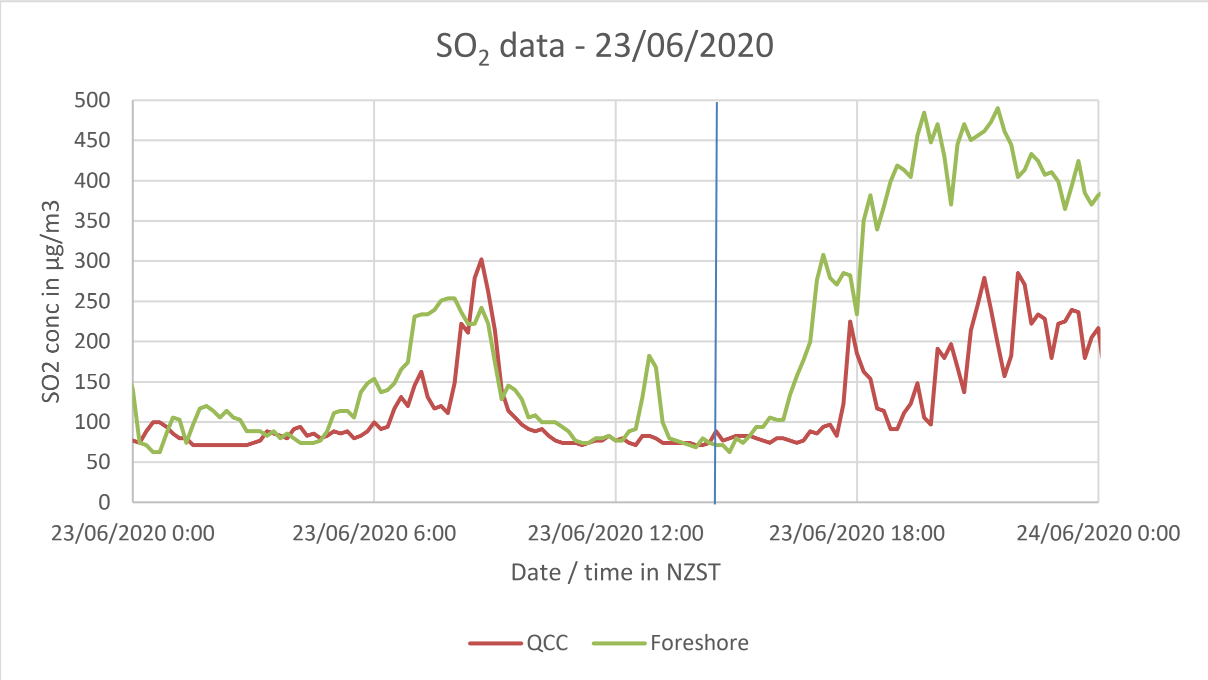
Figure 5-1: Photographs of ferry emissions in Picton. Left image with both ferries near the berth and the right image is as one passes Mabel Island.

One event when emissions were photographed in Picton was on 23rd June 2020 around 2.30pm as seen in Figure 5-2 which is one of several taken during this event.

Figure 5-2: Bluebridge in port on 23rd June 2020.

The plume from the exhaust funnel of a Bluebridge ferry can be clearly seen and along the hill line is the residue of an earlier plume, most likely from the KiwiRail vessel which had just departed. Around this time of the day, it is common for both ferries to be leaving on voyages northwards to Wellington. Having both ferries in port together is a common feature of the schedules for each operator.

Figure 5-3 shows the SO_2 concentrations and then the corresponding wind speed and direction data from the Picton AWS station. A vertical line has been positioned at 1430 NZST.



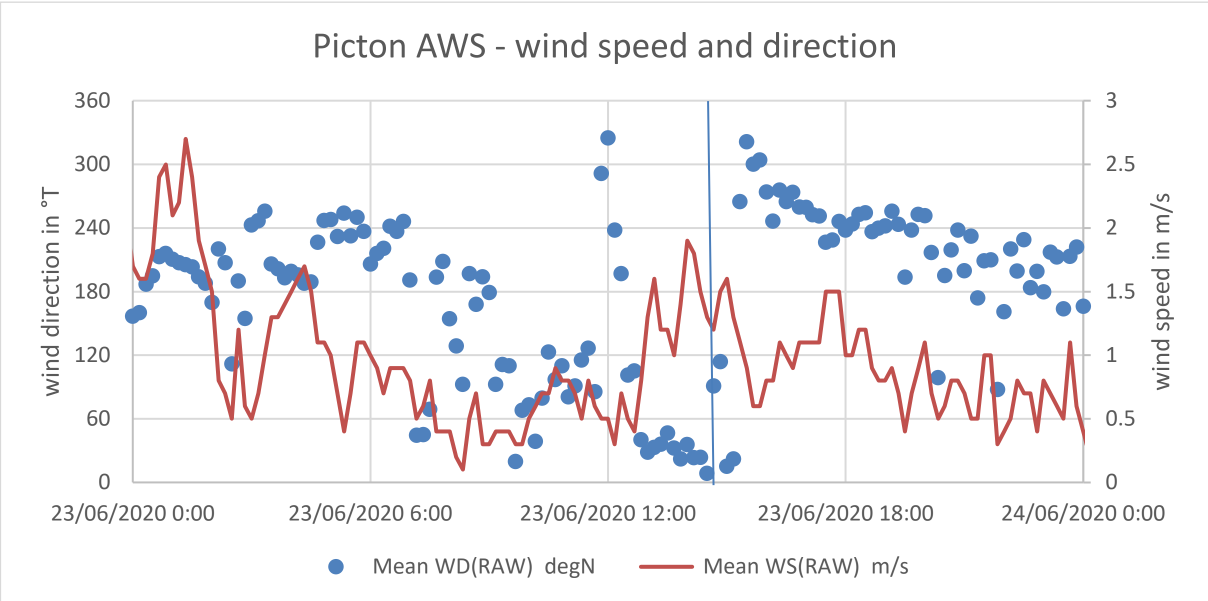


Figure 5-3: SO_2 and wind data from 23rd June 2020. Blue vertical line is at 1430 NZST.

From these plots we can see that SO_2 values at the Foreshore and Queen Charlotte College sites were relatively low in the period when the ship was at the wharf and through to about an hour after the ferry left for Wellington. This coincides with the predominant north/northeasterly winds, resulting in the exhaust plumes moving southwest around the western hillside of Picton. The interesting feature is that just after the ferries left, the wind changed to a southwesterly and then to a southerly. When this happened the SO_2 concentrations rose at the Foreshore site and a little later at the Queen Charlotte College site. This indicates the original plumes were blown back through the town and further north.

As discussed in the earlier section on the meteorological data, wind changes like this are common in the Picton area, so even though the wind may be southerly and blowing the plume out to sea through Queen Charlotte Sound, it can easily be brought back over the town if the wind direction changes to a more northerly or northeasterly flow. Not only are the surface winds an issue, but the upper level winds such as those along the hilltops can easily alter the direction of movement of any airmass. This effect is more likely to occur during relatively calmer conditions when cold air drainage from the southern part of town can carry gases and particulates caused by winter home-heating fires, as well as ferry and road traffic pollution, out into Queen Charlotte Sound. As the land heats up during the day, the sea breeze (northeasterly) then brings the pollution brought back into the town area later in the day.

5.1.2 Cruise ships

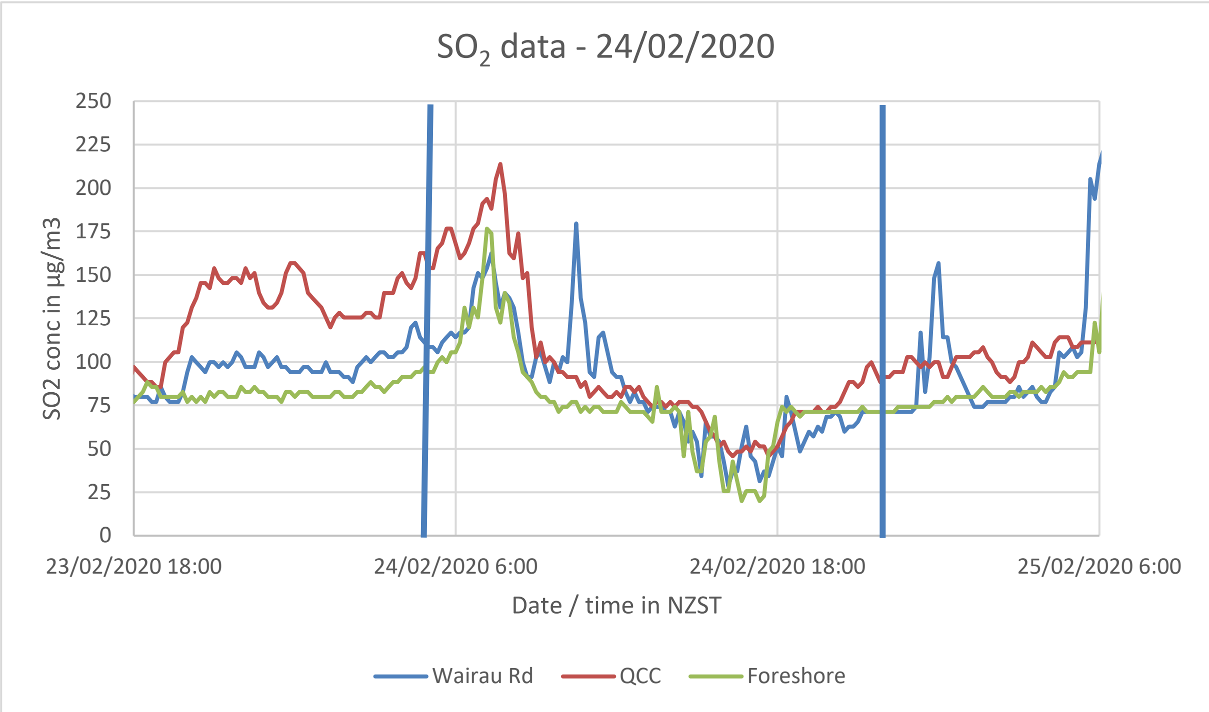
The cruise ships that were due in port during the summer period (October 2019 to March 2020) included Radiance of the Seas, Ovation of the Seas, Celebrity Solstice, Noordam, Norwegian Jewel, Ruby Princess, Pacific Princess and Carnival Spirit which all berthed at Waimahara Wharf in Shakespeare Bay, and Silver Muse, Aidaaura, Azamara Journey, Pacific Princess, Europa, Le Laperouse, Seabourn Encore which berthed at Waitohi West Wharf. The schedule prepared by Port Marlborough, and supplied by MDC is included as Appendix C.

An initial investigation looked at the vessels which berthed at Waitohi West wharf, as this is also in Picton Harbour near where the ferry terminal is located. On most of the days these vessels were in port, the wind was north- northeast while they were alongside the wharf and there were no discernible SO_2 increases.

One vessel was scheduled to arrive in port on 24th February 2020 at 0600 NZDT and to depart at 2300 NZDT (0500 and 2200 NZST respectively), although the actual arrival and departure times are not confirmed. This is one of the few events where the winds were initially south – southwesterly before a northeasterly came in, and as evening fell, the winds went back to the southwest. The data are shown in Figure 5-4, with the wind direction data from the Picton AWS shown below the concentration data.

The peak in SO_2 is at 0720 – 0730 NZST, while the change in wind directions happen at 0800 and 1730 NZST respectively. The additional SO_2 spikes at Wairau Road occur at 10:30 and 23:50 NZST. Even though there are higher spikes in SO_2 during the morning and evening hours, it is difficult to separate the response of this vessel to those of the ferries, especially as these spikes are at times when ferry movements are scheduled.

Without additional data on the exact times each vessel entered and left the Picton harbour (and out to at least Mabel Island), any further interpretation of the impact of cruise vessels or ferries is difficult.



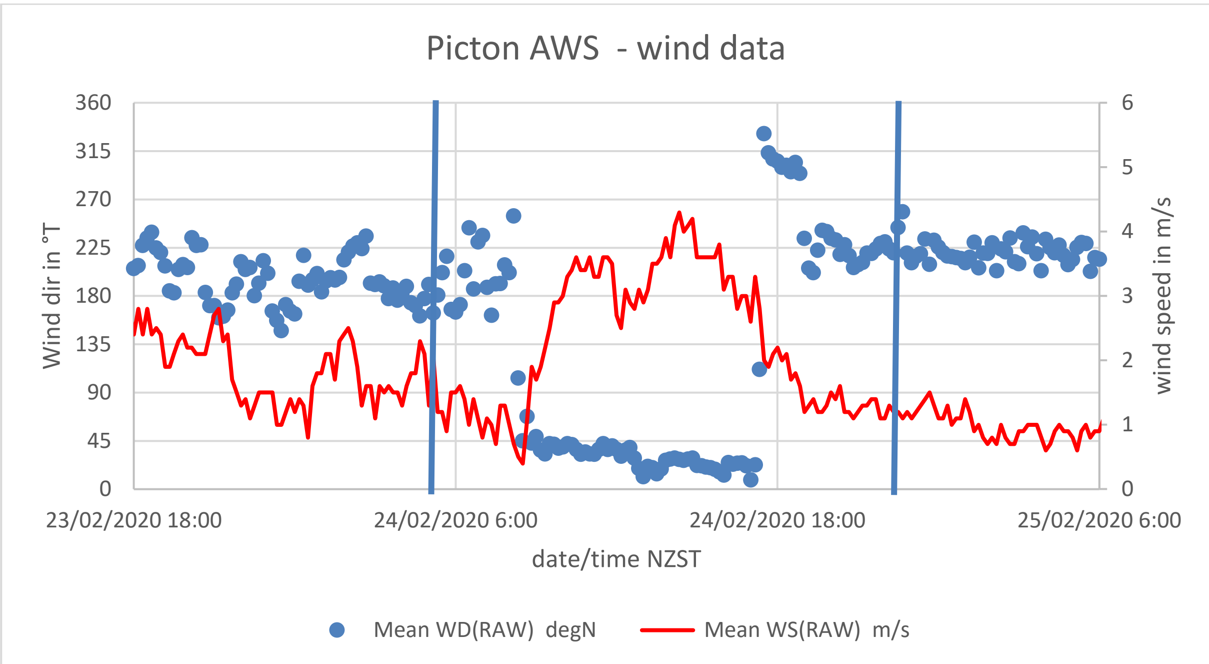


Figure 5-4: SO_2 and wind data for 24th February 2020. Blue vertical lines at 0500 and 2200 NZST

5.2 Home heating

The use of solid fuel heaters such as wood burners and open fires, results in the release of particulate and gas emissions to the atmosphere. The main pollutants of concern are PM_{10} and $PM_{2.5}$ as these small particles, especially those less than 2.5 microns ($PM_{2.5}$), can have a significant health impact. Carbon monoxide is also a pollutant as a result of incomplete combustion of the fuel used. During winter, dispersion of these emissions is reduced when these cooler periods coincide with lighter or calm wind conditions. This is a nationwide problem but the topography of Picton with hills around in most directions increases the risk of pollution being trapped in the valleys underneath an inversion layer.

The particulate data from Picton, as discussed in section 3.3, showed that these particles are being recorded throughout the town, and at times may exceed the NES ambient air standard for PM_{10}.

Taking into consideration the concerns about the sensor and fog, the data do still indicate that there is a dominant winter peak which is consistent with the home heating signal seen in other locations including Blenheim. This can also be seen in the Queen Charlotte College data where the night-time pollution comes from most directions when compared to the all data pollution rose (Figures 3-19 and 3-20). This comparison has not been done for the other two sites.

The CO signal, as discussed in section 3.2.1, clearly shows the higher concentration in winter and this helps in identifying that home heating is a major input of this gas into the atmosphere.

The impact of solid fuel home heating sources of pollution can be reduced through the use of good seasoned and dry timber, running the wood burner at a high rate when it is first turned on and not banking it down when heating is no longer needed. The use of coal should be avoided as this adds to the SO_2 pollution in the town.

5.3 Transport

The site at 30 Wairau Rd was selected to assist in investigating whether there were higher NO_2 concentrations due to traffic, especially by heavy duty vehicles (HDV) travelling to and from the port area along SH1. Heavy vehicles travel along this road to access both the ferry parking area and through the port area to reach the timber loading area at Shakespeare Bay.

NO_2 can also be emitted from the diesel used in light passenger vehicles, or by the locomotives used by KiwiRail on the train network. The train route runs to the east/south of this site.

Figure 5-5 shows the port freight areas and Figure 5-6 shows the HDV transport route (red line) and the train route (orange line) as they leave the port area and head south.

Figure 5-5: Map showing the port freight area.

Figure 5-6: HDV route (red line) and the train track (orange line) from the port area heading south.

To investigate the possible impact of heavy duty road transport, the data record was separated into two periods, night-time and day-time. The night data during summer, should have less residential traffic and no home heating, allowing the impact of trucks using the freight ferries to be the more dominant emission source. Both Bluebridge and KiwiRail operate dedicated freight services at night, with arrivals into Picton between midnight and 0200 and departures between 1230 – 0300 most days of the week. To cover these times, the “night” period is taken to be 9pm to 4am (2000 – 0300 NZST during daylight saving) and “summer” to be November to February inclusive. Ten-minute data have been used for this analysis.

The night data were then reviewed to see if there were periods of higher concentrations during weather conditions which would allow the traffic emissions to impact the sensor more directly. This corresponds to the quadrants from SW to W to NE where the wind is along or across road and compare this with data when winds were from the ENE to SE to SSW quadrants.

As Figure 5-7 shows, the most dominant wind directions during this night-time period are from the N and NNE (15 and 13% of the time respectively), which is in line with layout of the roads used for heavy duty ferry traffic. It is interesting the second most dominant region is from SSW, S and SSE quadrants which may be the result of drainage flow from the hills to the south of the site or could relate to the train line discussed below. The lack of winds coming from the east and west shows the dominance of the valley flow at this site.

The N-NNE quadrants have more consistent low-level concentrations of NO_2. These two quadrants have the highest percentage for all concentration bands up to 60-70 µg/m^3, with SSE-S having the highest percentage for bands above this concentration. Fifty-seven percent of the concentrations are below 40 µg/m^3 and of these, 9.5% come from the N direction and 8.9% from the NE. This compares with 6.1% from the SE, 7.4% from the S and 4.4% from the SSW directions. In total 97% of the NO_2 is below 70 µg/m^3 and of this 29% comes from the N and NNE directions. The full table of the statistics for this analysis is included as Appendix D.

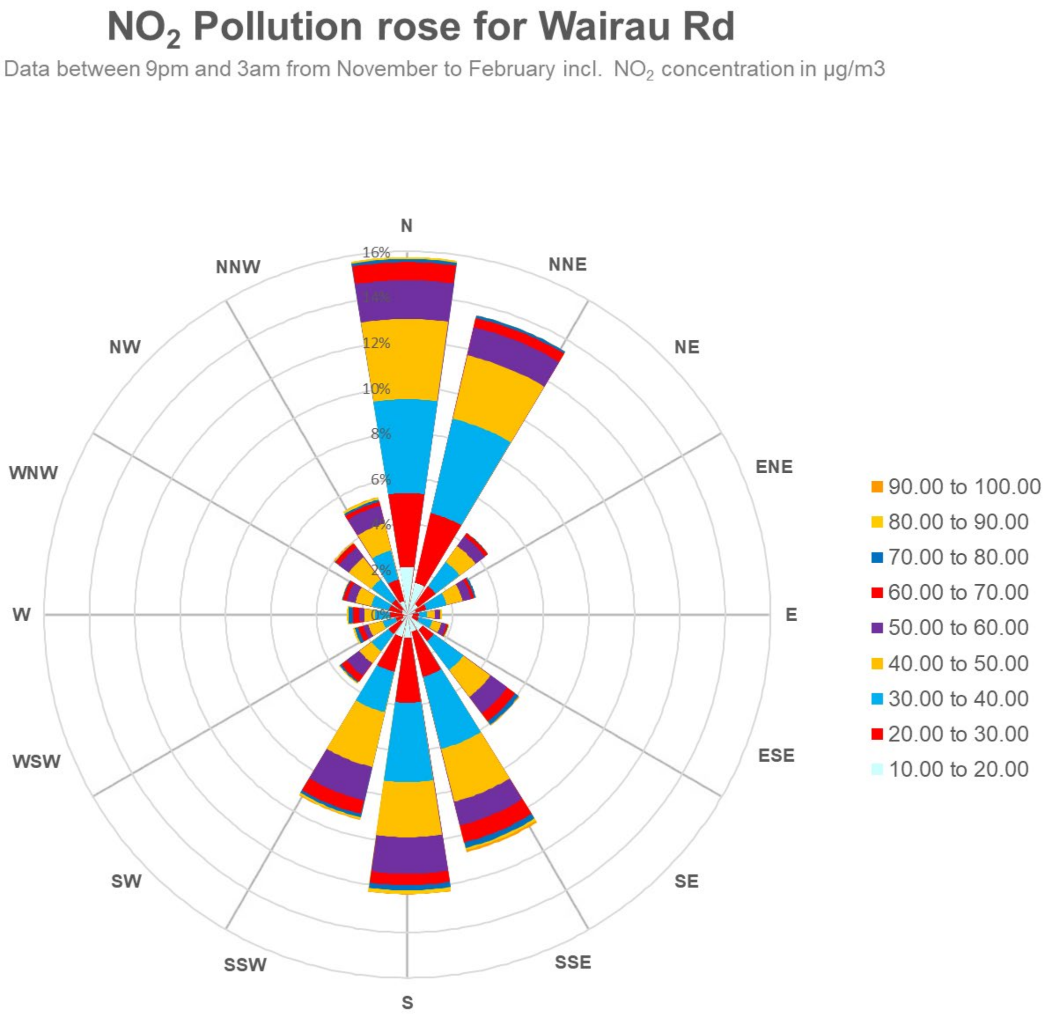


Figure 5-7: Wairau Rd NO2 pollution rose for night-time hours.

The only KiwiRail ferry which has a rail capacity is the Aratere. Taking the current schedule as a typical timetable, this ferry does three runs each day in summer (Picton to Wellington leaving around 0245, 1045 and 1845 and return sailings leaving Wellington around 0630, 1445 and 2245) with the daytime sailings (1045 and 1445) being a passenger service and the night ones being freight services. During winter this reduces to 2 sailings with the main freight sailing at 2045 northbound and 0630 for the southbound sailings. To investigate the possible impact of trains, the results from the above road study were used where the east and southeast winds could contain emissions from any trains.

As mentioned above, there is a secondary quadrant of dominant winds between SSW and SSE, and these emissions could be as a result of train traffic but more information on the times of trains going along the track would be needed to make more definitive comments.

5.4 COVID-19

The impact of the COVID-19 lockdown was observed in many air quality data sets throughout New Zealand and the world. As this project included this period, an investigation was undertaken to see whether impacts on air quality in Picton were observed.

The lockdown level and dates are shown in Table 5-1.

Table 5-1: COVID-19 lockdown - levels and dates.

Level	Dates
2	21/03/2020 – 22/03/2020
3	23/03/2020 – 24/03/2020
4	25/03/2020 – 26/04/2020
3	27/04/2020 – 12/05/2020
2	13/05/2020 – 08/06/2020
1	09/06/2020 - onwards

Nationally during COVID-19, large decreases in traffic volumes corresponded with a marked drop in NO_2 and CO concentrations, with a large amount of media coverage of these changes and implications for the future. Less media coverage was shown as to the changes as the restrictions were relaxed.

The Foreshore site (Figure 5-8) has been used to represent the wider Picton area with the Wairau Road site (Figure 5-9) has been used to represent the impact near a roadway. Both these sites show a drop off during the level 4 period as seen in many other locations. Note that the scales on the vertical axis are not the same, as these plots are to look at site differences not comparison between sites.

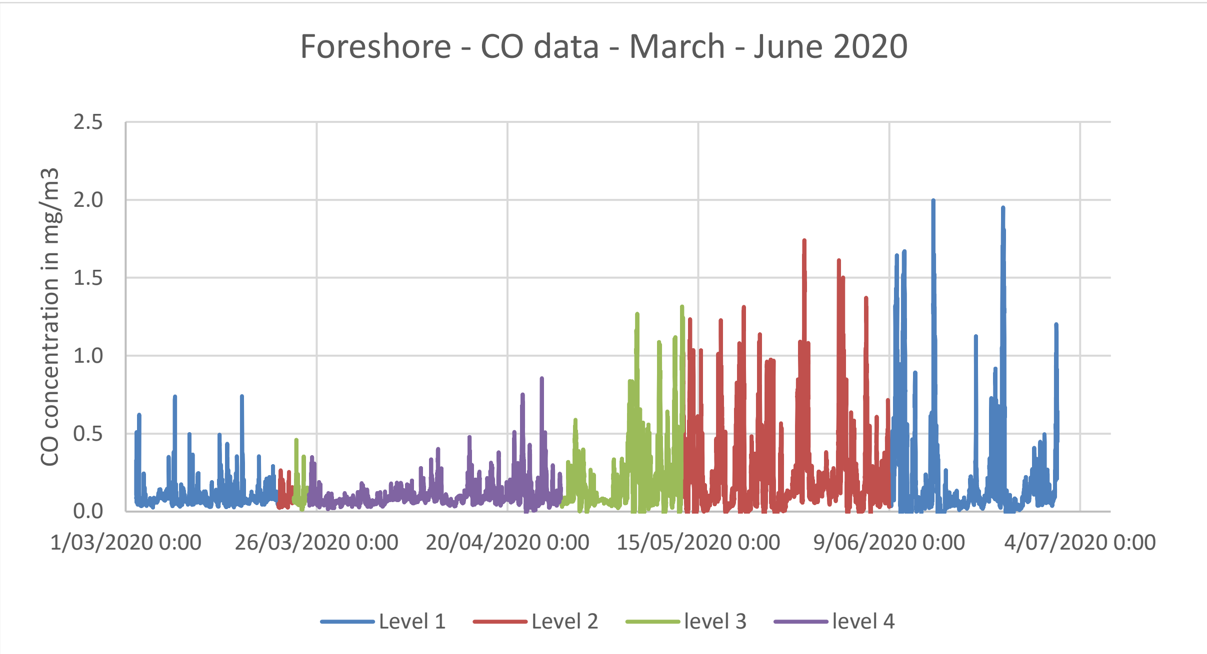


Figure 5-8: Foreshore - CO concentrations during different COVID-19 levels.

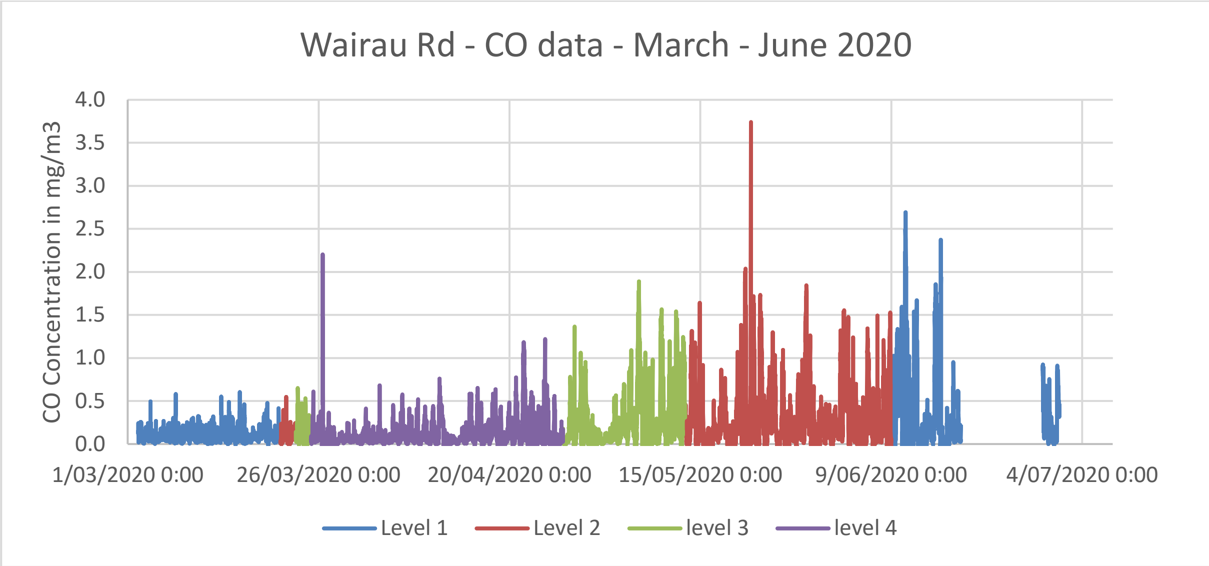


Figure 5-9: Wairau Rd - CO concentrations during different COVID-19 levels.

The interesting feature of the concentration plots above, is that CO started to increase towards the end of level 4 back to levels similar to those before the lockdown period started. It should be noted that the increase towards the end of this period may also be related to cooler weather starting and CO emissions coming from home heating sources.

A second feature is the drop-off in the middle of level 3 (1-3rd May) which is associated with a period of north – northeasterly winds and warmer temperatures especially at night.

Data during the COVID-19 period were also analysed using the R opeanair software to investigate if there were different patterns during these periods. Normalised CO data for level 4 and level 2 are shown below in Figures 5-10 and 5-11.

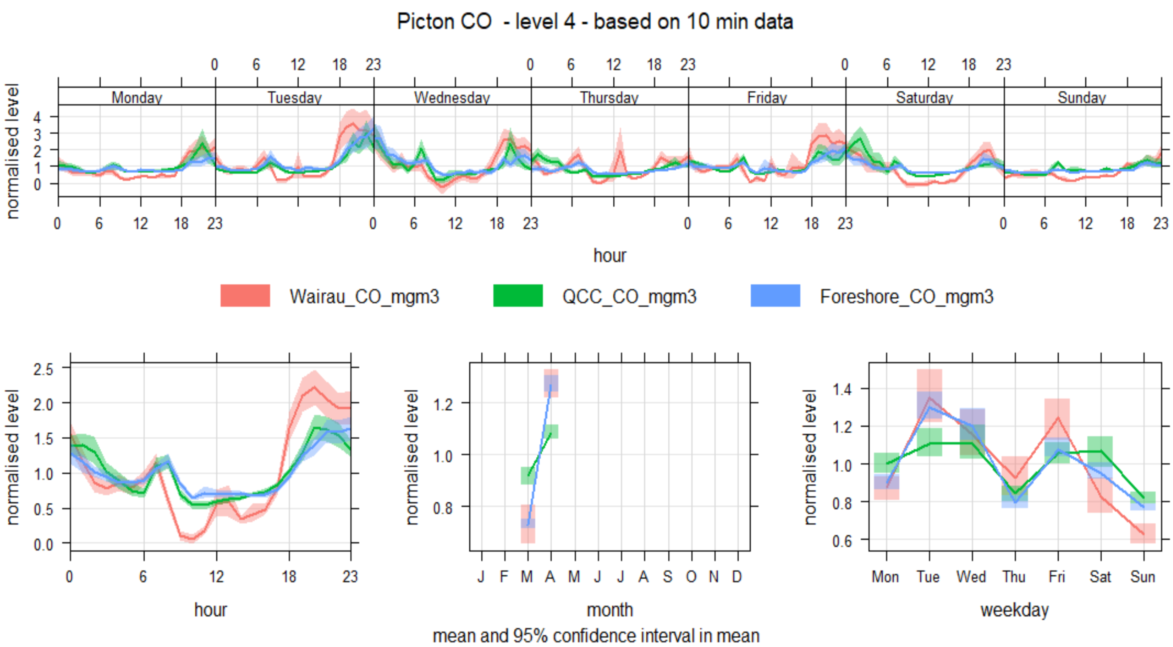


Figure 5-10: CO analysis during Level 4.

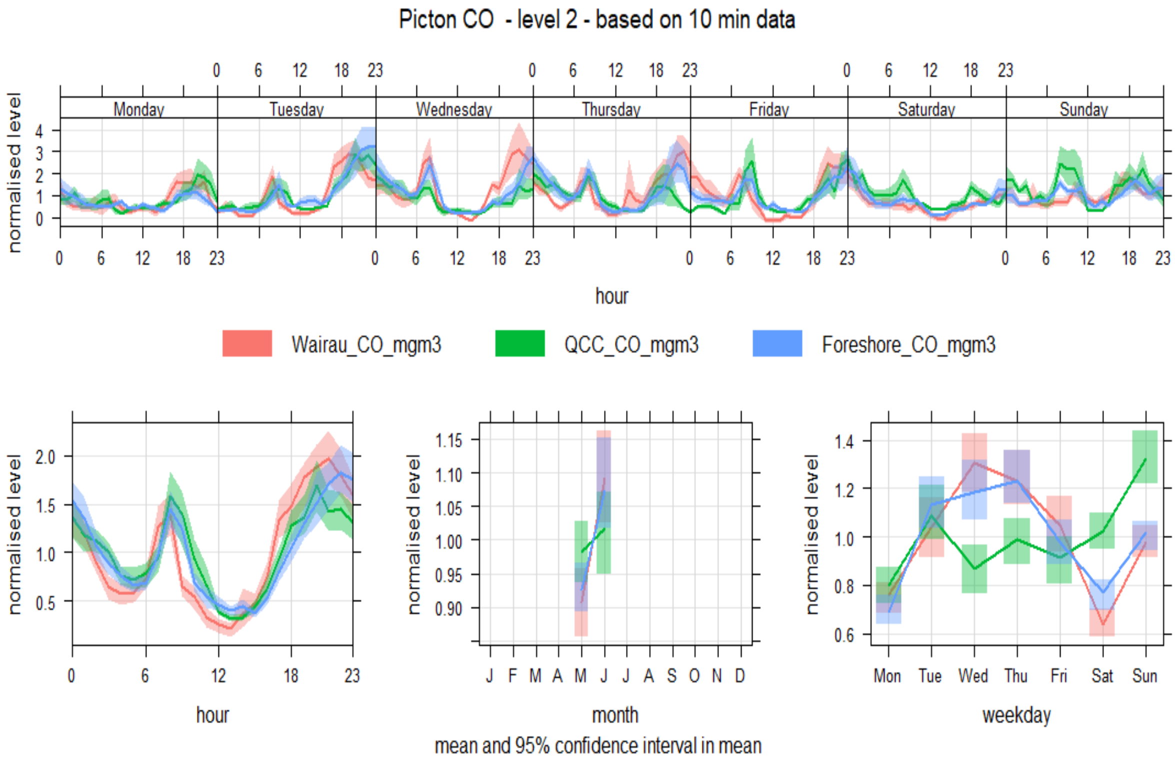


Figure 5-11: CO analysis during Level 2.

The most interesting feature is the change in the hourly data trend graph (bottom left) which shows the increase in a morning peak which may be associated with people driving to work, as the weekday plot (bottom right) shows a more distinct workday/weekend pattern at both the Foreshore and Wairau Rd sites in level 2.

6 Acknowledgements

NIWA and MDC wish to thank the residents of Picton, the board and staff of Queen Charlotte College, and the staff and management at E-Ko tours, for allowing us to install equipment on their properties and visit on a regular basis throughout the sampling period.

NIWA staff wish to acknowledge the significant assistance that Dr Sarah Brand from MDC gave, especially with the weekly task of downloading of the data and changing batteries at the meteorological stations.

NIWA also thanks Bay of Plenty Regional Council and Environment Canterbury for the use of their air quality data, and MBIE for provision of Envirolink funding to prepare this report.

7 References

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Appendix A Monitoring station information

Queen Charlotte College

This station was located on the northwestern side of the netball / tennis courts of the college and had both a meteorological station (left hand mast) and an air quality station (right hand mast).

Figure A-1: Left photo is the two masts with the sensors at the top and the right photo is the site looking to the SE.

Statistics for the station:

- Ground height - 22m above mean sea level (AMSL)
- Meteorological sensors - 4.1m above ground level (AGL)
- Air quality sensors - 3.9m AGL

Figure A-2: Map showing the area around the Queen Charlotte College site.

Milton / Sussex

This station was located on the corner of Milton Terrace and Sussex Street.

Figure A-3: Photo of the site looking to the S.

Statistics for the station:

- Ground height - 33m AMSL
- Meteorological sensors – 2.5m AGL

Figure A-4: Map showing the area around the Milton / Sussex site.

Water Reservoir

This station was located near the Picton Water Reservoir on the hills of the Victoria Domain.

Statistics for the station:

- Ground height - 91m AMSL
- Meteorological sensors – 5.0m AGL

Figure A-5: Photo of the site looking to the SE.

Figure A-6: Map of the area around the Lookout site.

Surrey St

This station was located at the MDC water treatment plant in Surrey Street near the Picton marina.

Figure A-7: Photo of the site looking to the S.

Statistics for the station:

- Ground height - 3m AMSL
- Meteorological sensors – 2.5m AGL

Figure A-8: Map of the area around the Surrey site.

Queen Charlotte Drive Lookout

This station was located at the lookout point on Queen Charlotte Drive with views to the north over the sounds and south towards Picton.

Figure A-9: Photo of the site looking to the NE.

Statistics for the station:

- Ground height - 30m AMSL
- Meteorological sensors – 2.5m AGL

Figure A-10: Map of the area around the Queen Charlotte Drive Lookout site.

Foreshore

Figure A-11: Photo of the site looking to the NE.

This station was located at the offices of E-Ko Tours on London Quay along the Picton foreshore.

Statistics for the station:

- Ground height - 2m AMSL
- Air Quality sensor – 6.95m AGL

Figure A-12: Map of the area around the Foreshore site.

Picton AWS

This station, operated by MDC, is located at the southwestern end of Waitohi Domain on Dublin St.

Figure A-13: Photo of the site looking to the SW.

Statistics for the station (estimated only):

- Ground height - 2m AMSL
- Meteorological sensors – 6m AGL

Figure A-14: Map of the area around the Picton AWS site.

Broadway

This station was located on the corner of Broadway and Wellington St.

Figure A-15: Photo of the site looking to the N.

Statistics for the station:

- Ground height - 15m AMSL
- Meteorological sensors – 2.5m AGL

Figure A-16: Map of the area around the Broadway site.

Harbour View Heights

This station was located near the upper end of Harbour View Heights, a new subdivision area on the hills on the western side of the town.

Figure A-17: Photo of the site looking to the E.

Statistics for the station:

- Ground height - 61m AMSL
- Meteorological sensors – 2.5m AGL

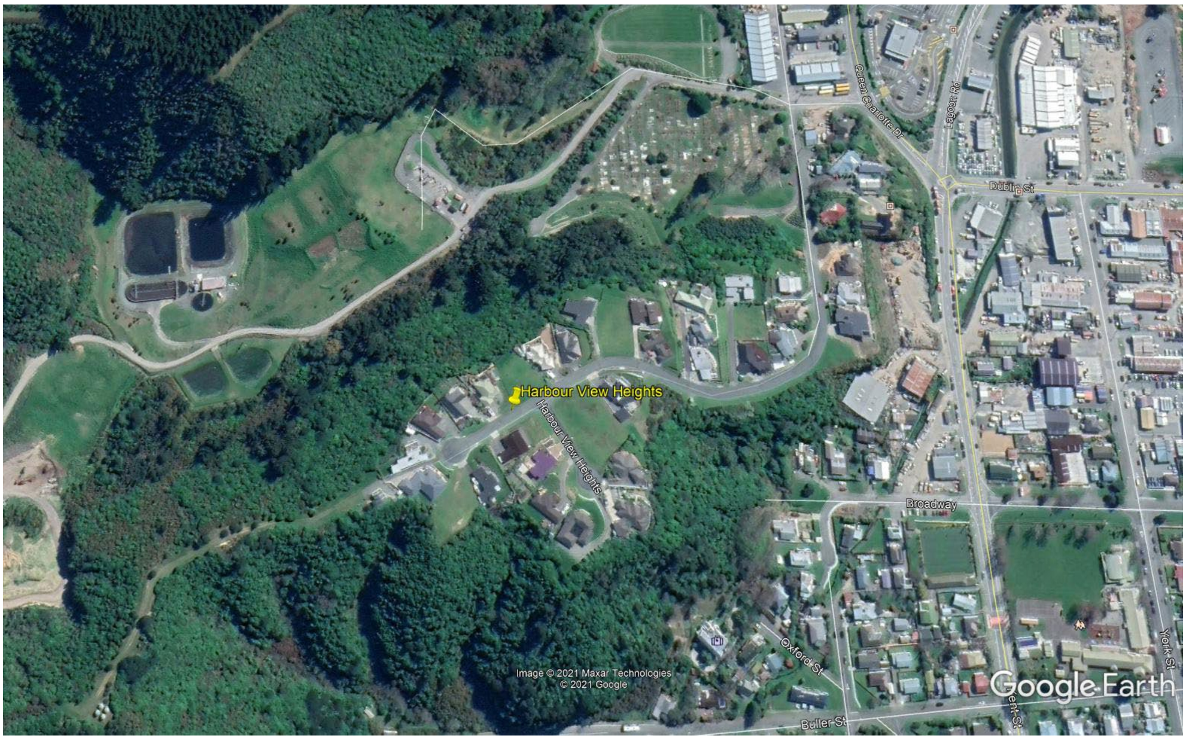

Figure A-18: Map of the area around the Harbour View Heights site.

30 Wairau Rd

This station was located at 30 Wairau Rd and had both a meteorological station (left hand mast) and an air quality station (right hand mast).

Figure A-19: Left photo is both sensors looking to the SE and the right image is looking to the N.

Statistics for the station:

- Ground height - 8m above mean sea level (AMSL)
- Meteorological sensors – 3.75m above ground level (AGL)
- Air quality sensors – 2.5m AGL

Figure A-20: Map of the area around the 30 Wairau Rd site.

68 Wairau Rd

Figure A-21: Photo of the site looking to the NE.

This station was located at 68 Wairau Road, near the southern end of the valley.

Statistics for the station:

- Ground height - 61m AMSL
- Meteorological sensors – 2.5m AGL

Figure A-22: Map of the area around the 60 Wairau Rd site.

Appendix B Additional data plots

These plots show the pollution data compared to MfE guidelines.

CO data

Hourly averaged data are shown here for each of the three sites. The MfE guideline for this data is 30 mg/m³. As the guideline is significantly higher than the data, the guideline has not been included in the plots.

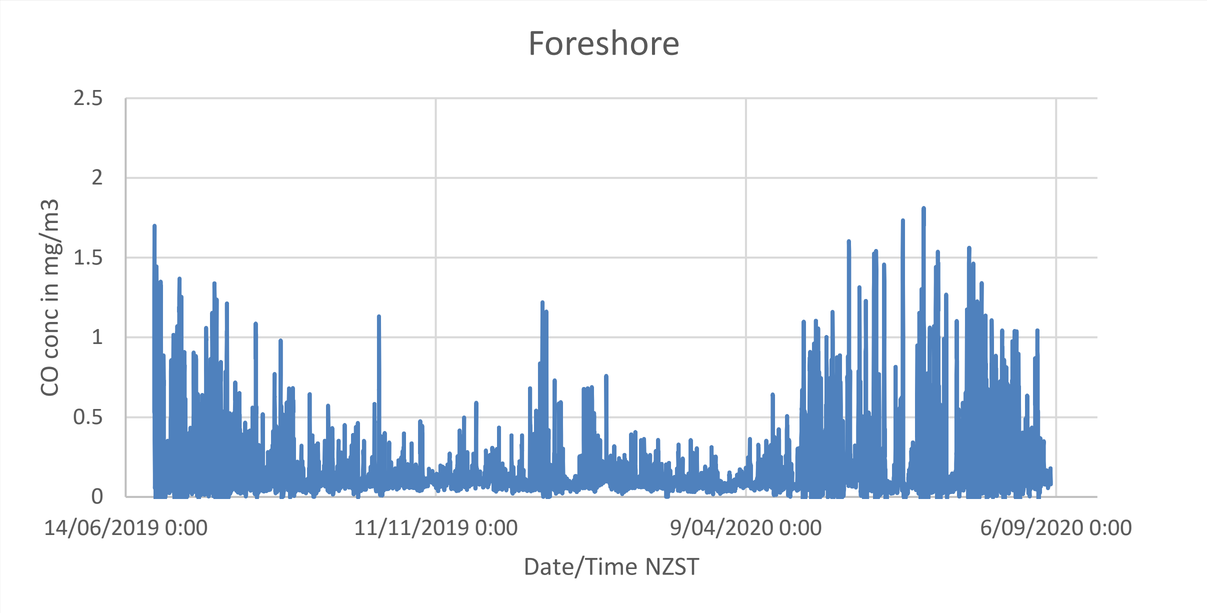

Figure B-1: Hourly CO data in mg/m³ from the Foreshore site.

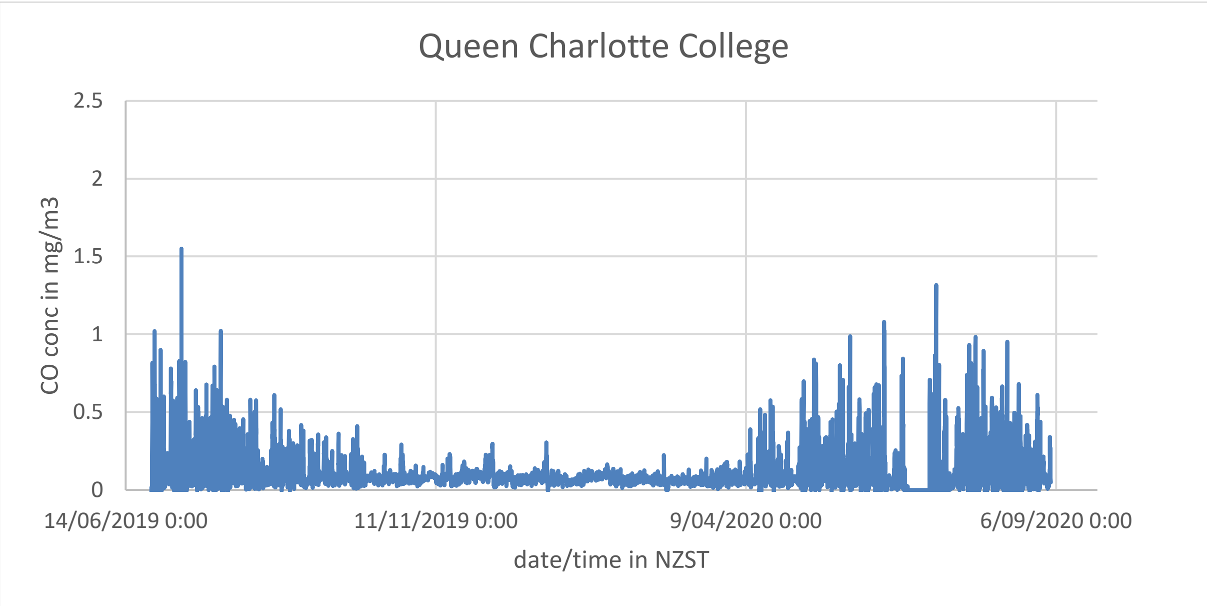

Figure B-2: Hourly CO data in mg/m³ from the Queen Charlotte College site.

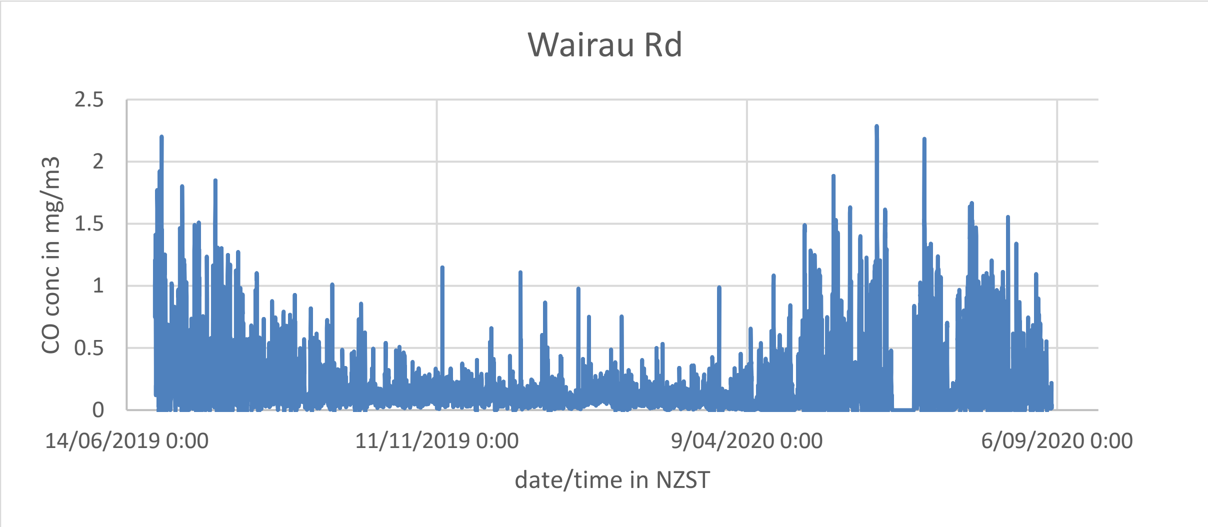

Figure B-3: Hourly CO data in mg/m³ from the Wairau Rd site.

SO_2 data

24-hour averaged data are shown here for each of the three sites. The MfE guideline for this data is 120 µg/m³ and shown in red.

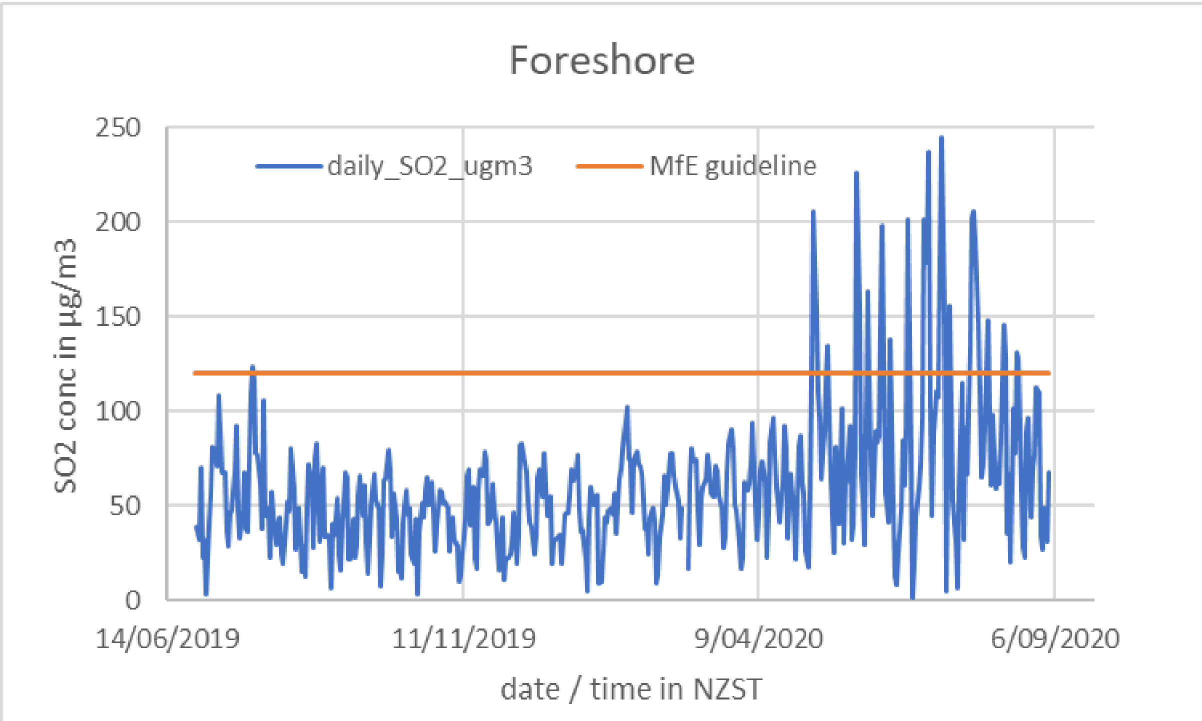

Figure B-4: 24-hour SO2 data in µg/m3 from the Foreshore site.

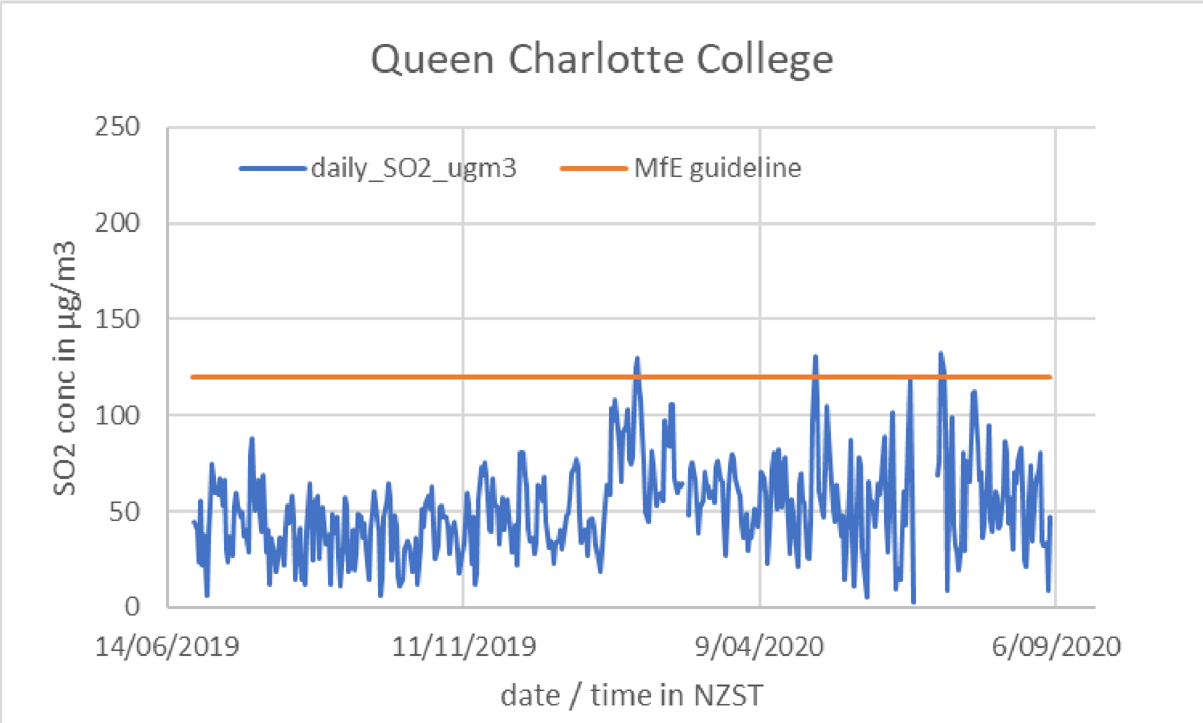

Figure B-5: 24-hour SO_2 data in $\mu g/m^3$ from the Queen Charlotte College site.

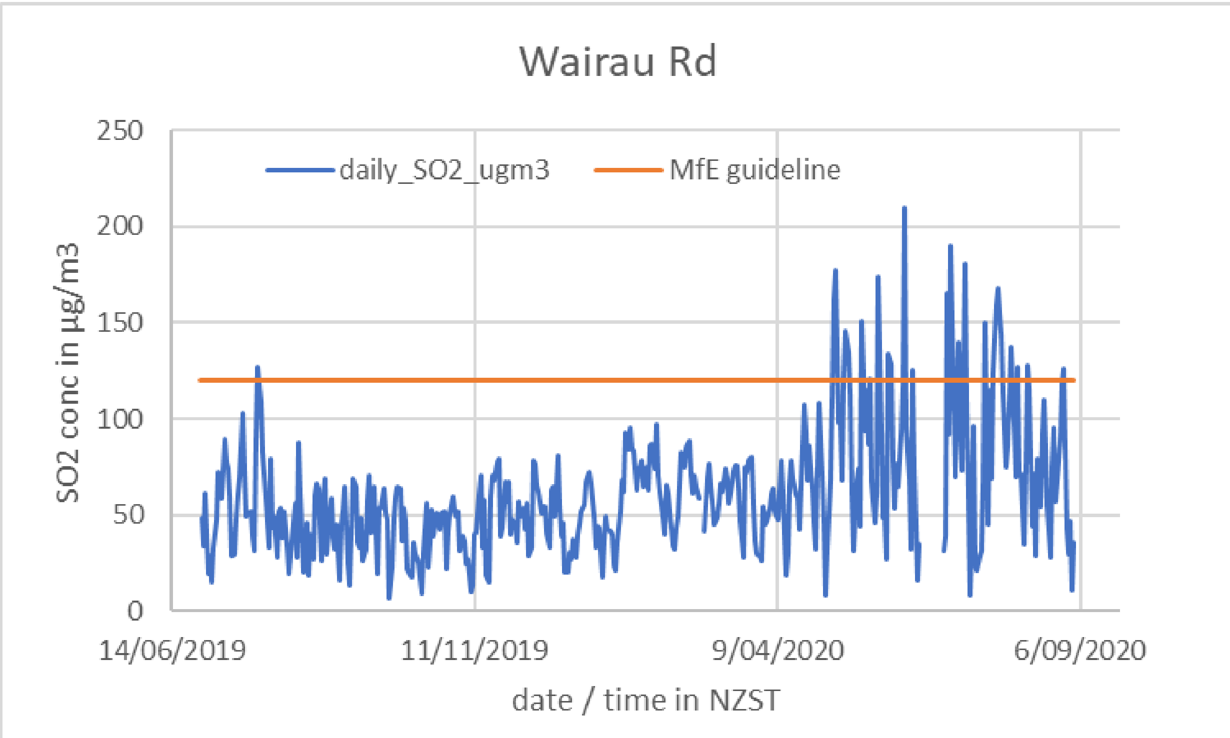

Figure B-6: 24-hour SO_2 data in $\mu g/m^3$ from the Wairau Rd site.

NO_2 data

24-hour averaged data are shown here for each of the three sites. The MfE guideline for this data is 100 µg/m^3 and is shown as a red line.

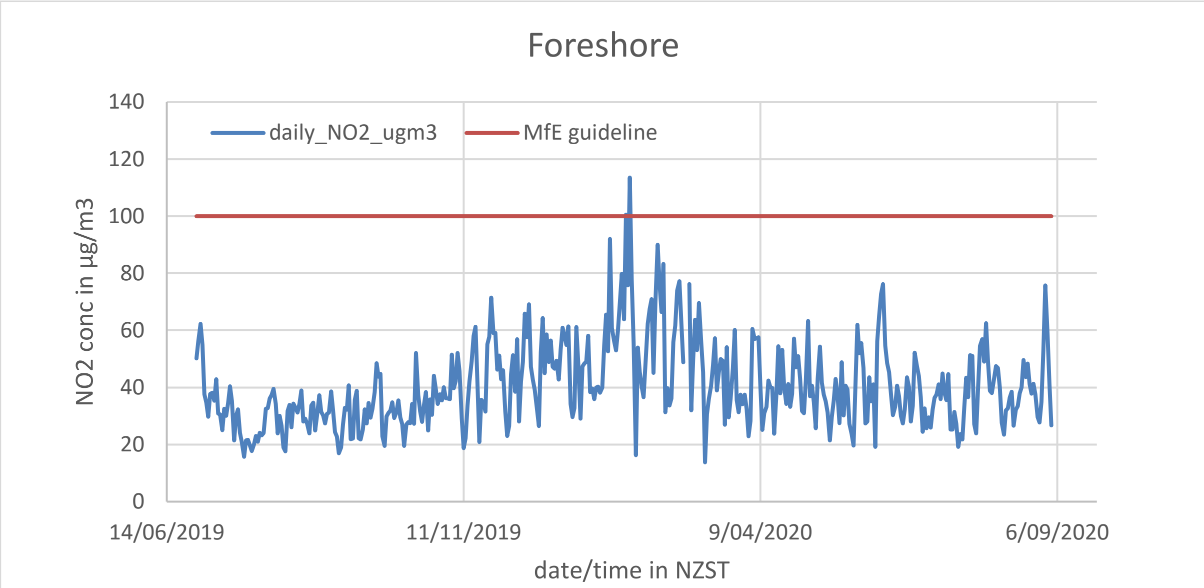

Figure B-7: 24-hour NO_2 data in µg/m^3 from the Foreshore site.

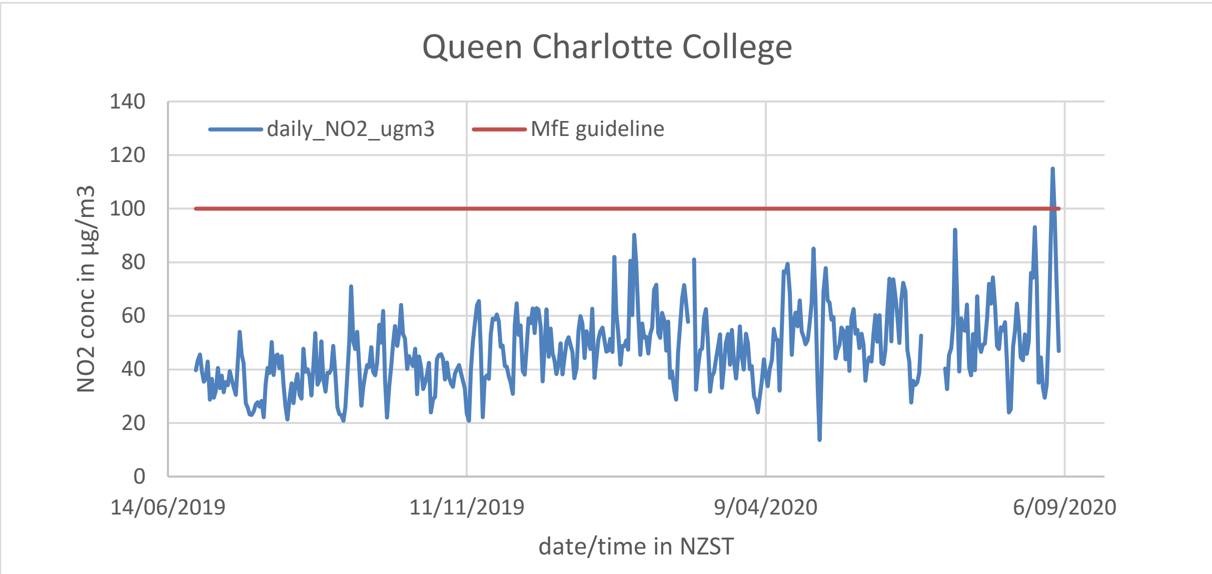

Figure B-8: 24-hour NO_2 data in µg/m^3 from the Queen Charlotte College site.

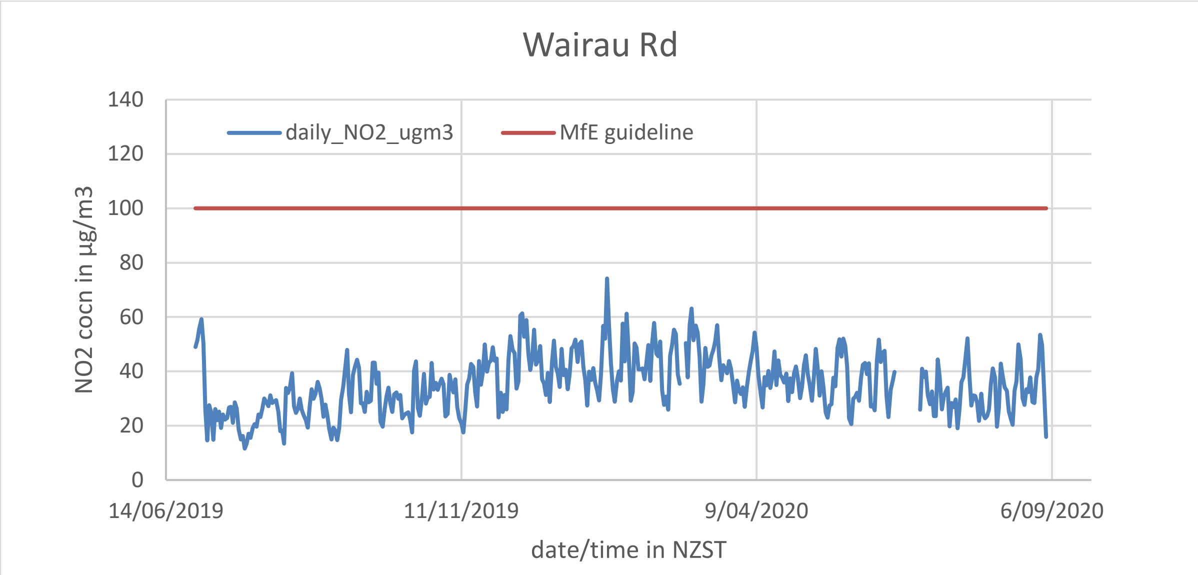

Figure B-9: 24-hour NO_2 data in µg/m^3 from the Wairau Rd site.

Appendix C Cruise ship schedule

This is the cruise information as supplied by MDC

Port Marlborough - Cruise Ship Arrivals

Cruise ship schedules updated on **10/04/2019 at 12:43.**

Vessel	ETA	ETD	Last port	IMO No.	Agent	Berth
NOORDAM	Sat, 13 Apr 19, 06:00	Sat, 13 Apr 19, 18:00	Akaroa	9230115	ISS-McKay	Waimahara
RADIANCE OF THE SEAS	Sun, 21 Apr 19, 09:00	Sun, 21 Apr 19, 21:00	Sydney	9195195	ISS-McKay	Waimahara
RADIANCE OF THE SEAS	Sun, 06 Oct 19, 06:00	Sun, 06 Oct 19, 17:00	Wellington	9195195	ISS-McKay	Waimahara
OVATION OF THE SEAS	Thu, 17 Oct 19, 06:00	Thu, 17 Oct 19, 17:00	Wellington	9697753	ISS-McKay	Waimahara
OVATION OF THE SEAS	Sat, 26 Oct 19, 06:00	Sat, 26 Oct 19, 17:00	Wellington	9697753	ISS-McKay	Waimahara
CELEBRITY SOLSTICE	Mon, 04 Nov 19, 06:00	Mon, 04 Nov 19, 18:00	Akaroa	9362530	ISS-McKay	Waimahara
CALEDONIAN SKY	Tue, 19 Nov 19, 05:00	Tue, 19 Nov 19, 12:00	Wellington	8802870	ISS-McKay	Ship Cove
NOORDAM	Tue, 19 Nov 19, 08:00	Tue, 19 Nov 19, 23:00	Akaroa	9230115	ISS-McKay	Waimahara
OVATION OF THE SEAS	Wed, 20 Nov 19, 06:00	Wed, 20 Nov 19, 17:00	Napier	9697753	ISS-McKay	Waimahara
RADIANCE OF THE SEAS	Tue, 26 Nov 19, 06:00	Tue, 26 Nov 19, 17:00	Wellington	9195195	ISS-McKay	Waimahara
NOORDAM	Wed, 27 Nov 19, 06:00	Wed, 27 Nov 19, 15:00	Wellington	9230115	ISS-McKay	Waimahara
CELEBRITY SOLSTICE	Thu, 28 Nov 19, 06:00	Thu, 28 Nov 19, 17:00	Wellington	9362530	ISS-McKay	Waimahara
CORAL DISCOVERER	Sat, 30 Nov 19, 13:00	Sun, 01 Dec 19, 12:00	Napier	9292747	ISS-McKay	Ship Cove
NORWEGIAN JEWEL	Sat, 07 Dec 19, 06:00	Sat, 07 Dec 19, 18:00	Akaroa	9304045	ISS-McKay	Waimahara
RADIANCE OF THE SEAS	Wed, 11 Dec 19, 07:00	Wed, 11 Dec 19, 18:00	Sydney	9195195	ISS-McKay	Waimahara
NORWEGIAN JEWEL	Sat, 14 Dec 19, 06:00	Sat, 14 Dec 19, 18:00	Napier	9304045	ISS-McKay	Waimahara
CORAL DISCOVERER	Mon, 16 Dec 19, 07:00	Tue, 17 Dec 19, 03:00	Kaikoura	9292747	ISS-McKay	Ship Cove
SILVER MUSE	Tue, 17 Dec 19, 06:00	Tue, 17 Dec 19, 18:00	To be advised	9784350	ISS-McKay	Waitohi West
NOORDAM	Tue, 17 Dec 19, 08:00	Tue, 17 Dec 19, 23:00	Akaroa	9230115	ISS-McKay	Waimahara
RUBY PRINCESS	Mon, 23 Dec 19, 05:00	Mon, 23 Dec 19, 18:00	To be advised	9378462	ISS-McKay	Waimahara
SILVER MUSE	Mon, 23 Dec 19, 06:00	Mon, 23 Dec 19, 18:00	Napier	9784350	ISS-McKay	Waitohi West
CELEBRITY SOLSTICE	Thu, 26 Dec 19, 09:00	Thu, 26 Dec 19, 20:00	Sydney	9362530	ISS-McKay	Waimahara
AIDA AURA	Fri, 27 Dec 19, 05:00	Sat, 28 Dec 19, 08:00	Wellington	9221566	ISS-McKay	Waitohi West
NORWEGIAN JEWEL	Sat, 28 Dec 19, 06:00	Sat, 28 Dec 19, 16:00	Akaroa	9304045	ISS-McKay	Waimahara
OVATION OF THE SEAS	Sun, 29 Dec 19, 07:00	Sun, 29 Dec 19, 18:00	Sydney	9697753	ISS-McKay	Waimahara
CALEDONIAN SKY	Mon, 30 Dec 19, 05:00	Mon, 30 Dec 19, 12:00	Wellington	8802870	ISS-McKay	Ship Cove
RUBY PRINCESS	Fri, 03 Jan 20, 06:00	Fri, 03 Jan 20, 18:00	To be advised	9378462	ISS-McKay	Waimahara
NORWEGIAN JEWEL	Thu, 09 Jan 20, 06:00	Thu, 09 Jan 20, 16:00	Akaroa	9304045	ISS-McKay	Waimahara
NOORDAM	Fri, 10 Jan 20, 08:00	Fri, 10 Jan 20, 20:00	Akaroa	9230115	ISS-McKay	Waimahara
CALEDONIAN SKY	Sun, 12 Jan 20, 06:00	Sun, 12 Jan 20, 13:00	Kaikoura	8802870	ISS-McKay	Ship Cove
CALEDONIAN SKY	Sun, 12 Jan 20, 14:00	Sun, 12 Jan 20, 18:00	Motuara Is.	8802870	ISS-McKay	Ship Cove
EXPLORER DREAM	Fri, 17 Jan 20, 04:00	Fri, 17 Jan 20, 14:00	Akaroa	9141077	ISS-McKay	Anchor
NORWEGIAN JEWEL	Fri, 17 Jan 20, 06:00	Fri, 17 Jan 20, 18:00	Napier	9304045	ISS-McKay	Waimahara

LE LAPEROUSE	Sun, 19 Jan 20, 06:00	Sun, 19 Jan 20, 18:00	Milford	9814020	ISS-McKay	Q - Anchorage
OVATION OF THE SEAS	Tue, 21 Jan 20, 06:00	Tue, 21 Jan 20, 17:00	Wellington	9697753	ISS-McKay	Waimahara
LE LAPEROUSE	Wed, 29 Jan 20, 05:00	Wed, 29 Jan 20, 17:00	Wellington	9814020	ISS-McKay	Q - Anchorage
NORWEGIAN JEWEL	Sat, 01 Feb 20, 06:00	Sat, 01 Feb 20, 17:00	Akaroa	9304045	ISS-McKay	Waimahara
AZAMARA JOURNEY	Mon, 03 Feb 20, 06:00	Mon, 03 Feb 20, 22:00	Wellington	9200940	ISS-McKay	Waitohi West
SILVER MUSE	Wed, 05 Feb 20, 06:00	Wed, 05 Feb 20, 18:00	Wellington	9784350	ISS-McKay	Waitohi West
NORWEGIAN JEWEL	Sat, 08 Feb 20, 06:00	Sat, 08 Feb 20, 18:00	Wellington	9304045	ISS-McKay	Waimahara
NOORDAM	Sun, 09 Feb 20, 08:00	Sun, 09 Feb 20, 23:00	Akaroa	9230115	ISS-McKay	Waimahara
PACIFIC PRINCESS	Wed, 12 Feb 20, 06:00	Wed, 12 Feb 20, 18:00	Auckland	9187887	ISS-McKay	Waitohi West
AZAMARA JOURNEY	Thu, 13 Feb 20, 05:00	Thu, 13 Feb 20, 16:00	Wellington	9200940	ISS-McKay	Waitohi West
EUROPA	Mon, 17 Feb 20, 06:00	Mon, 17 Feb 20, 18:00	Lyttelton	9183855	ISS-McKay	Waitohi West
LE LAPEROUSE	Fri, 21 Feb 20, 09:30	Fri, 21 Feb 20	Milford	9814020	ISS-McKay	Cruising
LE LAPEROUSE	Fri, 21 Feb 20	Fri, 21 Feb 20, 23:59	Cruising	9814020	ISS-McKay	Waitohi West
SEABOURN ENCORE	Mon, 24 Feb 20, 06:00	Mon, 24 Feb 20, 23:00	Tauranga	9731171	ISS-McKay	Waitohi West
LE LAPEROUSE	Fri, 28 Feb 20, 09:30	Fri, 28 Feb 20	Milford	9814020	ISS-McKay	Cruising
LE LAPEROUSE	Fri, 28 Feb 20	Fri, 28 Feb 20, 23:59	Cruising	9814020	ISS-McKay	Waitohi West
AZAMARA JOURNEY	Mon, 02 Mar 20, 06:00	Mon, 02 Mar 20, 21:00	Kaikoura	9200940	ISS-McKay	Waitohi West
LE LAPEROUSE	Mon, 02 Mar 20, 07:30	Mon, 02 Mar 20, 11:00	Lyttelton	9814020	ISS-McKay	Ship Cove
CARNIVAL SPIRIT	Sun, 08 Mar 20, 06:00	Sun, 08 Mar 20, 17:00	Napier	9188647	ISS-McKay	Waimahara
BREMEN	Wed, 11 Mar 20, 06:00	Wed, 11 Mar 20, 12:00	Kaiteriteri	8907424	ISS-McKay	Ship Cove
AZAMARA JOURNEY	Fri, 13 Mar 20, 05:00	Fri, 13 Mar 20, 16:00	Wellington	9200940	ISS-McKay	Waitohi West
CELEBRITY SOLSTICE	Fri, 13 Mar 20, 06:00	Fri, 13 Mar 20, 18:00	Tauranga	9362530	ISS-McKay	Waimahara
SILVER MUSE	Sun, 15 Mar 20, 06:00	Sun, 15 Mar 20, 14:00	Akaroa	9784350	ISS-McKay	Waitohi West
NOORDAM	Sun, 15 Mar 20, 07:00	Sun, 15 Mar 20, 18:00	Napier	9230115	ISS-McKay	Waimahara
LE LAPEROUSE	Tue, 17 Mar 20, 05:00	Tue, 17 Mar 20, 17:00	Wellington	9814020	ISS-McKay	Q - Anchorage
SILVER MUSE	Fri, 20 Mar 20, 10:30	Fri, 20 Mar 20, 18:00	Napier	9784350	ISS-McKay	Waitohi West
NOORDAM	Mon, 23 Mar 20, 06:00	Mon, 23 Mar 20, 15:00	Wellington	9230115	ISS-McKay	Waimahara
LE LAPEROUSE	Wed, 25 Mar 20, 06:00	Wed, 25 Mar 20, 18:00	Milford	9814020	ISS-McKay	Q - Anchorage
OVATION OF THE SEAS	Wed, 08 Apr 20, 06:00	Wed, 08 Apr 20, 17:00	Wellington	9697753	ISS-McKay	Waimahara

Appendix D NO₂ pollution rose statistics

This table is the statistics for the pollution rose presented as Figure 5-7 in section 5.3. The values are all percentages. The highest in each concentration band has been highlighted in green font.

	concentration of NO_2 in µg/m³										
	<10.0	10.0 to 20.0	20.0 to 30.0	30.0 to 40.0	40.0 to 50.0	50.0 to 60.0	60.0 to 70.0	70.0 to 80.0	80.0 to 90.0	90.0 to 100.0	**Total (%)**
N	**0.56**	**1.54**	**3.27**	4.13	**3.54**	**1.71**	**0.79**	0.13	0.08	0.00	**15.74**
NNE	0.19	1.25	3.15	**4.27**	2.86	1.27	0.42	0.12	0.00	0.00	**13.53**
NE	0.06	0.52	0.98	1.33	0.86	0.52	0.17	0.02	0.00	0.00	**4.46**
ENE	0.04	0.35	0.48	0.92	0.73	0.38	0.13	0.08	0.00	0.00	**3.11**
E	0.08	0.15	0.27	0.38	0.33	0.15	0.04	0.06	0.06	0.00	**1.52**
ESE	0.13	0.10	0.29	0.62	0.40	0.23	0.08	0.02	0.04	0.00	**1.90**
SE	0.38	0.44	0.62	1.61	1.48	0.90	0.44	0.19	0.00	0.04	**6.11**
SSE	0.08	0.69	2.06	3.27	2.40	1.08	0.77	**0.25**	0.01	**0.10**	**10.78**
S	0.06	0.96	2.86	3.50	2.42	1.61	0.50	0.23	**0.15**	0.02	**12.32**
SSW	0.12	0.88	1.58	1.83	2.48	1.52	0.62	0.13	0.08	0.04	**9.26**
SW	0.04	0.33	0.67	0.94	0.65	0.69	0.31	0.08	0.04	0.00	**3.75**
WSW	0.00	0.19	0.33	0.60	0.65	0.23	0.23	0.15	0.08	0.00	**2.46**
W	0.00	0.13	0.62	0.67	0.48	0.21	0.29	0.19	0.06	0.00	**2.65**
WNW	0.00	0.23	0.60	0.81	0.71	0.38	0.17	0.04	0.02	0.00	**2.96**
NW	0.06	0.23	0.54	1.11	1.23	0.54	0.21	0.02	0.04	0.02	**4.00**
NNW	0.17	0.44	0.98	1.33	1.21	0.81	0.19	0.01	0.10	0.02	**5.34**
Total (%)	**1.96**	**8.44**	**19.28**	**27.31**	**22.45**	**12.24**	**5.36**	**1.81**	**0.83**	**0.23**	**99.90**

Appendix E Additional climate trend information

Climate patterns during 2019

A central Pacific El Niño event (which persisted through to July) brought frequent bouts of high pressure with widespread sunny and dry weather to start the year. Warmth and dryness remained a theme into winter. It was NZ's 4th-warmest autumn and 7th-warmest winter on record.

A strongly negative Southern Annular Mode (SAM) at the start of August and stronger than normal polar and sub-tropical jet streams fuelled a more active weather pattern towards the end of winter. The cooler temperatures at the end of winter and start of spring were also influenced by a rare major Sudden Stratospheric Warming (SSW) event, which occurred in the polar stratosphere during late-August and peaked in mid-September (this was the Southern Hemisphere's strongest SSW on record and just the second major event on record).

Despite several sharp cold snaps, temperatures as a whole were near average for the time of year in September and continued on the near average note in October, before prevailing north-westerlies in November brought unseasonably warm temperatures and New Zealand's warmest November on record.

Another key climate driver during spring 2019 was a strongly positive Indian Ocean Dipole (IOD) event in October and November. The IOD's hallmark is cooler than average sea surface temperatures in the eastern Indian Ocean near Indonesia and warmer than average sea surface temperatures in the Arabian Sea. This particular IOD event was of near-record strength and caused abnormally dry conditions across Indonesia and Australia during the end of 2019 (and contributed to Australia's dangerous fire conditions). For New Zealand, it brought more westerly quarter winds than normal during spring, from cooler, drier south-westerlies in October to warm, moist north-westerlies in November. The atmospheric pressure pattern produced slightly more westerly wind flows than normal for the year.

The wider Nelson region experienced New Zealand's highest annual sunshine total during 2019 (2859 hours recorded at Nelson), followed by Marlborough (2799 hours - Blenheim).

Climate patterns during 2020

Along with the 47 months since a below normal temperature discussed in section 4.2.1, six of the past eight years have been amongst New Zealand's hottest on record. The annual temperature anomaly, as shown below in Figure E-1, illustrates the above average temperatures over the last few years. This trend is consistent with the overall pattern of global warming.

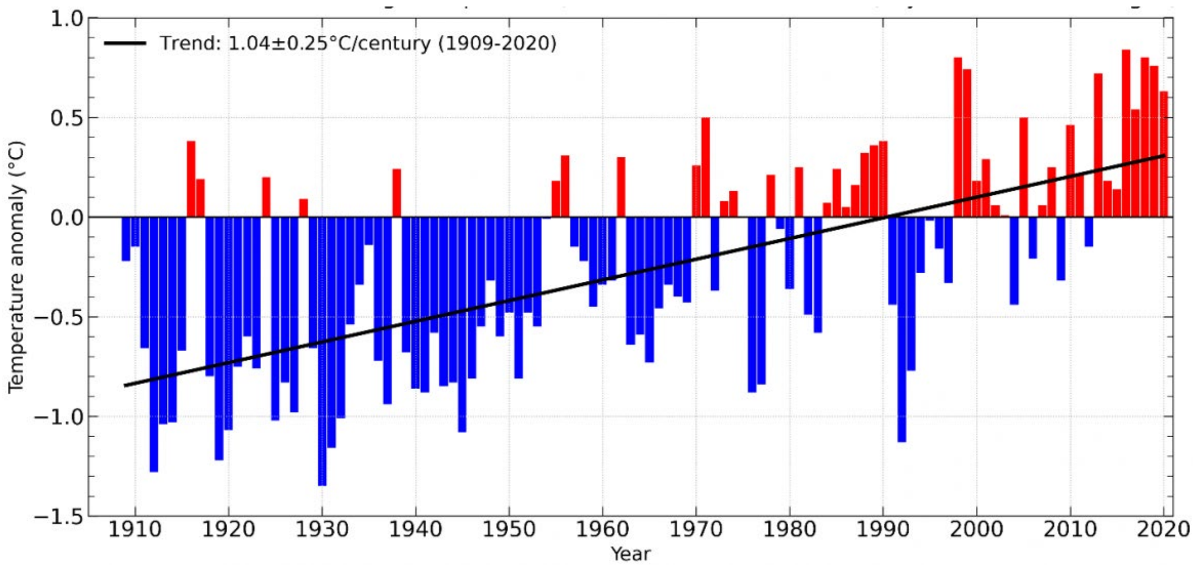

Figure E-1: Temperature anomolies since 1909.

The hot weather from late-January to early-February contributed to a record 64-day dry spell from 20 December 2019 to 21 February 2020 in Blenheim. From late-March to late-April, high pressure prevailed over the country, delivering mild and very dry conditions for many areas. Coastal Marlborough recorded less than 5 mm of rain during April.

A key contributing factor to the year's dry start was a near-record positive IOD. This persisted from late-2019 into early-2020, preventing plumes of tropical moisture (known as "atmospheric rivers") from forming north of the country. Atmospheric rivers are an important moisture source for New Zealand, but these were largely non-existent over the country in late-summer and early-autumn The SAM was positive 61% of the time during 2020. The positive SAM phase is associated with higher than normal air pressure around New Zealand, which tends to bring more tranquil weather conditions and lighter winds to the country.

Early in 2020, the El Niño Southern Oscillation (ENSO) phase was neutral. This phase persisted through May, before an increase in tropical trade winds contributed to cooling ocean temperatures about the equatorial Pacific. Accordingly, a La Niña Watch was put into place in June, which transitioned to a La Niña Alert in August as the atmosphere began to respond to the changes in the tropical Pacific Ocean. For New Zealand, air flow anomalies transitioned to north-easterly during winter — a traditional hallmark of La Niña.

Appendix F Ozone Data

The ozone data recorded in Picton does not appear to be realistic compared to the data measured at the NIWA Clean Air Station at Baring Head, which is at the entrance to Wellington Harbour. As sites at both Picton and Baring Head are exposed to the sea, it would be expected that they would have similar trends, although the Baring Head data should be lower during periods of southerly winds.

The areas of most concern are:

- the trends are not similar
- stable values around 45 ppb
- very low numbers
- the sensors are quite variable in response to each other which is unusual for an area the size of Picton

Two plots of the data for the winter of July 2019 (Figure F-1) and the summer of January 2020 (Figure F-2) period, are shown below to illustrate the concerns discussed above. There a periods in the data where the two locations are showing similar trends, but more often they are not.

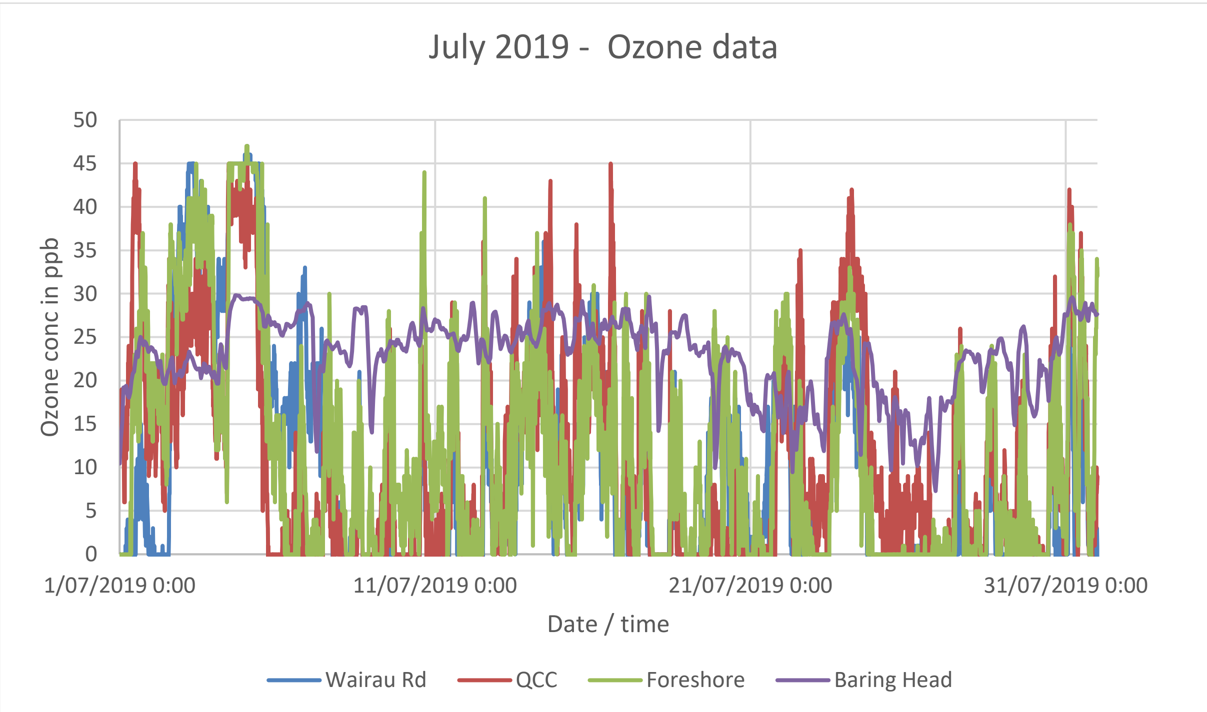

Figure F-1: Ozone data for July 2019.

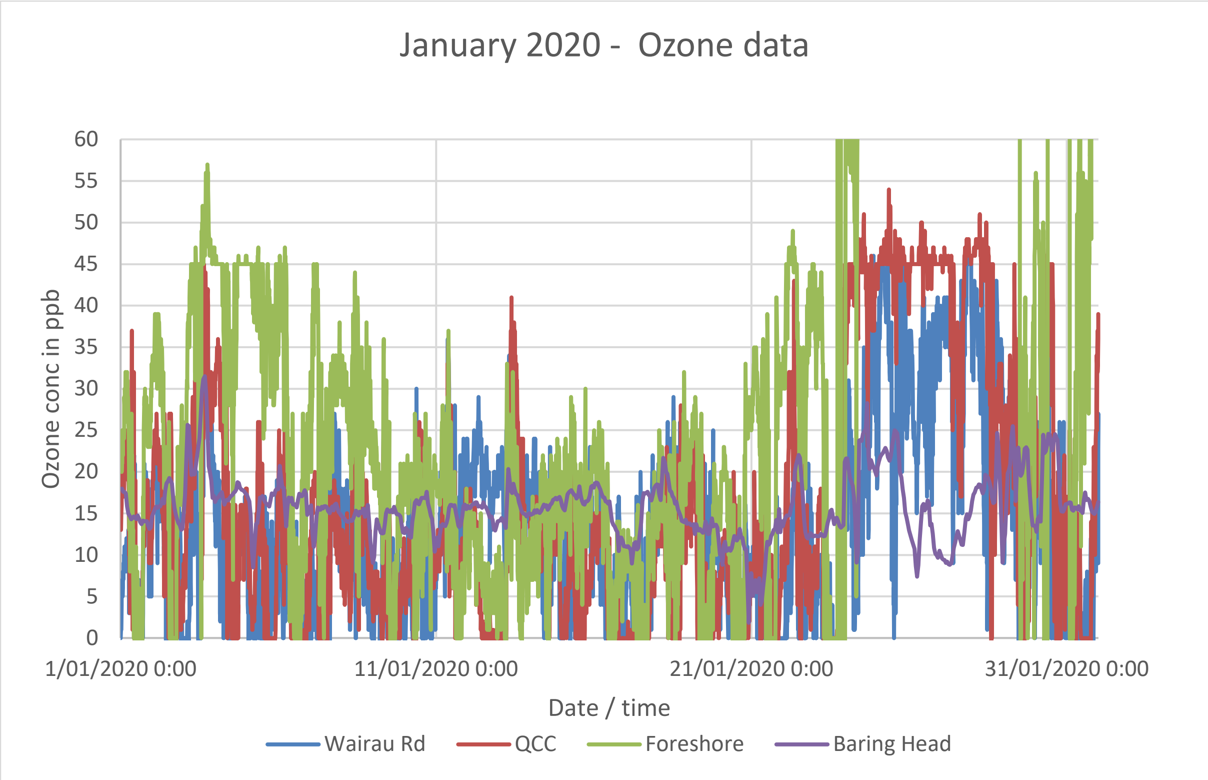

Figure F-2: ozone data for January 2020.