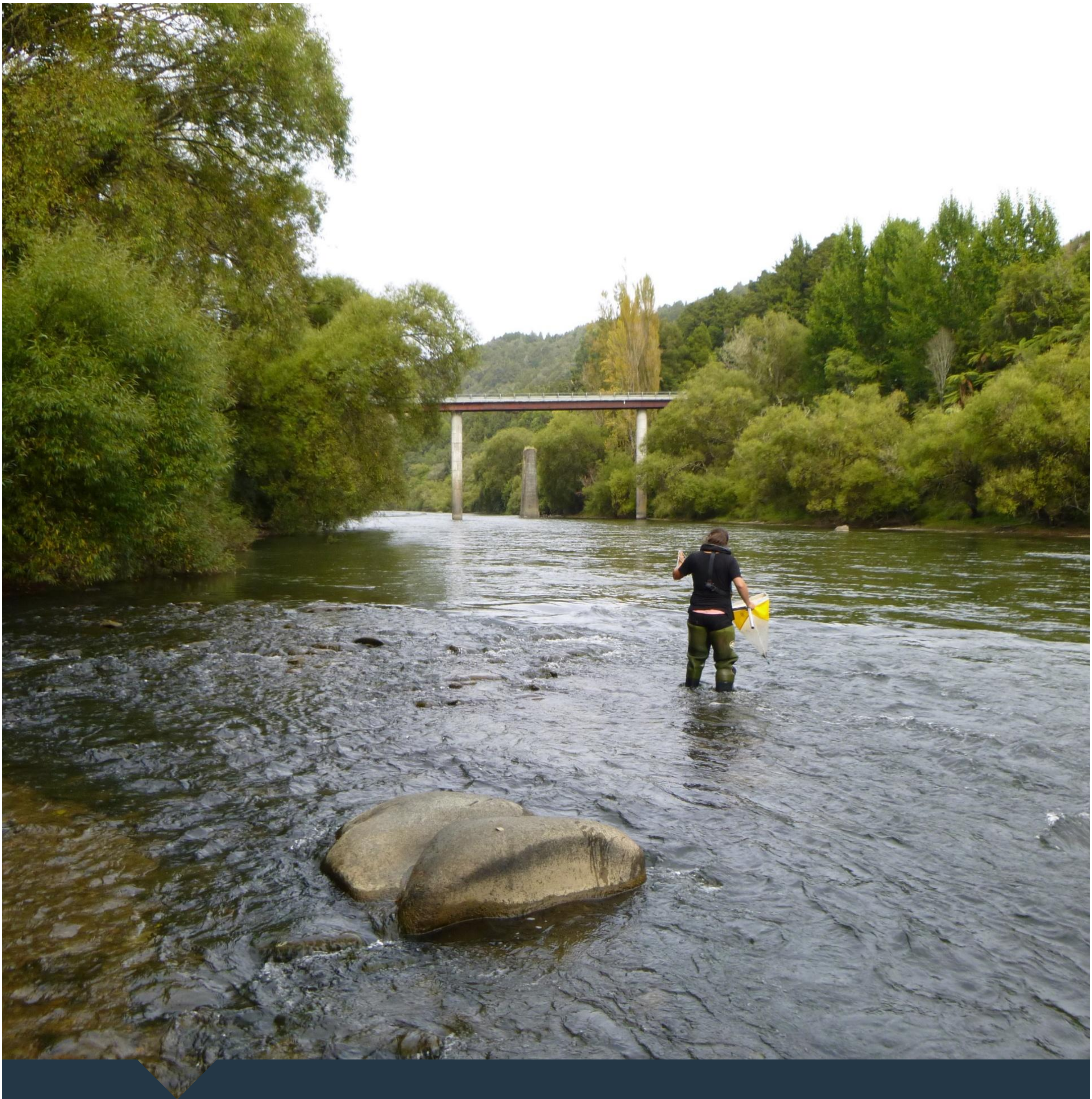

Air Quality Investigative Monitoring Pilot Study in Woodville

December 2025

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REGIONAL COUNCIL

Prepared for:

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Science Manager

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The Air Quality Collective

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Executive Summary

Horizons Regional Council (HRC) is responsible for the management of air quality across the Horizons region. This includes a requirement to monitor air quality in “airsheds” where non-compliance with National Environmental Standards for Air Quality (NESAQ) is likely (MfE 2011). For most towns and cities in the Horizons region, this likelihood is unknown. Furthermore, Regulations require air quality to be monitored in the most polluted location within an airshed, but with strong intra-airshed spatial variation in air quality expected, where these locations might be is also unknown.

This project was developed as a pilot demonstration of the first stage of a 2-stage approach previously described in a Monitoring Plan delivered to HRC earlier in 2025. This first stage uses non-regulatory “screening” methods to establish the likelihood of non-compliance and - where this is suspected – insight into where compliance monitoring should be established, thus optimising monitoring resources and costs. This pilot study focussed on Woodville.

10 low-cost air quality monitors were deployed in a regular rectangular grid of 3 rows and 3 columns and an additional tenth site to cover the whole town.

All monitors were fully functional between 17th July and 5th November 2025.

The results clearly showed that air quality during winter is not uniform across Woodville. On the contrary it showed that there is a persistent spatial pattern with higher concentrations towards the south side of the town. The most polluted area remained 1.5 to 2 times more polluted than the least on nearly every day of our observational campaign.

The data strongly suggests that home heating is the only significant emission source in the long-term, with elevated levels of particulate matter (PM_{10}) generally requiring air temperatures to be below 10 °C.

Although the data collected does not meet the requirements needed for formally establishing compliance with air quality Standards, the data collected nevertheless indicates that exceedances of the Standards may have occurred during the study, and may occur on a regular basis in mid-winter. Furthermore, the data implies that exceedance of the daily $PM_{2.5}$ standard proposed by the Ministry for the Environment is likely.

In accordance with the monitoring plan we developed for HRC, we recommend that additional monitoring is conducted. We present three options of varying cost and robustness. Each option involves collecting at least 12 months of data at a site towards the southern edge of the town. We discuss options if such as site is not logistically feasible.

1 Introduction

1.1 Background

Horizons Regional Council (HRC) is responsible for the management of air quality across the Horizons region. This includes a requirement to monitor air quality in "airsheds" where non-compliance with National Environmental Standards for Air Quality (NESAQ) is likely (MfE 2011). An airshed is effectively an air management area which, in most cases, corresponds to an urban area.

The regulatory requirement stated above implies a need to determine "likelihood" of non-compliance of an airshed before monitoring is commissioned. Furthermore, monitoring for the purposes of establishing compliance with the NESAQ needs to be conducted using specified methods to achieve a required level of accuracy and traceability. These requirements impose a minimum cost of the order of many tens of thousands of dollars per year.

If air quality were consistent in space across an airshed, "likelihood" could be established directly by deployment of an air monitoring station. However, previous research by ourselves and others has shown how air quality can be highly variable in time and space within airsheds, especially those with prevalent use of winter wood or coal-burning, such as Woodville. The Air Quality Regulations require compliance monitoring to be sited in the most polluted area of an airshed – failure to do so can lead to highly misleading results.

Earlier in 2025 we were commissioned by HRC to develop an air quality monitoring plan (Longley, 2025) to address these issues with regard to airsheds with limited or no previous monitoring data. In that work we recommended a two-stage approach. The first stage leverages new air monitoring technologies that - although they do not meet the requirements for compliance monitoring – are substantially less expensive and easy to deploy making them very well suited to providing reliable information on spatial patterns. By deploying these devices in a set of 3-month winter screening studies it should be possible to establish:

- the likelihood (with some uncertainty) of non-compliance with the NESAQ in each airshed, and
- where monitoring for the purposes of compliance with the NESAQ should be located if needed.

This potentially removes the need to commit to expensive monitoring fulfilling the requirements for formal compliance if the likelihood of non-compliance is low.

Spatial information can also be informative about the processes driving the formation of hot spots, such as whether prevalent airflows cause pollution to accumulate in particular areas, or whether some emission sources have more impact than others. This could indicate the potential for locally targeted mitigation options that may be more effective than airshed-wide approaches.

Finally, better spatial information may also identify previously unknown localised air quality hot-spots, or intense emission sources.

1.2 Scope

This project represents a pilot of the first stage (screening) of the approach proposed in our Monitoring Plan, and focusses on the Woodville airshed. This project's primary deliverable is data that provides a clearer picture of how winter air quality (expressed in terms of PM_{10}) varies in space across Woodville, and how that spatial variation also varies in time.

This information is intended to be used to:

a) Indicate the likelihood (albeit with some uncertainty) of compliance of the Woodville airshed with the current National Environmental Standards for Air Quality for PM_{10} and proposed Standard for $PM_{2.5}$,

b) Inform where a future regulatory monitoring site in Woodville should be placed (if one is required) in order to comply with the requirements of the Air Quality Regulations,

c) Demonstrate the value of this two-stage approach and the additional information it provides regarding the processes driving air quality in the airshed.

2 Methods

2.1 Observational methods

2.1.1 Instruments used

Original data for this study was collected using Clarity Node-S air quality monitors (www.clarity.io). These devices monitor particulate matter (PM) in a self-powered, FCC/CE certified, UV-resistant, and weatherproof package incorporating solar harvesting, internal battery, and global cellular communications.

Clarity monitors were installed on streetlight poles across Woodville in as regular a grid pattern as was practically achievable. All monitors were installed at approximately 2.5 m height.

2.1.2 Instrument siting design

Our principles for deploying gridded monitors are covered in Longley (2025). Several configurations were tested in a GIS environment to give the best coverage of residential areas with the 10 monitors available for the project.

The design chosen consisted of a regular rectangular grid of 3 rows and 3 columns with the whole grid covering an area of 0.6 km north-east to south-west and 0.45 km north-west to south-east and an average inter-monitor spacing of 260 m. An additional tenth site was installed just to the north of the main grid. All sites were in residential areas, except for one which was in the town centre's commercial zone.

Monitoring began at 7 sites at 6pm on 14th July 2025, with all 10 sites operational by 11:20am on 17th July. Monitoring concluded at 9am on 5th November 2025.

2.2 Instrument inter-comparability

The valid evaluation of spatial patterns requires a high degree of comparability between monitors. This is usually verified through a period of co-location.

In this study a co-location period was not included due to time constraints. However, we have high confidence in the comparability of the monitors based on previous co-locations studies conducted elsewhere (Longley, 2024a, b, c).

2.3 Data adjustment

The Clarity monitor is not an approved method for the purposes of establishing compliance with the NESAQ under the Air Quality Regulations. It is based on a different sensor technology (optical scattering) from the approved methods. Horizons Regional Council operate regulatory monitoring sites to approved methods at Taihape and Taumarunui, but not in Woodville. A co-location was considered but not undertaken due to a) constraints on resources, b) late start of the project relative to winter conditions, c) substantial co-location data collected in previous projects.

From studies we have conducted in other locations[1] with a similar emissions mix[2] we find that the Clarity monitor typically over-estimates PM_{10} measured using a regulatory method by a factor of 3 – 4.

The primary purpose of this study is to investigate **relative** difference in data from monitors, i.e. the spatial variation in air quality, not to establish **absolute** compliance with Standards. For this primary purpose it is not necessary to adjust the data to account for the measurement technology employed. Therefore, all data presented in this report is **unadjusted**, unless otherwise stated.

[1] Ashburton, Alexandra, Gore, Milton and Rotorua
[2] Data collected from April to October when homes heating sources dominate PM_{10}

3 Results

3.1 Data recovery

From 17th July onwards we recovered 100 % of the maximum possible data.

3.2 Anomalous data

There were periods when the monitor at site C4 (near 29 Fox Street) recorded very similar values of $PM_{2.5}$ and PM_{10} (and also PM_1). This is highly unusual for this kind of monitor. This corresponded to short periods of high concentrations (PM_{10} of at least 50 $\mu g\ m^{-3}$), began in late August and became more common in October. Together this evidence points either to a very local combustion source intermittently impacting the monitor, or an intermittent instrument fault. In either case we do not believe these data points are representative of the surrounding area, and therefore they have been removed from the analyses described below. This has resulted in the removal of 418 data points from the total record of 9532 at site C4 (i.e. 4 %).

3.3 Relationship between PM_{10} and $PM_{2.5}$

The Clarity instruments report both $PM_{2.5}$ (fine particles smaller than 2.5 μm) and PM_{10} ($PM_{2.5}$ plus coarse particles between 2.5 and 10 μm).

Figure 3-1 shows the relationship between hourly PM_{10} and $PM_{2.5}$ for all sites.

Figure 3-1 shows a very strong correlation indicating that (according to the monitors) PM_{10} was strongly dominated by fine $PM_{2.5}$ particles with coarse particles (2.5 – 10 μm in diameter and most likely dominated by mineral dusts) rarely making a significant contribution. It should be noted, however, that Clarity monitors, like most optical particle monitors, tend to have a lower sensitivity to coarse particles and are known to systematically under-report their concentrations. This is an area of current active research.

A small influence of coarse dust particles was periodically observed at site A3 (near 35 Grey Street).

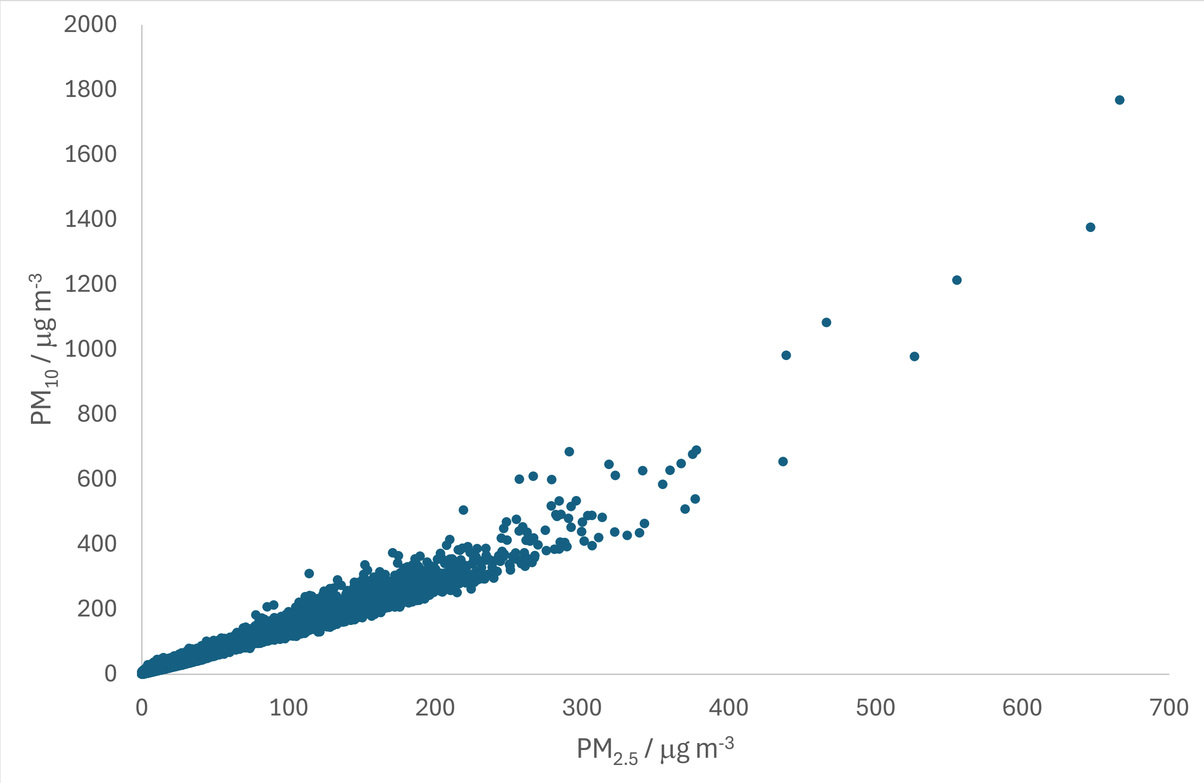

Figure 3-1: Relationship between PM_{10} and $PM_{2.5}$ measured by all monitors.

These results indicate that maps of $PM_{2.5}$ and PM_{10} derived from our data for Woodville will look very similar. For this reason, we present maps of PM_{10} only.

3.4 Temporal variation of 24-hr averages

We understand that one of Horizons Regional Council's primary interests is the spatial pattern in air quality across the whole town, and particularly the area most likely to report the highest concentrations over a 24-hour period, as such a location would make a suitable potential future compliance monitoring site.

Figure 3-2 shows the range of average PM_{10} concentrations across the whole grid for each 24-hour period. In general, the concentration across the grid varied by +/- 30% around the grid-average, regardless of the concentration. Over time, concentrations could rise and fall substantially (e.g. grid-average concentrations fell from 90 $\mu g\ m^{-3}$ on 29th July to 8 $\mu g\ m^{-3}$ on the following day). However, as the study progressed the maximum concentrations gradually fell, with concentrations above 60 $\mu g\ m^{-3}$ not observed beyond 25th August (with one exception on 20th September). This is consistent with a relatively large increase in nighttime temperatures at the end of August (minima jumping from 1 °C to 11 °C), and one final sub-zero temperature night on 20th September. Figure 3-3 shows how – between 6 pm and 11 pm (which we presume to be the dominant hours of home heating emissions) - grid-mean instantaneous PM_{10} was strongly linked to air temperature below 10 °C.

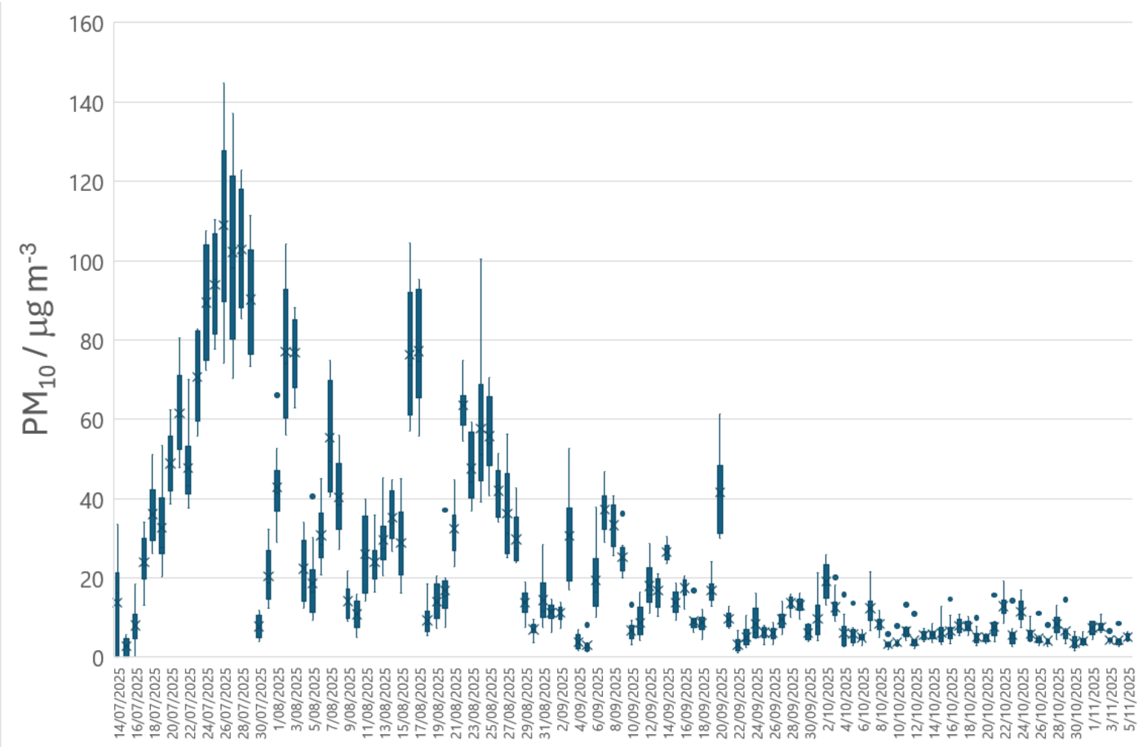

Figure 3-2: Distributions of 24-hour PM_{10} concentrations across the whole town for each day of the campaign.

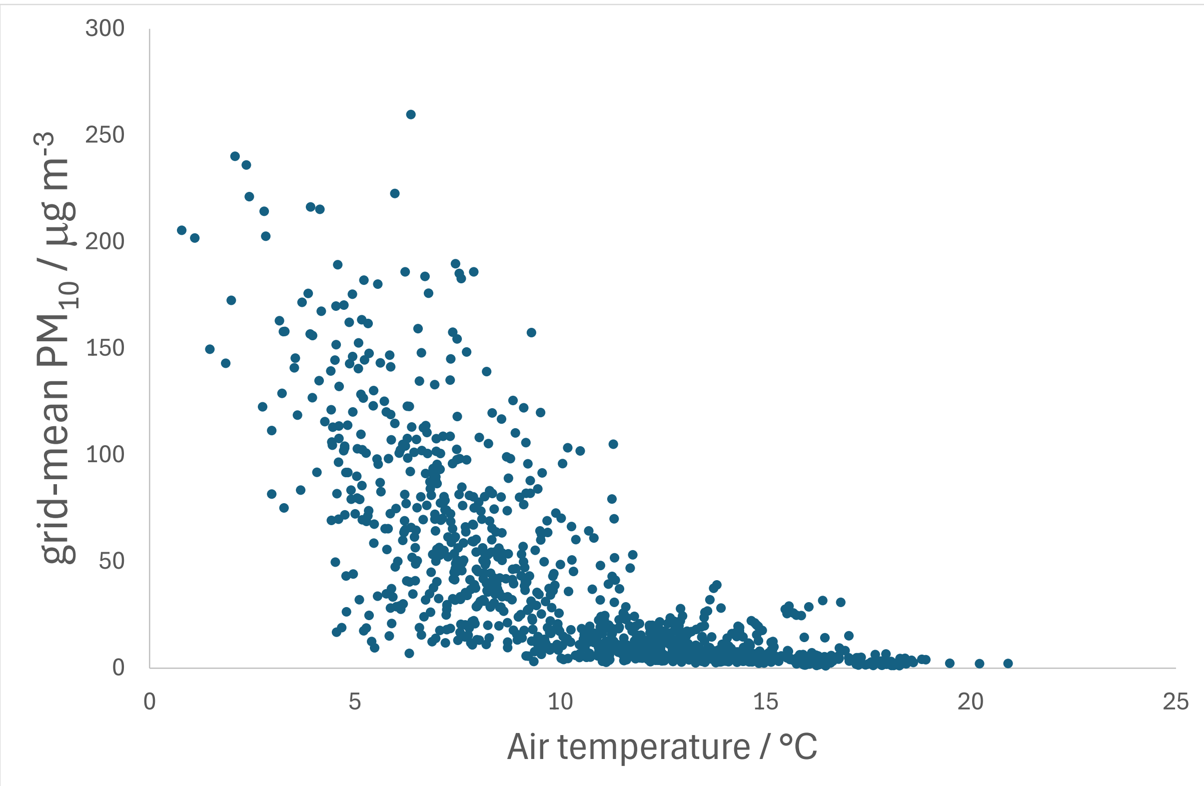

Figure 3-3: 20-minute average grid mean PM_{10} against air temperature for the hours of 6 pm to 11 pm

3.5 Magnitude of spatial variation of 24-hour averages

Figure 3-4 shows the same data as in Figure 3-2, but with days ranked in order of grid-mean concentration. This shows that - going from more polluted days (left) towards less polluted (right) – minimum and maximum concentrations also decreased roughly in proportion so that the range (difference between minimum and maximum concentrations across the town) also decreased.

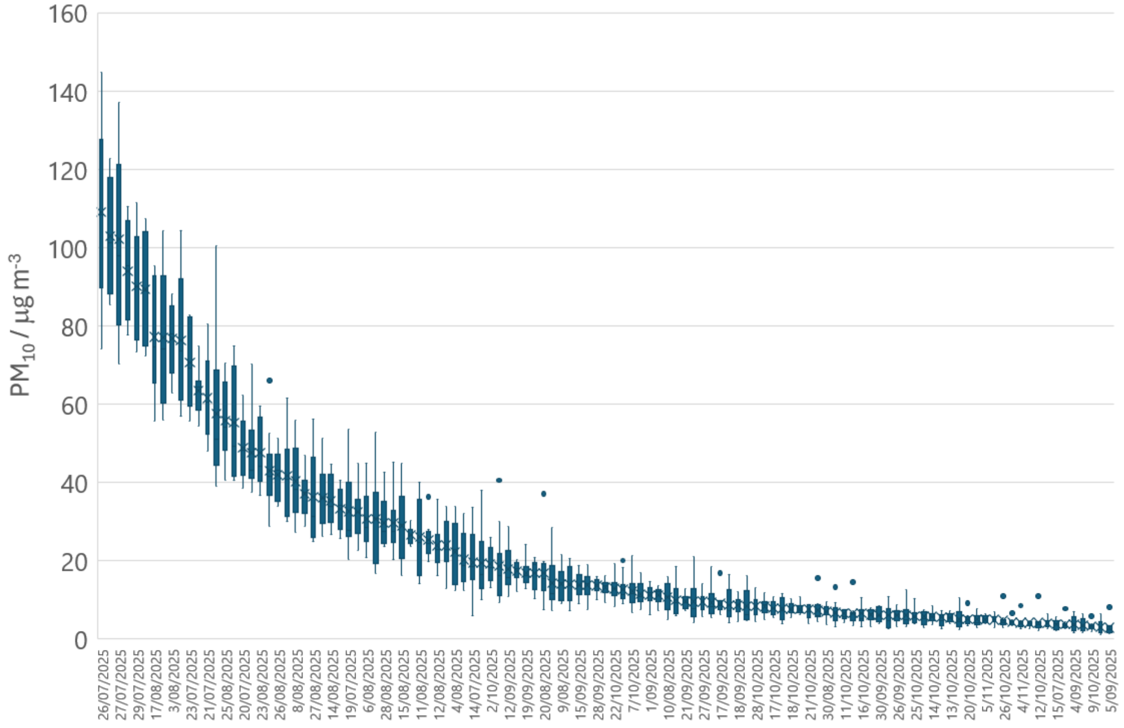

Figure 3-4: Distributions of 24-hour PM_{10} concentrations across the whole town. Days are ranked in terms of grid-mean concentration.

3.6 Map of spatial variation of 24-hour averages

Figure 3-5 presents a map of average (unadjusted) PM_{10} for the whole observational campaign. It therefore represents our best estimate of the long-term spatial variation in PM across Woodville all winter. Figure 3-6 shows the average over the 20 most polluted 24-hour periods – 10 of which were in July and 10 in August. In both cases there is a clear and consistent pattern with higher concentrations in the southern half of the town. The lowest concentrations were observed in the town centre around Vogel Street and Atkinson Street.

Figure 3-5: Mean (unadjusted) PM_{10} for the whole observational campaign.

Figure 3-6: Mean (unadjusted) PM_{10} for the 20 most polluted days.

3.7 Day-to-day variability in spatial variation across the town

Over the 115 days for which complete 24-hour concentrations could be calculated, the **highest** 24-hour concentration was recorded at 8 different locations, but most frequently (21 days or 28 %) at either sites A3 or C4. Over the top 20 most polluted days the peak concentration was recorded at 5 different sites, all in the southern half of the town, but most frequently at sites A3 or C4.

However, in our view, concentrations recorded at sites A3, A4, B4 and C4 were very similar and any one could credibly function as a "peak" site.

On polluted nights the **lowest** 24-hour average concentrations were observed mainly at site C2 (9 times out of 20) or B2 (6 times out of 20)

3.8 Hour-to-hour variability in spatial variation across the town

Figure 3-7 below shows the diurnal-average PM_{10} concentration at each site for the period up to and including 20th September. This shows that the north-south spatial variation is typically present all night. By the morning the spread in concentrations is smaller but still present. The large spike at site A3 is driven by a single outlier on one evening. It is left in because we assume the measurement to be real rather than an error.

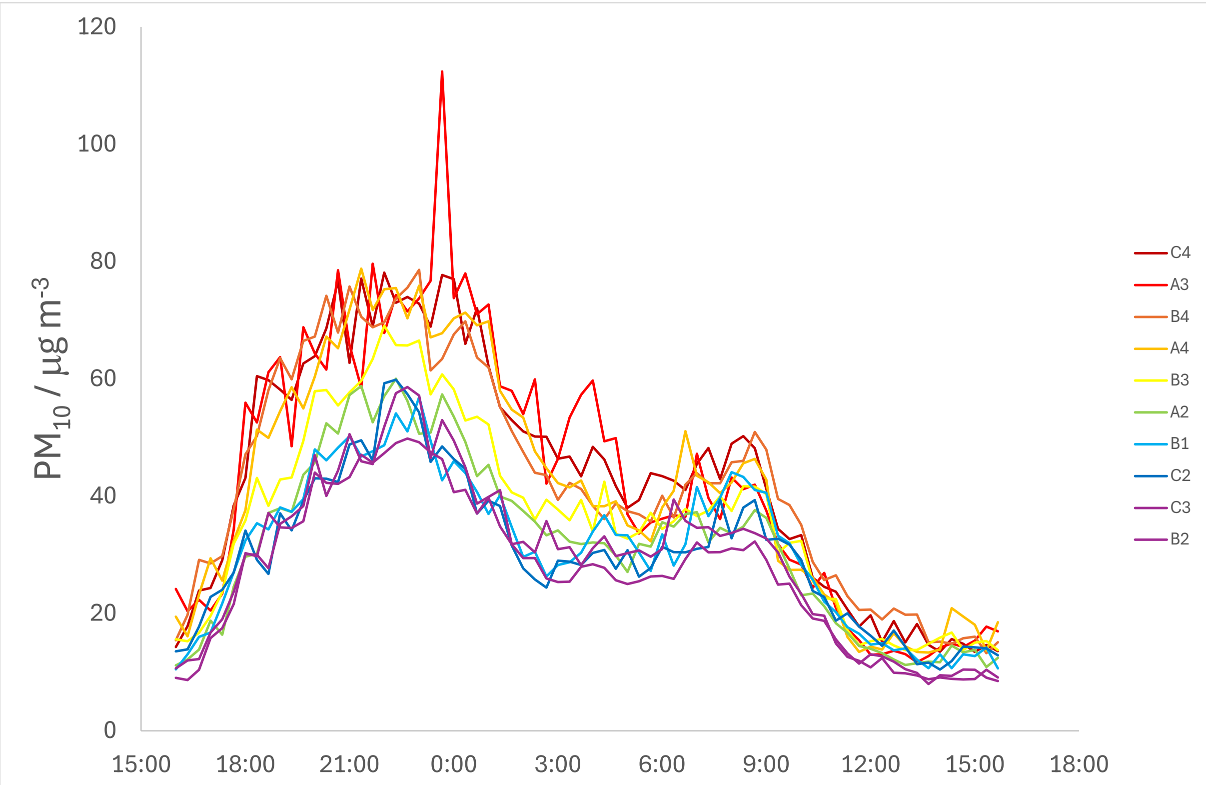

Figure 3-7: Diurnal average PM_{10} at each site for the period up to 20th September

Our review of the data has highlighted a few additional features of interest.

- We found no periods during which the north-south concentration gradient was reversed.
- Concentrations across the grid were generally correlated in terms of averaging times of a few hours, but on sub-hourly timeframes were highly variable (i.e. there was a lot of local "noise" superimposed on a town-wide trend).
- In terms of town-wide trends, some nights saw concentrations falling very slowly, and on others very abruptly. This implies that dispersion of the airshed is very sensitive to wind or thermal conditions.
- The strong localised variation (temporary deviation of any site from the town-wide trend) is to be expected from a small town and measurements made very close to sources (domestic chimneys).
- In some more constrained airsheds we may expect the airshed to accumulate pollutants during the night. This can be inferred if the grid minimum concentration continues rising after midnight as the grid maximum falls. This was only observed on two nights, implying that Woodville is not an "accumulative" airshed.
- In some airsheds we may expect 24-hour average concentrations to be elevated due to the "return" of an urban plume that has earlier travelled away from the town but returned due to a reversal in wind direction. We have observed this phenomenon in the past at airsheds near the coast which we have associated with a land/sea breeze system. This process can be inferred from a "double peak" in the overnight PM_{10} time series. Although this analysis has not been exhaustive, we find little to no evidence of this occurring.

Bringing all of these pieces of evidence together, we conclude that, on a short timescale, the Woodville airshed is very sensitive to small variations in wind conditions. However, when averaged over several hours or more the only systematic pattern we see is a persistent north-south gradient. Without local wind data it is difficult to conclude whether this gradient is caused by spatial differences in emissions, or the southward transport of smoke on the prevailing wind, or both.

3.9 Prediction of compliance of the Woodville airshed with the PM_{10} National Environmental Standard

The relevant National Environmental Standard for Air Quality is that for PM10. The Standard is a PM_{10} concentration, expressed as a 24-hour average (from midnight to midnight), of 50 $\mu g\ m^{-3}$. One exceeedence of this value is permitted within a 12-month period.

As noted above, data from the Clarity monitors used in this study are not suited for direct assessment of compliance with regulatory standards. However, there are two methods that can be used to get some insight into the likelihood of compliance of the Woodville airshed.

The first method is to compare the data captured in Woodville with data collected in another airshed where we have derived an equation to adjust the Clarity data to regulatory equivalence.

The second method is to apply that equation directly to the Woodville data.

We apply the first method by comparing the Woodville data to data we collected with the same instruments in Alexandra, Otago during winter 2025. We fit a simple harmonic (cosine) function to encompass the maximum daily unadjusted PM_{10} concentrations for Woodville. In Figure 3-8 this model is plotted (line) along with the daily average PM_{10} concentrations from Woodville site C4 (this study – open triangles) and from the ORC regulatory monitoring site in Alexandra (orange circles).

The model fitting method is more uncertain if the data available does not span the mid-winter period of late June to early July. This period was narrowly missed by this study. Nevertheless, we found that the maximum daily unadjusted PM_{10} concentration in late July was around 130 $\mu g\ m^{-3}$, and that the value for the same time of the winter in Alexandra was 160 – 180 $\mu g\ m^{-3}$. More generally it can be seen in Figure 3-8 that the range of concentrations in Woodville is not hugely dissimilar to those recorded in Alexandra. During winter 2025, a total of 6 exceedances of the PM_{10} standard were recorded by ORC at Alexandra. Given the broad similarity of concentrations observed we can conclude that the likelihood of exceedances of the PM_{10} standard having occurred in Woodville in 2025 cannot be ruled out.

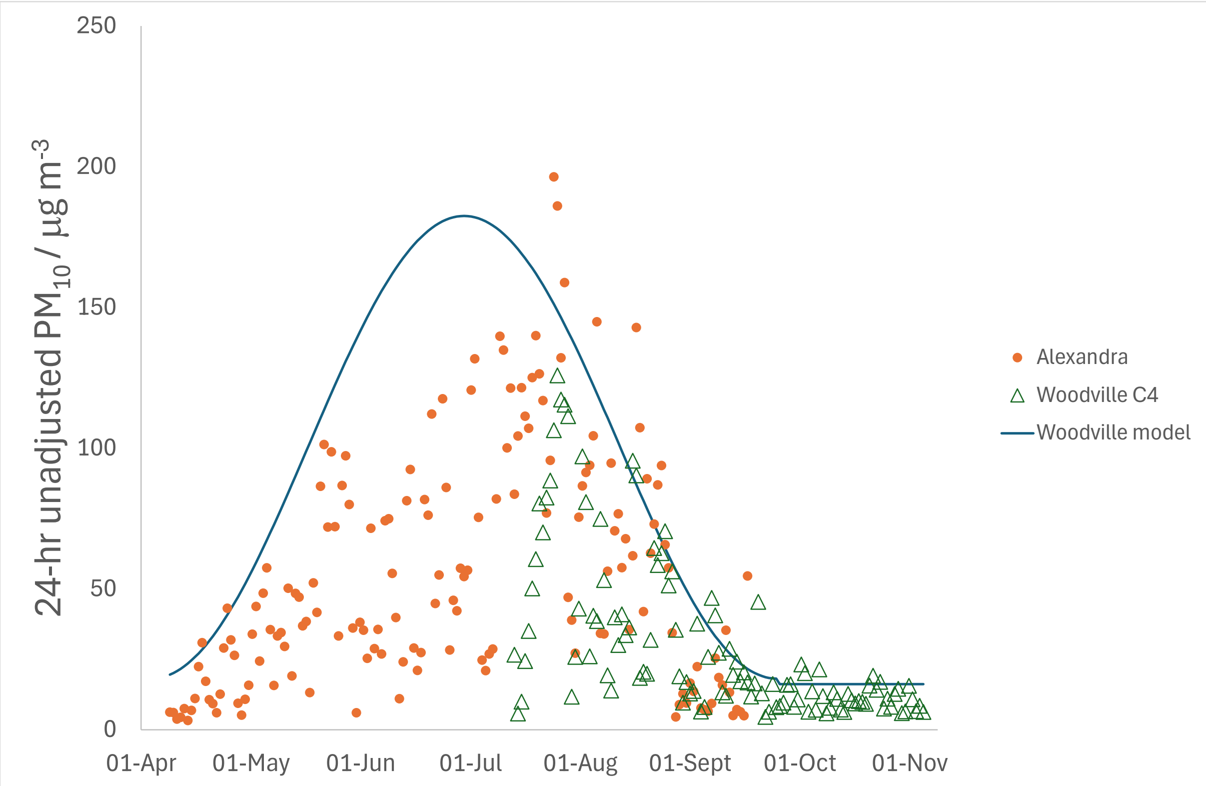

Figure 3-8: 24-hour average unadjusted PM_{10} at ORC site in Alexandra, site C4 in Woodville and a model envelope of maximum concentrations in Woodville:

The second method has a limitation in that an equation to convert Clarity data into regulatory-equivalent data ideally needs a way of quantifying the component of PM_{10} that an optical sensor like the Clarity has a very low sensitivity to. These tend to be regional background particles. We have no means of estimating that component for Woodville.

However, we make two conservative assumptions:

- That the ratio of the sensitivity of the Clarity to combustion particles relative to a regulatory method is 3 (we have previously found values ranging from 3 to 4)
- That the background contribution that is undetected by the Clarity has a constant value of 8 $\mu g\ m^{-3}$, based on values observed at other inland locations (Longley 2023a,b, 2024a,b,c).

We therefore apply the equation:

Adjusted PM_{10} = (unadjusted PM_{10} / 3) + 8

Doing this results in the prediction of a single exceedance of the PM_{10} standard at site A4. However, the margin of compliance is fine with 2 daily concentrations over 45 $\mu g\ m^{-3}$.

A standard for daily concentrations of $PM_{2.5}$ has also been proposed by the Ministry for the Environment and is already in force in many jurisdictions around the world, The proposed standard (25 $\mu g\ m^{-3}$) is harder to meet than the current PM_{10} standard in airsheds dominated by home heating emissions. In other words, an airshed that meets the PM_{10} standard by a fine margin is unlikely to meet the $PM_{2.5}$ standard. In our view, this study raises a strong possibility that Woodville would not comply with the proposed $PM_{2.5}$ standard.

3.10 Study limitations and methodological issues

This study was resource-constrained and also deploying relatively new techniques. As such there are inevitable limitations and potential lessons.

We opted to forego a co-location period, relying on the previously highly stable performance of the Clarity Node-S. A co-location against a regulatory monitor was not possible in Woodville as there isn't one. Conducting a study in Taihape or Taumarunui would have been feasible, but at the cost of reducing the time the monitors spent in the field in Woodville. Given that the monitors were not fully deployed until 17th July, i.e. more than halfway through the winter, time in the field was prioritised. However, we recommend that future work of this type in the Horizons area includes a co-location period.

Meteorological data was not collected for this study. Although meteorological data is not required to assess air quality (and spatial variation), local wind speed and direction data are particularly useful in interpreting and explaining air quality data. Deployment of meteorological instrumentation is more demanding than monitors like the Clarity Node-S. Convention dictates that wind measurements require instruments ideally elevated at 10 m above the ground, although heights of 6 m and 2 m are often used. Sites should also not be impacted by structures or vegetation that can locally impact air flows and make measurements unrepresentative and analyses misleading. This condition is quite difficult to fulfil in an urban area with meteorological measurements often limited to open parkland or school fields. In conclusion, meteorological data can be misleading unless considerable resources are spent on ensuring its validity. In studies like this one we remain unconvinced that the investment in meteorological observations is generally worth it. However, this issue should be assessed on a case-by-case basis.

4 Conclusions

This work clearly shows that air quality during winter is not uniform across Woodville. On the contrary it shows that there is a persistent spatial pattern with higher concentrations towards the south side of the town. The most polluted area remained 1.5 to 2 times more polluted than the least on nearly every day of our observational campaign.

The data strongly suggests that home heating is the only significant emission source in the long-term, with elevated PM_{10} generally requiring air temperatures to be below 10 °C.

Current guidance states that air quality monitoring for the purpose of establishing compliance with the NESAQ should be conducted at the most polluted location within an airshed. However, in advance of highly spatially detailed monitoring such as this (which has only very recently become feasible), it is very difficult to ascertain where such a location is, whether there is more than one such location, and how large an area can be considered to qualify.

The study method used in this work prioritised understanding spatial variation in Woodville over assessing compliance with National Environmental Standards. However, the data collected does indicate that exceedances of the NESAQ may have occurred during the study, and therefore may occur on a regular basis in mid-winter. Furthermore, we believe that exceedance of the proposed daily $PM_{2.5}$ standard is likely.

This work strongly indicates that any future monitoring of Woodville’s compliance with the National Environmental Standards should be undertaken in the southern part of the town.

5 Recommendations

Our key recommendations follow the process proposed in the Monitoring Plan we previously delivered to Horizons Regional Council (Longley, 2025). In brief, this recommends that a method approved for NESAQ compliance monitoring (e.g. a BAM) is deployed if the screening study finds a high likelihood of a breach of the NESAQ. If the likelihood is more uncertain, then an extended screening study is recommended.

In the author's view this report provides evidence that is on the border of these two options, and so the two options are explored a little further.

Deployment of a regulatory monitor would ideally include both PM_{10} and $PM_{2.5}$. This should happen before April 2026 and ideally last 12 months to capture the full winter and provide a complete annual mean concentration. This would provide the most robust information for judging compliance against existing and proposed future standards.

Alternatively, $PM_{2.5}$ monitoring could be conducted using a lower-cost device, such as a Clarity Node-S, or similar device at a peak site in Woodville. To ensure data from these devices is regulatory-equivalent a second device such device should be deployed at the existing Taihape or Taumarunui monitoring sites for the same period so that a regionally specific adjustment equation can be derived. This study should also start before April 2026 and ideally last 12 months to capture the full winter. This approach will reduce total costs but introduce some uncertainty into the results.

In all of the above cases, the monitoring in Woodville should be conducted in the southern half of the town at, or near, sites A3, A4, B4 or C4. Given the consistency of the north-south gradient observed in this study we find it highly unlikely that this area does not represent the "peak zone" in the airshed as meant by the Air Quality Regulations. However, if siting a compliance monitor within that peak zone is unfeasible, an extended screening study can be mounted to investigate the relationships between air quality in this area, and at any feasible monitoring site outside the peak zone.

If an extended screening study confirms the likelihood of breaches of the NESAQ (i.e. with reduced uncertainty) then a compliance monitor should be installed.

These options are summarised in Table 1.

Table 1: Summary of recommended options for an extended screening study

Option	Woodville	Taihape or Taumarunui	comment
1	BAM (or equivalent) at southern site		Higher cost, lower uncertainty
2a	Clarity (or equivalent) at southern site	Clarity (or equivalent)	Lower cost, some uncertainty
2b	Clarity (or equivalent) at southern site and at logistically feasible long-term site	Clarity (or equivalent)	Only needed if long-term site in peak zone is considered not feasible

Given that Woodville has never been subject to air quality monitoring before, and given its small size, there may be some surprise and perhaps scepticism within the community regarding the results of this study, as well as concern. As noted in the Monitoring Plan, we contend that the establishment of a community-participatory monitoring network – in which members of the community either own, part-own or co-manage the monitoring assets - can be highly valuable in combatting scepticism, addressing concerns and building appetite for action. We recommend that HRC explore the appetite for such an approach. The Air Quality Collective are leaders in designing and delivering such programmes.

In our view, this study was highly successful. We achieved 100 % data recovery and believe our main conclusion regarding spatial variation is robust. The study also yielded strong evidence that the NESAQ might be breached in Woodville. We recommend that the same approach is rolled out to other Horizons airsheds as described in our Monitoring Plan.

6 Acknowledgements

Permission to mount air quality monitors on street light poles was provided by Tararua District Council.

Thanks to HRC for undertaking instrument deployment.

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