AMBIENT AIR QUALITY (NITROGEN DIOXIDE) MONITORING PROGRAMME

Annual report 2007-2020

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EXECUTIVE SUMMARY

Waka Kotahi NZ Transport Agency (Waka Kotahi) instigated a national nitrogen dioxide (NO_2) monitoring programme, known as the National Air Quality Monitoring Network, in 2007. The purpose of the monitoring programme is to determine relative levels of vehicle pollution across New Zealand with the aim of seeing a decreasing trend in NO_2 concentrations measured at the sites. NO_2 concentrations are recorded monthly using diffusion tubes (a type of passive sampler). The results from passive samplers are less accurate than continuous monitoring but, because they are relatively less expensive, the monitoring network can cover a large number of sites.

Although a recent report confirmed that passive monitoring results are typically higher than the corresponding continuous data (on average 33% higher), passive sampling is useful as a screening method and can be used to identify hotspots and look at trends in longer term average NO_2 concentrations.

This report shows that, from 2016 to 2020, 97% of monitoring sites are expected to have met the World Health Organisation (WHO) annual NO_2 guideline value. Furthermore, when we look at the average results over the past few years, there is a general decline in NO_2 concentrations (improved air quality) across almost all of the monitoring areas.

The Waka Kotahi has plans to further refine the Network by including new sites and relocating some existing sites to more optimal locations.

HOW DO MOTOR VEHICLES AFFECT AIR QUALITY?

Good outdoor air quality is fundamental to our well-being. On average, a person inhales about 14,000 litres of air every day, and pollutants in this air can adversely affect peoples' health. People with pre-existing respiratory and heart conditions, the young, and older people are particularly vulnerable. Air and air quality are both a taonga (all things prized or treasured, tangible and intangible, treasured resource, possession or cultural item, including te reo, culturally significant species) and part of the kaitiakitanga (guardianship and stewardship - particularly for the natural environment) for Maori[1].

Air pollution comes from many sources including burning of fuels for home heating, vehicle exhausts, industrial processes, volcanoes, wind-blown dust, and pollen. There are many pollutants emitted from these sources including particles and gases. The level (or concentration) of pollutants in the air at any given time depends on the quantity of pollutants being released into the air (known as emissions), and how these emissions are affected by the weather. They can be dispersed by winds or removed by rain.

Vehicles are the main source of nitrogen dioxide (NO_2) in the air in New Zealand. In 2015, on-road vehicle emissions were the main contributor to nitrogen oxides in our air, producing 39% (47,800 tonnes) of human-generated emissions, 70% of which was from diesel vehicles[2].

Exposure to NO_2 can irritate the lungs, increasing susceptibility to asthma and lowering resistance to respiratory infections. Long-term exposure to low levels of NO_2 can affect lung growth in children and cause damage to plants.

This report describes the results from the Waka Kotahi National Air Quality Monitoring Network and reviews data gathered from the beginning of 2007 up to the end of 2020. Results are compared spatially (i.e. at different sites) and temporally (i.e. year to year and seasonally).

Why is nitrogen dioxide used as an indicator of air quality?

Motor vehicles produce a complex mix of contaminants so it is not feasible to monitor all of these. Therefore, Waka Kotahi uses one pollutant, NO_2, as a proxy for motor vehicle pollutants. This is consistent with the recommendations of the World Health Organisation (WHO) which states[3] that:

> "*Nitrogen dioxide concentrations closely follow vehicle emissions in many situations, so nitrogen dioxide levels are generally a reasonable marker of exposure to traffic-related emissions. Health risks from nitrogen oxides may potentially result from nitrogen dioxide itself, correlated exhaust components such as ultrafine particles and hydrocarbons, or nitrogen dioxide chemistry products, including ozone and secondary particles.*"

Waka Kotahi instigated a national NO_2 monitoring programme, known as the National Air Quality Monitoring Network, in 2007 with 53 locations across the state highway network throughout New Zealand. In 2009, the network was expanded to include background and local road sites with a further expansion in 2010 and again in 2016. By the end of 2020, monitoring was being conducted at 135 locations. Waka Kotahi's overall aim is to see a decreasing trend in NO_2 concentrations measured at these sites.

The previous reports that were prepared to summarise the results from the National Air Quality Monitoring Network were published in 2017 and 2019 and covered the period from the beginning of

[1] Land Air Water Aotearoa website, https://www.lawa.org.nz/learn/factsheets/why-is-air-quality-important/, accessed June 2020.

[2] Our air 2018, Ministry for the Environment & Stats NZ (2018). New Zealand's Environmental Reporting Series: Our air 2018.

[3] WHO (2006). Air quality guidelines global update 2005: particulate matter, ozone, nitrogen dioxide, and sulphur dioxide, World Health Organisation, October 2006

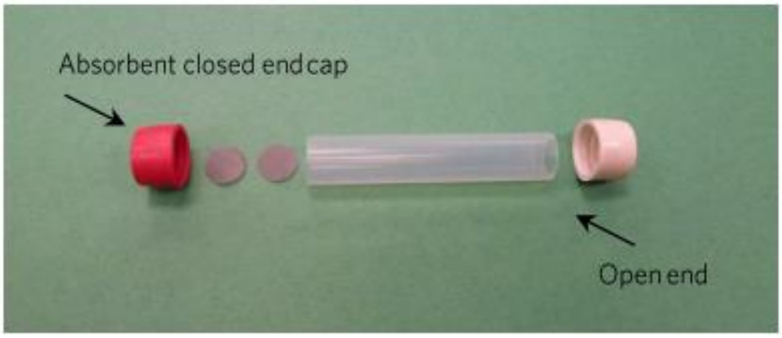
2006 to the end of 2019. This report builds on that earlier work and includes data collected up to the end of 2020.

How do we monitor NO_2?

Ambient NO_2 concentrations can be measured by continuous analysers or passive samplers. Passive samplers are easy to operate and relatively inexpensive, so they can be installed in large numbers over a wide area giving good spatial coverage. However, their results are indicative only and provide longer term (monthly) rather than daily averages. In addition, a recent report[4] confirmed that passive monitoring results are typically higher than the corresponding continuous data (on average 33% higher). Passive sampling is therefore useful as a screening method and can be used to identify hotspots and look at trends in NO_2 concentrations. It is not a regulatory method, for which continuous analysers are used. Continuous analysers measure instantaneous concentrations and are the regulatory method for assessing compliance against National Environmental Standards for Air Quality (Air Quality NES) and Ambient Air Quality Guidelines (AAQG), based on 1-hour and 24-hour averages.

The monitoring programme is operated by Watercare Services Ltd on behalf of Waka Kotahi. The programme uses diffusion tubes for passive sampling of NO_2. Passive samplers consist of a small plastic tube, approximately 7cm long. During sampling, one end is open and the other closed. The closed end contains an absorbent for the NO_2. At the end of each month, the exposed tubes are replaced and sent to a laboratory for analysis.

Figure 1: Diffusion Tube



Where are the monitoring sites?

Waka Kotahi monitoring zones have been established for each main urban area in New Zealand, as well as for Taupo, Otaki, Blenheim, Greymouth and Queenstown. The number of monitoring sites within each zone reflects the risk of being exposed to elevated levels of air pollution arising from vehicles using the state highway network. This is based on the population of urban areas in each zone.

The monitoring programme uses a simple classification scheme in which each monitoring site is designated as either:

— State Highway which are located within 100 metres of the highway being monitored,

— Local roads which are located within 50 metres of the road being monitored, or

— Urban background sites which are located more than 100 metres from a state highway and more than 50 metres from a busy local road.

[4] Emission: Impossible Ltd (June 2020). National air quality (NO2) monitoring network: Correlations between passive and continuous results 2010 to 2019. Prepared for Waka Kotahi NZ Transport Agency.

The monitoring sites are spread across each Waka Kotahi region and are generally intended to measure exposure to road vehicle emissions at locations:

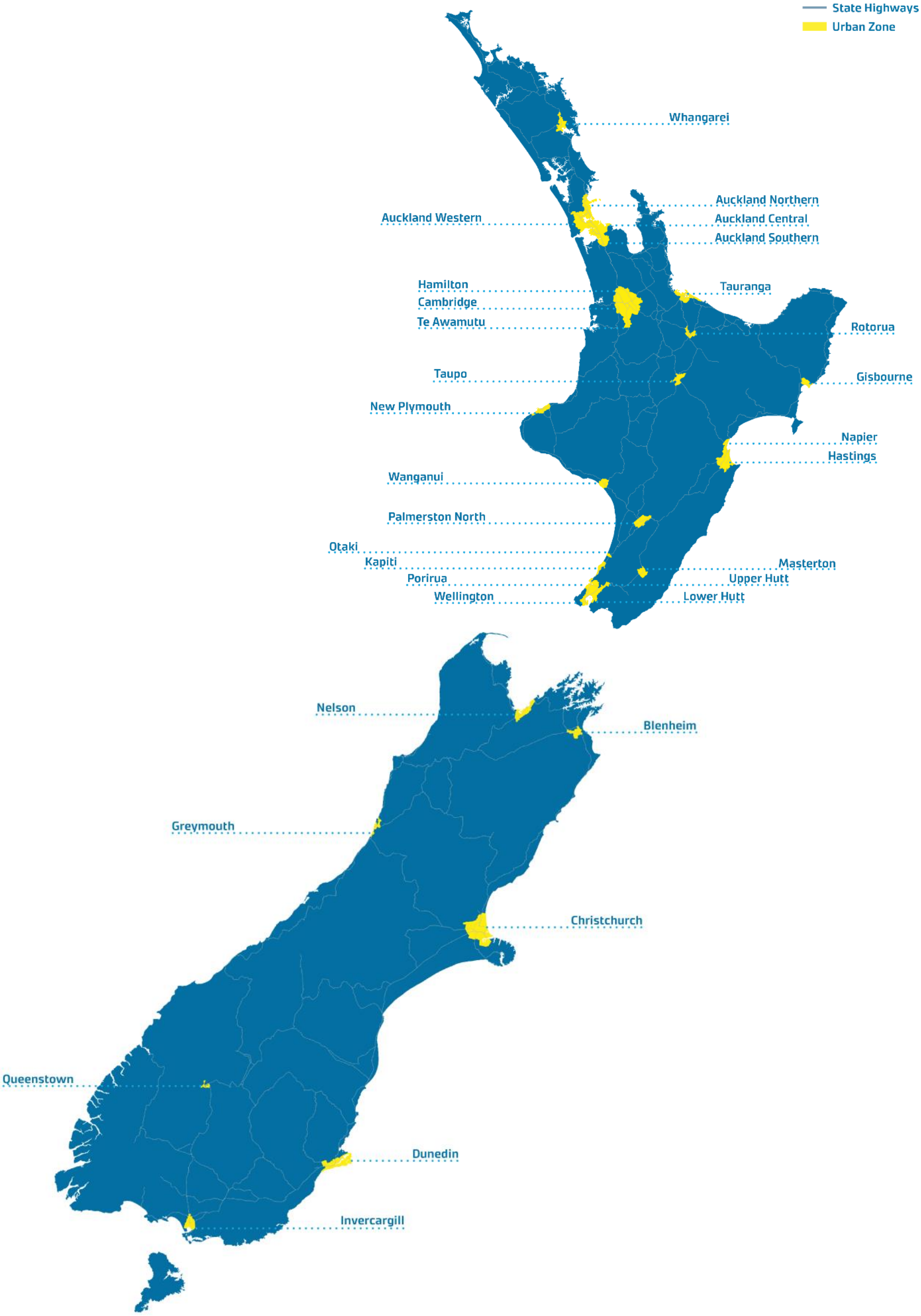
— that are sensitive to adverse air pollution effects (i.e. sites are generally within 50m of either a school or residential areas)

— where elevated concentrations are most likely to occur.

Sites are classified by monitoring zone (refer to Figure 2), broadly corresponding to towns or cities with populations greater than approximately 30,000 and site type (highway, local or background).

Each site is also allocated a unique site identification (site ID) code. Where sites have been re-located and a new source of elevated NO_2 concentrations have been identified the unique site identification code has been updated accordingly (e.g. siteID(a), siteID(b)).

Figure 2: Waka Kotahi passive monitoring zones



How do we interpret the results?

The passive monitoring results are expressed as a **monthly average** concentration. A **seasonal average** concentration is calculated if there are at least two valid monthly averages for summer and winter (i.e. at least 66% valid data for the season).

An **annual average** concentration can be calculated where there is a minimum of 75% valid data (i.e. at least nine months out of 12 of results), and at least one valid monthly average for winter (i.e. a valid average for July, August or September) and summer (i.e. a valid average for January, February or March).

In New Zealand, the health-based air quality standards and guidelines for NO_2 are set for short term exposures, i.e. 1-hour and 24-hour average concentrations. There are no New Zealand health-based guidelines for exposure to NO_2 over time periods longer than 24 hours. However, the World Health Organization (WHO)[5] has set an annual average guideline of 40 micrograms[6] per cubic metre (µg/m^3).

There is also a New Zealand annual average guideline value of 30 µg/m^3 for protecting the health of ecosystems. These relevant standards and guidelines are shown in Table 1.

Table 1: NO_2 ambient air quality standards and guidelines

Standard or guideline	Averaging period	Concentration
Air Quality NES	1 - hour	200µg/m^3
AAQG	24 - hour	100µg/m^3
AAQG (ecosystems)	Annual	30µg/m^3
WHO	Annual	40µg/m^3

The National Air Quality Monitoring Network measures monthly average NO_2 concentrations, which are not directly comparable to the short-term standards and guidelines. A 2008 review of regional council monitoring results suggested that any site which exceeds the annual average WHO guideline is also likely to exceed the 1-hour average Air Quality NES for NO_2[7]. This means that, through careful choice of sampling sites and the use of passive samplers as screening devices, locations where standards and guidelines are most likely to be exceeded due to motor vehicle emissions can be identified.

[5] WHO (2006). Air quality guidelines global update 2005: particulate matter, ozone, nitrogen dioxide, and sulphur dioxide, World Health Organisation, October 2006.

[6] 1 microgram = 0.000001 grams.

[7] NZTA (2017). Ambient air quality (nitrogen dioxide) monitoring programme – Operating manual 2017/18, prepared by Watercare Services Ltd and Emission Impossible Ltd for NZ Transport Agency, October 2017.

Waka Kotahi uses the assessment criteria shown in Table 2 to help identify locations with degraded air quality due to motor vehicle emissions, including those where the WHO annual average guideline may be exceeded.

Table 2: Waka Kotahi assessment criteria for annual average NO_2 passive monitoring results

Annual average concentration	Descriptor	Notes
≥ 40 μg/m^3	High	Identifies locations where the WHO annual NO_2 guideline may be exceeded and air quality effects of motor vehicles need further investigation
≥ 30 μg/m^3 to 39.9 μg/m^3	Medium	Identifies locations where air quality may be degraded because of motor vehicle emissions and may cause adverse effects

WHAT DO THE MONITORING RESULTS TELL US?

Is NO_2 air quality improving?

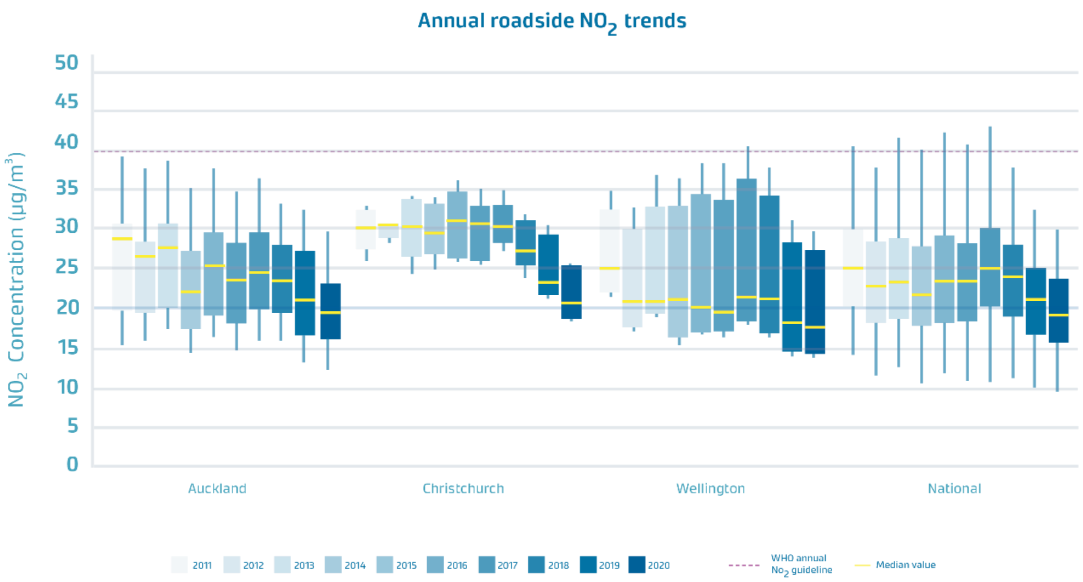
The monitoring results indicate that 97 percent[8] of monitoring sites over the period 2016 to 2020 were below the WHO annual NO_2 guideline.

Figure 3 shows the annual average NO_2 concentrations for the state highway monitoring sites in the three largest cities and the aggregated national results[9]. There has been a gradual decline in median values (represented by the inner yellow line within the boxes) from 2011 to 2020[10], with a clearer trend of improving air quality over the last 3 years.

The reasons for this trend of reducing average and median NO_2 concentrations at roadside sites over the last 3 years despite the increase in vehicle travel[11] is likely due to changes in source emissions (e.g. improvements in the emissions from the vehicle fleet) and/or meteorology (e.g. emissions may be better dispersed in some years because of weather patterns).

In 2020, the results were likely to have been impacted by the Covid-19 pandemic. The Covid-19 lockdown resulted in regional travel restrictions, greatly reducing vehicle travel. Minimum NO_2 concentrations were recorded in April and May at many sites in 2020, which is consistent with the timeframe of the nationwide Covid-19 lockdown. This may have contributed to the trend of decreased NO_2 concentrations in 2020.

Figure 3: State highway sites and NO_2 concentration levels 2011-2020



Since monitoring began in 2007, high annual average NO_2 concentrations (≥40µg/m^3) have been recorded at ten of the monitoring sites (please refer to the table in Appendix B).

The changes in NO_2 levels over time at the three monitoring sites that recorded high (≥40µg/m^3) annual average NO_2 concentrations in 2017 have been investigated in more detail. These sites are discussed in the table below and the changes in NO_2 concentrations are illustrated in Figure 4.

[8] Calculated from the monitoring sites which had at least one valid annual average recorded from 2016 to 2020
[9] All sites from across the country, including those outside of major cities
[10] 2011 was chosen because this is when the first set of complete data is available for majority of sites
[11] https://www.nzta.govt.nz/assets/userfiles/transport-data/VKT.html

The three state highway monitoring sites (in Auckland and Hamilton) which recorded high (≥ 40µg/m^3) concentrations in 2017, continued to have high NO_2 concentrations values recorded for the subsequent three years (2018-2020). The monitoring triplicate site CHR017-CHR019 at ECan Riccarton Rd had previously recorded high concentrations but the site has not exceeded 40µg/m^3 as an annual average NO_2 concentration since 2016.

Table 3: Locations recording high NO_2 annual average concentrations in 2017[12]

Site ID	Site name	Site type	Distance from Road	Discussion
AUC009 (a&b)	CMJ/Canada St	State highway	11 m	Located at Canada Street, Newton near the Central Motorway. It is likely to be impacted by very high traffic volumes. In 2017, the Waterview Tunnel which is in the vicinity of site AUC009, was opened[13] and this may have contributed to the decrease in average NO_2 concentrations recorded in 2018, 2019 and 2020.
HAM003	Lorne St/Ohaupo Rd	State highway	10 m	Both are state highway sites and are located in Hamilton. In the future, there may be an improvement of air quality in both locations due to the Waikato Expressway project which is being completed in stages and the Hamilton section is due to be completed in late 2021[14].
HAM013	Greenwood St/Killarney St	State highway	16 m	

[12] NZTA (2020). Ambient air quality (nitrogen dioxide) monitoring network – Annual report 2007-19, NZ Transport Agency, August 2020

[13] https://www.nzta.govt.nz/projects/the-western-ring-route/waterview-tunnel/, accessed May 2021

[14] https://www.nzta.govt.nz/projects/waikato-expressway/, accessed May 2021

Figure 4: Locations which recorded high (≥40µg/m³) NO_2 annual average concentrations in 2017 and the concentrations in subsequent years

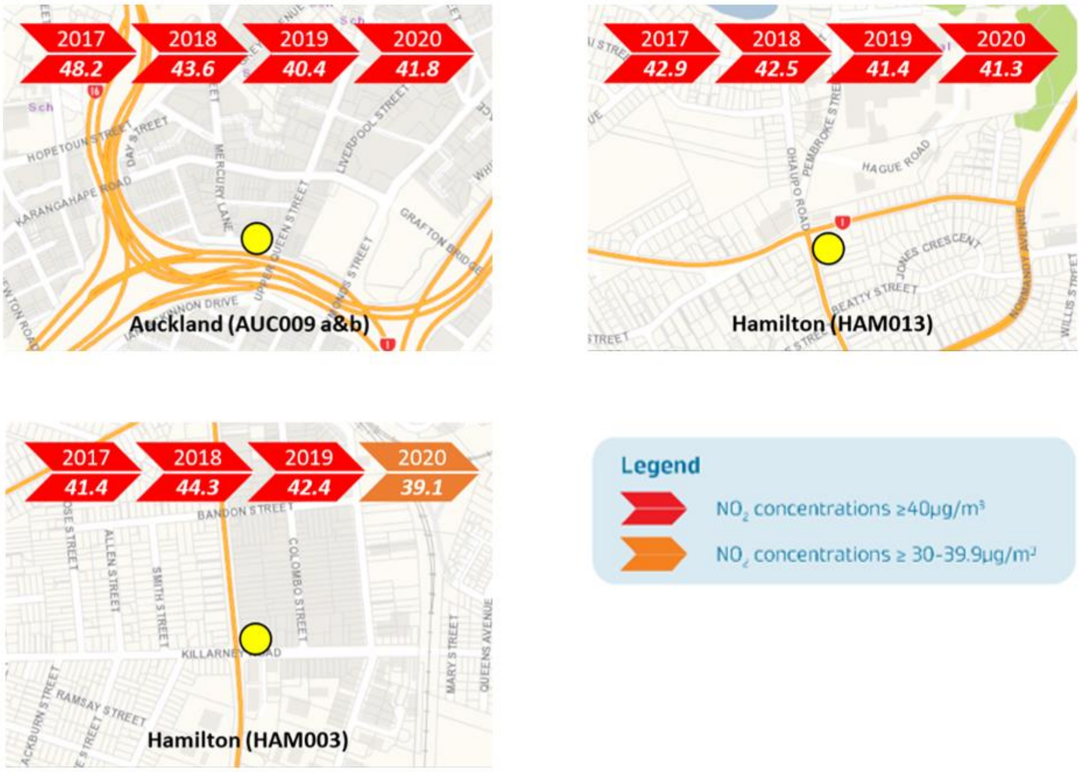
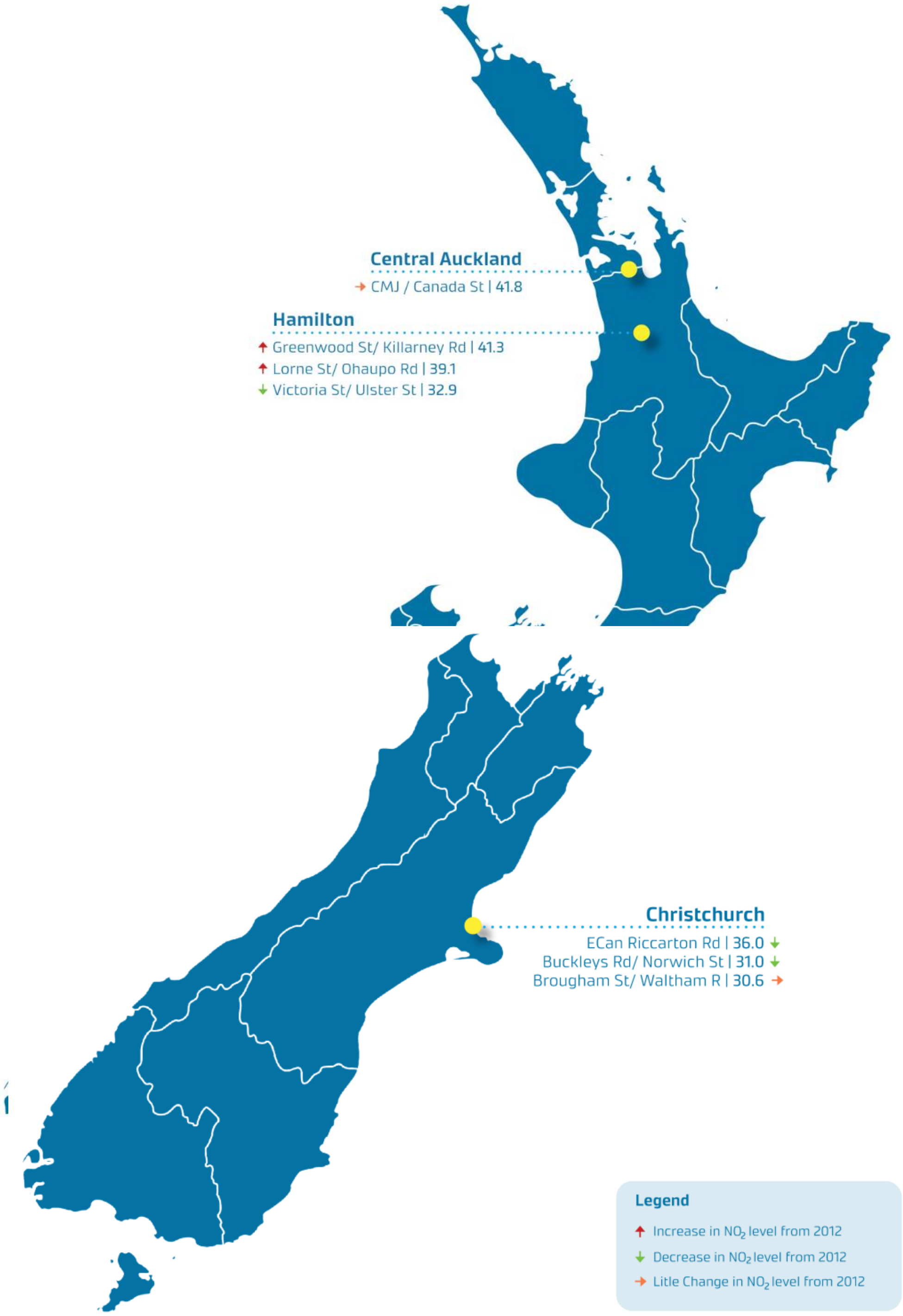


Figure 5 shows the locations that recorded high (≥40µg/m³) and medium (≥30-39.9µg/m³) annual average NO_2 concentrations in 2020 and indicates whether NO_2 concentrations are generally increasing or decreasing since 2012 (2012 was chosen for comparison because this is when the first set of complete data is available for majority of sites).

Two out of the six sites show a reduction in NO_2 concentrations since 2012. One site has had little change in NO_2 concentrations since 2012 and two sites (both in Hamilton) have had an increase in NO_2 concentrations since 2012.

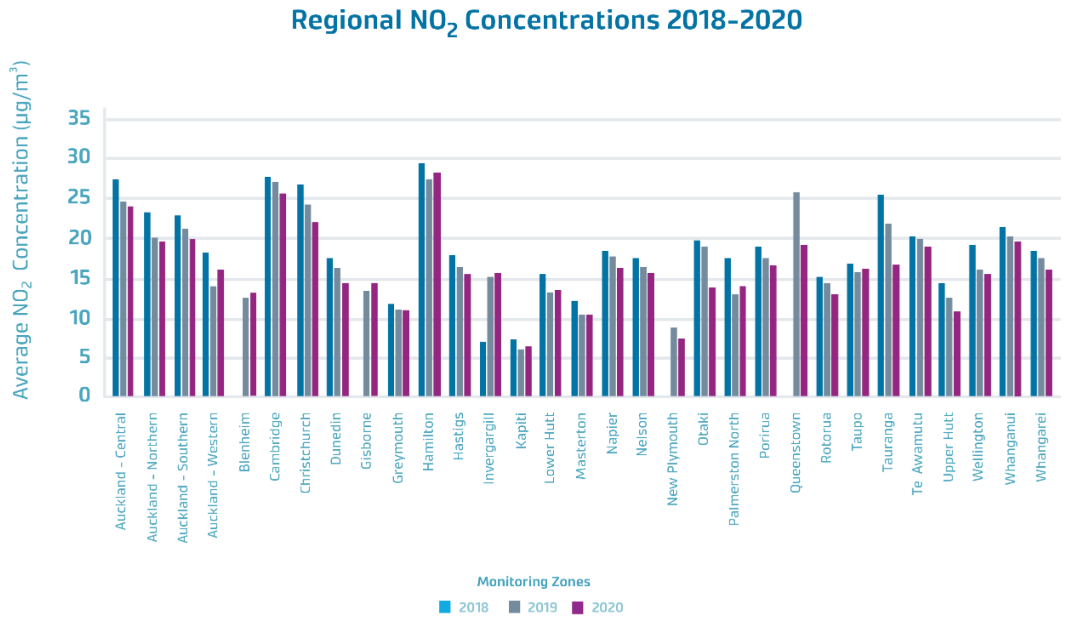
Figure 5: Locations of medium (≥ 30-39.9µg/m³) and high (≥ 40µg/m³) average NO_2 concentrations recorded in 2020 and change compared to 2012



How do the results differ across New Zealand?

As can be seen from Figure 6 below, the highest average NO_2 monitoring results in 2020 were recorded in the Central Auckland, Cambridge and Hamilton monitoring zones[15]. The lowest average monitoring results in 2020 were recorded in the Kapiti, Masterton and New Plymouth monitoring zones. When we look at the average results over the three years, there is a general decline in NO_2 concentrations (improved air quality) across almost all of the monitoring zones[16].

Figure 6: Average NO_2 concentrations measured in NZ monitoring zones



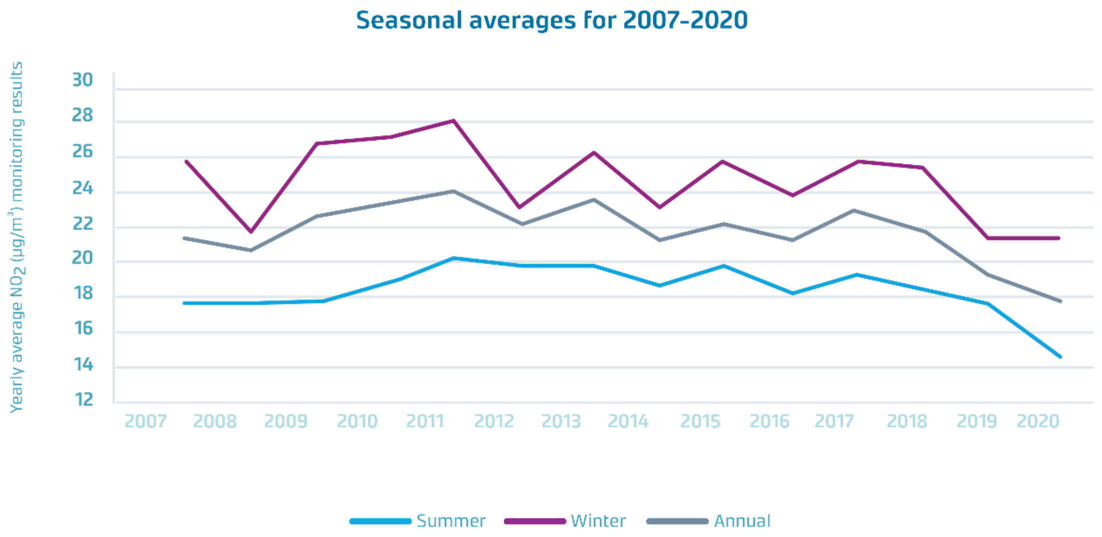
[15] This is based on data from all road types however the numbering of monitoring sites varies between zones, e.g. Queenstown only has one monitoring site, whereas Auckland Central has 18 monitoring sites.
[16] Complete data for the three years is unavailable for Blenheim, Cambridge, Gisborne, New Plymouth and Queenstown.

Are the NO_2 concentrations higher in summer or winter?

Figure 7 illustrates that NO_2 concentrations vary seasonally and further analysis of the data shows that the highest NO_2 concentrations are observed during July and the lowest NO_2 concentrations are observed during December (please refer to Appendix C).

This seasonal trend in NO_2 concentrations close to roads is likely to be because weather conditions in winter tend to inhibit dispersal of emissions compared to summertime conditions.

Figure 7: Varying NO_2 concentration levels during the seasons[17]



HOW DO WE KNOW THE DATA IS RELIABLE?

At a small number of the monitoring sites (seven in 2020), three passive samplers (referred to as triplicate samples) are co-located with continuous NO_2 monitors operated by the local regional council to assess the precision and accuracy of results.

A recent report found that the passive monitoring results were typically higher than the corresponding continuous monitoring data (on average 33% higher)[18]. It was noted that this finding is broadly consistent with a database of over one thousand co-location studies compiled by the UK Department of Environment, Food and Rural Affairs. The report also found that there was a strong non-linear correlation between the annual average NO_2 concentrations measured using passive and continuous techniques. This finding increases confidence in the reliability of passive sampling as a screening method, but also confirms that the results should not be directly compared to guideline values.

The precision of the passive samplers' results is checked by comparing the monthly variation (coefficient of variation, CV) between the triplicate samples (presented graphically in Appendix A).

The CV is calculated according to:

$$CV\ (\%) = \frac{\text{standard deviation of the sampler results x 100}}{\text{mean of the sampler results}}$$

[17] Includes data from every site with either valid summer, winter or annual values.

[18] Emission Impossible Ltd (2020). National air quality (NO2) monitoring network: Correlations between passive and continuous results 2010 to 2019. Prepared for Waka Kotahi NZ Transport Agency.

The precision of the diffusion tubes is categorised as “good” or “poor” as follows[19]:

- Diffusion tubes are considered to have "good" precision where the CV of duplicates or triplicates based on 8 or more individual periods during the year is less than 20%, and the overall average CV of all monitoring periods is less than 10%.
- Diffusion tubes are considered to have "poor" precision where the CV of four or more individual periods is greater than 20% and/or the overall average CV is greater than 10%.

The distinction between "good" and "poor" precision is an indicator of how well the same measurement can be reproduced.

For the triplicate sites in the network between 2007-2016, the average CV for all triplicate samples taken between 2007 and 2016 has been less than 8%[20]. For the triplicate sites in the network between 2016-2020, the overall average of all monthly CV's was calculated to be 4.8%.

The CV has been less than 20% for 99.5% of the triplicate samples during 2016-2020, indicating that the precision of the passive samplers is good.

ARE THERE ANY FUTURE CHANGES PROPOSED TO THE PROGRAMME?

Waka Kotahi has plans to split the monitoring network into a Regional Network of representative sites, and Local Networks covering sites subject to highly local influences. This will involve maintaining current monitoring sites, establishing new monitoring sites and relocating some existing sites to more optimal locations, following recommendations by National Institute of Water & Atmospheric (NIWA) who recently carried out a review of the National Air Quality Monitoring Network. NIWA also recommended improving coverage in parts of the existing local network – mainly busy city centre streets, but also Ports and growth areas. Waka Kotahi will be working with Regional Councils to take forward the NIWA recommendations.

A non-linear correlation can be used to “adjust” the annual average NO_2 concentrations from passive sampling so they are closer to the results that would be obtained using a continuous (regulatory) monitoring technique. The correlation developed for the 2019 year (Emission Impossible Ltd, 2020) is as follows:

Equivalent reference NO_2 concentration ($\mu g/m^3$, annual average) = $-0.0279x^2 + 2.1556x - 3.5442$

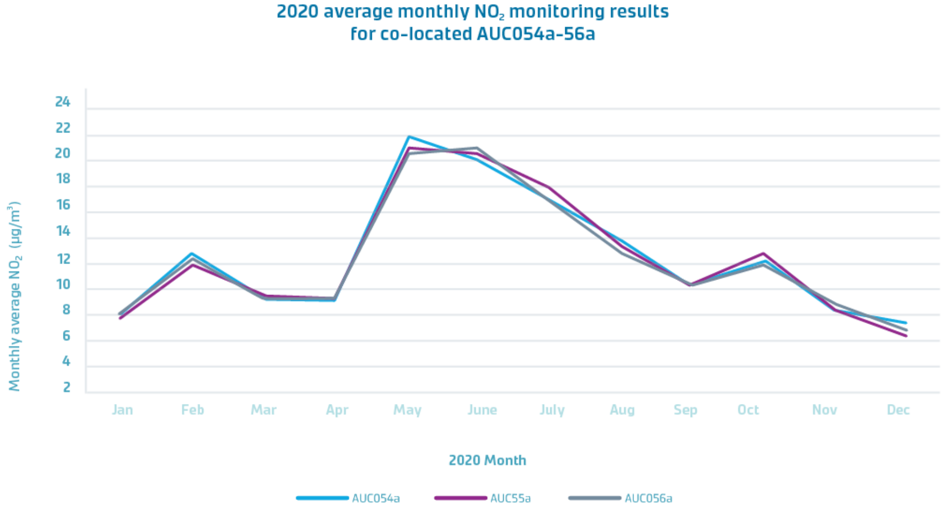
Where:

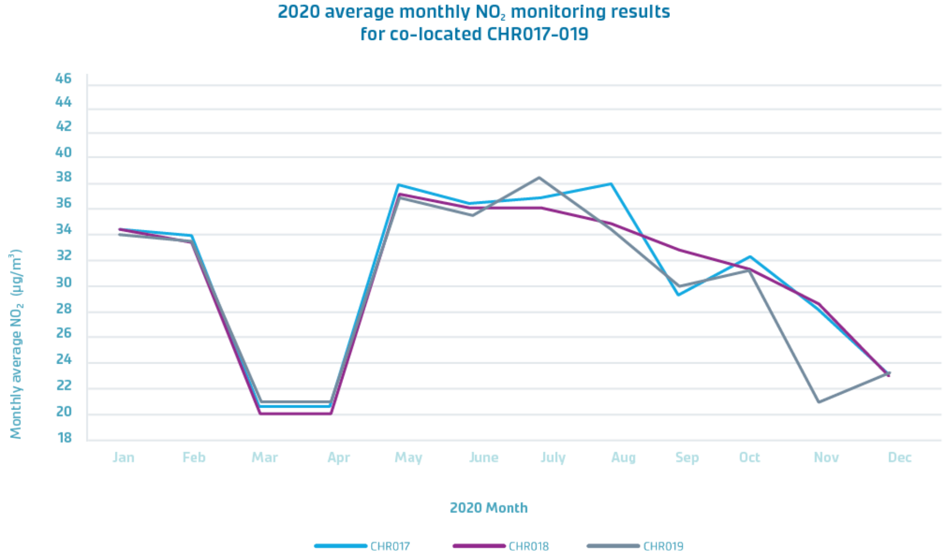
x is the concentration of NO_2 measured using a passive sampler ($\mu g/m^3$, annual average)

If this relationship is applied to the 2020 results at the two state highway monitoring sites (in Auckland and Hamilton) which recorded high ($\geq 40\mu g/m^3$) concentrations in 2020, then all of these sites would be expected to comply with the World Health Organisation ambient air quality guideline. In the future, the use of an adjustment factor will give Waka Kotahi greater confidence in identifying any areas in the national network where the annual average NO_2 air quality guideline value may be exceeded.

[19] DEFRA (2016). Local air quality management, technical guidance LAQM TG(16). Published by Department for Environment, Food and Rural Affairs, April 2016.
[20] NZTA (2017). Ambient air quality (nitrogen dioxide) monitoring network – Annual report 2007-16, NZ Transport Agency, November 2017

Graphs showing 2020 NO_2 levels recorded for three co-located passive monitors.





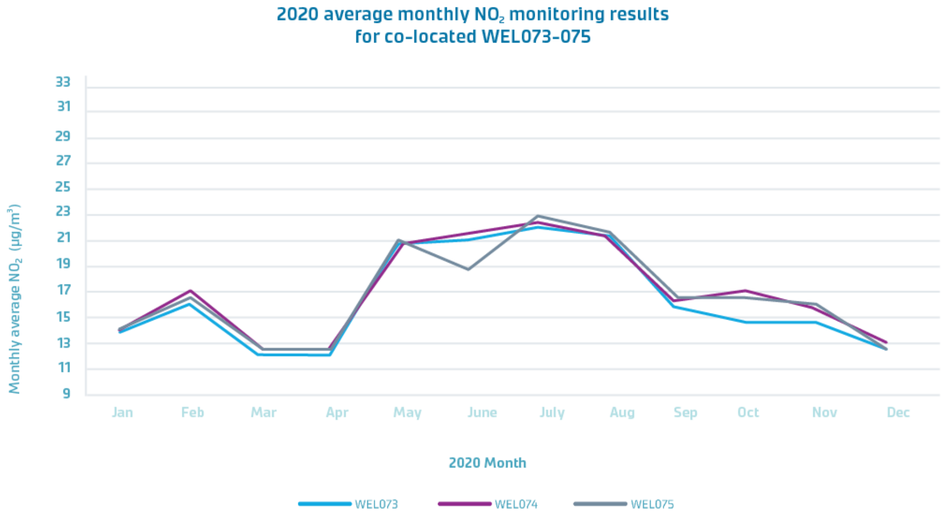


Table showing the ten locations which recorded high (≥40μg/m^3) annual average NO_2 concentrations since the monitoring programme began in 2007.

Zone	Site ID	Site type	2020	2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007
Auckland - Central	AUC009(a&b)	SH	41.8	40.4	43.6	48.2	47.7	Insuf data	41.0	46.5	41.3	43.9	40.8	44.0	35.8	41.9
Hamilton	HAM013	SH	41.3	42.4	44.3	41.4	40.4	42.2	39.9	41.4	36.8	40.1				
Hamilton	HAM003	SH	39.1	41.4	42.5	42.9	40.5	41.4	38.7	38.4	37.5	40.4	39.0	40.0	38.3	36.1
Christchurch	CHR017-19	Local	30.5	36.0	36.8	38.4	40.8	39.7	36.1	41.6	41.4					
Wellington	WEL008	SH	29.8	31.1	37.8	40.3	38.2	38.3	36.4	36.7	32.7	34.8	35.5	33.3	31.3	39.4
Christchurch	CHR016	Local	27.9	31.0	35.0	40.7	32.1	35.1	35.3	37.5	33.6	36.8				
Wellington	WEL049	Local	27.5	30.3	38.7	38.1	37.0	39.6	36.9	38.8	31.0	39.0	40.3			
Auckland - Central	AUC060	Local	26.9	28.8	32.0	36.2	36.7	38.9	34.9	38.8	37.6	40.3	39.9			
Auckland - Western	AUC063	Local	26.2	Insuf data	30.2	32.5	33.7	35.8	34.6	37.4	36.8	40.8	38.3			
Auckland - Southern	AUC068	SH						Decom	40.9	46.0	41.5	44.7	43.3			

The sites are listed in order based on the annual average NO_2 concentrations recorded in 2020.

During 2020, 93% of the monitoring sites had the highest NO_2 concentrations observed during the May to July period and 52% of the monitoring sites had the lowest NO_2 concentrations observed during December. Other years show a similar trend with the same dominant months. There was a trend of more frequent minimum monitoring values in the months of March and April. This is most likely due to the COVID-19 lockdown.