Measuring the impact of cruise ships on air quality in Lyttelton

August 2025

Mote Limited 2025/033B

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Prepared by:

Paul Baynham[1]

[1] Mote Limited, 40a George Street, Mount Eden, Auckland

Prepared for:

Lyttelton Port Company

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Approved for release by:

First draft published: August 2025
Final draft published: September 2025

Disclaimer:

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1. ACKNOWLEDGMENTS

Mote Limited would like to thank C3 Limited for allowing access to the log handling area and the Lyttelton Port Company for providing meteorological data and details of cruise ship arrivals and departures.

2. INTRODUCTION

In response to concerns from local residents, Lyttelton Port Company (LPC) contracted Mote Limited to perform an independent assessment to quantify the impact of emissions from cruise ships on the air quality in the Lyttelton community.

Between 20 December 2024 and 16 May 2025 Mote Limited deployed four particulate monitors around Lyttelton Port to measure the concentration of fine particulate matter ($PM_{2.5}$) that is discharged from all combustion vehicles including cruise ships. The purpose of the deployment was to determine the extent of any increase in $PM_{2.5}$ concentration during periods when cruise ships were present in Lyttelton Harbour from when they were absent.

In conjunction with the particulate monitors, gaseous diffusion tubes for both nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) were also deployed at the same locations as the particulate monitors. These gaseous pollutants are associated with the combustion of fuel and this investigation was also focussed on determining whether the concentration of these gaseous pollutants increased during periods when cruise ships were present in Lyttelton Harbour from when they were absent.

3. AIR QUALITY INVESTIGATION

The first step of the investigation was to determine the most appropriate locations to position the monitoring instruments. Mote Limited reviewed a 2017 report completed by Tonkin and Taylor (T+T)[1] that used computer dispersion modelling to predict the maximum worst-case impact of cruise ship emissions in Lyttelton from when the world's largest international cruise ships – the Royal Caribbean Oasis Class range, was in Port.

The T+T report predicted a maximum increase in the 24-hour average $PM_{2.5}$ concentration of approximately 7.6 micrograms per cubic meter over existing background concentrations. This increase applies in areas that members of the public could reasonably be expected to be exposed over a 24-hour period – primarily areas along the Lyttelton foreshore.

The report assumed the Oasis ships would be using 3.5% w/w fuel sulphur. However, on the 26th of May 2022 New Zealand ratified Annex VI of MARPOL (the International Convention for the Prevention of Pollution from Ships) which addressed (among other things) emissions from ships. This Annex reduced the allowable sulphur content in fuel from 3.5% to 0.5% (w/w). A reduction in the sulphur content of fuel also reduces the amount of fine particulate ($PM_{2.5}$) that is produced. On the basis of the reduction in sulphur content, the T+T report estimated a maximum increase in the 24-hour average $PM_{2.5}$ concentration of approximately 1.7 micrograms per cubic meter.

3.1 Site locations

The 2017 T+T modelling report identified four areas where the $PM_{2.5}$ concentrations were expected to be slightly elevated relative to other areas of Lyttelton. These four areas included:

1. The logyard area bounded by Norwich and Sutton Quay
2. The land occupied by Waterfront House and extending down to the LPC tug boat wharf
3. The easternmost end of Naval Point
4. The elevated terrain near the Windy Point lookout

Only the logyard area had mains power available meaning that the three remaining sites would require the use of solar panels and batteries to operate.

Site visits were conducted to each of the identified locations and suitable sites selected that had good exposure to the areas frequented by cruise ships and wind flow around the monitors was not significantly impeded by large objects.

The location of the four sites is shown below in **Figure 1**.

[1] Tonkin & Taylor Ltd, Impacts of discharge to air from cruise ships, December 2017.

Figure 1: Location map of the four $PM_{2.5}$ and gaseous diffusion tubes monitoring stations in Lyttelton. *Map sourced from Google earth (image collected 19 February 2025)*.

3.2 Instrument selection

A dual sensor mono-chromatic optical sensor was used (SDS011). This instrument works by drawing the air into the analysing chamber by using a small fan. The instrument uses a low powered laser operating in the near infra-red range. As the laser passes through the air, some of the laser light is scattered. The instrument detects the intensity of the scattered light at specific angles and then uses Mie theory to convert this into a $PM_{2.5}$ particle concentration. The instruments also record the air temperature, relative humidity and atmospheric pressure.

Optical instruments are susceptible to periods when humidity increases, causing false positives (i.e. the instrument can record an increase in $PM_{2.5}$ concentration that is actually just fog and not dust). This issue is more prevalent during the early hours of the morning. To overcome this issue, the inlet air on the optical sensors is heated slightly – an increase of approximately 5 degrees above the ambient temperature. This slight increase converts water droplets to water vapour and reduces the impact of particle swelling during high humidity events.

Each sensor takes a reading every second and this data is collected and averaged to produce one-minute $PM_{2.5}$ averages. This one-minute data is then averaged to hourly and 24-hour averages to enable comparison of periods when cruise ships were present with periods when they were absent.

Each instrument utilises GPS satellites for both a fixed location and to accurately timestamp data associated with that instrument. Timestamped data is typically accurate to ±0.2 seconds.

3.3 Pre-deployment co-location

Before these instruments are deployed, they are installed alongside an equivalent monitor and operated over a two-week period to ensure:

1. They are precise – i.e. all instruments should record very similar values when exposed to a similar level of $PM_{2.5}$. The hourly averages should typically be within 2 micrograms of each other during testing.
2. They are accurate – the 24-hour averages are installed next to a USEPA (United States Environmental Protection Agency) approved equivalent analyser and operated for 7 days. In this case a Thermo Scientific 5014i Beta Attenuation Monitor (BAM) was used to compare against the optical instruments. In general, the 24-hour average for each instrument should be within 2 micrograms of the equivalent analyser.

Figure 2 below shows the average 1 hour concentration measured by each of the four monitors during a period of co-location at a roadside monitoring station.

Figure 3 below displays the 24-hour average calculated for each instrument in comparison to a USEPA approved $PM_{2.5}$ analyser.

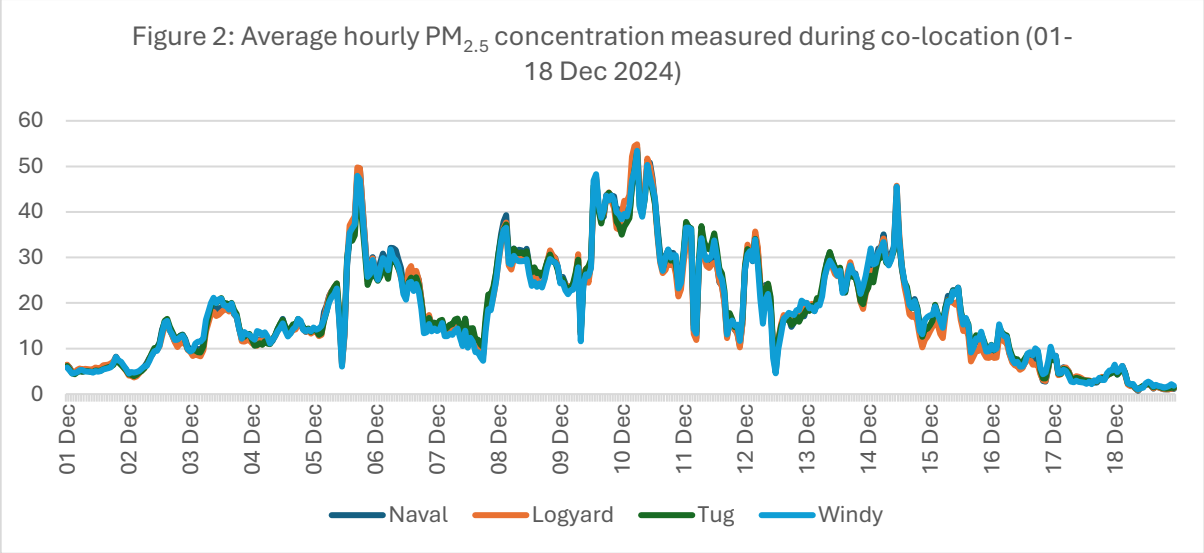


Figure 2: Displays the hourly averages for each of the four instruments during the pre-deployment co-location monitoring.

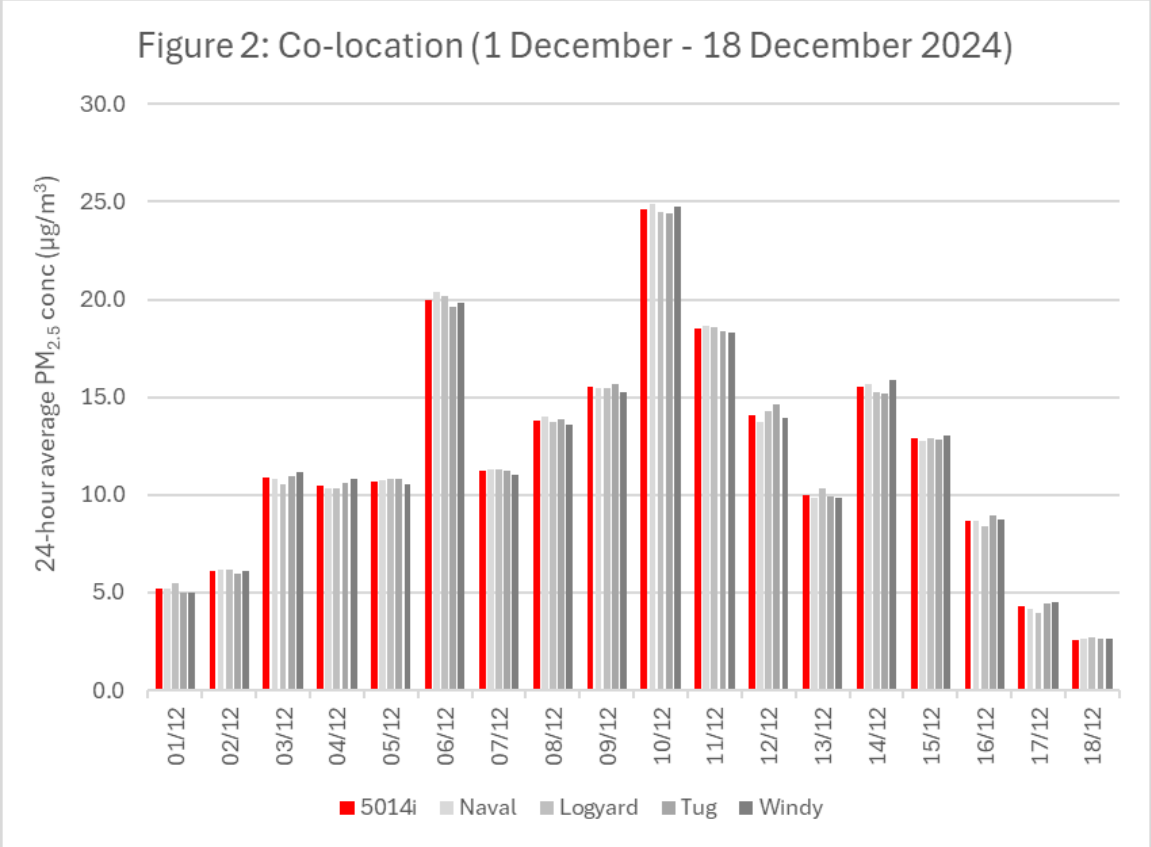


Figure 3: A comparison of the 24-hour average from each instrument with a USEPA approved $PM_{2.5}$ equivalent instrument over an 18-day period immediately prior to deployment.

Figure 2 demonstrates that the monitors are precise – the hourly average recorded by each instrument is within 2 micrograms. **Figure 3** demonstrates that the monitors are accurate in that they recorded 24-hour average $PM_{2.5}$ concentrations that were within 2 micrograms of a USEPA approved equivalent instrument.

On this basis, the instruments were considered suitable for assessing the impact of cruise ship emissions in Lyttelton.

3.4 Installation and commissioning

All four monitors were installed on Friday 20 December 2024. Three of the monitors including the Windy Point, Naval Point and Tug boat wharf were installed with solar panels to maintain battery charge throughout the investigation. The remaining fourth monitor located on the seaward side of the Norwich Quay footpath used mains power to operate.

Figure 4 below displays an image of one of the $PM_{2.5}$ monitors following installation.

Figure 4: Installation of the $PM_{2.5}$ monitor at the end of the LPC tug boat wharf at the Port. *(Image taken on 26 March 2025 looking towards the cruise berth)*

3.5 Gaseous pollutant monitoring

As well as monitoring for $PM_{2.5}$, gaseous diffusion tubes were also deployed at each of the four site locations shown in Figure 1.

Diffusion tubes are routinely used to determine the concentration of gaseous pollutants over several weeks. In this case, diffusion tubes for sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) were used.

Diffusion tubes work by absorbing a specific pollutant of interest onto a chemical absorbent during the period they are deployed. At the end of the monitoring period, the tubes are sealed and sent to a laboratory where the amount of each pollutant is calculated. This total mass is divided by the number of hours the tube was deployed to provide an average concentration during the period of deployment.

Figure 5: Nitrogen dioxide and sulphur dioxide diffusion tubes (with QR codes) mounted underneath the $PM_{2.5}$ monitor at the end of the LPC tug boat wharf at the Port. *(Image taken on 26 March 2025)*

4. RESULTS

4.1 Particulate monitoring results

The monitoring period commenced on Friday 20 December 2024 and concluded on Friday 16 May 2025 – a period of approximately 5 months.

The data capture rate or the percentage of valid data collected during the monitoring period ranged between 97% for Windy Point and 99.9% for Naval Point, the Tug wharf and the Logyard. Missing data can occur due to power outages, transmission faults or instrument re-starts. Data capture rates above 95% are considered excellent.

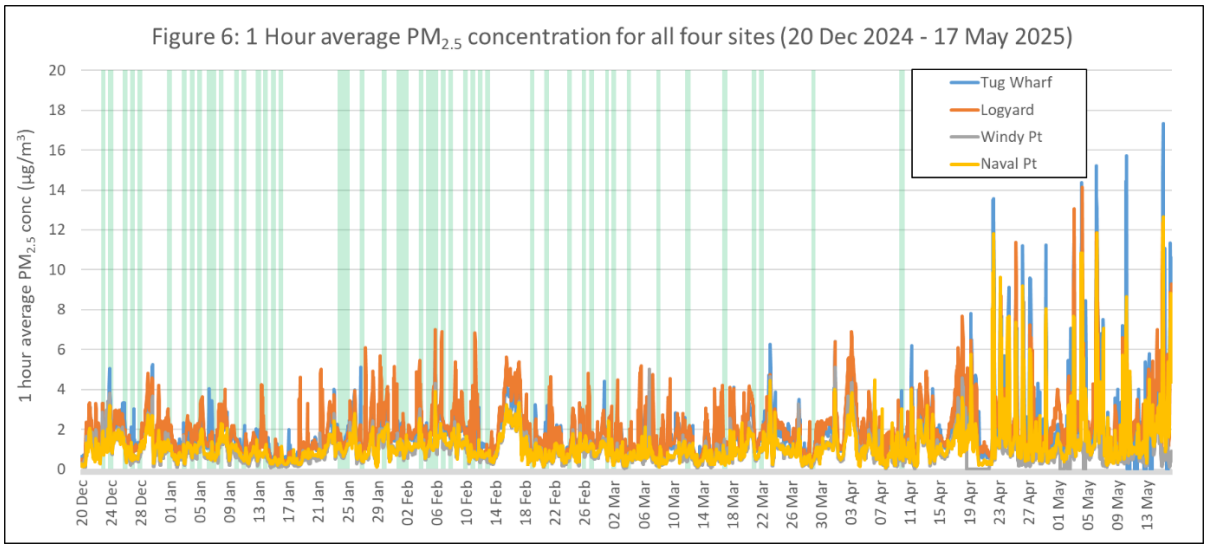


Figure 6: 1-hour average $PM_{2.5}$ at each of the 4 sites during the installation period. The vertical green lines represent periods when cruise ships were present.

Several points are evident from **Figure 6** above.

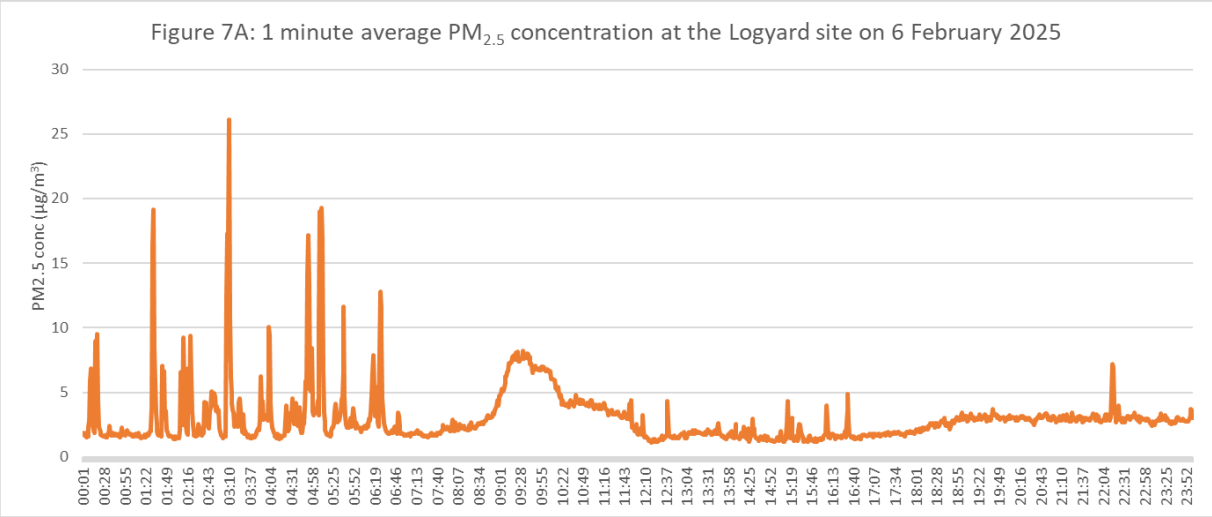
i. Firstly, $PM_{2.5}$ concentrations are relatively low from December through until mid-April when concentrations increase.
ii. $PM_{2.5}$ concentrations are reasonably similar at all four sites during the period of monitoring.
iii. There is no clear visible difference between periods when cruise ships were present with periods when cruise ships were absent.

While there is no current international guideline or standard for hourly concentrations of $PM_{2.5}$, the patterns of variation can be useful in ascribing likely causes for the variation.

For example, **Figure 7A** below depicts the 1-minute average $PM_{2.5}$ concentration at the logyard along Norwich Quay on 06 February 2025. This depicts what appears to be occasional (probably heavy diesel) vehicle movements in the early hours of the morning when the wind speed was very low (0-1 m/s). There is an increase in the $PM_{2.5}$ concentration commencing around 8am. This could be a morning traffic peak or an increase in emissions from nearby diesel buses operating tour buses for the cruise ship

on this day. The wind speed gradually increased from 9am and changed to an easterly wind direction when concentrations reduced.

Figure 7B illustrates the change in hourly $PM_{2.5}$ concentration at all four monitoring sites on a cool day from midday on 29 April through to midday on 30 April. An increase in the concentration of $PM_{2.5}$ between 8 and 9pm is most likely associated with emissions from domestic home heating (wood and/or coal burning).



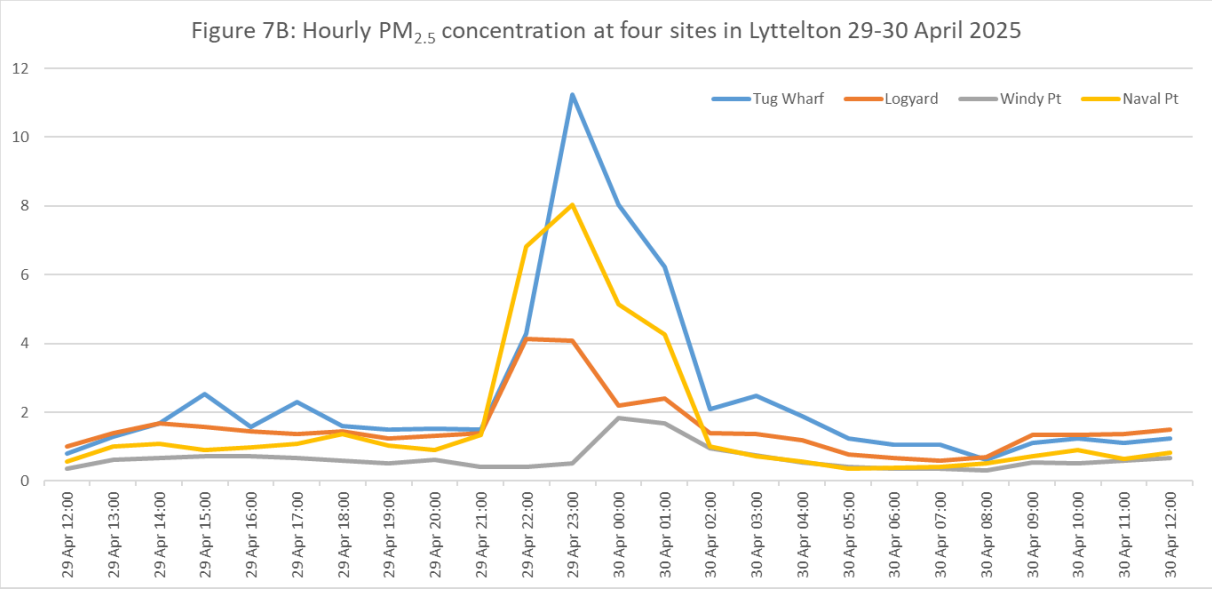


Figure 7A: 1-minute average $PM_{2.5}$ concentration at the waterfront logyard in Lyttelton on 6 February 2025 when a cruise ship was present.
Figure 7B: 1-hour average $PM_{2.5}$ concentration at four monitoring sites from midday on 29 April through to midday on 30 April.

Figure 8 below portrays the 24-hour average $PM_{2.5}$ concentration at each of the four sites during the monitoring period (20 December 2024 – 17 May 2025).

While there is no evidence for a safe threshold below which health effects do not occur, the World Health Organisation recommends that the 24-hour average $PM_{2.5}$ concentration should remain below 15 micrograms per cubic meter. This value is

depicted as a red line on **Figure 8** below. All 24-hour average $PM_{2.5}$ concentration data collected during this investigation met the World Health Organisation guideline.

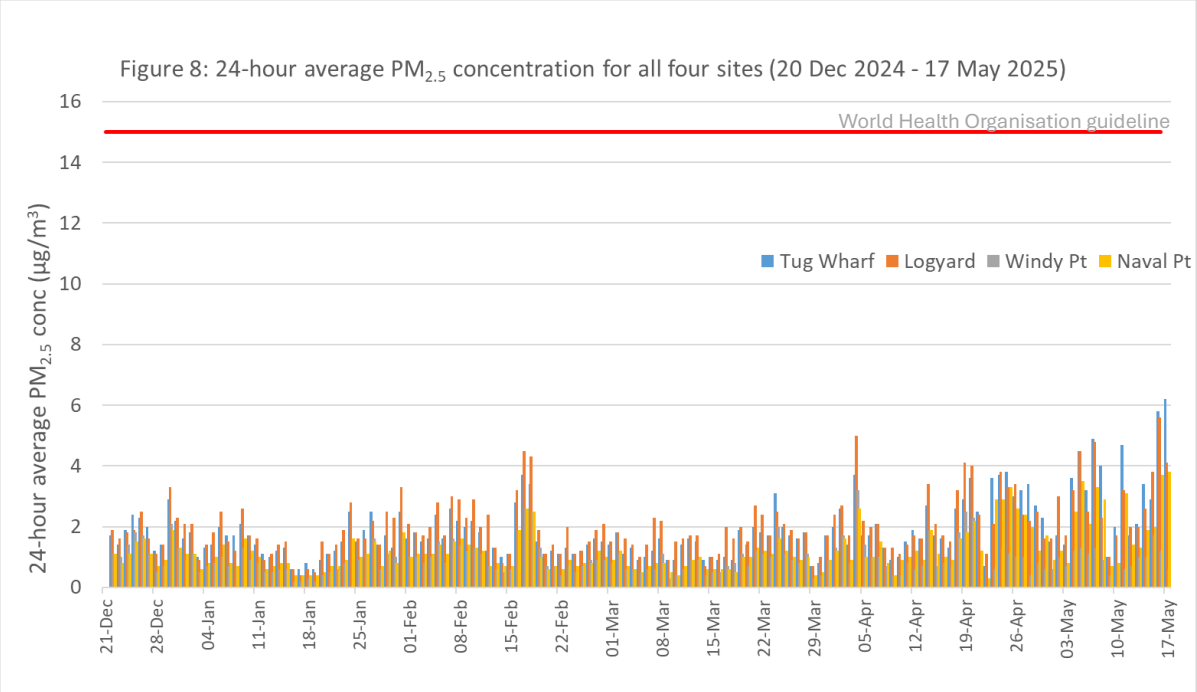


Figure 8: 24-hour average $PM_{2.5}$ concentration at all four monitoring sites in comparison to the World Health Organisation guideline (red line).

4.2 Impact of cruise ships

The impact of cruise ships was assessed by comparing the hourly average $PM_{2.5}$ concentration during times when cruise ships were present with periods when they were absent. To account for meteorological factors affecting air quality, the analysis included only intervals when the wind direction was from the harbour toward the monitoring site. For each instrument, the wind direction considered encompassed the area from the harbour entrance to the designated mooring and berthing locations for cruise ships.

Table 1: Average one-hour $PM_{2.5}$ concentration with or without cruise ship present

	Tugboat wharf	Logyard	Windy Point	Naval Point
No cruise ship	2.0	2.1	1.0	1.3
Cruise ship	2.3	2.2	0.9	1.5
Difference*	+0.3	+0.1	-0.1	+0.2

*Uncertainty is ±0.3 micrograms per cubic meter.

Table 1 shows that cruise ships have a minimal effect on 1-hour average $PM_{2.5}$ concentrations. The measurement uncertainty is ±0.3 micrograms, so the observed increase at Tugboat wharf is not statistically significant.

Figure 9 below depicts the one-minute average $PM_{2.5}$ concentration at all four sites on Saturday 1 February 2025. This date coincides with the arrival of the cruise ship "Celebrity Edge". The period when the cruise ship was present is shaded green in the **Figure 9** below.

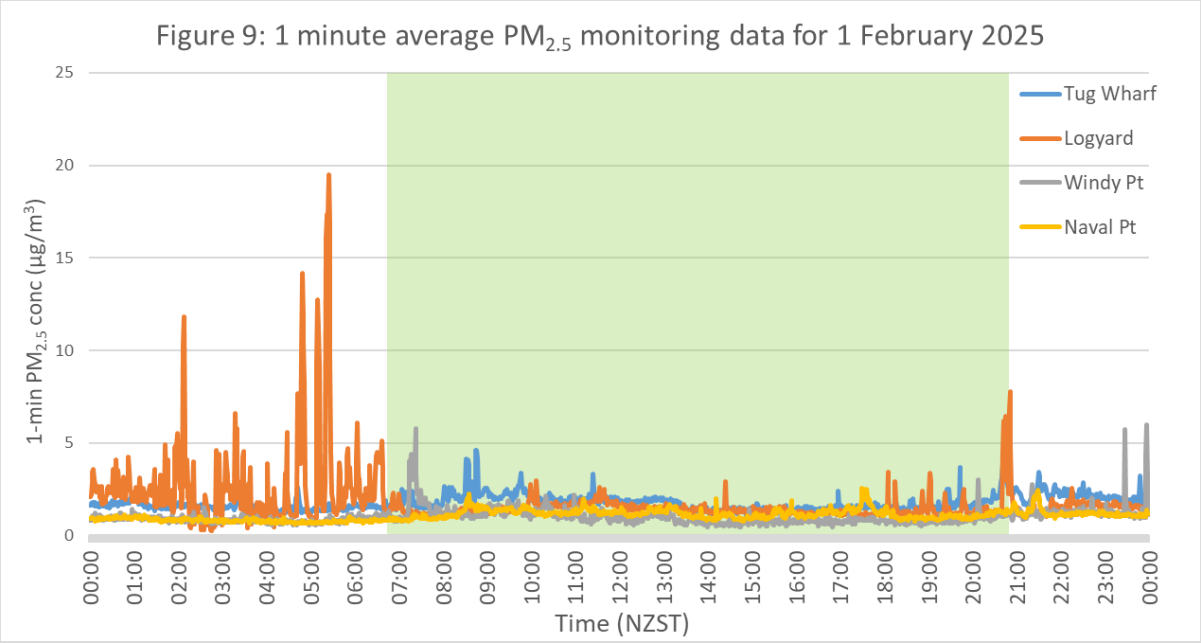


Figure 9: 1-minute PM2.5 data on Saturday 1 February 2025. The green shaded zone represents the time that the cruise ship "Celebrity Edge" was present at the Port.

In general, $PM_{2.5}$ concentrations remained low throughout the duration of the visit from this cruise ship. The wind direction was generally easterly through to south easterly for the duration of the visit and any impact of increased emissions from the cruise ship would most likely be measured either at the Logyard or the Tug wharf or possibly Windy Pt. Generally, the $PM_{2.5}$ concentration remained low at these sites during the visit. The brief spike in the $PM_{2.5}$ concentration (7.8 micrograms per cubic meter) at the logyard as the ship was departing (8:40pm) is probably unrelated to the cruise ship as the wind direction changed to a south westerly about 7pm that evening.

To be clear, the instrumental data is not stating that there is not increase at the monitoring locations during visits by the cruise ships, just that any increase is likely to be below the detection limit of the instrumentation used in this study and that PM2.5 concentrations were well below the World Health Organisation 24-hour guideline of 15 micrograms per cubic meter.

4.2 Gaseous monitoring results

Two sets of diffusion tubes were deployed adjacent to each of the $PM_{2.5}$ monitors. One set of diffusion tubes were deployed to measure nitrogen dioxide (NO_2) while the other set of diffusion tubes were deployed to measure sulphur dioxide (SO_2).

Within diffusion tubes the target gas such as NO_2 is at a higher concentration in the surrounding air than inside the tube. This concentration difference drives the target gas to migrate into the tube where the gas can react with a chemical absorbent. The absorbent traps the gas, preventing it from diffusing out and maintaining the concentration gradient which allows more gas to diffuse into the tube.

4.2.1 Nitrogen dioxide results

Each tube was deployed for approximately 4 weeks before being sealed and sent to a laboratory for analysis. The analysis results are attached as **Appendix A**.

The resulting concentration in **Figure 10** is the average NO_2 concentration for each month of the deployment. The first four months (Dec/Jan through to Mar/Apr) are periods where cruise ships were present. The final period (Apr/May) is a period when cruise ships were absent.

Figure 10 below depicts the average monthly NO_2 concentration for each month in comparison to the 24-hour average World Health Organisation guideline of 25 µg/m^3.

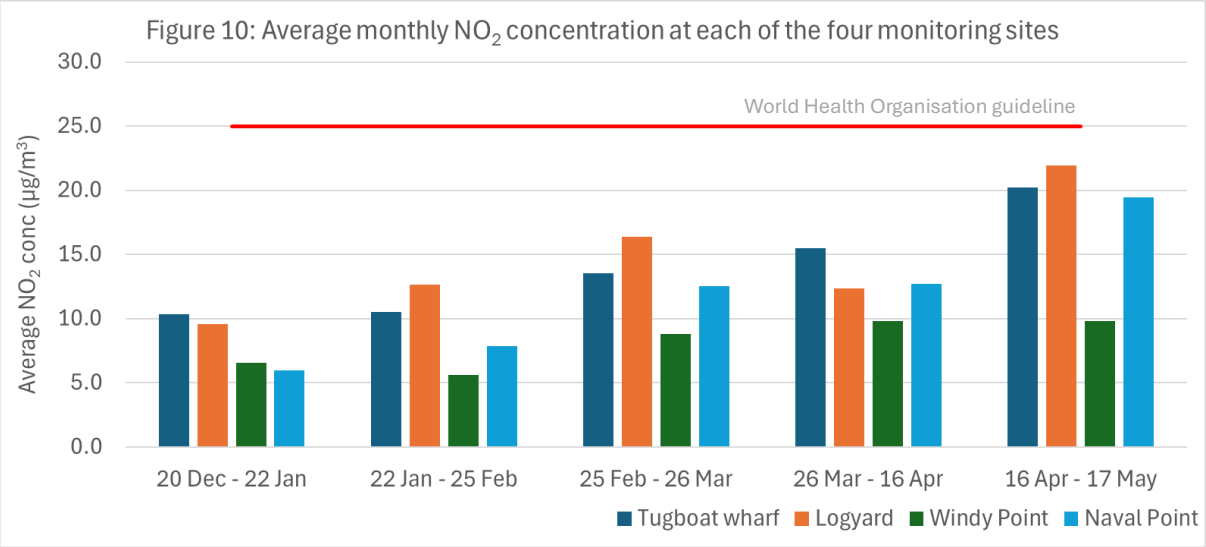


Figure 10: Average nitrogen dioxide concentration (µg/m^3) at each of the four monitoring sites.

Table 2 below compares the average NO_2 concentration from the period when cruise ships were present with the average NO_2 concentration for periods when cruise ships were absent.

The results in **Table 2** indicate that the last monitoring period (16 April through to 17 May) was characterised by elevated concentrations of NO_2 at three of the four sites. Windy Pt did not experience a substantial increase during this period.

Table 2: Average NO_2 concentrations with or without cruise ships present

	Tugboat wharf	Logyard	Windy Point	Naval Point
No cruise ship	20.2	21.9	9.8	19.4
Cruise ship	12.5	12.7	7.7	9.8
Difference*	-7.8	-9.2	-0.1	**+0.2**

The results from **Figure 10** show that while the average NO_2 concentration complied with the relevant 24-hour World Health Organisation guideline, the result for the period from 16 April to 17 May of 21.9 micrograms per cubic meter is likely to have exceeded the World Health Organisation 24-hour nitrogen dioxide guideline at some time during this period.

Given the likely exceedance occurred during the period when cruise ships were absent, the elevated concentrations are most likely associated with a reduction in dispersion due to inversion conditions during cooler weather. However, determining the source of the NO_2 is outside the scope of this investigation.

The arrival and departure of cruise ships does not appear to have had any substantial impact on the NO_2 concentration given that the highest frequency of arrivals and departures (December and January) had the lowest average NO_2 concentration.

4.2.2 Sulphur dioxide results

As with the NO_2 tubes, each SO_2 tube was deployed for approximately 4 weeks before being sealed and sent to a laboratory for analysis. The analysis results are attached as **Appendix B**.

The resulting concentration in **Figure 11** is the average SO_2 concentration for each month of the deployment. The first four months (Dec/Jan through to Mar/Apr) are periods where cruise ships were present. The final period (Apr/May) is a period when cruise ships were absent.

Figure 11 below depicts the average monthly SO_2 concentration for each month in comparison to the 24-hour average World Health Organisation guideline of 40 µg/m^3. **Figure 11** shows that concentrations were consistently low throughout the monitoring period. A comparison of the SO_2 concentrations between periods when cruise ships were present or absent in **Table 3** does appear to show a small increase in the concentration of this pollutant when cruise ships were present. However, the magnitude of this increase (1-2 µg/m^3) is small and within the margin of error for the diffusion tubes. In any event, the monitoring results demonstrate that SO_2 concentrations are low in Lyttelton.

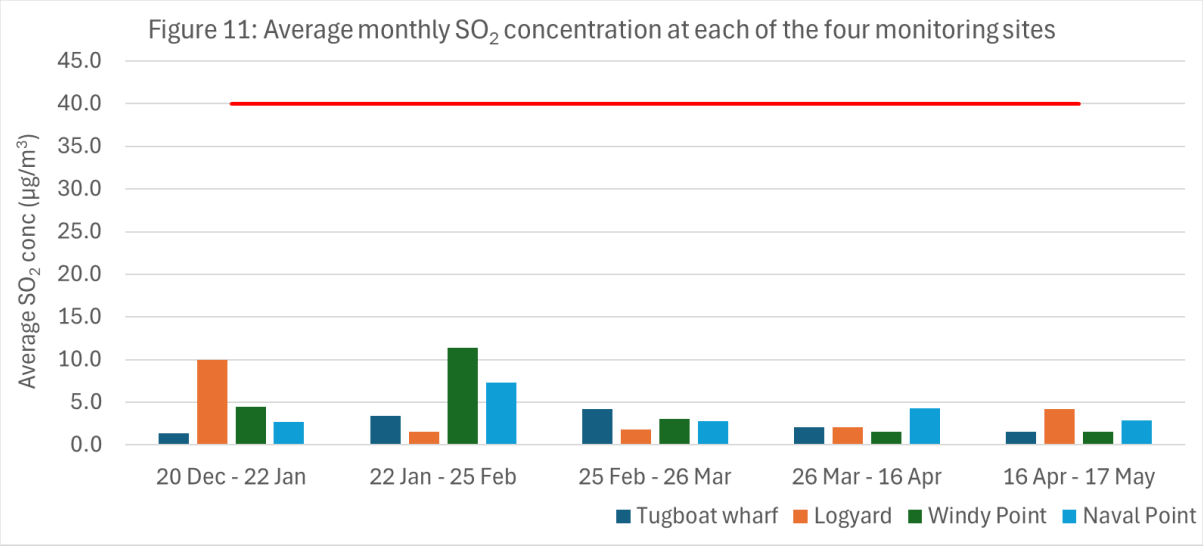


Figure 11: Average sulphur dioxide concentration (µg/m^3) at each of the four monitoring sites.

Table 3: Average sulphur dioxide concentrations with or without cruise ships present

	Tugboat wharf	Logyard	Windy Point	Naval Point
No cruise ship	1.2	3.9	1.2	2.7
Cruise ship	2.5	3.6	4.8	4.0
Difference*	+1.3	-0.3	+3.6	+1.3

5. SUMMARY

Monitoring for three pollutants - $PM_{2.5}$, nitrogen dioxide and sulphur dioxide was undertaken at four sites between 20 December 2024 and 17 May 2025. The purpose of the monitoring was to quantify what impact cruise ships visiting Lyttelton Port were having on air quality in Lyttelton.

Monitoring results revealed that the air quality in Lyttleton is generally good over the summer and autumn period.

A comparison of periods when cruise ships were present with periods when cruise ships were absent found that the cruise ships resulted in a small net increase in $PM_{2.5}$ of between 0.1 and 0.3 micrograms per cubic meter (µg/m^3) on an hourly basis but that the increase was not statistically significant.

Results for nitrogen dioxide indicated that average concentrations were within World Health Organisation guidelines. However, during the final monitoring period (16 April to 17 May), some locations may have exceeded the 24-hour World Health Organisation nitrogen dioxide guideline of 25 µg/m^3. The reason for these higher concentrations is uncertain, but cruise ships were not a contributing factor as they were not present during this time frame.

A comparison of periods with and without cruise ships indicated a possible small increase in 24-hour average sulphur dioxide concentrations by 1 to 2 µg/m^3. However, this change was within the measurement margin of error and not statistically significant. Sulphur dioxide levels remained consistently low and well below the World Health Organisation 24-hour guideline of 40 µg/m^3.

In summary, the monitoring over the summer 2024/25 cruise ship season found that the air quality in Lyttelton is generally good and that the impact of emissions from cruise ships on air quality at the four sites around Lyttleton was relatively low. The monitoring results from this investigation are consistent with the prediction and assessment made by T+T.

APPENDIX A: Nitrogen dioxide diffusion tube results

Location	Number	Date On	Date Off	Time (hr.)	μg/m³	ppb	on tube
Windy Pt	2587907	20/12/2024	22/01/2025	792.50	8.04	4.20	0.42
Tug boat Wharf	2587908	20/12/2024	22/01/2025	792.67	11.87	6.20	0.63
Naval Pt	2587909	20/12/2024	22/01/2025	792.25	7.49	3.91	0.39
Logyard	2587910	20/12/2024	22/01/2025	792.25	11.06	5.77	0.58
Tug boat Wharf	2587923	22/01/2025	25/02/2025	822.50	12.01	6.27	0.66
Tug boat Wharf	2587911	25/02/2025	26/03/2025	690.00	15.06	7.86	0.69
Windy Pt	2587925	22/01/2025	25/02/2025	822.32	7.14	3.73	0.39
Windy Pt	2587919	25/02/2025	26/03/2025	689.42	10.29	5.37	0.47
Logyard	2587916	25/02/2025	26/03/2025	689.92	17.88	9.33	0.82
Logyard	2587926	22/01/2025	25/02/2025	821.53	14.17	7.40	0.77
Naval Pt	2587927	22/01/2025	25/02/2025	822.17	9.38	4.89	0.51
Naval Pt	2587922	25/02/2025	26/03/2025	689.08	14.03	7.32	0.64
Windy Pt	2587915	26/03/2025	16/04/2025	983.01	11.33	5.91	1.12
Naval Pt	2587920	26/03/2025	16/04/2025	509.92	14.21	7.41	0.48
Tug boat Wharf	2587913	26/03/2025	16/04/2025	509.83	16.96	8.85	0.57
Logyard	2587912	26/03/2025	16/04/2025	509.50	13.86	7.24	0.47
Naval Pt	2587914	16/04/2025	17/05/2025	982.83	20.93	10.92	1.37
Logyard	2587921	16/04/2025	17/05/2025	983.08	23.44	12.23	1.53
Tug boat Wharf	2587917	16/04/2025	17/05/2025	983.83	21.74	11.34	1.42
Windy Pt	2587918	16/04/2025	17/05/2025	983.01	11.33	5.91	1.12
Blank	2587919			1493.75	1.50	0.78	0.15
Laboratory Blank				1493.75	0.03	0.02	0.003

APPENDIX B: Sulphur dioxide diffusion tube results

Location	Number	Date on	Date off	Time (Hr.)	SO_4^{2-} µg on tube	SO_2 µg/m^3	SO_2 ppb
Windy Pt	2587930	20/12/2024	22/01/2025	792.50	0.29	4.45	1.67
Tug boat Wharf	2587931	20/12/2024	22/01/2025	792.67	0.09	1.34	0.50
Naval Point	2587932	20/12/2024	22/01/2025	792.25	0.18	2.74	1.03
C3 logyard	2587933	20/12/2024	22/01/2025	792.25	0.65	10.00	3.75
Tug boat Wharf	2587945	22/01/2025	25/02/2025	822.42	0.23	3.39	1.27
Tug boat Wharf	2587943	25/02/2025	26/03/2025	690.08	0.24	4.19	1.57
Windy Pt	2587946	22/01/2025	25/02/2025	822.25	0.77	11.44	4.29
Windy Pt	2587939	25/02/2025	26/03/2025	689.20	0.17	3.02	1.13
Logyard	2587948	22/01/2025	25/02/2025	822.25	0.10	1.52	0.57
Logyard	2587936	25/02/2025	26/03/2025	689.67	0.10	1.77	0.66
Naval Pt	2587949	22/01/2025	25/02/2025	821.67	0.49	7.32	2.75
Naval Pt	2587941	25/02/2025	26/03/2025	689.08	0.16	2.78	1.04
Windy Pt	2587935	26/03/2025	16/04/2025	983.01	0.18	1.49	0.56
Naval Pt	2587937	26/03/2025	16/04/2025	509.88	0.18	4.30	1.61
Tug boat Wharf	2587934	26/03/2025	16/04/2025	509.83	0.09	2.08	0.78
Logyard	2587940	26/03/2025	16/04/2025	509.50	0.09	2.08	0.78
Naval Pt	2587944	16/04/2025	17/05/2025	982.83	0.24	2.94	1.10
Logyard	2587938	16/04/2025	17/05/2025	983.08	0.34	4.17	1.56
Windy Pt	2587951	16/04/2025	17/05/2025	983.01	0.18	1.49	0.56
Tug boat Wharf	2587942	16/04/2025	17/05/2025	983.83	0.12	1.52	0.57
Blank	2587950			1493.77	0.04	0.29	0.11