NIWA
Taihoro Nukurangi

Review of the National Air Quality Monitoring Network

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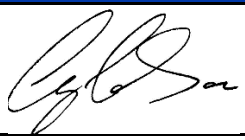
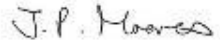
Guy Coulson, Group Manager (Air Quality), NIWA Auckland	Reviewed by:	
Jonathan Moores Regional Manager Auckland	Approved for release by:	

Contents

Executive summary **6**

1 Introduction **9**

1.1 Background 9

1.2 Scope of the project 9

2 Review of the Network as a whole **11**

2.1 Overview of the Network 11

2.2 Brief history of the Network 11

2.3 Objectives of the Network 11

2.4 Other comparable monitoring networks 12

2.5 Main outputs and lessons from the Network 12

2.6 Additional uses of data from the Network 13

2.7 Review of relevant recent research 14

2.8 Main limitations of the Network 19

2.9 Brief review of stakeholder needs and opportunities 20

2.10 Relevant developments in monitoring and related technology 20

2.11 Reviewing objectives 21

3 Review of Network Sites – Methods **22**

3.1 Overview 22

3.2 Tools and datasets used 22

3.3 Assessment of site representativeness 23

3.4 Site re-classification 24

4 Review of Network sites - Results **26**

4.1 Modelled NO_2 for each monitoring zone 26

4.2 Traffic trends 28

4.3 Definition of monitoring zones 29

4.4 Site re-classification 29

5 Recommendations for re-organisation and optimisation of the Network **31**

5.1 Overview 31

5.2 Calibration campaigns and model update 31

5.3 Proposed optimum network coverage 32

5.4 Currently unmonitored urban areas 33
5.5 New, redundant sites and site relocations - overview 34
5.6 Network changes – priorities and options to partially implement recommendations 34
5.7 New sites – location details 35
5.8 Metadata 35
5.9 Management of the data 36
5.10 Long-term optimisation of the Network 36
5.11 New measurement technologies 36
5.12 Summary of recommendations 36

6 References 38

Appendix A Site re-classification 39

Appendix B Representativeness of existing Network sites for each monitoring zone 43

A guide to interpreting the figures in this Appendix 43

Figures for each monitoring zone 44

Appendix C Proposed Network coverage by monitoring zone 58

Tables

Table 2-1: Recommended background NO_2 concentrations from NZTA Background Air Quality Guide. 13
Table 2-2: Summary of major NO_2 sampling datasets since 2007, other than the NZTA Network. 14
Table 5-1: Monitoring zones for which we have recommended more than one regional roadside monitoring site. 32

Figures

Figure 2-1: Annual mean NO_2 in 2018 for all sites across five cities. 13
Figure 2-2: Sites AUC068 and AUC190 in Mangere, and two sites from the Future Streets project indicating strong spatial gradients around the intersection. 16
Figure 2-3: Intensive sampling of NO_2 (annual mean concentrations) in and around Adelaide Road, Wellington (NIWA, University of Otago, 2017). 17
Figure 3-1: Example of modelled NO_2 (coloured base map) and deviation of observed NO_2 from the model (coloured circles). 24
Figure 4-1: Distribution of NO_2 across monitoring zones, according to the Traffic Impact Model v3.1. 27
Figure 4-2: Recent 5-year traffic volume trends in Auckland. 28

Figure B-1:	Example of cumulative frequency distribution of NO_2 across a city and where on that distribution current NZTA sites lie.	43
Figure C-1:	Proposed Network for Auckland - Central.	60
Figure C-2:	Proposed Network for Auckland - Central (CBD detail).	61
Figure C3	Proposed Network for Auckland - Northern.	63
Figure C-4:	Proposed Network for Auckland - Southern.	65
Figure C-5:	Proposed Network for Auckland - Western.	67
Figure C-6:	Proposed Network for Blenheim.	68
Figure C-7:	Proposed Network for Cambridge.	69
Figure C-8:	Proposed Network for Christchurch.	70
Figure C-9:	Proposed Network for Dunedin.	72
Figure C-10:	Proposed Network for Gisborne.	73
Figure C-11:	Proposed Network for Greymouth.	74
Figure C-12:	Proposed Network for Hamilton.	76
Figure C-13:	Proposed Network for Hastings.	77
Figure C14	Proposed Network for Hibiscus Coast.	78
Figure C-15:	Proposed Network for Invercargill.	80
Figure C-16:	Proposed Network for Kāpiti Coast.	81
Figure C-17:	Proposed Network for Lower Hutt.	82
Figure C-18:	Proposed Network for Masterton.	83
Figure C-19:	Proposed Network for Napier.	84
Figure C-20:	Proposed Network for Nelson.	85
Figure C-21:	Proposed Network for New Plymouth.	86
Figure C-22:	Proposed Network for Ōtaki.	87
Figure C-23:	Proposed Network for Palmerston North.	88
Figure C-24:	Proposed Network for Porirua.	89
Figure C-25:	Proposed Network for Queenstown.	90
Figure C-26:	Proposed Network for Rotorua.	91
Figure C-27:	Proposed Network for Taupō.	92
Figure C-28:	Proposed Network for Tauranga.	93
Figure C-29:	Proposed Network for Te Awamutu.	94
Figure C-30:	Proposed Network for Upper Hutt.	95
Figure C-31:	Proposed Network for Wellington.	97
Figure C-32:	Proposed Network for Wellington - CBD detail.	98
Figure C-33:	Proposed Network for Whanganui.	99
Figure C-34:	Proposed Network for Whangarei.	100

Executive summary

In 2007, the NZ Transport Agency began a national monitoring programme to determine relative levels of vehicle pollution across the state highway network. Samplers are now located at more than 120 sites across New Zealand, mostly mounted on street lights at urban roadsides, forming a Network to collect monthly samples of airborne nitrogen dioxide (NO_2) as a proxy for vehicle-related air pollution. The overall aim is to see a decreasing trend in concentrations measured at these sites. This review considers whether the Network remains fit for purpose, whether it can provide data for a wider range of purposes than originally intended, and whether it can take advantage of developments in technologies and science that have occurred since the Network was established or are anticipated in the near future.

The review covers

- the Network, including its objectives and fitness for purpose relative to its objectives in the context of improved understanding of traffic-related air pollutants,
- Opportunities to derive additional value and uses from the Network,
- A review of the sites and sampling technology that currently make up the Network,
- Recommendations for changes to the Network.

The review considers anticipated needs and opportunities for approximately a decade into the future. The review does not consider detailed costs (saved, re-directed or additionally incurred) of any recommended changes, except in the broadest approximate terms.

We find that the Network has been successful in terms of identifying many (but not all) locations where the contribution of road traffic to local air pollution is most significant (mainly road intersections), and in tracking trends over time (which are relatively weak but varying between different sites). The Network has established that concentrations are below World Health Organisation guideline in most monitored locations but have exceeded the guideline at between 2 and 9 sites each year.

When combined with other comparable measurements made by other organisations, and research conducted by NIWA, data from the Network has also revealed very strong local variations in NO_2 in space which act to introduce uncertainty into how representative or biased any given monitoring site is. This uncertainty has made data from the Network less suitable for project and health risk assessment, inter-city comparison, or any application where the data is to be used to infer impacts at unmonitored locations such as homes and workplaces. However, the realisation of the importance of local influences on measurements also provides a new range of opportunities for the Network, such that it can be re-orientated to monitor not just the effect of national or regional trends or policies (such as the evolving vehicle fleet), but the effect of local-scale and micro-scale changes and interventions, such as traffic demand management, infrastructure design, and low-emission policies.

In our review of Network objectives, we found that original objectives for the Network are still valid and that the Network is broadly meeting them. However, we find that the Network objectives can and should be expanded to better serve additional purposes, including:

- More accurate assessment of baseline air quality for project assessment
- Unbiased, representative and nationally consistent monitoring coverage consistent with the Environmental Reporting Act
- Estimation of total and regional health burden (enabled through a known relationship between monitoring data and (as a minimum) concentrations at place of residence, and ideally personal exposure)
- More robust and meaningful indicators of progress in reducing emissions and their impacts
- Better support for cost-benefit analysis of transport projects
- Improved evidence base for both transport and land-use planning interventions and policies which impact air pollution

Our review of individual monitoring sites on the Network was largely based on establishing the temporal and spatial representativeness of each existing site, using a combination of a new spatial model of air quality developed by NIWA (the "Traffic Impact Model"), and other available information. A new site classification system was developed in which each site is classed as either "regionally representative" or "locally-influenced", based on whether concentrations and their trends could be predicted at other locations in a city based on measurements at that site. For "local" sites, the primary influence was also estimated (mainly high emissions due to busy intersections, but also non-road sources, or reduced dispersion due to street canyons and other local factors). Finally, all sites were classified as "Roadside" or "Urban Background", depending on whether concentrations are dominated by one or a few nearby roads or the well-mixed contribution of many more distant roads. Finally, a revised Network was designed intended to give equal and unbiased coverage of representative, local, roadside and urban background sites across all the towns and cities currently covered by the Network.

Our review of the monitoring technology used across the Network is relatively brief, but strongly informed by a current separate project by NIWA for NZTA.

Our recommendations for the re-organisation and optimisation of the Network are as follows:

- Most sites in the current Network should remain in place.
- The Network should be split into a Regional Network of representative sites, and Local Networks covering sites subject to highly local influences.
- We propose that the top priority is to establish Regional Networks which ensure a minimum coverage for each monitoring zone (town or city) including:
  - One regionally representative urban background site
  - One regionally representative roadside site
  - This will require that 28 new sites be established - 16 new regional urban background sites and 12 new regional roadside sites
- Local Networks should be developed in partnership with key local stakeholders, particularly regional councils and territorial local authorities. These will provide

coverage that is largely missing from the existing Network – mainly busy city centre streets, but also ports and growth areas.

- Spatial sampling campaigns should be conducted in monitoring zones with higher model uncertainty and repeated on a long-term basis (e.g. 5 - 10-year cycle). We recommend Christchurch be addressed as a high priority due to substantial variability in traffic post-earthquakes and large population, followed by Tauranga, Palmerston North, Nelson, Rotorua, Whangarei, New Plymouth and Invercargill.
- Monthly traffic data relating to major roads adjacent to Network sites should be made readily and easily available.
- A structured database should be created with an open application programming interface (API) so that data can be readily ingested into other models or services.
- The Network should be reviewed at least every 5 years to reconsider trends in NO_2 and how they relate to local and regional trends in traffic.
- The recently conducted trial of emerging sensors in the Waterview Tunnel should be extended to test more sensors over a longer period. Promising sensors should then be deployed at a small number of high-concentration sites across the Network for a trial period (e.g. one year). Sites in central Auckland are likely to be most promising.

1 Introduction

1.1 Background

In 2007, the NZ Transport Agency began a national monitoring programme to determine relative levels of vehicle pollution across the state highway network. Passive samplers are now located at more than 120 sites across New Zealand to measure nitrogen dioxide (NO_2) as a proxy for vehicle-related air pollution. The overall aim is to see a decreasing trend in NO_2 concentrations measured at these sites. This aligns with the government's desired long-term impact which seeks a 'reduction in adverse environmental (air quality) effects from land transport' as stated in the Government Policy Statement for Land Transport.

As a result of a review of research and data needs conducted through the Transport Emissions Knowledge Hub (https://www.transport.govt.nz/mot-resources/transport-knowledge-hub/environment/) it has become apparent that there is a need to review the monitoring network. The review should consider whether it remains fit for purpose, whether it can provide data for a wider range of purposes than originally intended, and whether it can take advantage of developments in technologies and science that have occurred since the network was established or are anticipated in the near future.

This review has been conducted approximately concurrently with a similar review by NIWA for Greater Wellington Regional Council (GWRC). GWRC have augmented the NZTA Network with extra monitoring sites in their region. Our review for GWRC used the same principles and methods as found in this work and we make the same recommendations as they relate to the GW region.

1.2 Scope of the project

This work aims to assist the NZ Transport Agency aim of optimising the Network, which we have broadly interpreted to mean increasing its utility and value to the Agency and other stakeholders without significantly increasing costs. The Agency indicated at the start of the project that a 2-stage implementation is anticipated, where relatively minor adjustments (e.g. re-location of sites) are implemented first, and more fundamental changes (additional pollutants, continuous monitoring, etc) are implemented at a later stage.

This review includes both the existing NZTA network of passive NO_2 tubes and the data publicly available from it. The review consists of four main parts:

- Review of the Network, including its objectives and fitness for purpose in the context of improved understanding of traffic-related air pollutants,
- Opportunities to derive additional value and uses from the Network
- Review of the sites and sampling technology that currently make up the Network
- Recommendations for changes to the Network

This review considers anticipated needs and opportunities for approximately a decade into the future. It also considers the role that long-term monitoring sites operated by Regional Councils can play in supplementing the NZTA Network.

This review does not consider detailed costs (saved, re-directed or additionally incurred) of any recommended changes, except in the broadest approximate terms.

2 Review of the Network as a whole

2.1 Overview of the Network

The Ambient Air Quality (Nitrogen Dioxide) Monitoring Network (hereafter referred to as "the Network") uses a passive sampling technology (palmes-type diffusion tubes) to collect month-long samples of nitrogen dioxide (NO_2) at several sites around the country, every month. NO_2 is monitored because passive sampling provides a reliable but low-cost means of measuring NO_2 as a pollutant of concern, and as a proxy for all road traffic-related air pollutants.

Various documents relating to the Network are available from NZTA (https://www.nzta.govt.nz/resources/air-quality-monitoring/), including annual reports, a metadata report (2007 – 2012) and Operating manuals (2013-14 and 2017-18). Collectively these reports describe the purpose, methods and main findings of the Network. In brief, the Network is established in response to the Agency's Environmental Plan (NZTA, 2008), recognising that understanding the contribution of vehicle traffic to air quality is an essential step in reducing that contribution where it is significant.

2.2 Brief history of the Network

The Network was established by the NZ Transport Agency in 2007. The Network originally consisted of sampling at 53 locations with a focus on sites along state highways where high traffic contributions, and hence peak concentrations were expected. This means that the Network (much like regulatory air quality monitoring conducted by Regional Councils) was explicitly **not** designed to be representative of population exposure. Expansions occurred in 2009 and 2010 including some 'background' sites with lower concentrations, although sites alongside busy roads still dominate the Network.

By the end of 2018, monitoring was conducted at 135 locations, 25 of which were classed as 'background'. Sites were organised into Monitoring Zones, broadly corresponding to towns or cities with populations greater than approximately 30,000. Auckland is split into four zones – Central, Northern, Western and Southern.

2.3 Objectives of the Network

The objectives, as stated by the NZ Transport Agency (NZTA, 2017a), are to support the Agency's objectives for improving air quality, specifically:

- Understand the contribution of vehicle traffic to air quality.
- Ensure new state highway projects do not directly cause national environmental standards for ambient air quality to be exceeded.
- Contribute to reducing emissions where the state highway network is a significant source of exceedances of national ambient air quality standards.

The overall aim is to see a decreasing trend in NO_2 concentrations measured across the Network. Beyond that, however, the available documentation is relatively opaque regarding the how the Network is intended to support these higher-level objectives.

2.4 Other comparable monitoring networks

A complementary NO_2 monitoring network, using the same sampling technology, monthly sampling schedule and site naming convention, was established by Greater Wellington Regional Council in 2017. This network was co-designed by NIWA (Longley et al., 2016) and is intended to complement the NZTA Network in that region by filling gaps in coverage, rather than providing duplicate information.

2.5 Main outputs and lessons from the Network

At the time of writing the most recent Network Annual Report (NZTA, 2017b) - covering the years 2007 to 16 - included the following conclusions:

- The sites reporting the highest concentrations have been consistently high over the years and include major road intersections.
- Long-term trends in annual mean NO_2 concentrations at the 34 sites operating since 2007 were relatively slow, were rising prior to 2012 and unchanging since then.

For this work we have reviewed all Network data from 2007 to 2018 inclusive. We find the following additional conclusions:

- Annual mean concentrations measured within the Network have varied from 5.4 – 48.2 $\mu g\ m^{-3}$, with a mean of 22.1 $\mu g\ m^{-3}$.
- Four sites have been in the top 10 annual mean concentrations in every year from 2010 – 2018:
  - AUC009 (Auckland Central Motorway Junction)
  - AUC068 (junction George Bolt Dr and Kirkbride Rd, Mangere, Auckland)
  - CHR017/019 (junction Riccarton Rd and Division Str, Christchurch)
  - HAM003 (junction Lorne Str and Ohaupo Rd, Hamilton)
- Each year between 2 and 9 sites have reported annual mean concentrations above the WHO guideline of 40 $\mu g\ m^{-3}$.
- Most towns and cities have one or two sites. However, the largest five cities have more. This has allowed us to determine that variation in concentrations within cities can be greater than that between cities, as shown in Figure 2-1.
- When considering all sites, and contrary to the findings of the 2016 NZTA Annual Report, we found a weak downward trend in concentrations before 2012 and a weak upward trend since.

- The data shows that many sites exhibit correlated year-to-year fluctuations, typically of the order of a few µg m^{-3}, most likely due to temporary meteorological deviations from the long-term climate.

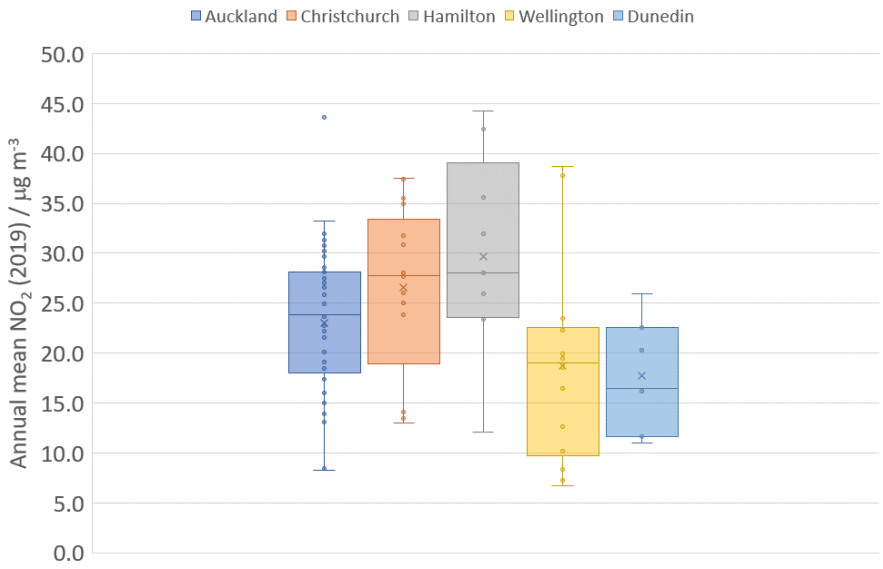


Figure 2-1: Annual mean NO_2 in 2018 for all sites across five cities. Boxes shows interquartile range, whiskers show max and min, crosses show mean concentrations.

2.6 Additional uses of data from the Network

Since its establishment, data from the Network has found two main uses additional to air quality monitoring.

An important part of the assessment of environmental effects for significant road projects is the quantification of background air quality – i.e. air quality arising from all emissions sources that are not related to the project being assessed. Although specific monitoring for the project can be undertaken, this is not always practical, or not in the most desirable location. In recognition of this the NZTA established a Background Air Quality Map[1] for this purpose. This map sought to use available observational data, including data from the NZTA Network. However, the original version released in 2014 is very crude – consisting of only 4 numbers (see Table 2-1) - and does not provide the spatial resolution that may be required for some projects.

Table 2-1: Recommended background NO_2 concentrations from NZTA Background Air Quality Guide.

Location	Annual mean NO_2 / µg m^{-3}
Auckland central	19
Other main urban areas	16
Secondary or minor urban area	13

[1] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/tools/air-quality-map/

Location	Annual mean NO_2 / $\mu g\ m^{-3}$
Rural	4

The Environmental Reporting Act 2015 requires the Ministry for the Environment and Stats NZ to report regularly on the state of the environment, as well as pressures on this state and impacts on the environment and human wellbeing. It required a shift in emphasis from monitoring the state of compliance with standards (implying monitoring the most polluted locations) towards more balanced coverage of the distribution of pollution (both high and low levels), with emphasis on where people are exposed. From 2014 onwards, data from the NZTA Network has been included in the reporting of state the Air Domain report (MfE & StatsNZ, 2018) and Environment Aotearoa synthesis report (MfE & StatsNZ, 2019), despite its relative bias to more polluted locations. However, this bias has prevented the data being used for reporting of impacts.

2.7 Review of relevant recent research

Since the Network was established in 2007, other monitoring and research has been conducted which have improved our understanding of spatial and temporal patterns in NO_2 and can be used to better understand the representativeness of the Network.

2.7.1 Other NO_2 monitoring data

Other than within the NZTA Network, extensive monitoring of NO_2 (using the same passive diffusion tube technology) has been conducted across New Zealand. This monitoring has been conducted by different agencies for different purposes, using different siting strategies over different time periods. The monitoring has not been evenly distributed across the country but is strongly clustered in certain areas. Nevertheless, we estimate that NO_2 has now been sampled at over 2000 locations across New Zealand, with over 700 of those locations being in Auckland. Some of the larger monitoring campaigns are summarised in Table 2-2.

Table 2-2: Summary of major NO_2 sampling datasets since 2007, other than the NZTA Network.

	Locations	Dates
NZTA Projects	Various, especially Auckland Western Ring Route	Monthly, typically for 1 – 4 years
NIWA research	234 sites across Auckland, especially CBD	various
"Future Streets" (University of Auckland/NIWA/MBIE)	60 sites across Mangere, Auckland	3 monthly samples, 2014
Gisborne District Council	18 sites across Gisborne	5 monthly samples, 2018
Auckland Council	101 locations around Auckland	3 x winter monthly samples; 2006, 2011

	Locations	Dates
Hawkes Bay Regional Council	22 sites in Napier, 21 sites in Hastings	1 monthly sample, 2012
Greater Wellington Regional Council	130 sites across region	3 or 6 monthly samples; 2015, 2016, 2019
Adelaide Rd (University of Otago/NIWA/Health Research Council)	36 sites	3 or 5 monthly samples; 2016, 2017
Waikato RC	39 sites across Hamilton	12 monthly samples; 2016

2.7.2 Selected findings from additional monitoring datasets

Several of the additional datasets have confirmed the highly localised nature of peak concentrations. Substantial additional sampling has been conducted in the vicinity of two NZTA Network sites that have regularly reported high concentrations.

- As noted above NZTA site AUC068 was one of the consistently most polluted sites in the country, reporting an average concentration of averaged 44 μg m^{-3} from 2010 – 2015. The site was at a signalised intersection on SH20A in Mangere, south Auckland. In 2014 the surrounding suburb was sampled at high density for the "Future Streets" project (Somervell et al., 2015). This sampling showed that the median concentration in the area, and at the second nearest site to AUC068 (350 m away), was 15 μg m^{-3}. The nearest site, 70 m on busy Massey Road, recorded 22 μg m^{-3}. In September 2015 AUC068 was decommissioned due to works to replace the intersection with an underpass. A new site, AUC190, was established 100 m from the original site of AUC068, and 25 m away from the edge of SH20A. This site has recorded an average of 26 μg m^{-3}. Together these pieces of evidence (Figure 2-2) make it clear that concentrations at AUC068 were elevated three times above the local average within a radius of less than 350 m.

Figure 2-2: Sites AUC068 and AUC190 in Mangere, and two sites from the Future Streets project indicating strong spatial gradients around the intersection.

- Sites WEL008 and WEL049 in Wellington have recorded average concentrations of 37 and 38 respectively over the last decade. The two sites are only 1.1 km away from each other: WEL008 at Basin Reserve and WEL049 at a signalised intersection on Riddiford Street. The two sites are linked by Adelaide Road/Riddiford Street. In 2017 a research project funded by the Health Research Council led to the sampling at 36 sites along the Adelaide Road corridor between WEL008 and WEL049. This work (Figure 2-3) revealed that at sites more than 100 m from Adelaide Road, average concentrations were ~12 μg m^{-3}. Concentrations along the road were up to 10 μg m^{-3} lower in the mid-block sections (~25 μg m^{-3}) than at the intersections (~35 μg m^{-3}). As with the Mangere example above, this confirmed the highly localised nature of concentrations recorded at the two NZTA sites which were ~3 times higher than in most of the surrounding neighbourhoods.

Figure 2-3: Intensive sampling of NO_2 (annual mean concentrations) in and around Adelaide Road, Wellington (NIWA, University of Otago, 2017).

There are many other examples where higher density sampling has shown that concentrations are strongly elevated at **signalised intersections** (up to an additional 20 μg m^{-3} as an annual mean) but only over a relatively short radius (probably less than 200 m).

Extensive sampling for research purposes in downtown Auckland and downtown Wellington has indicated that the presence of clusters of tall buildings (perhaps 3 floors high or more) on both sides of a busy road (thus creating a '**street canyon**' effect) can strongly elevate concentrations within the canyon. The magnitude of the effect is difficult to predict as it is likely to be strongly influenced by traffic volumes, building configuration, vehicle fleet/fuel mix, road gradient and other factors. However, we estimate the effect can contribute up to an additional 30 μg m^{-3} as an annual mean.

2.7.3 NIWA's Traffic Impact Model

NIWA has recently developed a Traffic Impact Model to map annual mean NO_2 at 10 m resolution. The model is semi-empirical, meaning it is based on observational data (both the NZTA Network and the other sources described above), but uses physical principles to use that data to make predictions for locations with no observations.

At the time of writing, the latest version of the model (3.1) uses empirical parameters to describe average dispersion and emission characteristics across a model zone. A zone is typically a town or city. Where observational NO_2 is available the parameters are calibrated using that data. Where it is not, default values are used derived by combining all data for the whole country.

This has the following consequences:

- Model uncertainty is lower where data from more sites is available, and vice versa.
- In densely built-up downtown areas, the model assumption of average dispersion is violated. The degree to which observations are higher than modelled estimates (in the absence of other effects) equates to the 'street canyon' effect.
- At busy signalised intersections, the model assumption of average emissions is violated, due to excess acceleration. The degree to which observations are higher than modelled estimates (in the absence of other effects) equates to the 'intersection' effect.
- As the model predicts impacts due to road traffic only, it will under-predict concentrations in locations significantly impacted by other sources. This effect has been noted close to airports and sea ports and may impact some industrial areas.
- Any other discrepancy between model prediction and observation may indicate other violations of the 'average dispersion, average emissions' assumption. This may arise due to
  - Steep road gradients (extra emissions)
  - Differences in grade (receptors are above or below the road(s))
  - Higher than average concentration of heavy-duty diesel vehicles

By providing detailed maps of estimated annual NO_2 for the whole country, the Traffic Impact Model (TIM) provides an ideal platform for guiding this review, as well as making fuller use of the data from the NZTA Network. In principle, the TIM can indicate the spatial representativeness of any Network site and indicate gaps in Network coverage, while improvements to the Network and ongoing monitoring can be used to further calibrate, improve and update the model. The model then enables a new range of applications, including

- Background air quality for project assessment
- Health risk assessment
- Regional and National indicators
- Research into personal exposure and health outcomes.

2.8 Main limitations of the Network

In our view the current Network suffers from the following limitations, which prevent it from reaching its full potential:

1. The Network contains sampling biases in the way different kinds of site are selected in different places and in different cities. This can include differences in the balance between background, roadside and intersection sites, or differences in the typical distances of sites to roads (e.g. kerbside or setback, plus differences in road widths). Data from the Network (and other research) have shown how these micro-factors, and differences of only a few metres, can make a significant difference to the concentrations observed (Figures 2-2 and 2-3). These biases **inhibit comparisons**, for example, between cities. For example, high concentrations are regularly observed at intersections and the Network in Hamilton contains an unusually high number of large intersections. This results in concentrations in Hamilton generally being higher than other cities.

2. The spatial representativeness of sites on the Network is unknown or unquantified. Many sites are deliberately sited to provide coverage of 'hotspots' but the size and extent of the hotspot, and its relationship to the wider neighbourhood and city is unknown. This means such sites cannot be used to provide estimates of local background air quality or concentrations at other locations in the vicinity. Consequently, this introduces uncertainty into any project assessment or health risk assessment that requires an assumption of spatial representativeness beyond ~10 m.

3. Whereas the Network effectively enables the monitoring of trends, its ability to explain trends is limited. This is due, in part, to the relatively poor availability of time-resolved metadata describing traffic characteristics on those roads strongly impacting each site on a monthly basis, i.e. total volumes, light/heavy vehicle splits, speeds and congestion. There is also no systematic capture of changes in nearby land-use, including changes to vegetation, changes to road alignment, construction or removal of buildings which may impact airflow, noise walls, growth in nearby car parking, etc. Consequently, it remains unclear if sites represent regional trends in traffic and vehicle emissions, or localised deviations from trends or temporary step-changes

4. The Network is currently limited to the monitoring of NO_2 only due to the relatively low cost of suitable sampling technology. Whereas NO_2 is broadly correlated with other tailpipe pollutants, precise trends and relative levels may be different for other pollutants or vary differently in space. In the long-term it has been clear that concentrations of benzene and carbon monoxide (for instance) have fallen much faster at roadside sites than NO_2. This has limited the ability of Network data to explain or quantify the relative contribution and significance of road vehicle emissions (relative to other sources), or changes in vehicle fleet and fuel mixes, to local air quality.

5. The finest time resolution for Network data is monthly. This is a limitation of the sampling technology used – shorter sampling times would degrade data quality and significantly increase operational costs. This means Network data is unable to

distinguish poor air quality episodes or compare concentrations at different times of the day.

6. The technology and data process used introduces a significant lag time between a sample being collected and the data being available for users – often over a year.

2.9 Brief review of stakeholder needs and opportunities

Since the creation of the Network in 2007, there have been several developments and emerging trends and needs in road transport that are pertinent to the objectives of the Network.

- Changes in the vehicle technologies on New Zealand's roads regarding emissions are accelerating, especially with the government-led promotion of battery-electric and hybrid vehicles. These have the potential to substantially reduce total emissions and radically improve air quality.
- The Climate Change Response (Zero Carbon) Amendment Act is likely to add further pressure to reduce emissions whilst also require better monitoring of policy effectiveness. There is currently no requirement to monitor black carbon emissions in New Zealand, but this may change in the near future.
- Weaknesses in methods to monitor the social cost of transport emissions have been identified as a priority research need by the NZTA, Ministry for the Environment and Transport Emissions Knowledge Hub. These weaknesses include the unsuitability of the current NZTA Network for this purpose as it is not orientated around the monitoring of human exposure.
- New Zealand's population is rapidly growing, especially in its larger cities. There is pressure to increase the density as well as the size of our cities. Current road traffic volume trends are uncertain, but trends to increasing congestion seem likely. It seems likely that more active forms of traffic management will be implemented here, as they are overseas, such as road pricing and dynamic speed limits. Demand for urban land is likely to continue the trend of infill and transit-orientated development and the gradual reduction of buffers between major roads and homes, buildings and pedestrian areas. The evidence base on the impact of these trends on emissions, air quality and human exposure is relatively weak, but the impacts of infrastructure design can be very long lasting.

2.10 Relevant developments in monitoring and related technology

In the 12 years since the NZTA Network began, there have been substantial and significant developments in both air monitoring technology, air data availability and public expectations around air quality data. This is a large topic and this review will be necessarily brief. NIWA have recently conducted a trial of a selection of new air monitoring technologies in the Waterview tunnel and readers are directed to the project report for further details (Olivares et al., *in preparation*).

There has been a recent proliferation of low-cost air monitoring technologies that can collect data continuously. Sensors for carbon monoxide have generally proven stable and fit for purpose,

whereas sensors for nitrogen dioxide have more often failed to provide enough stability and sensitivity for the range of concentrations observed across the NZTA Network. Sensors for particulate matter are improving rapidly but are difficult to evaluate in a roadside context due to the high relatively expensive and require significant maintenance. The findings of NIWA's recent sensor trial were that there is no device currently available that offers a suitable replacement for the passive sampler technology used in the NZTA Network, but that there are some promising products that may provide useful additional information at high concentration sites. We recommend an extended carefully controlled trial at such sites, while maintaining a test facility at the Waterview Tunnel in anticipation of new emerging sensors.

2.11 Reviewing objectives

- We find that the original objectives for the Network are poorly articulated (section 2.3). Nevertheless, we find that the Network is reasonably effective in monitoring long-term trends in the impact of road vehicle emissions on local air quality and provides partial information on where and when those impacts are larger or smaller. Although the current Network has been relatively ineffective to date at indicating the contribution of road traffic to air quality (relative to other sources), we believe this is still a valid and important objective.
- However, we also find that there is growing demand for the Network to meet wider objectives, particularly of other stakeholders. These specifically include:
  - More accurate assessment of baseline air quality for project assessment
  - Unbiased, representative and nationally consistent monitoring coverage consistent with the Environmental Reporting Act
  - Estimation of total and regional health burden (enabled through a known relationship between monitoring data and (as a minimum) concentrations at place of residence, and ideally personal exposure)
  - More robust and meaningful indicators of progress in reducing emissions and their impacts
  - Better support for cost-benefit analysis of transport projects
  - Improved evidence base for both transport and land-use planning interventions and policies which impact air pollution.

3 Review of Network Sites – Methods

3.1 Overview

In chapter 2 we concluded that two of the main weaknesses of the current Network are limited understanding of the spatial representativeness of sites, and limited understanding of whether each site is tracking regional or local traffic and emission trends.

Our over-arching principle is to assess the representativeness of each site in the Network relative to the town or city in which it lies.

The current NZTA Network is split into 31 monitoring zones, roughly aligning with individual cities. Auckland is split into four zones (Northern, Central, Western and Southern).

In this work each zone is assessed one at a time and independently of each other. The representativeness of each site is assessed in terms of its spatial representativeness across that zone and in terms of whether traffic on the nearest main road is following the regional trend or not over the last 10 years. Sites are then classified based on the results. Finally, a recommendation is made for that monitoring zone in terms of maintaining, adding or removing sites to provide what we propose to be optimum coverage.

This review does not cover the GWRC network, which (at the time of writing) is subject to a separate review on behalf of GWRC based on the same principles and approach. However, the results of that review and this work are consistent.

3.2 Tools and datasets used

For this work we used the full NZTA Network data and metadata covering the years 2007 – 2018 inclusive, downloaded from the NZTA website and an Excel spreadsheet.

NIWA's Traffic Impact Model version 3.1 was used to assess site representativeness.

Traffic representativeness was assessed using State Highway traffic volumes for 2010 – 2018, using spreadsheets downloaded from the NZTA website. For Auckland, traffic data was also downloaded from the Auckland Transport Open GIS data website ("Auckland Daily Traffic Counts"). We did not access traffic data from other Territorial Local Authorities due to the high complexity.

Land-use around sites was also assessed using satellite and street view imagery using Google Earth Pro.

Several sites in the NZTA Network are duplicates, established for inter-comparison and quality control purposes. For instance, AUC013, AUC014 and AUC015 are all at the same location at the Auckland Council air quality monitoring site in Penrose, Auckland. For the purposes of this review, they are treated as a single site – AUC013. We therefore do not review AUC014 or AUC015.

3.3 Assessment of site representativeness

3.3.1 What is representativeness?

The representativeness of a monitoring site has two dimensions – space and time.

For this work we define **spatial** representativeness to mean the degree to which long-term NO_2 concentrations measured at a given site can be used to predict concentrations at most other locations across that monitoring zone.

The Traffic Impact Model is currently the best available means of establishing spatial representativeness. Version 3.1 of the Model (used in this work) predicts the impact of regionally-typical emissions and dispersion. If concentrations observed at a site match those predicted by the model (within a margin of acceptable error), then we can reasonably assume that the site is generally representative of the whole city. The Model does not, however, predict factors that can locally increase or decrease emissions or dispersion and hence locally alter concentrations. Such factors include intersections, street canyons, barriers, and high concentrations of diesel exhausts. Therefore, if observed concentrations significantly differ from those predicted by the model then we assume that local factors are influencing that site reducing its representativeness, most likely to tens of metres. The degree to which these assumptions are valid is dependent upon the uncertainty in the model for that monitoring zone, which in turn is dependent upon the number and suitability of sites covered by historic data available (discussed further in section 4.1.1).

For this work we interpret temporal representativeness to mean the degree to which long-term traffic volumes, speeds and vehicle emissions on the road that most influences a given Network site broadly match, or differ from, typical trends across that monitoring zone.

3.3.2 Assessing spatial representativeness using the Traffic Impact Model

The Traffic Impact Model can predict long-term mean NO_2 at any location within the urbanised area of a monitoring zone. Values have been predicted for every point in a 10 m grid across the whole zone. Measured annual mean NO_2 concentrations at each site are then compared with modelled concentrations at the same locations. In principle, the greater the difference between the observed and modelled value, the less spatially representative (and more locally influenced) that site is. Although representativeness is a continuum, we found that the difference falls within +/- 4 $\mu g\ m^{-3}$ for 50 % of all sites and have adopted this value as an (admittedly arbitrary) threshold for a site being regionally-representative or locally-influenced.

This is illustrated in Figure 3-1. This figure shows the Traffic Impact Model prediction for annual mean NO_2 at 10 m resolution across Hamilton (coloured base map). Each circle represents an observation of annual NO_2 – in this case combining NZTA sites with data from a separate campaign by Waikato Regional Council. The colours in each circle indicate whether the observations match the model (white), in which case we conclude the site is representative, or whether observed concentrations are higher than those modelled by more than 4 $\mu g\ m^{-3}$ (orange) in which case the site is locally influenced (in this case there are no sites where observed concentrations are substantially lowered than those modelled). The locally-influenced sites are clustered in the CBD (high emissions, low dispersion), at major intersections (high emissions) and in the Te Rapa commercial zone (high diesel).

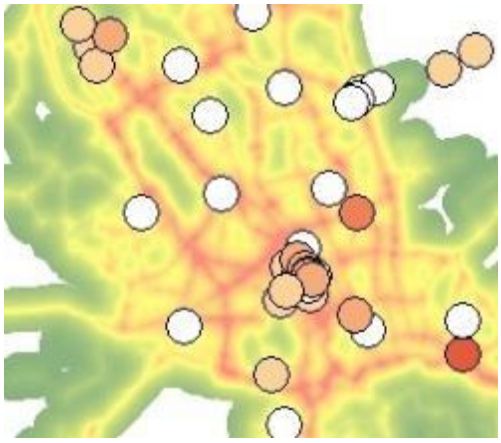


Figure 3-1: Example of modelled NO_2 (coloured base map) and deviation of observed NO_2 from the model (coloured circles). White circles indicate observations match the model indicating the site is representative. Orange circles indicate observations exceed model due to local (unmodelled) influences.

3.3.3 Assessing traffic trends

Traffic trends over 10 years are hard to assess objectively due to the complex variations that can occur between years. Due to data availability, for this work we have adopted two approaches.

At a national level, a subjective approach was used by visually comparing annual State Highway AADT data (normalised to 2018) for the nearest traffic count site to each Network site, with similarly normalised data for all other traffic counts in the region. This results in a binary output that traffic at each site follows a 'regional' trend or a 'local' trend.

For Auckland, a more detailed assessment was conducted. We calculated a linear normalised trend (percentage per year) for all available locations that met the following criteria:

- Most recent count data was collected after 1st Jan 2016 (to ensure the results are recent)
- Trends were calculated over no more than a 5-year span (to ensure the results are recent)
- At least three datapoints in time were available (to identify a trend)
- Most recent ADT was greater than 8000 (to reduce bias towards smaller and less significant roads)
- Motorway on- and off-ramps were excluded (as being unrepresentative of roads in general)

3.4 Site re-classification

The existing Network has a simple classification scheme (NZTA, 2017) in which each site is designated as either:

- State Highway,

- Local roads, or
- Background.

Based on the new understanding regarding how each site may be regionally representative, or locally-influenced (described in chapter 2 above), we propose a new classification scheme:

- Regional or Local (depending upon representativeness – see 3.3 above)

Local sites are further classified depending upon the primary cause of their local influence:

- Local traffic trend
- Major intersection (locally increases emissions)
- Street canyon (locally reduces dispersion)
- Steep road gradient (locally increases emissions)
- Grade difference (site is substantially higher or lower than road, e.g. cuttings, bridges)
- Barrier (a significant barrier lies between the road and the site)

Furthermore, sites may be classed:

- Roadside or Urban Background

Although these terms are widely used in air quality management, they are very ill-defined. NIWA is working on a formal and workable definition of these two classes based on observational data. Work to date has indicated that many commonly used and intuitive definitions of urban background also roughly correspond to the 20 - 80th percentile of modelled concentrations across a whole city. For modelling purposes, we propose that the first quintile (0 – 20th percentile) is discarded, so that the urban background corresponds to the range 20th – 80th percentile range.

Following this approach, each site is classified according to this scheme using the Traffic Impact Model and inspection of the terrain and land-use around the site using satellite or other imagery.

4 Review of Network sites - Results

4.1 Modelled NO_2 for each monitoring zone

4.1.1 Method limitations

Whereas differences in model uncertainty in different monitoring zones cannot be quantified in a robust and comparable way (due to data gaps), uncertainty in the Traffic Impact Model is likely to vary between monitoring zones, broadly in proportion to the number of sampling sites that meet the model assumptions (from all data sources) in a zone. This is qualitatively summarised below:

Low uncertainty:

- Wellington
- Porirua
- Lower Hutt
- Upper Hutt
- Auckland
- Hamilton
- Hastings
- Napier

Medium uncertainty:

- Dunedin
- Gisborne
- Kāpiti Coast

High uncertainty:

- Blenheim
- Cambridge
- Christchurch
- Greymouth
- Invercargill
- Nelson
- New Plymouth
- Palmerston North
- Queenstown

- Rotorua
- Taupō
- Tauranga
- Te Awamutu
- Whanganui
- Whangarei

4.1.2 Inter-city comparison of NO_2 distributions

Figure 4-1 below summarises the modelled distribution of NO_2 concentrations across each monitoring zone. By definition, this does not include "hotspot" locations that are not captured by the model. The box and whisker plots indicate the interquartile range (box), the 0.1th to 99.9th percentiles (whiskers) and median (bar) concentrations. For modelling purposes western, southern and central Auckland are combined as they form a continuous urban area.

The ranges are broadly similar for many zones. They are systematically higher in Auckland and lower in the outlying zones of Greater Wellington. Higher concentrations are evident in Christchurch and Nelson, but it should be noted that model uncertainty is relatively high for these cities.

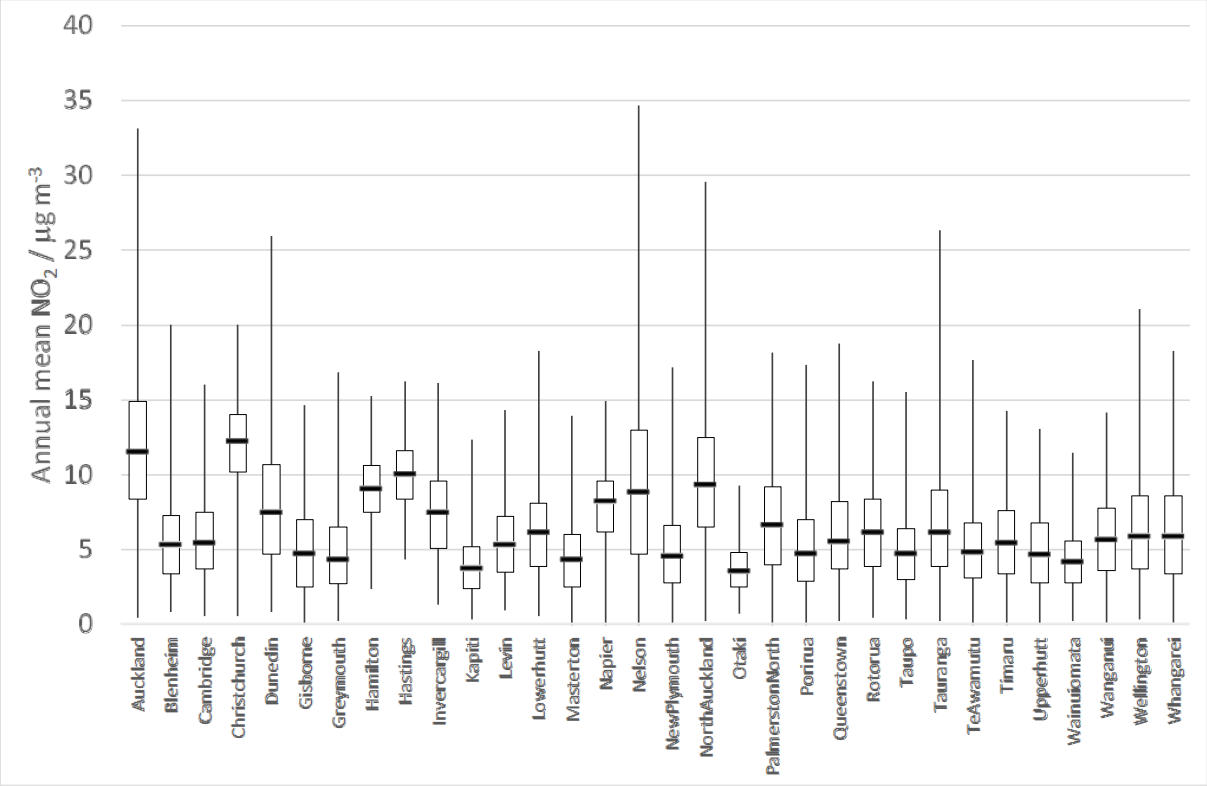


Figure 4-1: Distribution of NO_2 across monitoring zones, according to the Traffic Impact Model v3.1. Note that the model does not capture "hotspots" such as street canyons and intersections. Model uncertainty varies between zones. The high values in Nelson are yet to be verified.

4.2 Traffic trends

Our analysis of traffic trends was relatively limited. For simplicity, outside of Auckland, we considered State Highways only. In Auckland we considered traffic count data for all roads.

In all monitoring zones but Auckland and Christchurch we found a distinct regional trend. This allowed us to evaluate whether individual road links close to Network sites deviated from this regional trend. We found none that did.

Traffic trends in Christchurch are quite variable post-earthquakes. We opted not to try and impose a 'typical' regional trend in Christchurch.

We found that traffic trends in Auckland fit into three groups (see also Figure 4-2):

- Falling (24 % of all road links in our analysis)
- Rising between 0 and 5 % per year (50 % of all road links in our analysis)
- Rising faster than 5 % per year (26 % of all road links in our analysis)

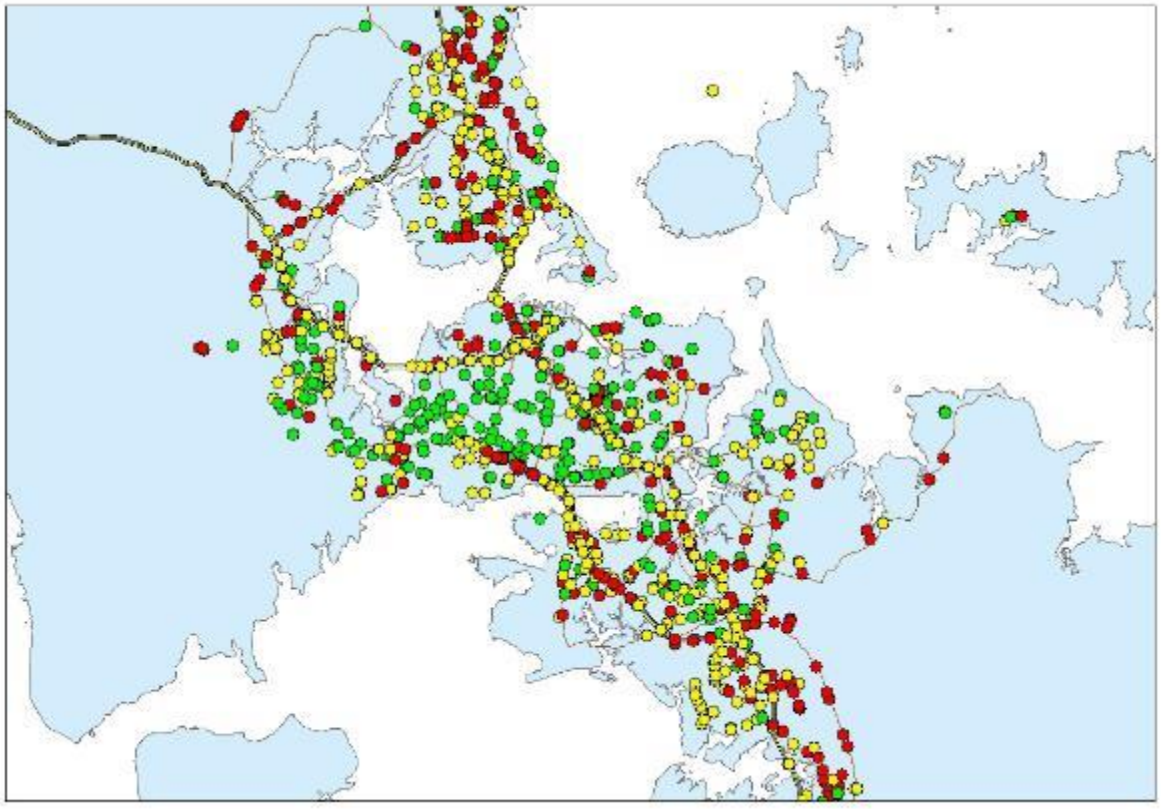


Figure 4-2: Recent 5-year traffic volume trends in Auckland. Red = rising faster than 5 % per year, yellow = rising 0 - 5 % per year, green = falling.

Data for State Highways in Auckland indicated a broad pattern where sections with higher volumes were experiencing slower rates of growth, converging on a value of ~1.5 % per year on the busiest sections. This (alongside other data we have reviewed for other projects) indicates the impact of capacity constraints acting on a large proportion of Auckland's roads, which generally reduces the growth in traffic volumes. Those roads experiencing faster growth (red points in Figure 4-2) are

typically newer roads (including relatively new sections of the Western Ring Route) and roads towards the periphery of the city where capacity constraints have not yet become significant.

Those roads experiencing traffic reduction (green points in Figure 4-2) are mostly in the central Auckland area. Further analysis would be required to determine whether falling volumes on these roads is due to decreased demand (e.g. through modal shift) and hence reduced congestion, or increased demand causing enough congestion to reduce overall volumes. It should be noted that the most recent data for State Highways in this analysis was from 2016, i.e. before the opening of the Waterview Tunnel.

We therefore opt to class sites alongside roads with either falling or faster rising volumes as representing local trends. We assume that the central group (slower rising – yellow dots in figure 4-2) is more generally representative of the whole Auckland region. However, we also note that this group may contain two sub-groups – with different levels of congestion or congestion trends, which it may be useful for the Network to cover.

4.3 Definition of monitoring zones

The rapidly growing Hibiscus Coast area is currently classed as part of the Auckland-Northern monitoring zone. We question whether a site in Auckland's North Shore can be considered representative of the Hibiscus Coast (especially the Whangaparaoa Peninsula) and vice versa, and recommend that the Hibiscus Coast is considered an independent monitoring zone. Current coverage of the Hibiscus Coast is provided by a single roadside site.

4.4 Site re-classification

Out of the 135 sites in the existing Network, it was difficult to establish the regional or local representativeness of 15 sites. This was due to observed concentrations being significantly higher than those modelled, which would indicate atypical dispersion or emissions, but we were unable to determine a clear cause (although speculative causes were identified). In these cases we erred on the side of caution and have allocated them to the locally-influenced class until such time as regional representativeness can be established.

Of the remaining 121 sites, we classified:

- 57 as regionally representative, of which…
  - 19 represent urban background
  - 38 are roadside sites
- 64 as locally-influenced, of which…
  - 9 are due to local traffic trends
  - 45 are at a major intersection
  - 3 are street canyon sites
  - 2 are due to steep road gradients

- 1 is due to grade differences
- 0 are due to barriers
- 4 are due to additional sources

Appendix A presents a table of full results for each site.

Appendix B provides figures indicating the modelled and observed concentrations at each site and hence the representativeness of each site.

5 Recommendations for re-organisation and optimisation of the Network

5.1 Overview

The recommendations presented below are intended to meet NZTA's goal of increasing the utility of data from the Network without substantially increasing its size (and cost). Broadly we find that the underlying technology (passive NO_2 samplers replaced at monthly intervals at fixed sites across a network) to be sound and appropriate and should be retained in the near future (long-term prospects are discussed separately below).

We propose that the Network is effectively split into two: a "Regional" network of regionally-representative sites (i.e. generally representative of the whole city or monitoring zone) and "Local" networks of locally-specific or atypical sites.

Our recommendations are that the Regional Network would consist of 50 of the existing sites, the relocation of 2 existing sites plus the establishment of **38 new sites**, i.e. 90 sites in total.

78 of the existing sites would form the starting point for the Local networks. These sites cover mainly intersections. However, the Local Networks are also intended to provide coverage of atypical locations that is largely missing from the existing Network – mainly busy city centre streets, but also ports and growth areas. We have recommended **52 new sites** to provide this additional coverage, however this should be considered as both a minimum, and as a 'best guess' of appropriate locations. We recommend that further research is conducted to inform how best to provide monitoring coverage of such locations.

We also find that 17 of the current sites could be discontinued without significantly impacting the value of the network. A further 8 sites could potentially be discontinued in the future once new sites are established.

5.2 Calibration campaigns and model update

Our approach depends upon the validity of the Traffic Impact Model. The version of the model used for this work (v3.1), being empirical, is based upon the data available at the time. This varies substantially between cities, and consequently, so does the uncertainty in the model (see section 4.1.1). Our proposed approach is not dependent upon this one model alone – any valid modelling approach may be used. However national consistency is strongly recommended.

We recommend that a spatial sampling campaign is conducted in a range of monitoring zones and repeated on a long-term basis (e.g. 5 - 10-year cycle) to reduce modelling uncertainty. We recommend Christchurch be addressed as a high priority due to substantial variability in traffic post-earthquakes, and large population, followed by Tauranga, Palmerston North, Nelson, Rotorua, Whangarei, New Plymouth and Invercargill due to relatively high populations.

5.3 Proposed optimum network coverage

We propose that the minimum coverage for each monitoring zone should be:

- One regionally representative urban background site
- One regionally representative roadside site

In larger monitoring zones, especially those with complex terrains (micro-airsheds) we recommend additional pairs of urban background and roadside sites for each micro-airshed. An example would be Dunedin, where the area could be considered as distinct and separate (from an air quality point of view) from the rest of Dunedin.

We have specifically recommended more than one regional roadside site for 8 zones as shown in table 5-1.

Table 5-1: Monitoring zones for which we have recommended more than one regional roadside monitoring site.

zone	Regional roadside sites	comment
Auckland - Central	7	Differing trends
Auckland - Northern	2	Potential for differing trends
Auckland – Southern	4	Covering different trends on different road types
Auckland – Western	3	Covering three different road types
Dunedin	2	Green Island-Caversham area is potentially separate airshed
Hibiscus Coast	2	Silverdale and Whangaparaoa different airshed and different traffic conditions
Nelson	2	Need to be reviewed by NIWA in 2021
Wellington	3	Covering major and suburban roads and separate airsheds

More than one regional urban background site has been recommended in 8 monitoring zones which consist of two or more ‘airsheds’, i.e. zones with distinctly different or independent dispersion conditions, which may be evidenced by poor temporal correlations in urban background concentrations. This is more common in hilly areas and has been applied to Auckland- Northern, Auckland-Western, Christchurch (under review in 2021), Dunedin, Hibiscus Coast, Lower Hutt, Porirua and Wellington.

The coverage of Local sites in a monitoring zone should be informed by both national, regional and local issues. For example, sites where high emissions are experienced (such as intersections) are

informative not only for local air quality risk management, but also for tracking national emission trends under high loads (as opposed to conventional roadside sites which are effectively monitoring emissions at lower loads). We recommend permanent (subject to periodic review) coverage of:

- An urban background and roadside pair in any area where major roads have a distinctly different long-term traffic, speed or fleet trends from the rest of the region
- At least one major intersection
- At least one CBD site where canyoning, traffic and high pedestrian exposures coincide
- Near any port, airport, major inland port or rail yard (see below for further comments)
- In any major industrial or commercial zone where high volumes of trucks might be expected

We furthermore recommend temporary coverage by Local sites of:

- An urban background and roadside pair in any area where major roads have a distinctly different short-term or temporary traffic, speed or fleet trends to the rest of the region
- In areas of significant or rapid growth and urban development
- Along roads expected, or targeted, to experience significant changes to traffic, especially through policy measures, such as removal of trucks, buses or cars.

Ports are generally large area sources with restricted access. Our understanding of their influence on local air quality is generally limited. In a few cases dispersion modelling may have been conducted, but this frequently excludes additional road transport emissions due to abnormally high volumes of trucks, or port-only vehicles and stationary sources. This leads to very high uncertainties as to where their impact can be best monitored and a high risk of any chosen site being unsuitable. Given the relatively low cost of passive sampling, we recommend that ports are subject to initial high-density screening campaigns to establish their spatial impact and to aid selection of a long-term monitoring site or sites. NIWA has developed approaches to achieve this (e.g. recent 30-site campaign around the Port of Auckland) and is able to assist agencies in the design and execution of such a campaign.

5.4 Currently unmonitored urban areas

The following urban areas with estimated populations above 20,00 currently have no coverage in the Network:

- Timaru
- Pukekohe
- Rolleston
- Ashburton

Although we do not make specific recommendations for monitoring in these cities a minimum network could be established in each using the principles described in this report.

5.5 New, redundant sites and site relocations - overview

Full details of the recommended new Network are provided in Appendix C.

In summary we propose the establishment of at least

- 22 new regional urban background sites
- 16 new regional roadside sites
- New Local city centre sites in all 32 monitoring zones
- New port monitoring sites in all relevant monitoring zones
- New sites to monitor traffic growth around major new and forthcoming roads and major urban developments.

We find that 19 existing sites are potentially redundant and could be removed, although that it is not our recommendation.

We find that 2 sites should be relocated over a relatively short distance, generally away from major roads to improve their representativeness.

For the 'growth' category we have made only 4 specific site recommendations related to:

- The Long Bay development in Auckland's North Shore
- The Hamilton Bypass (Waikato Expressway)
- Growth around Frankton and the Wakatipu Basin in Queenstown
- The Dairy Flat – Wainui development in Hibiscus Coast.

Identifying appropriate sites for other growth areas is dependent upon analysis and understanding of development plans and traffic projections and is best done in partnership with the planners responsible. We have highlighted a potential need to do this for the Kumeu-Huapai, Whenuapai-Westgate, Drury-Opaheke and Paerata developments in Auckland at least.

5.6 Network changes – priorities and options to partially implement recommendations

We recommend that the top priority is the completion of the Regional Network, i.e. the establishment of regionally representative Urban Background and Roadside sites in all zones based on supplementing a subset of existing sites with new sites to fill gaps.

Secondary priorities then include establishment of Local Networks (particularly Intersections, Canyons and Ports) in partnership with Local Authorities, and the execution of zone-wide screening campaigns for model calibration in areas of higher uncertainty (particularly Christchurch, Tauranga, Palmerston North, Nelson, Rotorua, Whangarei, New Plymouth and Invercargill due to relatively high populations).

5.7 New sites – location details

Whereas some specific recommendations for the locations of new sites are made in Appendix C, these should be treated as suggestions. They have not been checked for logistical practicalities, nor have potential permissions been sought. Alternative sites may be equally suitable. However, we recommend in choosing sites that the following general principles are followed:

- Some specific roads have been suggested for new **Urban Background** sites following the principles below (alternative locations can therefore be chosen following these principles):
  - They represent the approximate modelled median concentrations for each zone (the yellow areas in the maps in Appendix C).
  - Uncertainty in representation of median concentrations is minimised by choosing locations with low spatial gradients.
  - They are located nearby Roadside locations where practical.
- Some specific roads have been suggested for new **Regional Roadside** sites following the principles below (alternative locations can therefore be chosen following these principles):
  - They are alongside the busier roads in the zone.
  - They are as close to the road as practical.
  - They are > 200 m from signalised intersections or regular traffic queues.
  - They are near Urban Background sites (approximately < 1 km) where practical.
  - Uncertainty in representation of median concentrations is minimised by choosing locations with low spatial gradients, as indicated by modelling.
- Some specific roads have been suggested for new **Canyon** sites following the principles below (alternative locations can therefore be chosen following these principles):
  - They are located on streets with at least a small volume of traffic, a high building height to street width ratio (above ~0.6), and high pedestrian volumes.
  - Streets with high volumes of buses are particularly suitable.
- We also make some recommendations to relocate sites to make them compliant with these principles (see Appendix C).

5.8 Metadata

Existing, readily available data describing the Network consists of a static document available on the NZTA website, describing each site. However, each site is not static, but subject to significant relevant change. This is particularly relevant for traffic volumes and speeds on the roads immediately surrounding the site, but also includes changes to land-use.

The utility of the Network, and particularly the ease of analysis, would be greatly improved if detailed traffic data were easily and directly linked to the Network metadata. Furthermore, we recommend that metadata includes regular (at least annually) updated surface and satellite photography of the site, with attention drawn to changes in vegetation, building works, changes in road configuration, installation of noise walls of other relevant barriers, etc.

5.9 Management of the data

This review recommends that the Network better serves multiple uses and users. This would be greatly facilitated if the database were more easily interrogated. We recommend that a structured database is created with an open application programming interface (API) so that data can be readily ingested into other models or services. This could include health risk assessment models or GIS mapping applications.

5.10 Long-term optimisation of the Network

We recommend that the Network is periodically reviewed to reconsider trends in NO_2 and how they relate to local and regional trends in traffic. Trends and correlations are liable to change over time, and sites that were not previously correlated (thus providing independent information) may become correlated (and hence providing duplicate information) in the future.

Furthermore, it may be advantageous to re-locate some sites to provide more even and unbiased coverage between cities. For example, it may be advantageous for each monitoring zone to have a site that directly represents the median concentration in that zone. Such potential locations can be identified using the Traffic Impact Model and specified in Appendix C.

5.11 New measurement technologies

We find that new measurement technologies are emerging with the potential to replace the passive sampling technique used across the Network, and greatly increase its utility, but that none are yet sufficiently mature or proven.

We recommend that the recently conducted trial of emerging sensors in the Waterview Tunnel is extended to test more sensors over a longer period, and that promising sensors are then deployed at a small number of high-concentration sites across the Network for a trial period (e.g. one year). Sites in central Auckland are likely to be most promising.

We also recommend that a watching brief be maintained to systematically identify, acquire and test potential new technologies or equipment as it arises.

5.12 Summary of recommendations

- Most sites in the Network should remain in place.
- The Network should be split into a Regional Network of representative sites, and Local Networks covering sites subject to highly local influences.

- We propose that the top priority is to establish Regional Networks which ensure a minimum coverage for each monitoring zone including:
  - One regionally representative urban background site
  - One regionally representative roadside site
  - This will require that 38 new sites be established - 22 new regional urban background sites and 16 new regional roadside sites
- Local Networks should be developed in partnership with key local stakeholders, particularly regional councils and territorial local authorities. These will provide coverage that is largely missing from the existing Network – mainly busy city centre streets, but also ports and growth areas.
- Spatial sampling campaigns should be conducted in monitoring zones with higher model uncertainty and repeated on a long-term basis (e.g. 5 - 10-year cycle). We recommend Christchurch be addressed as a high priority due to substantial variability in traffic post-earthquakes, and large population, followed by Tauranga, Palmerston North, Nelson, Rotorua, Whangarei, New Plymouth and Invercargill.
- Monthly traffic data relating to major roads adjacent to Network sites should be made readily and easily available.
- A structured database should be created with an open application programming interface (API) so that data can be readily ingested into other models or services.
- The Network should be reviewed at least every 5 years to reconsider trends in NO_2 and how they relate to local and regional trends in traffic.
- The recently conducted trial of emerging sensors in the Waterview Tunnel should be extended to test more sensors over a longer period. Promising sensors should then be deployed at a small number of high-concentration sites across the Network for a trial period (e.g. one year). Sites in central Auckland are likely to be most promising.

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Appendix A Site re-classification

Each existing Network site has been assessed as described in section 3. Each site is assigned as either Regionally-representative, Locally-influenced or Undetermined (column 4); where Locally-influenced the dominant suspected influence is listed (column 5), and sites are also designated as Urban Background or Roadside (column 6).

site_ID	Type (NZTA)	NZTA_zone	Regional/Local	local_type	UB/Roadside
AUC004	Local	Auckland - Northern	Undetermined (assumed Local)	Borderline intersection	Roadside
AUC005	Local	Auckland - Northern	Undetermined (assumed Local)	Borderline intersection	Roadside
AUC007	SH	Auckland - Northern	Regional	N/A	Roadside
AUC008	SH	Auckland - Central	Regional	N/A	Roadside
AUC009	SH	Auckland - Central	Regional	N/A	Roadside
AUC011	SH	Auckland - Central	Regional	N/A	Roadside
AUC013	SH	Auckland - Central	Local	extra source	Roadside
AUC018	SH	Auckland - Southern	Undetermined (assumed Local)	Vegetation barrier?	Roadside
AUC019	SH	Auckland - Southern	Regional	N/A	Roadside
AUC020	SH	Auckland - Western	Regional	N/A	Roadside
AUC021	Background	Auckland - Central	Regional	N/A	Roadside
AUC022	SH	Auckland - Central	Regional	N/A	Roadside
AUC025	SH	Auckland - Central	Local	local traffic trend	Roadside
AUC026	SH	Auckland - Southern	regional	N/A	Roadside
AUC027	SH	Auckland - Southern	regional	N/A	Roadside
AUC039	SH	Auckland - Northern	Local	local traffic trend	Roadside
AUC040	SH	Auckland - Northern	Local	local traffic trend	Roadside
AUC041	Local	Auckland - Northern	Local	local traffic trend	Roadside
AUC042	Local	Auckland - Northern	Local	Canyon/extra source	Roadside
AUC043	SH	Auckland - Northern	regional	N/A	Roadside
AUC046	Local	Auckland - Northern	local	Intersection	Roadside
AUC047	Background	Auckland - Northern	regional	N/A	Urban Background
AUC049	Local	Auckland - Western	Local	local traffic trend	Urban Background
AUC050	SH	Auckland - Western	Local	local traffic trend	Roadside
AUC051	SH	Auckland - Western	regional	N/A	Roadside
AUC052	Local	Auckland - Western	regional	N/A	Roadside
AUC053	Local	Auckland - Western	regional	N/A	Roadside
AUC054	Local	Auckland - Western	Local	local traffic trend	Roadside
AUC057	Background	Auckland - Western	regional	N/A	Urban Background
AUC060	Local	Auckland - Central	local	intersection	Roadside
AUC061	Local	Auckland - Central	regional	N/A	Roadside
AUC062	Local	Auckland - Central	regional	N/A	Roadside

site_ID	Type (NZTA)	NZTA_zone	Regional/Local	local_type	UB/Roadside
AUC063	Local	Auckland - Western	local	intersection	Roadside
AUC064	Local	Auckland - Central	Undetermined (assumed Local)	Bus Stop?	Roadside
AUC067	SH	Auckland - Southern	local	local traffic trend	Roadside
AUC069	Local	Auckland - Southern	local	intersection	Roadside
AUC070	Local	Auckland - Southern	local	intersection	Roadside
AUC071	Local	Auckland - Central	local	intersection	Roadside
AUC072	Local	Auckland - Southern	regional	N/A	Roadside
AUC073	Background	Auckland - Southern	regional	N/A	Urban Background
AUC115	motorway	Auckland - Western	regional	N/A	Roadside
AUC170	SH	Auckland - Northern	local	Intersection/grade	Roadside
AUC171	Background	Whangarei	regional	N/A	Roadside
AUC187	SH	Whangarei	local	Intersection	Roadside
AUC190	SH	Auckland - Southern	regional	N/A	Roadside
CHR001	SH	Greymouth	regional	N/A	Roadside
CHR002	SH	Christchurch	local	Intersection	Roadside
CHR003	SH	Christchurch	local	Intersection	Roadside
CHR004	Background	Christchurch	regional	N/A	Urban Background
CHR006	SH	Christchurch	local	intersection	Roadside
CHR011	SH	Christchurch	local	intersection	Roadside
CHR012	Local	Christchurch	local	intersection	Roadside
CHR013	SH	Christchurch	local	intersection	Roadside
CHR014	SH	Christchurch	local	intersection	Roadside
CHR015	Local	Christchurch	local	intersection	Roadside
CHR016	Local	Christchurch	local	canyon	Roadside
CHR017	Local	Christchurch	local	Intersection/canyon	Roadside
CHR020	Background	Christchurch	regional	N/A	Urban Background
DUN001	SH	Dunedin	local	Intersection/canyon	Roadside
DUN002	SH	Dunedin	regional	N/A	Roadside
DUN004	SH	Queenstown	local	gradient	Urban Background
DUN005	SH	Invercargill	local	canyon	Roadside
DUN006	SH	Dunedin	local	intersection	Roadside
DUN007	Background	Dunedin	regional	N/A	Urban Background
DUN008	Local	Dunedin	local	gradient	Roadside
DUN009	Local	Dunedin	local	intersection	Roadside
DUN010	Background	Invercargill	regional	N/A	Roadside
DUN011	SH	Dunedin	regional	N/A	Urban Background
HAM001	SH	Hamilton	local	intersection	Roadside
HAM002	SH	Hamilton	Undetermined (assumed Local)	Rail yard?	Urban Background

site_ID	Type (NZTA)	NZTA_zone	Regional/Local	local_type	UB/Roadside
HAM003	SH	Hamilton	Local	intersection	Roadside
HAM004	SH	Cambridge	Local	intersection	Roadside
HAM005	SH	Taupō	Local	intersection	Roadside
HAM006	SH	Rotorua	Local	intersection	Roadside
HAM007	SH	Tauranga	Local	intersection	Roadside
HAM008	SH	Tauranga	Local	intersection	Roadside
HAM010	SH	Tauranga	Local	intersection	Roadside
HAM012	SH	Hamilton	Local	extra source	Roadside
HAM013	SH	Hamilton	Local	intersection	Roadside
HAM014	Local	Hamilton	Local	intersection	Roadside
HAM015	Local	Hamilton	Local	intersection	Roadside
HAM016	Local	Hamilton	Local	intersection	Roadside
HAM017	Background	Hamilton	regional	N/A	Urban Background
HAM018	SH	Tauranga	Local	intersection	Roadside
HAM019	Local	Tauranga	regional	N/A	Roadside
HAM020	Local	Tauranga	Local	intersection	Roadside
HAM021	Background	Tauranga	regional	N/A	Urban Background
HAM022	SH	Te Awamutu	Local	intersection	Roadside
HAM023	Background	Rotorua	regional	N/A	Urban Background
NAP001	SH	Gisborne	Undetermined (assumed Local)	Car parking?	Roadside
NAP002	SH	Napier	Local	grade	Roadside
NAP003	SH	Napier	Local	intersection	Roadside
NAP004	SH	Hastings	Local	intersection	Roadside
NAP005	Background	Hastings	regional	N/A	Urban Background
NAP006	Background	Napier	regional	N/A	Urban Background
WAN004	SH	Palmerston North	Local	intersection	Roadside
WAN005	SH	Palmerston North	regional	N/A	Roadside
WAN006	SH	Palmerston North	Local	intersection	Roadside
WAN007	Local	Palmerston North	regional	N/A	Roadside
WAN008	Background	Palmerston North	Undetermined (assumed Local)	Rail yard?	Roadside
WAN009	Background	New Plymouth	regional	N/A	Urban Background
WAN010	SH	Whanganui	local	extra source	Roadside
WAN011	SH	New Plymouth	regional	N/A	Roadside
WEL003	SH	Lower Hutt	Regional	N/A	Roadside
WEL005	SH	Porirua	Regional	N/A	Roadside
WEL007	SH	Wellington	Undetermined (assumed Local)	Grade difference	Roadside
WEL008	SH	Wellington	local	Local traffic trend	Roadside

site_ID	Type (NZTA)	NZTA_zone	Regional/Local	local_type	UB/Roadside
WEL009	SH	Nelson	regional	N/A	Roadside
WEL010	SH	Nelson	regional	N/A	Roadside
WEL011	SH	Nelson	regional	N/A	Roadside
WEL012	SH	Blenheim	regional	N/A	Roadside
WEL047	Local	Wellington	Regional	N/A	Roadside
WEL048	Background	Wellington	Regional	N/A	Urban Background
WEL049	Local	Wellington	Local	Intersection	Roadside
WEL050	SH	Wellington	Local	Intersection	Roadside
WEL051	Local	Wellington	Regional	N/A	Roadside
WEL052	SH	Lower Hutt	Undetermined (assumed Local)	Rail? Sheltering hills?	Roadside
WEL053	Local	Lower Hutt	Local	Intersection	Roadside
WEL054	Background	Lower Hutt	Regional	N/A	Roadside
WEL057	SH	Upper Hutt	Local	Intersection	Roadside
WEL061	SH	Otaki	Local	Intersection	Roadside
WEL062	Background	Nelson	regional	N/A	Roadside
WEL063	SH	Kapiti	Undetermined (assumed Local)	Bend?	Roadside
WEL064	SH	Wellington	Undetermined (assumed Local)	Grade difference	Roadside
WEL072	Background	Porirua	Regional	N/A	Urban Background
WEL073	SH	Wellington	Local	Intersection	Roadside
WEL078	SH	Lower Hutt	Local	Extra source?	Roadside
WEL080	Background	Porirua	Local	Extra source?	Roadside
WEL087	SH	Otaki	Undetermined (assumed Local)	Outlier	Roadside
WEL088	SH	Porirua	Undetermined (assumed Local)	Outlier	Roadside
WEL089	SH	Masterton	Undetermined (assumed Local)	Outlier	Roadside
WEL091	Background	Lower Hutt	Regional	N/A	Urban Background
WEL092	Background	Upper Hutt	Regional	N/A	Urban Background
WEL094	Background	Wellington	Regional	N/A	Urban Background
WEL096	Background	Masterton	Regional	N/A	Roadside

Appendix B Representativeness of existing Network sites for each monitoring zone

A guide to interpreting the figures in this Appendix.

This Appendix contains one figure for each monitoring zone (city). Each figure (see annotated example below) includes a cumulative frequency distribution of modelled NO_2 across the zone. For clarity the y-axis is on a logarithmic scale and the percentiles are inverted. The blue line represents the proportion of urban land area in this zone which has annual mean NO_2 concentrations above any given value. The numbered squares represent the current NZTA sites (the first four characters are omitted). For example, site HAM019 (box 19) reports an annual mean concentration of 19 µg m^{-3}. This approximately corresponds to the 1st percentile – i.e. 1% of locations have concentrations above this (conversely 99 % have concentrations below this). For clarity sites will not appear on this diagram if they are representative of the highest 0.1% of concentrations (i.e. 'extreme peak' sites). This is the case for HAM010, for instance. Sites close to the modelled distribution (filled in green) are – by definition – regionally representative and coloured green, unless they are believed to be locally-influenced (for instance representing local traffic trends) and the correspondence with the model is coincidental. Sites away from the blue line are locally influenced and coloured orange with concentrations locally elevated (to right of blue line) or more rarely reduced (to left of blue line).

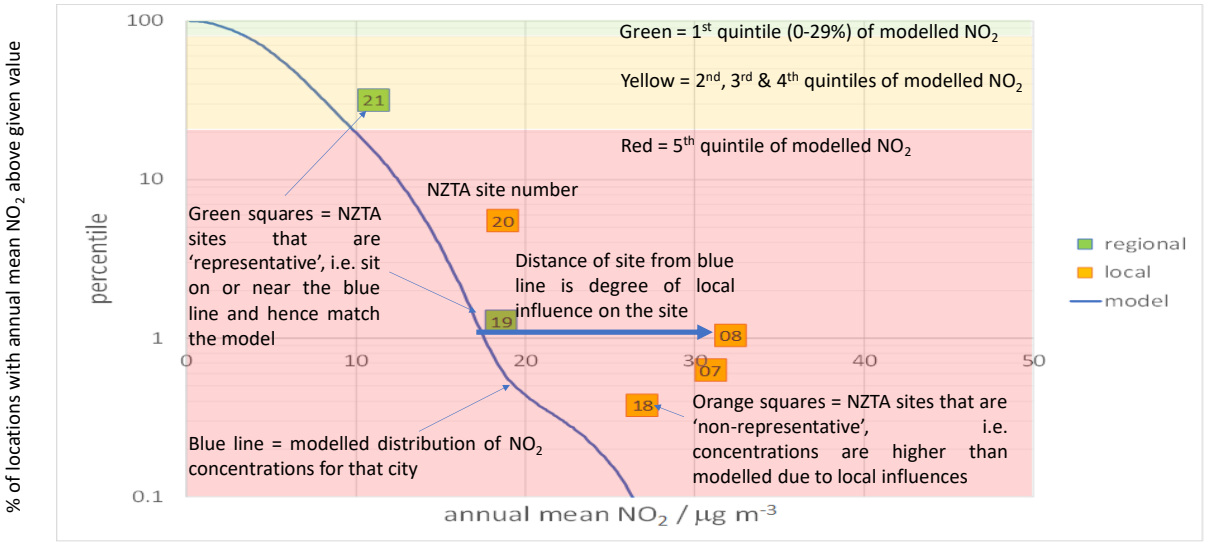
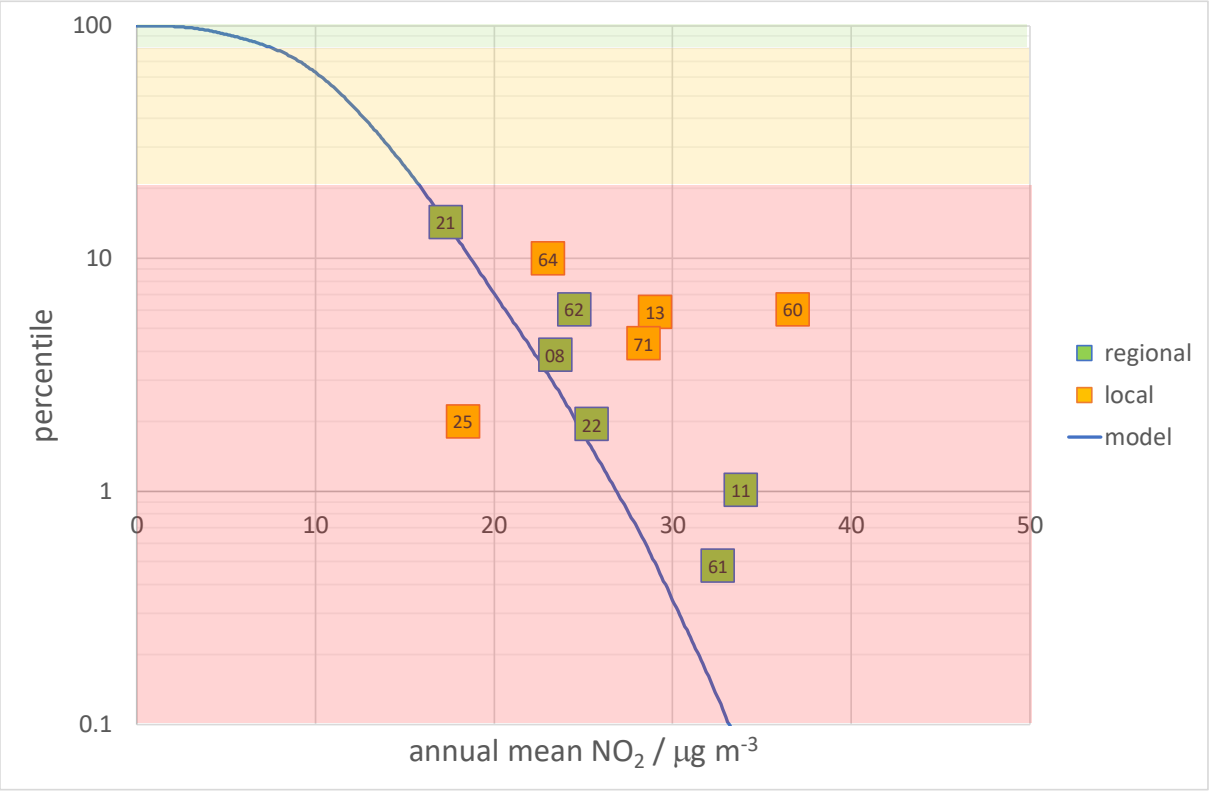


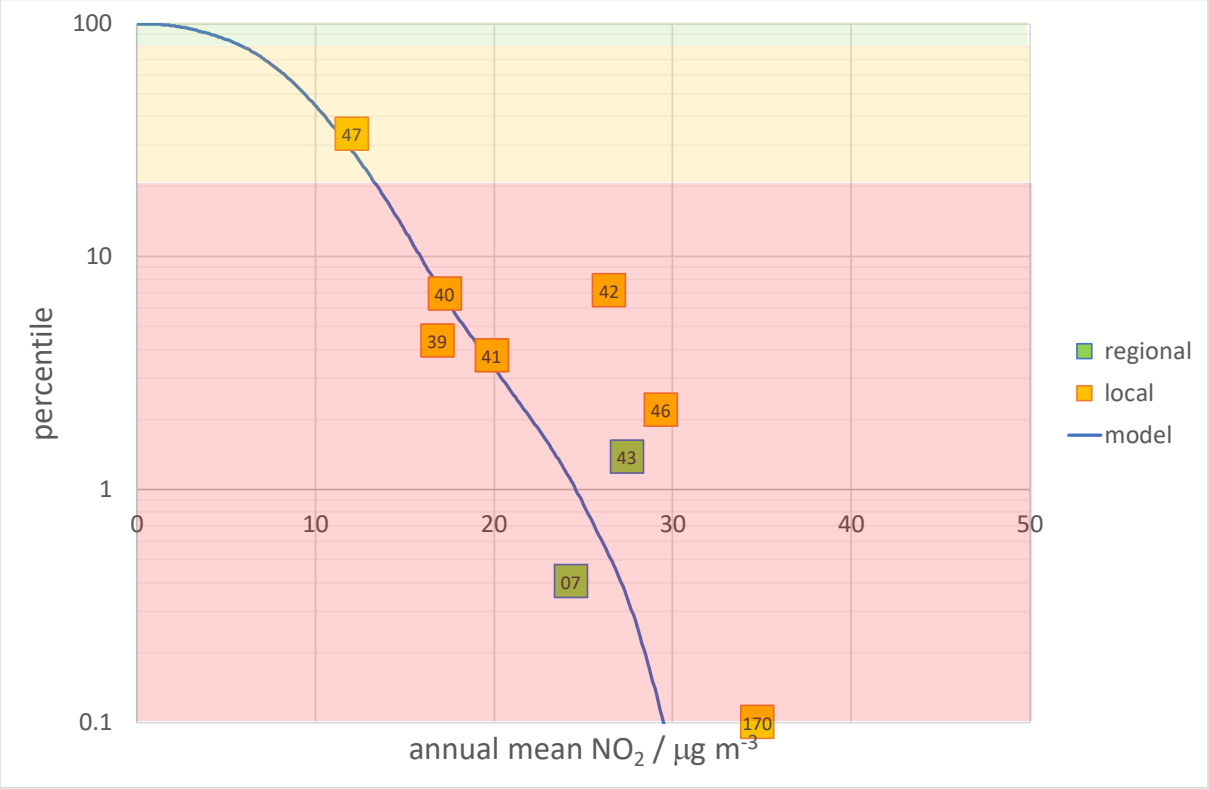
Figure B-1: Example of cumulative frequency distribution of NO_2 across a city and where on that distribution current NZTA sites lie.

Figures for each monitoring zone

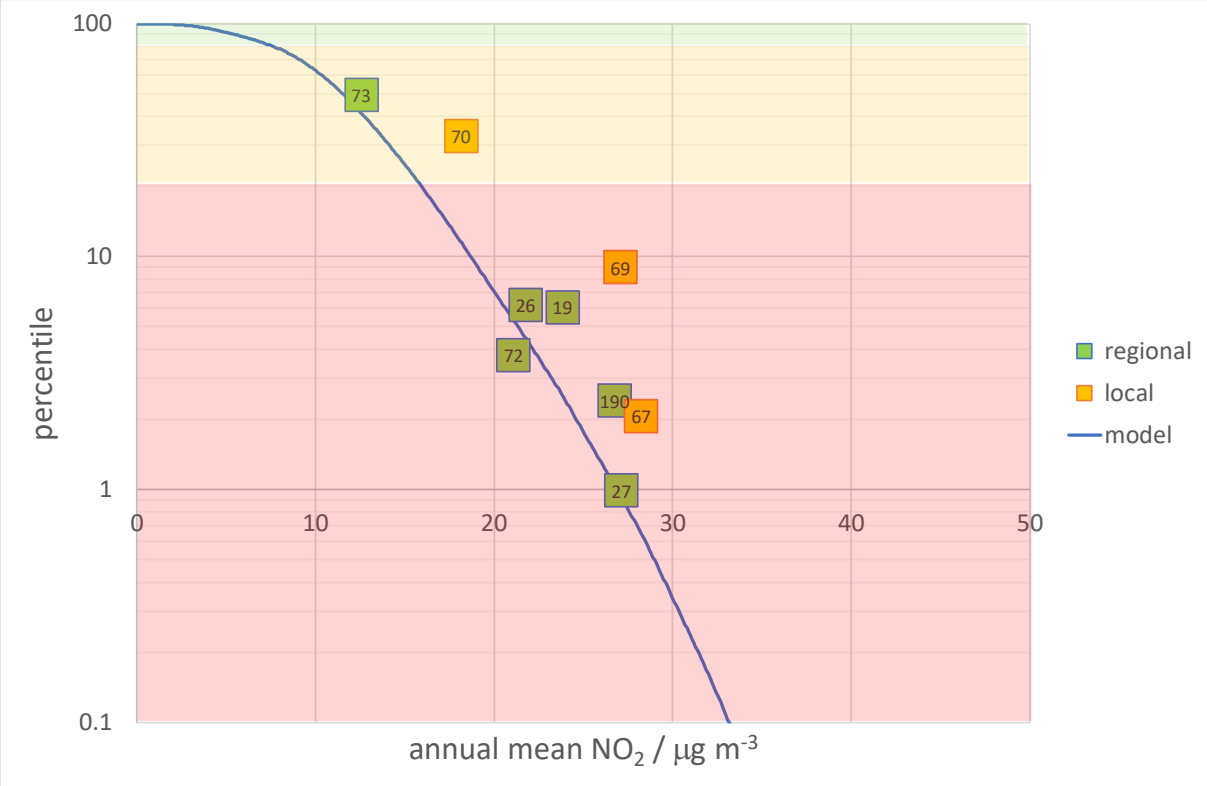
Auckland – Central



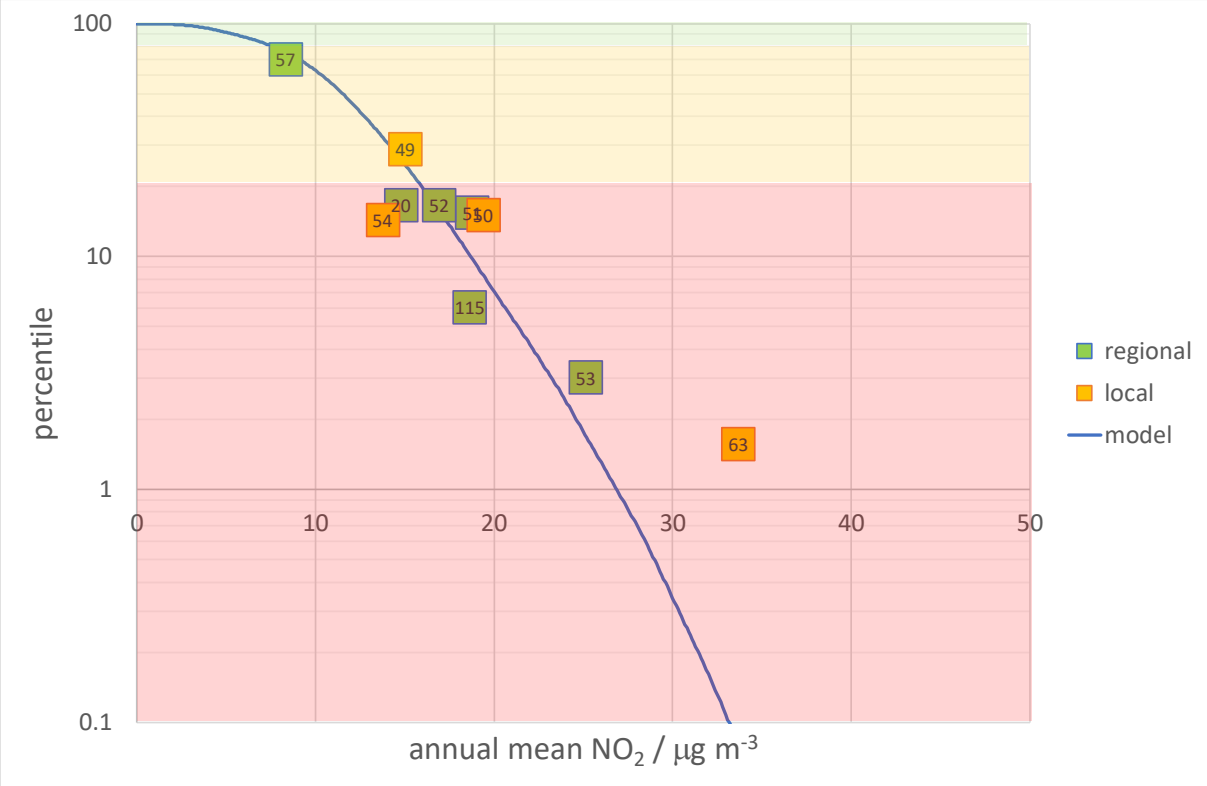
Auckland - North



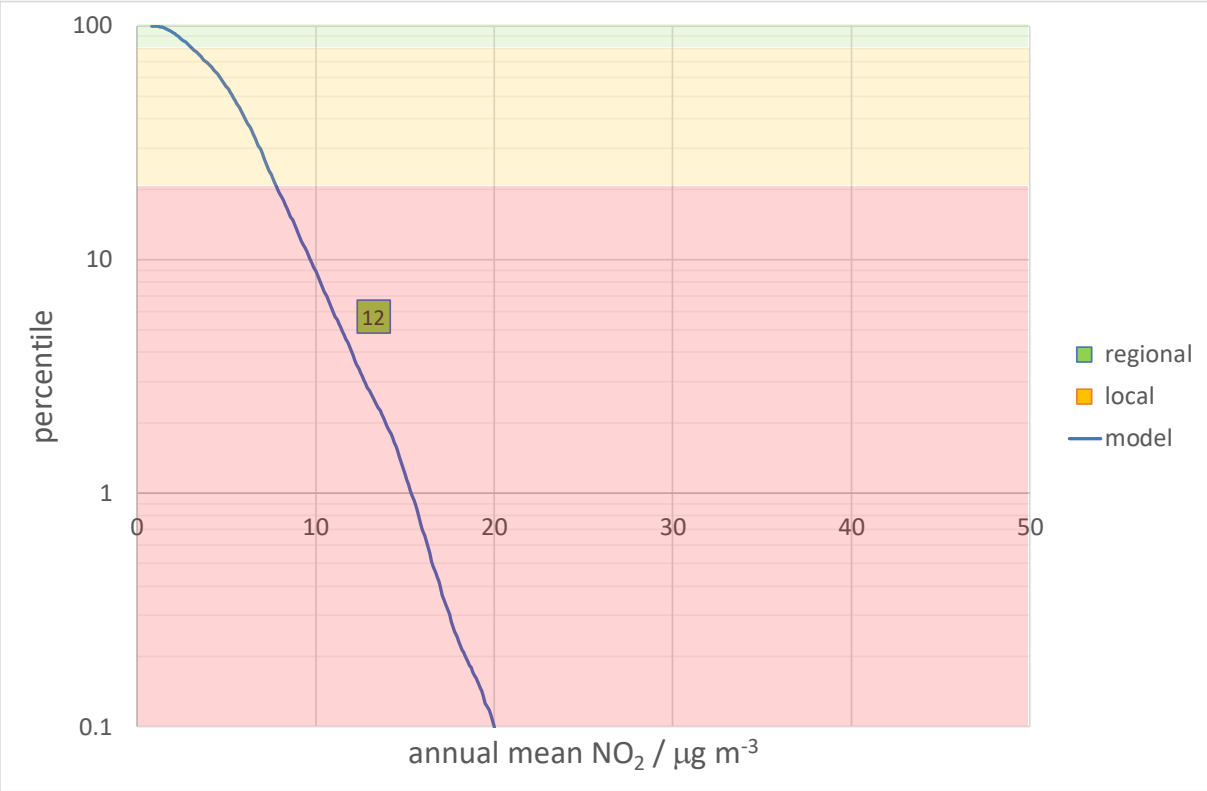
Auckland - South



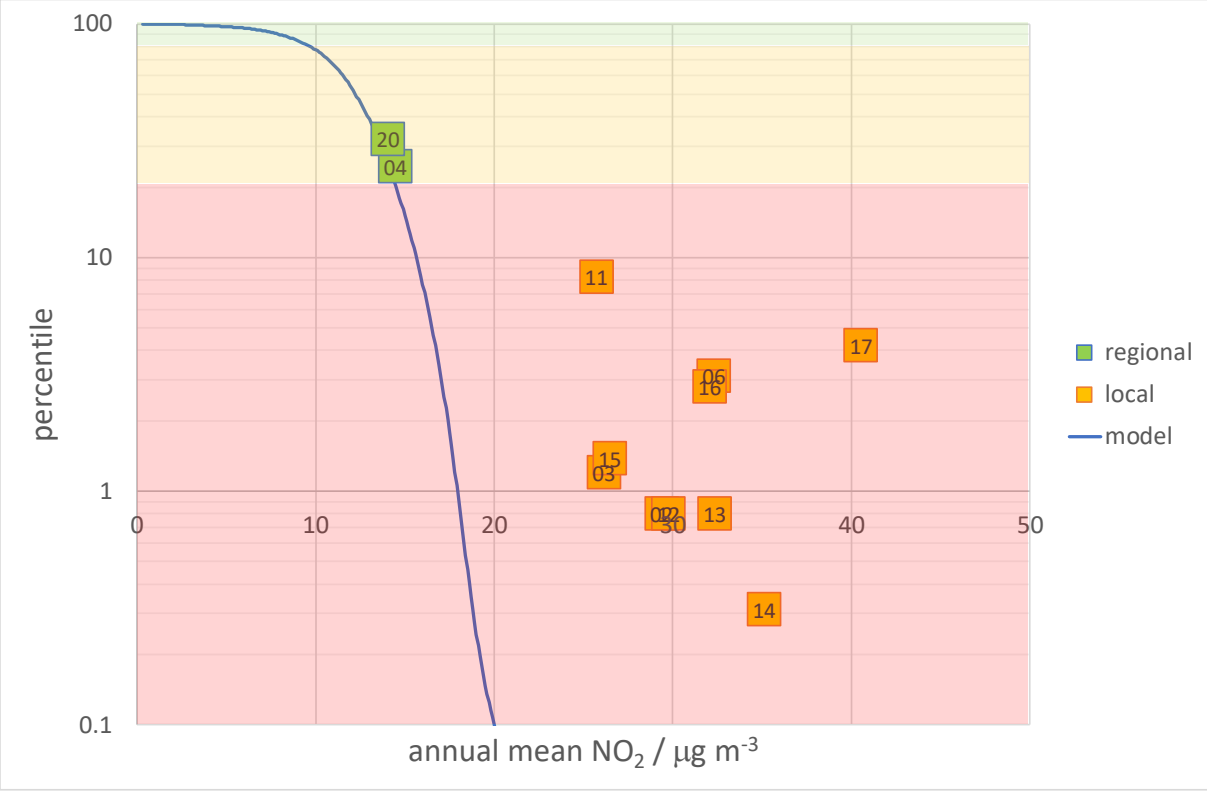
Auckland - West



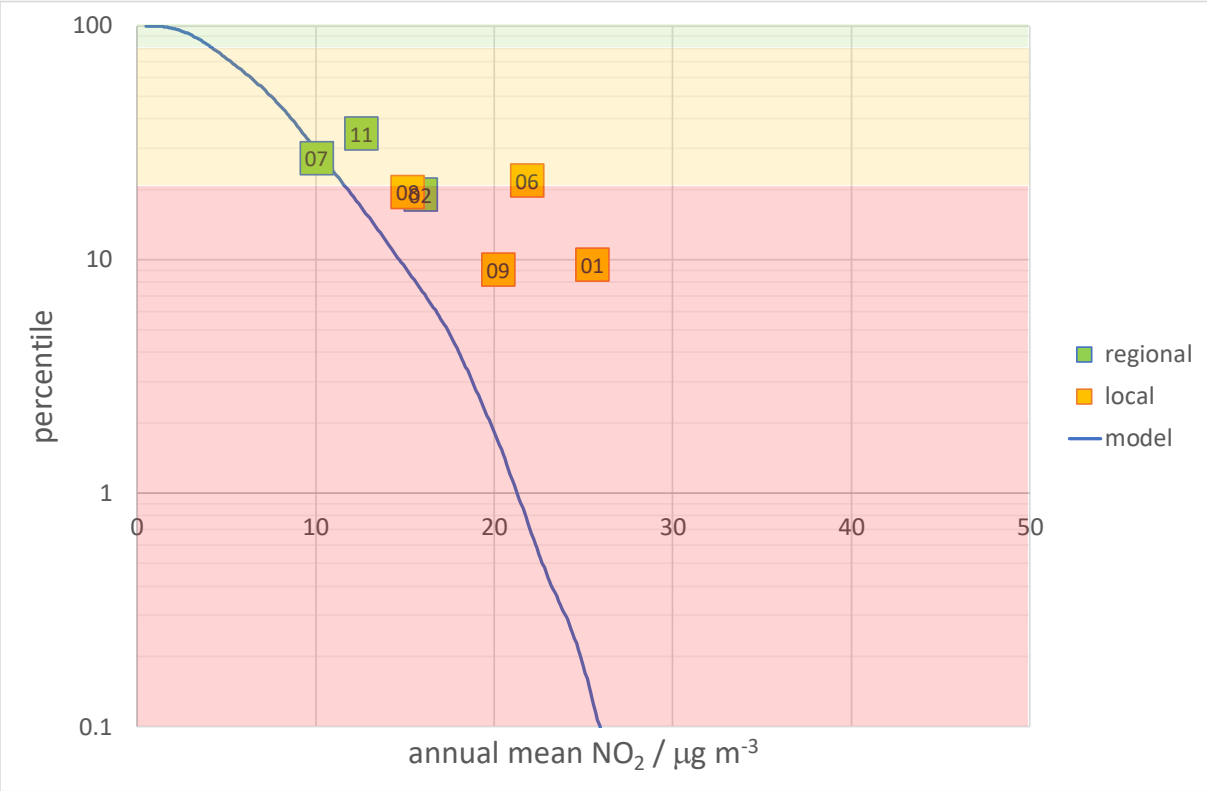
Blenheim



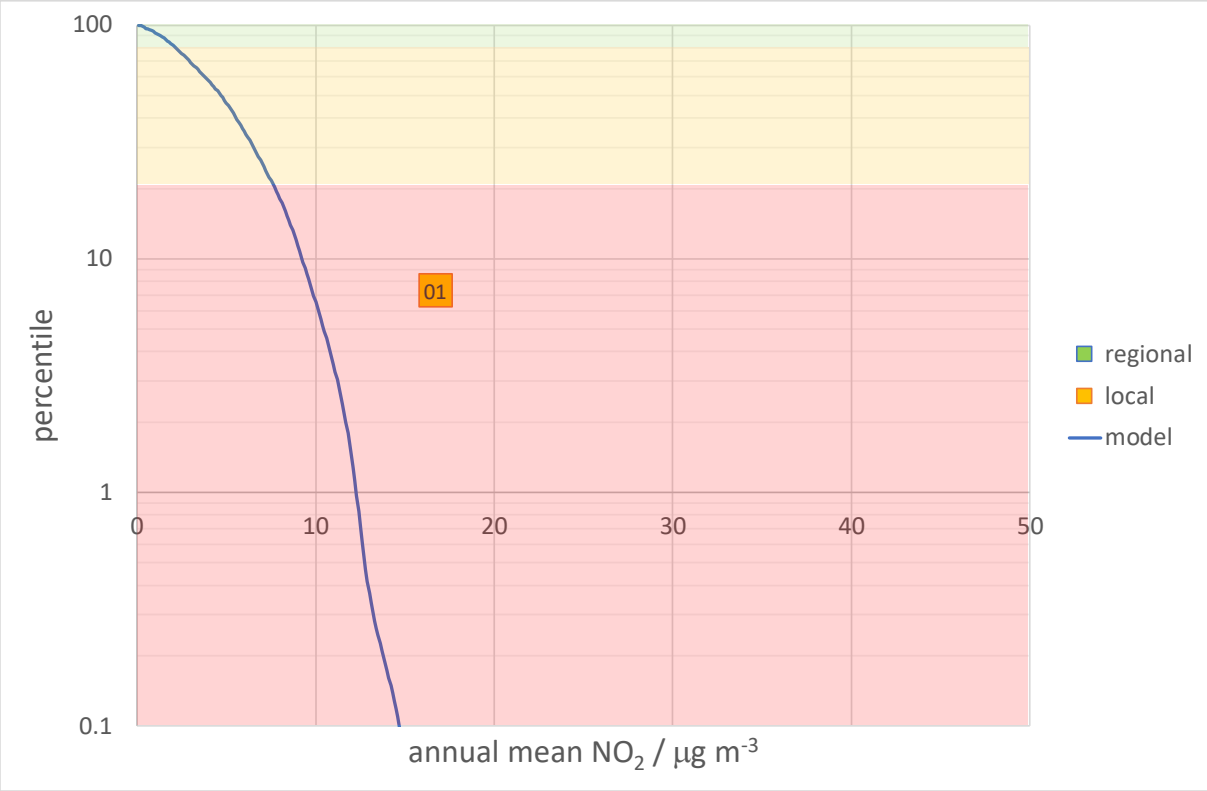
Christchurch



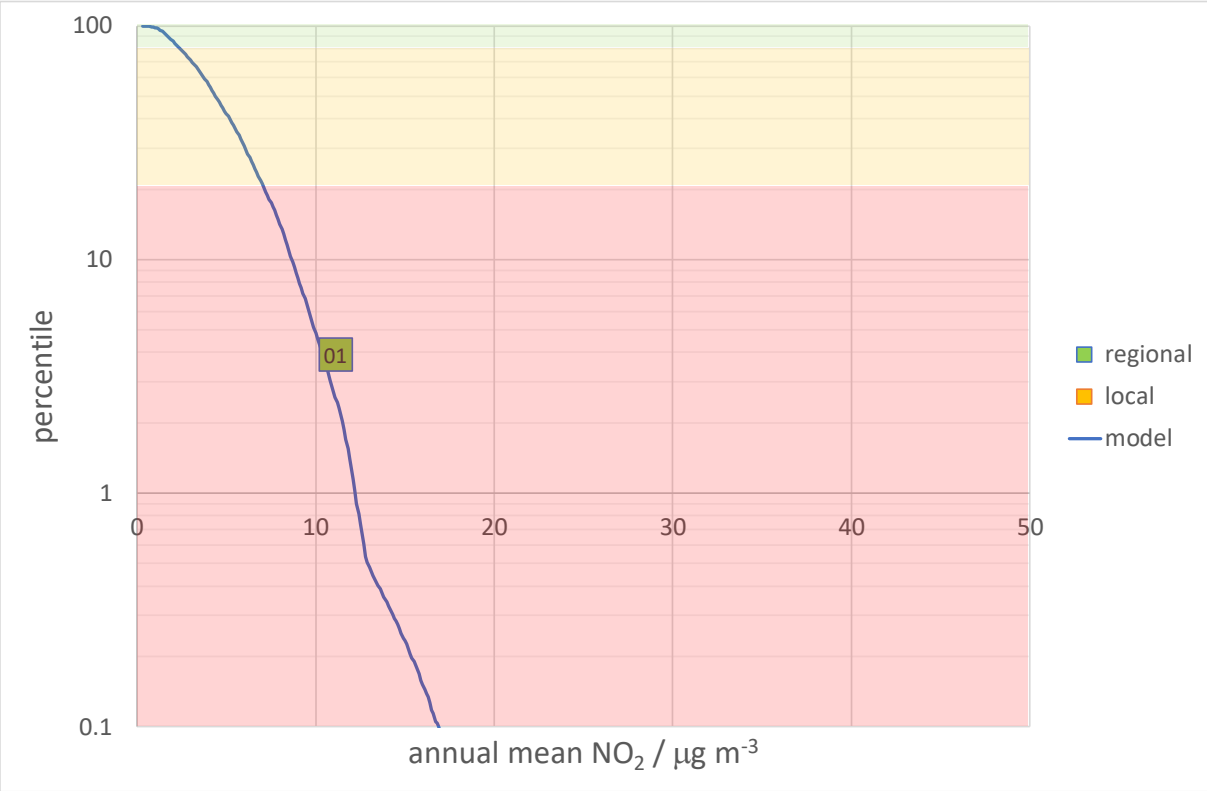
Dunedin



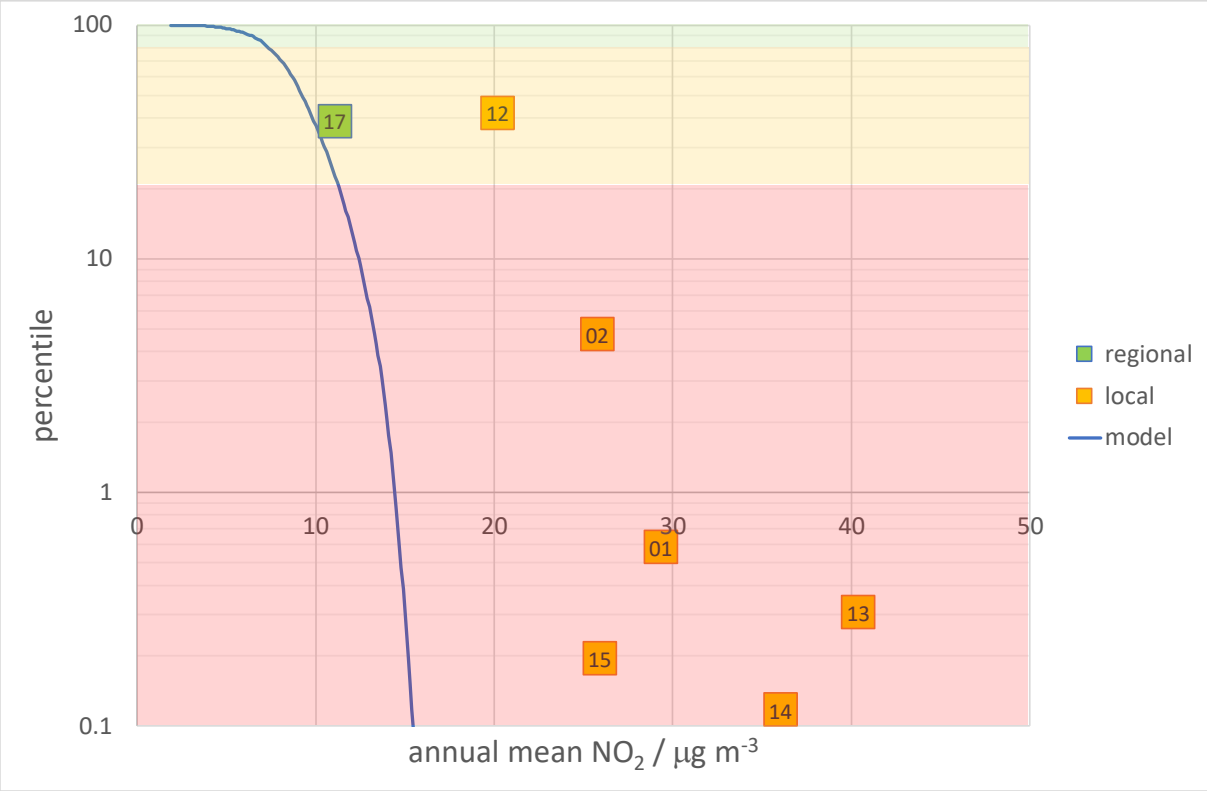
Gisborne



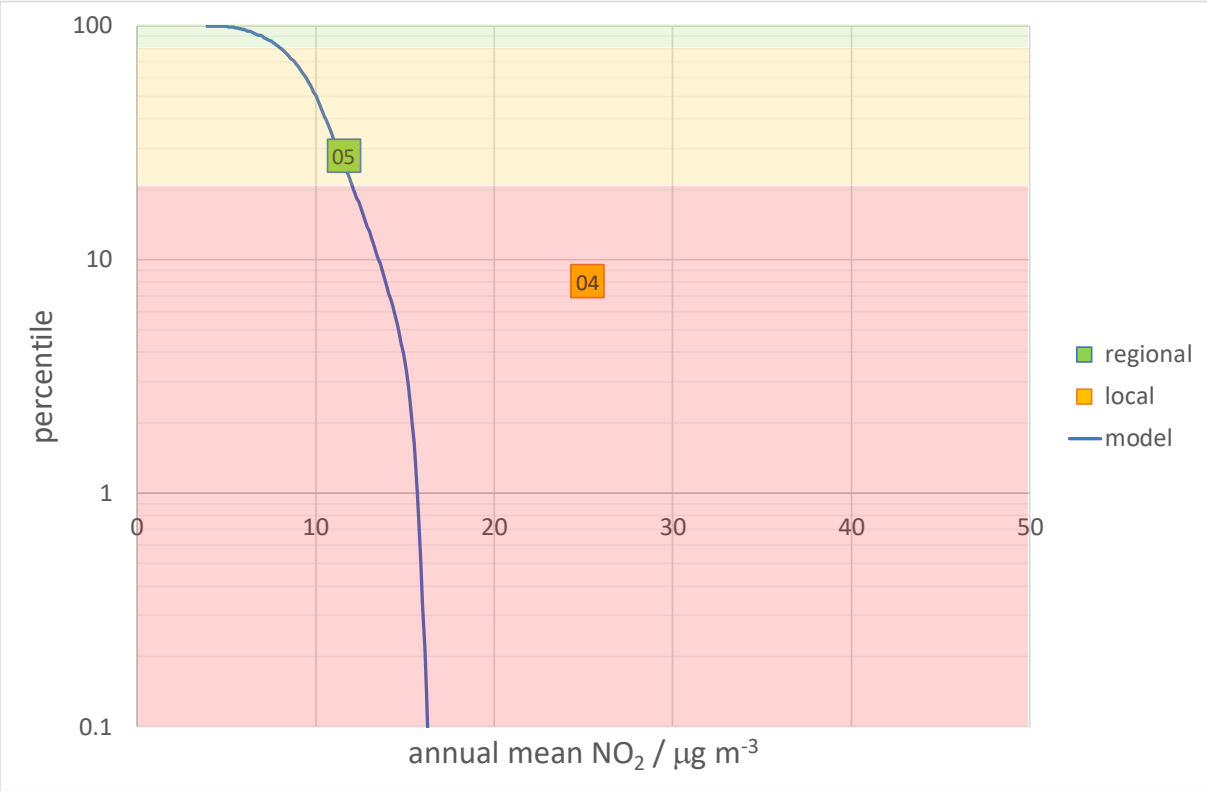
Greymouth



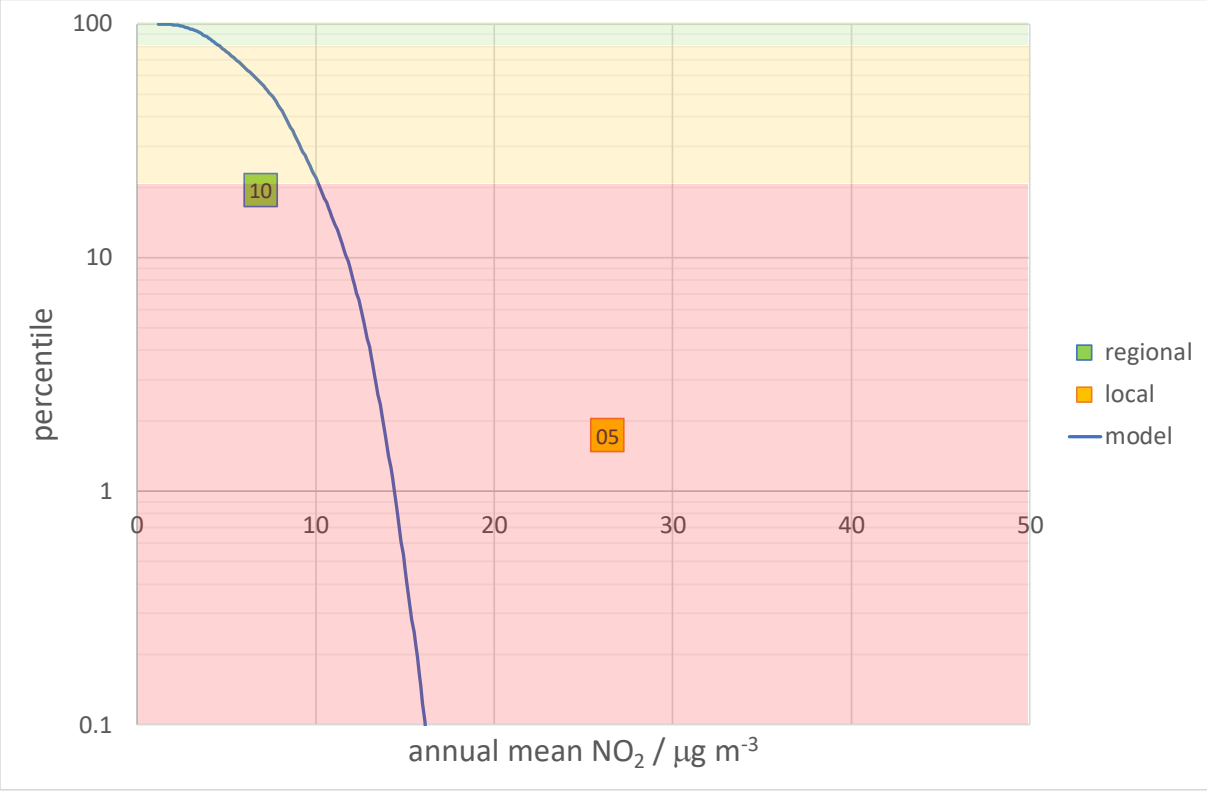
Hamilton



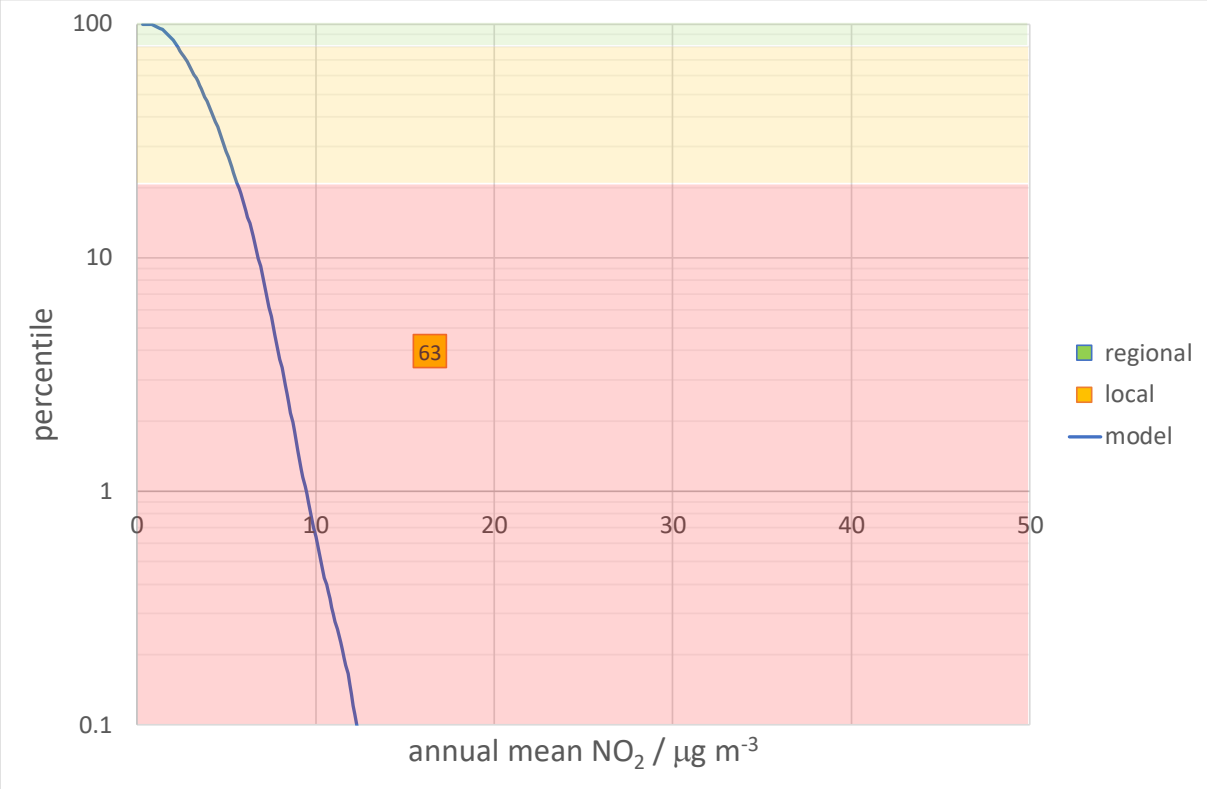
Hastings



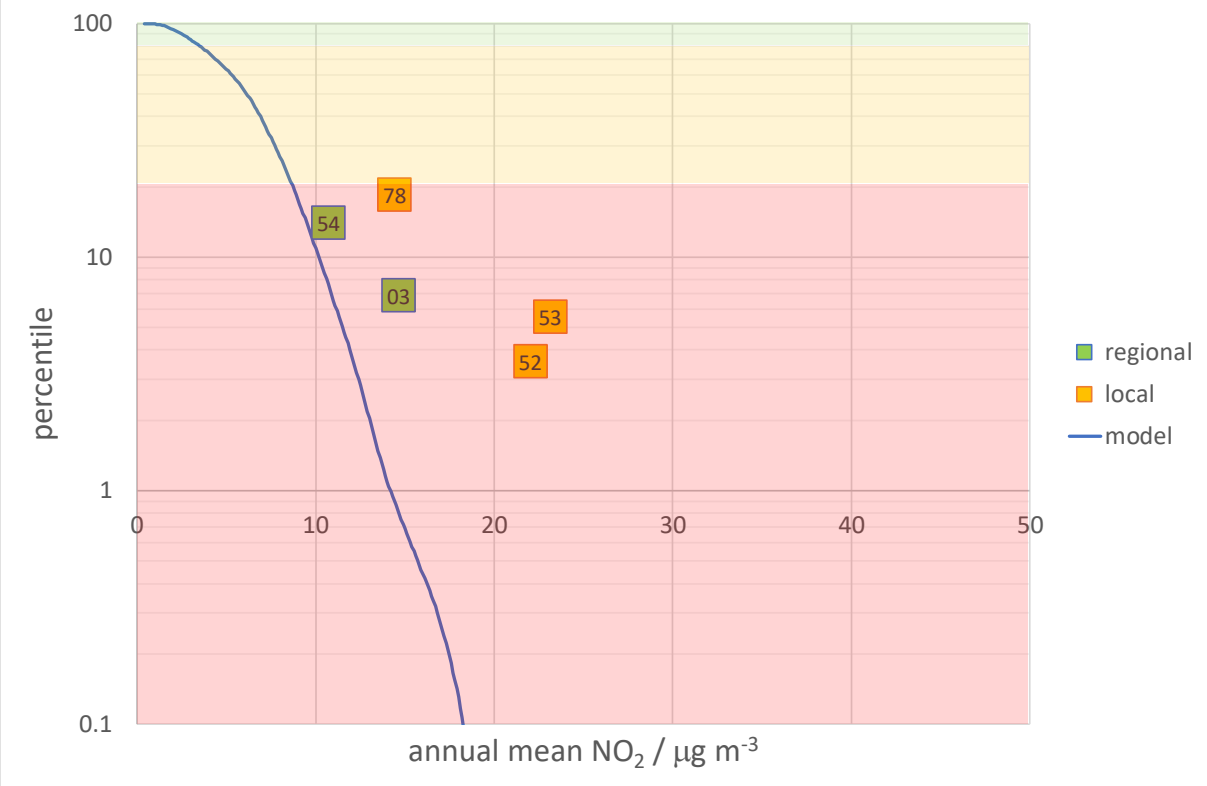
Invercargill



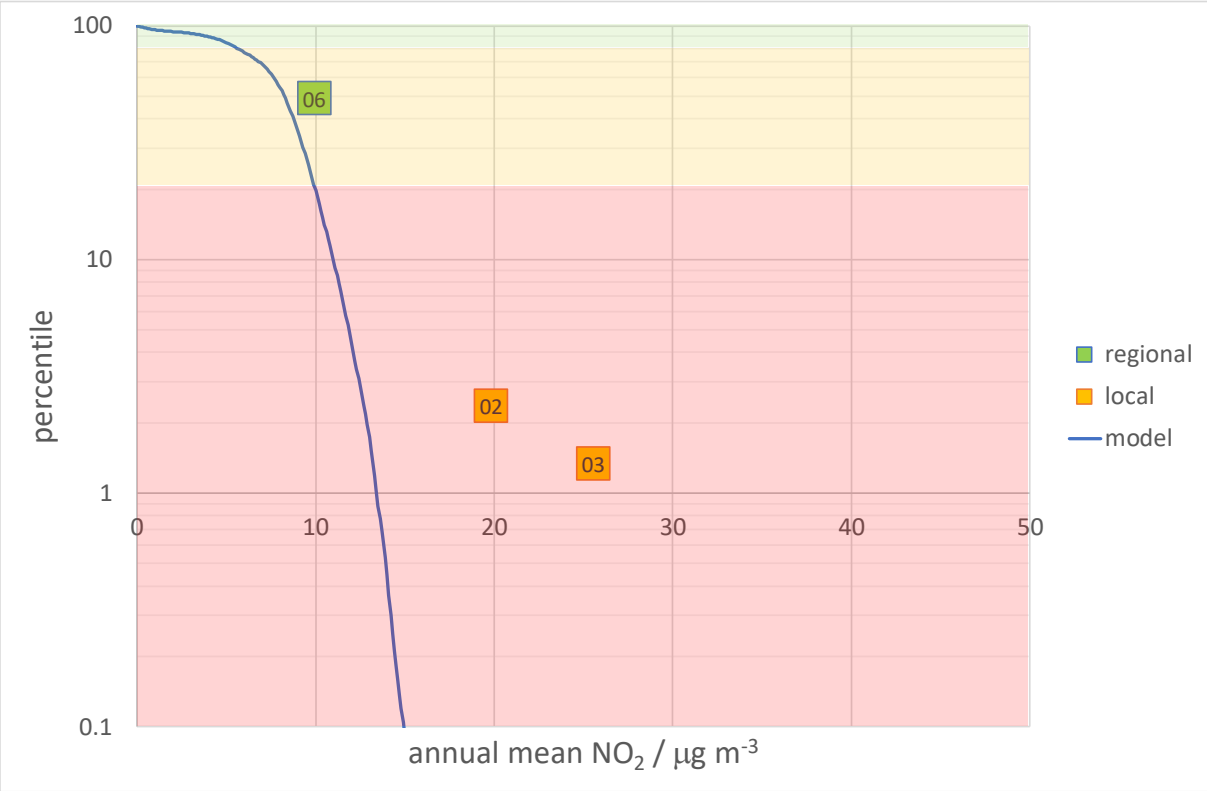
Kapiti Coast



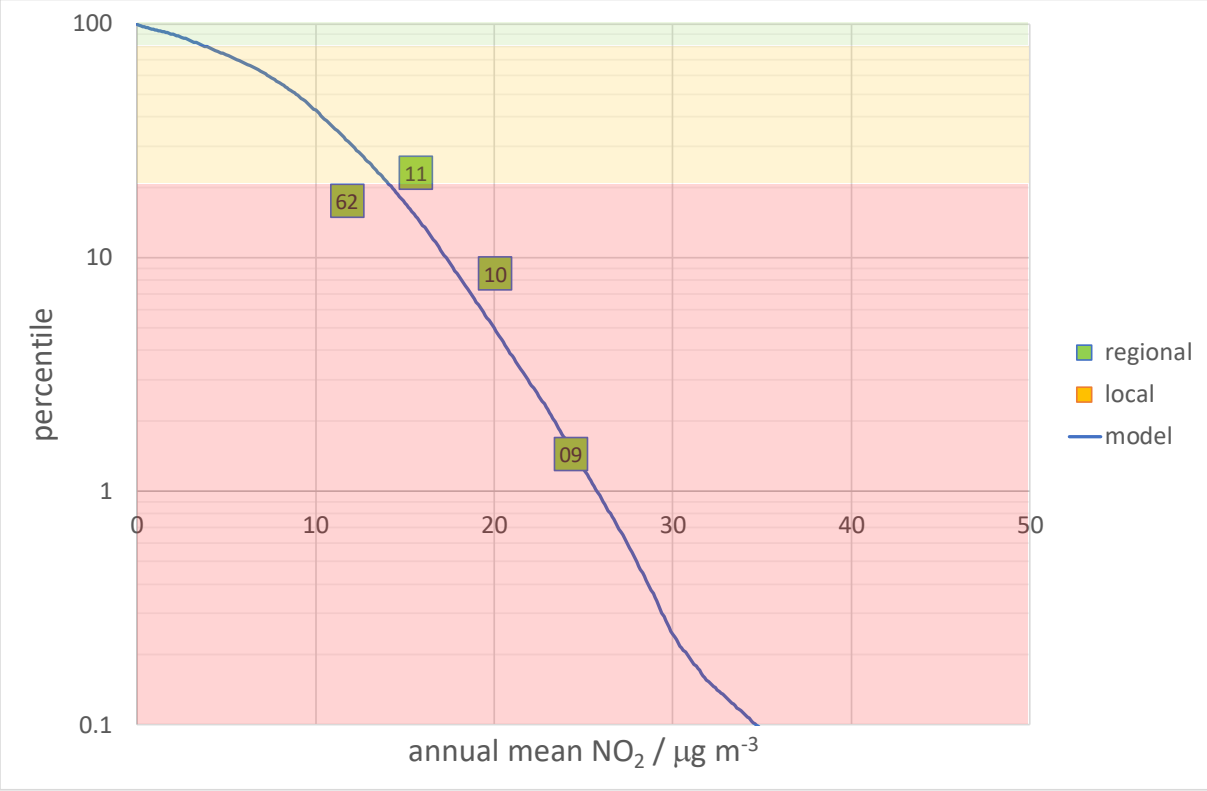
Lower Hutt



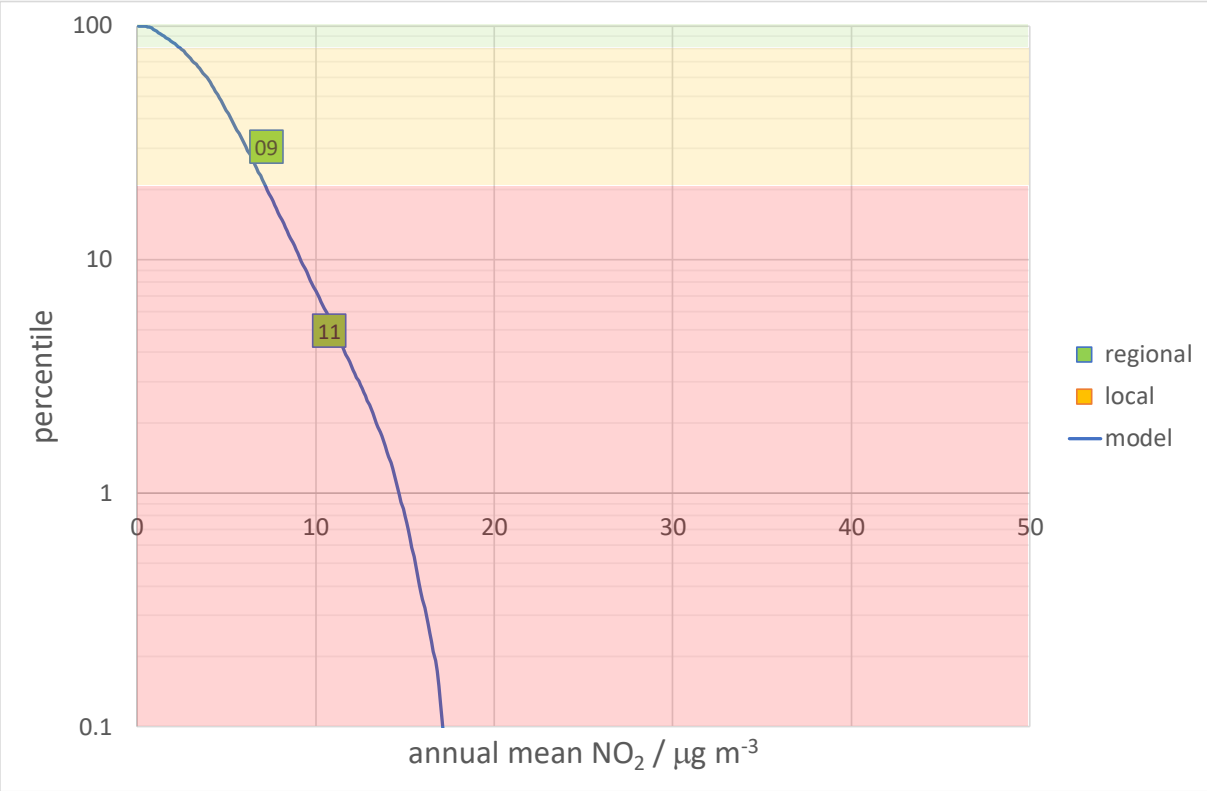
Napier



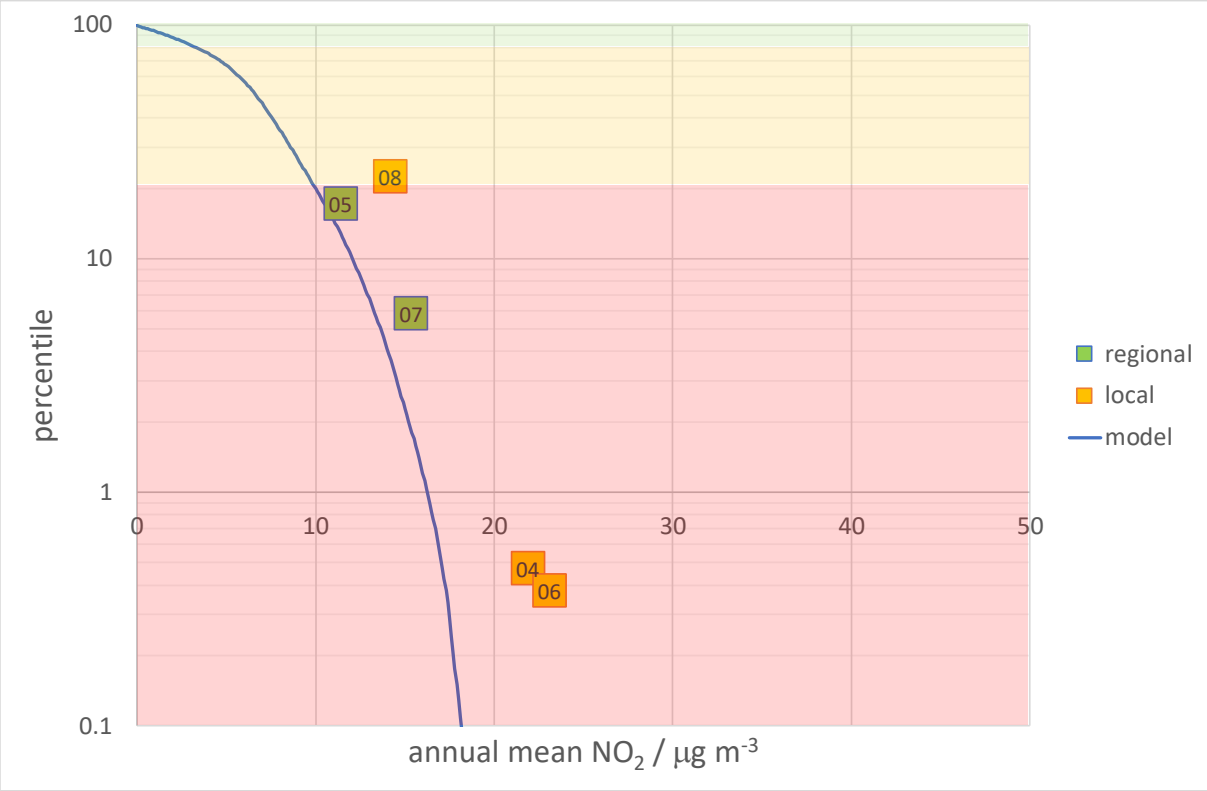
Nelson



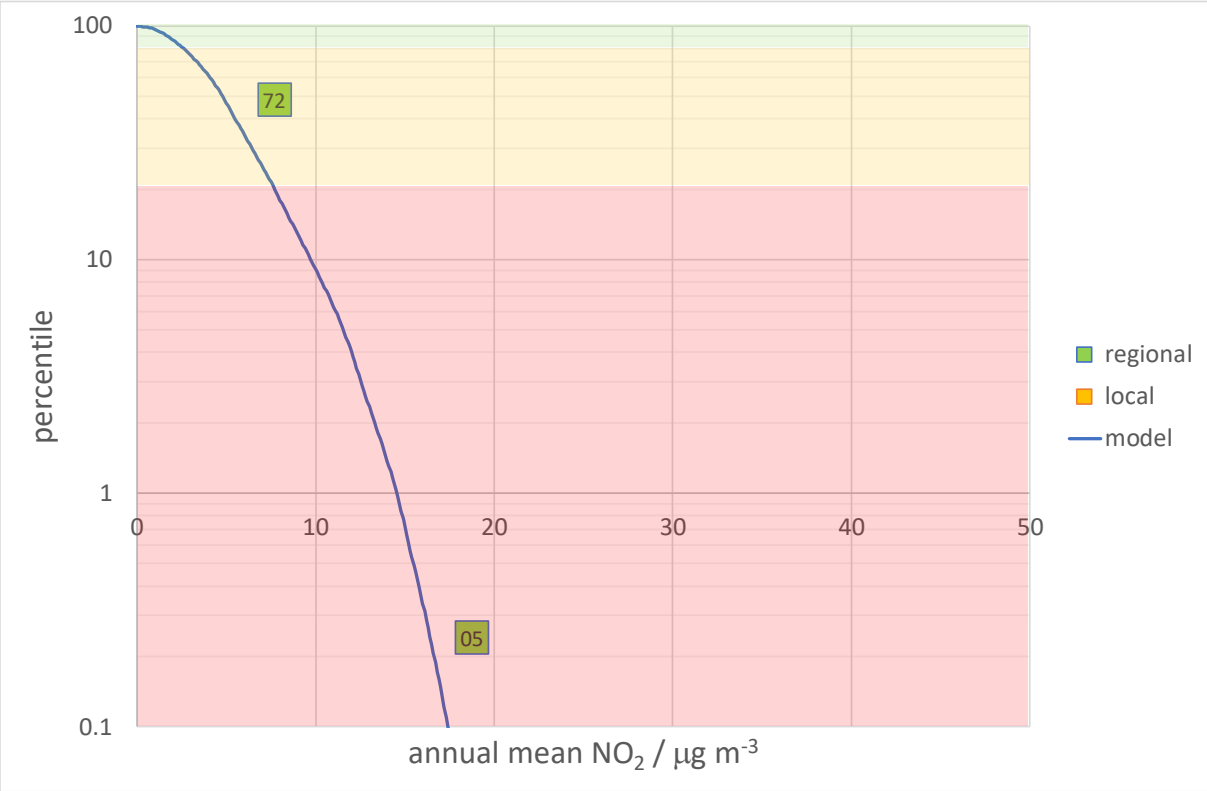
New Plymouth



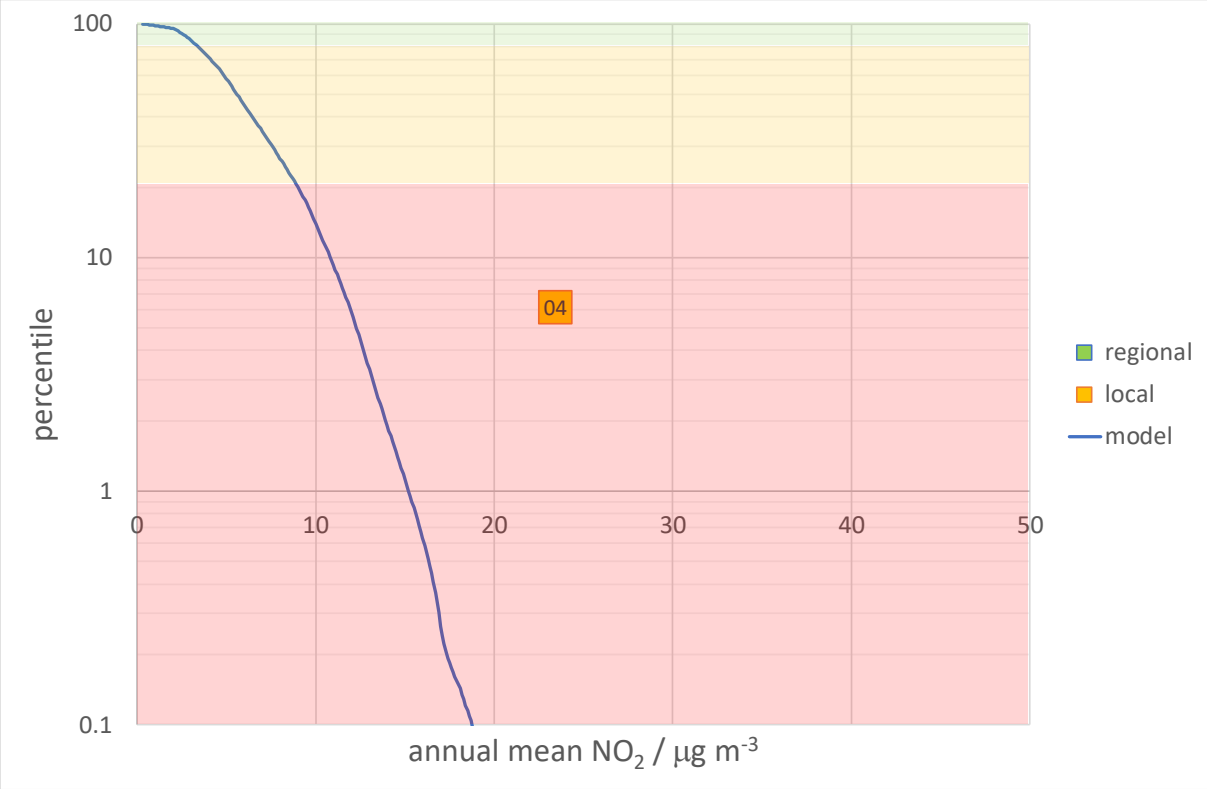
Palmerston North



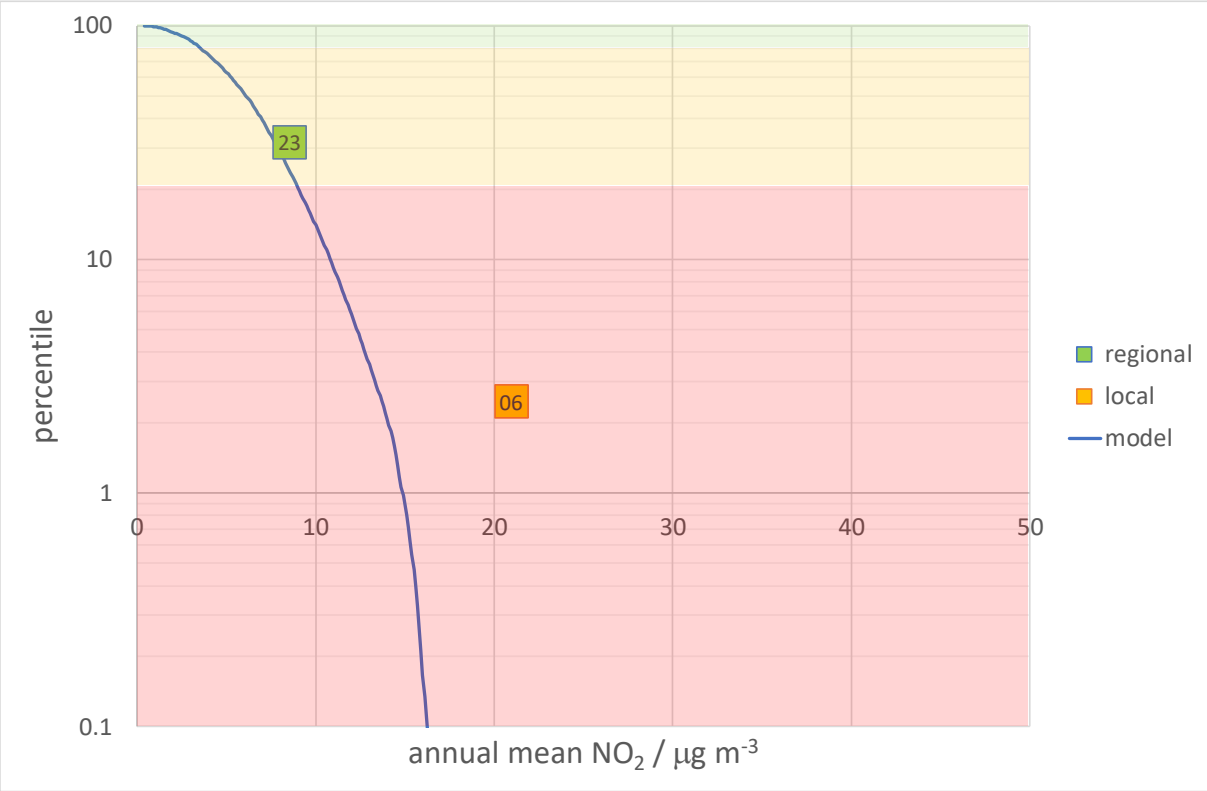
Porirua



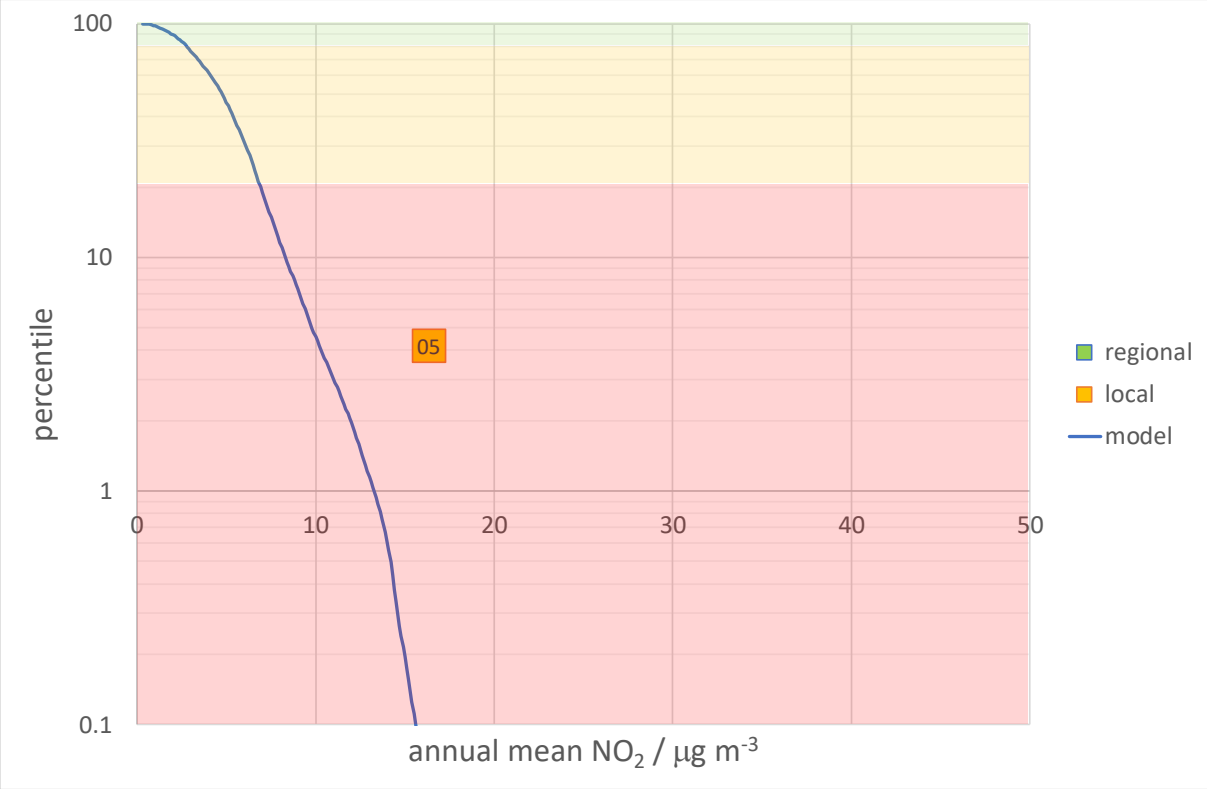
Queenstown



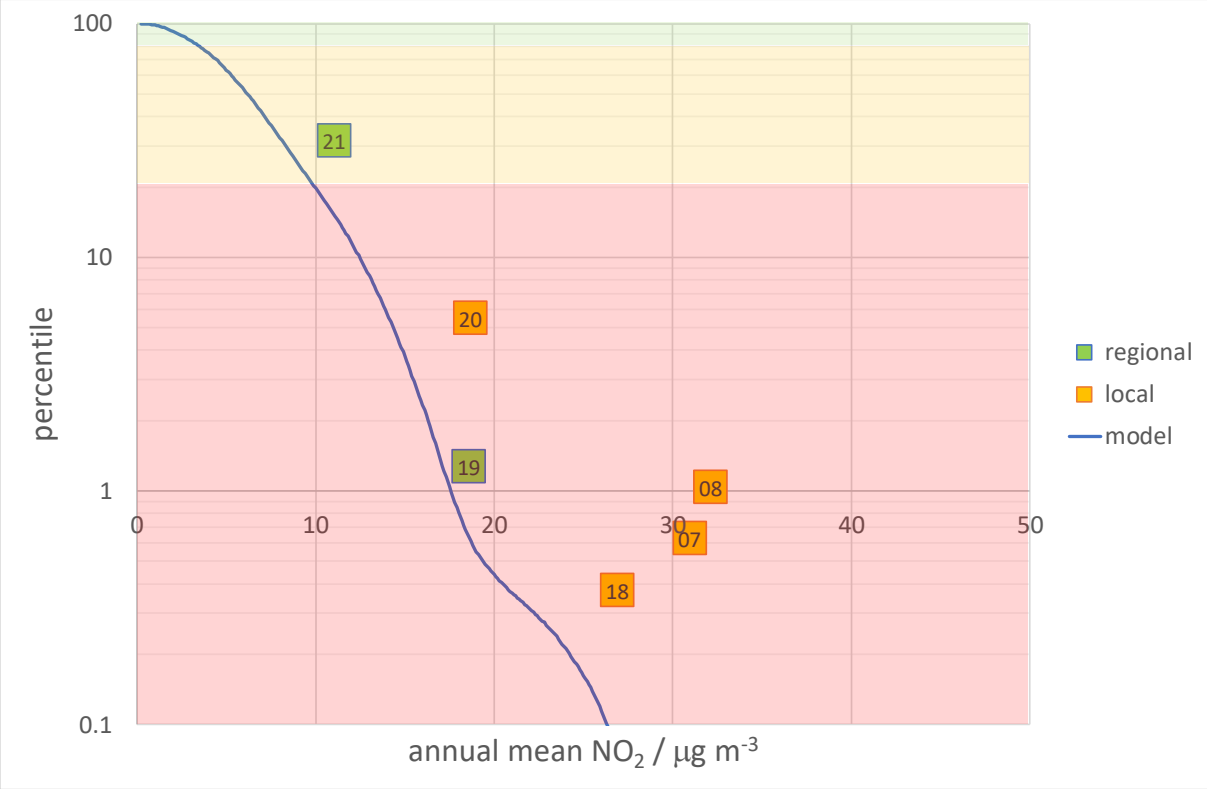
Rotorua



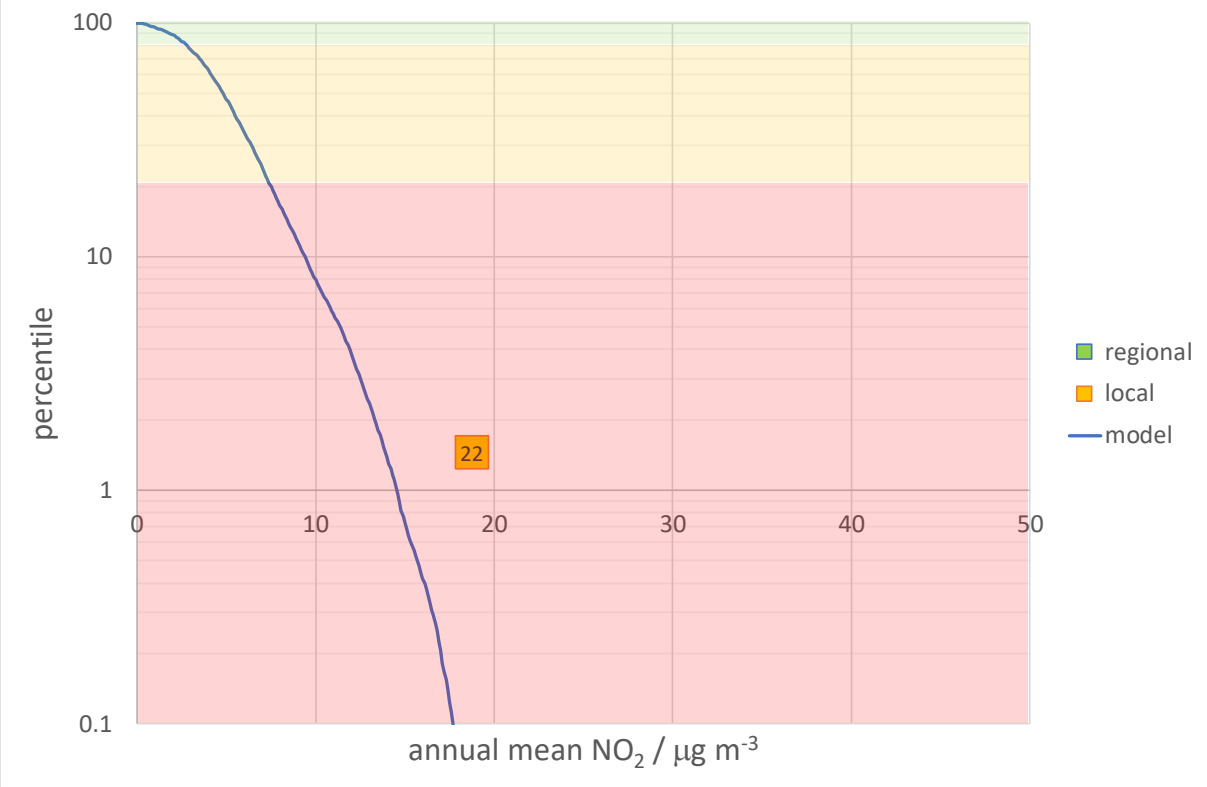
Taupō



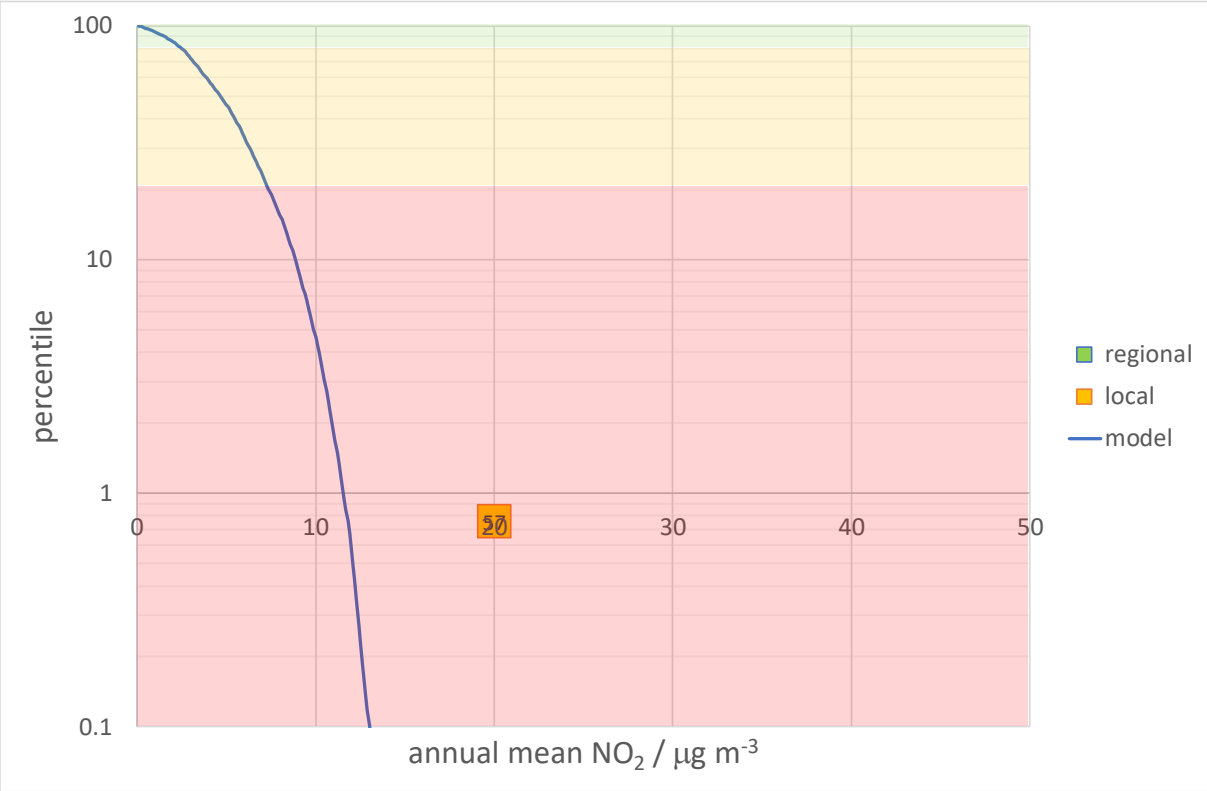
Tauranga



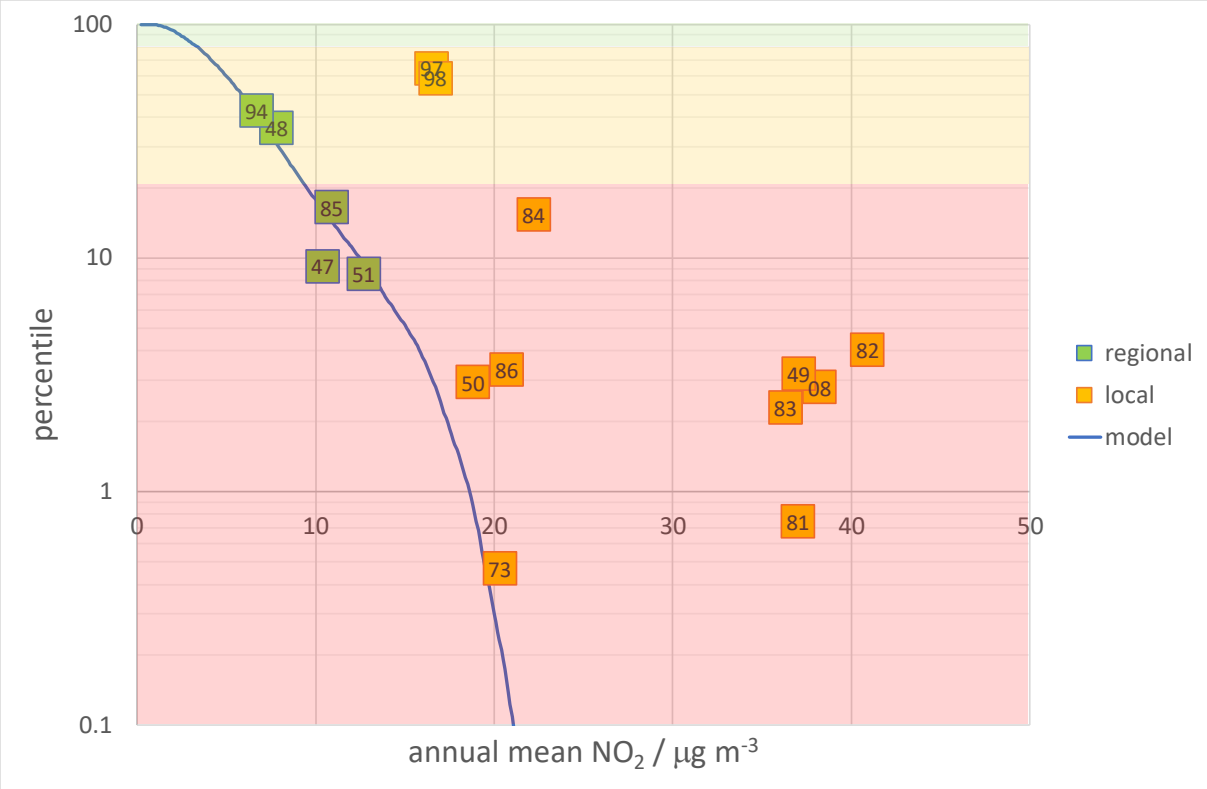
Te Awamutu



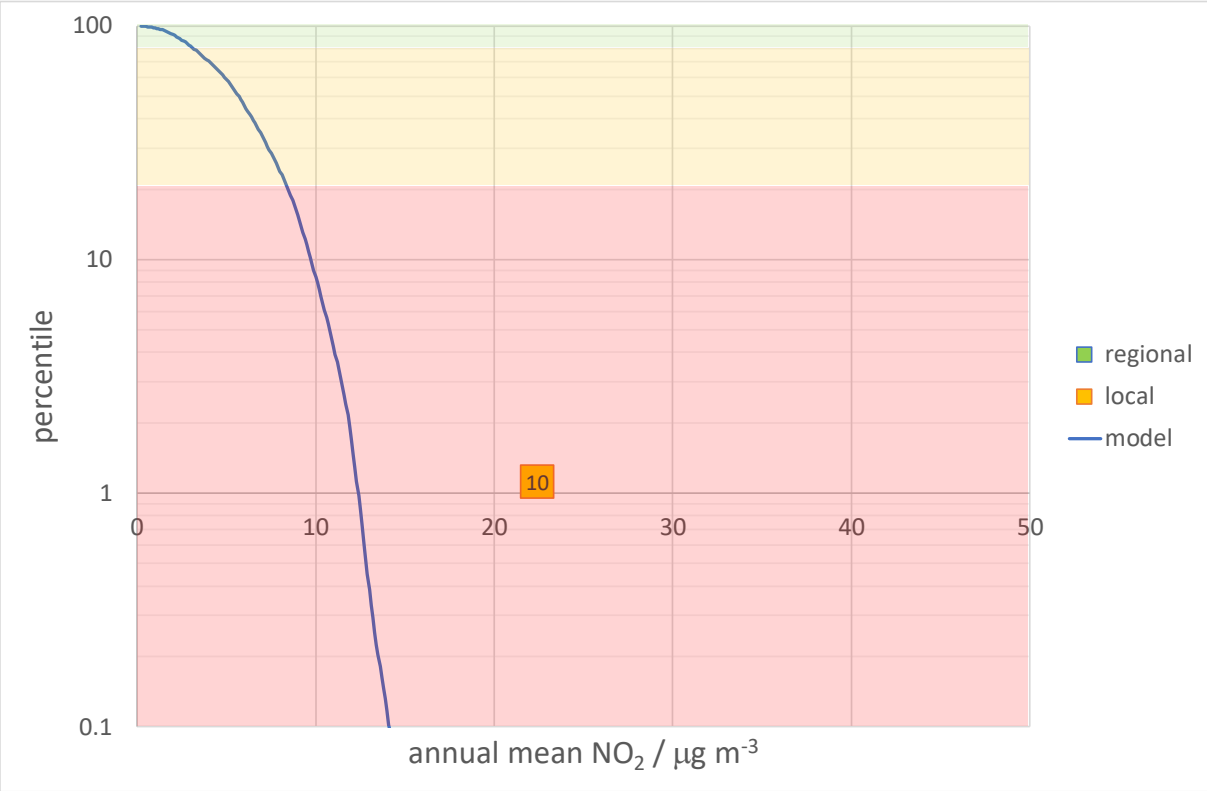
Upper Hutt



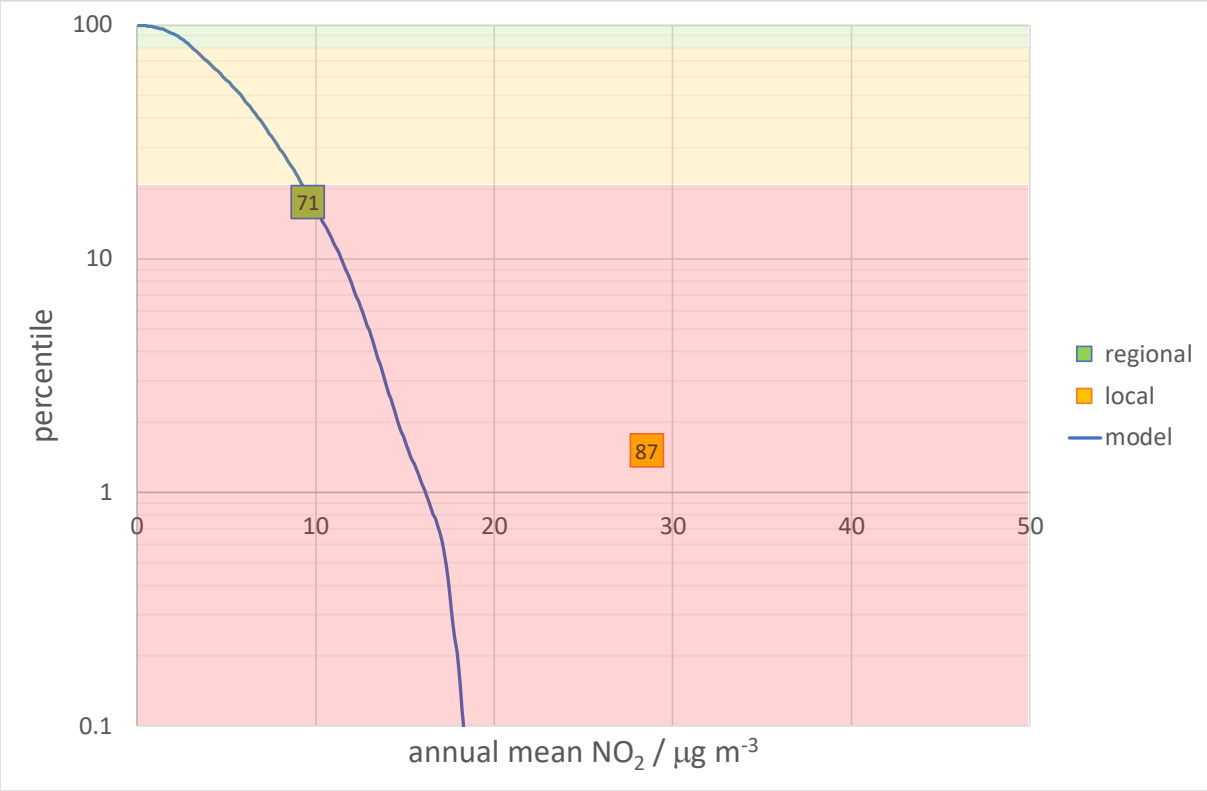
Wellington



Whanganui



Whangarei



Appendix C Proposed Network coverage by monitoring zone

A guide to interpreting the figures in this Appendix.

This Appendix contains one table and one figure for each monitoring zone (city).

To aid interpretation we have allocated site ID numbers to recommneded new sites following the same convention currently used in the Network (*ABC123*), with the three-letter code representing a major city and the three digit code incrementing as new sites are added. Numbers starting with zero (e.g. *ABC0xx*) refer to existing network sites, including sites run by GWRC. Numbers atarting with a one (e.g. *ABC1xx*) are future sites that are recommended in this work but have also been recommended by us to GWRC. Numbers atarting with a two (e.g. *ABC2xx*) are future sites that are recommended in this work to Waka Koyahi only.

In each **existing sites** in the Network are smaller and have black labels, and **new sites** are larger and have red labels.

Circles represent **Regional** sites and **squares** represent **Local** sites.

Colours are as follows:

- Yellow = urban background
- Orange = roadside
- Red = canyon/CBD
- Brown = sea port/airport/industrial
- Blue = intersection
- Purple = local traffic trend
- Green = growth area
- Grey = other

Auckland – Central

Network	Sub-Class	Sites	comments
Regional	Urban Background	Min 1 new site needed	Recommend 30 Parry Str, Sandringham (AUC201)
	Roadside	AUC008 AUC009 AUC011 AUC021 AUC022 AUC061 AUC062	AUC008 and AUC022 show similar trends – one could be removed if similarity is expected to continue. All others show differing trends, so suggest all are retained
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)	AUC025 AUC064 Min 1 new site needed (traffic falling)	AUC025 traffic rising. For new site suggest ~825 Dominion Rd (AUC202)
	Intersection	AUC060 AUC071	
	CBD	New sites needed	Recommend minimum of 4: 12 Customs Str (AUC203), 144 Hobson Str (AUC204), 155 Queen Str (AUC205), 187 Broadway (Newmarket) (AUC206)
	Port, industry, etc	AUC013 2 new site(s) recommended at Port	 Recommend 'near' on Quay Str/Tinley Str (AUC207) and 'far' on corner of The Strand/Ronayne Str (AUC208)
	Growth		
Sites that could be removed		AUC064 AUC008 AUC022	This site is an unrepresentative outlier for reasons unknown (possibly bus stop?) See above See above

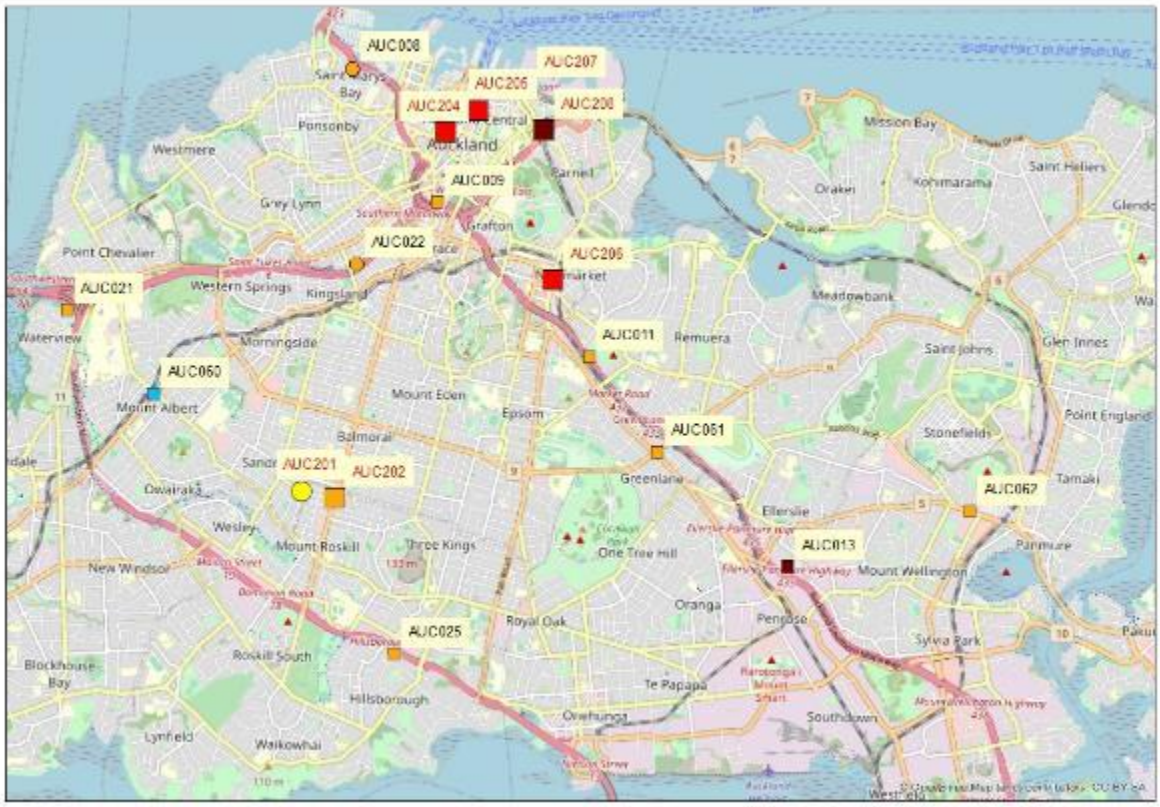


Figure C-1: Proposed Network for Auckland - Central.

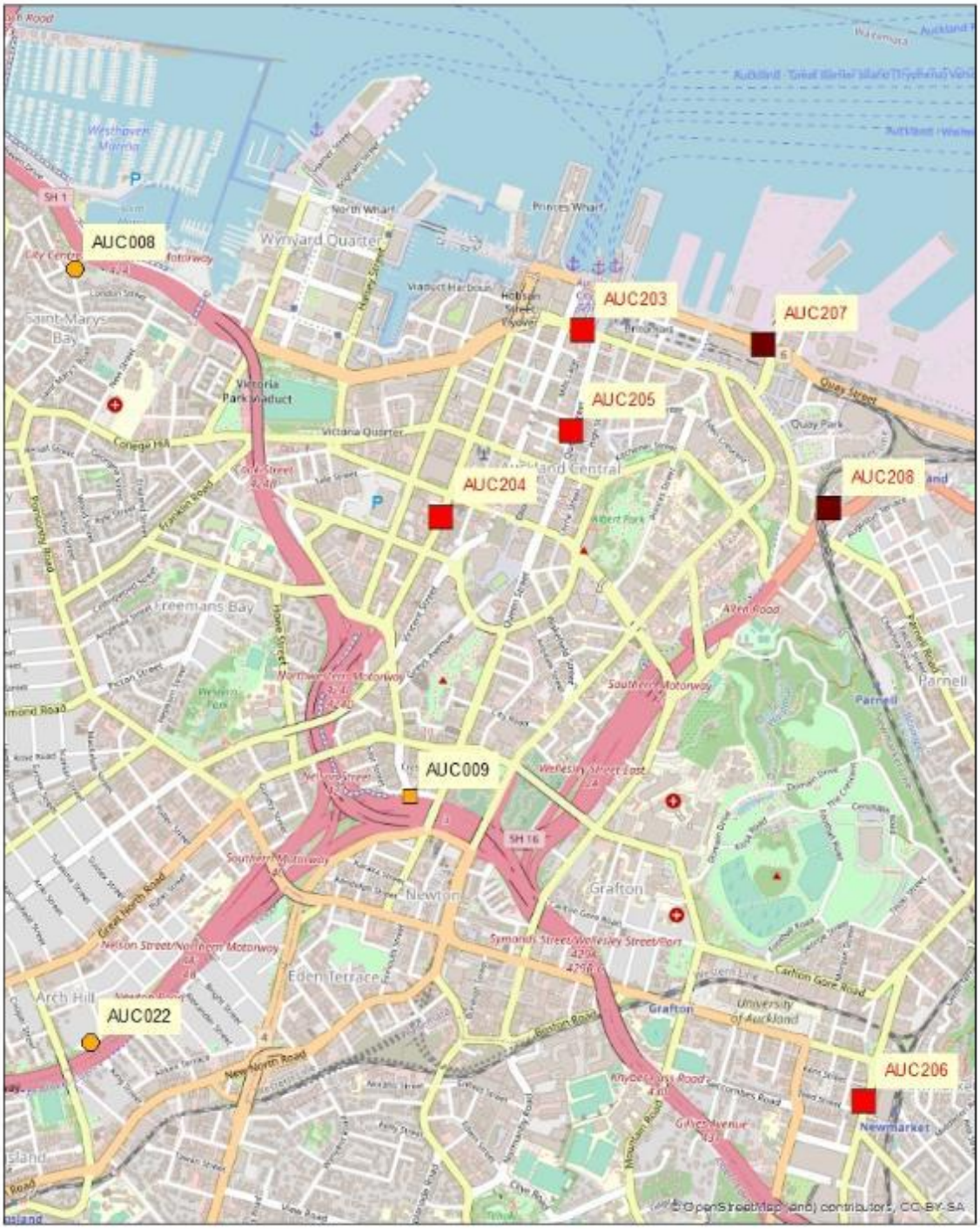


Figure C-2: Proposed Network for Auckland - Central (CBD detail).

Auckland – Northern

Network	Sub-Class	Sites	comments
Regional	Urban Background	Min 1 new site needed	Recommend 86 Nile Rd, Milford (AUC209)
	Roadside	AUC007 AUC043	moderately correlated – one could be removed but we recommend both are retained
Local	Urban Background (local traffic trend)	AUC047	Consider future relocation to Marlborough Ave
	Roadside (local traffic trend)	AUC040 AUC041 AUC005	Rising traffic trend Falling traffic trend
	Intersection	AUC005 AUC046 AUC170	
	CBD/canyons	AUC042	
	Port, industry, etc		
	Growth		Recommend Glenvar Road, Torbay (AUC210).
Sites that could be removed		AUC039	Duplicating AUC041

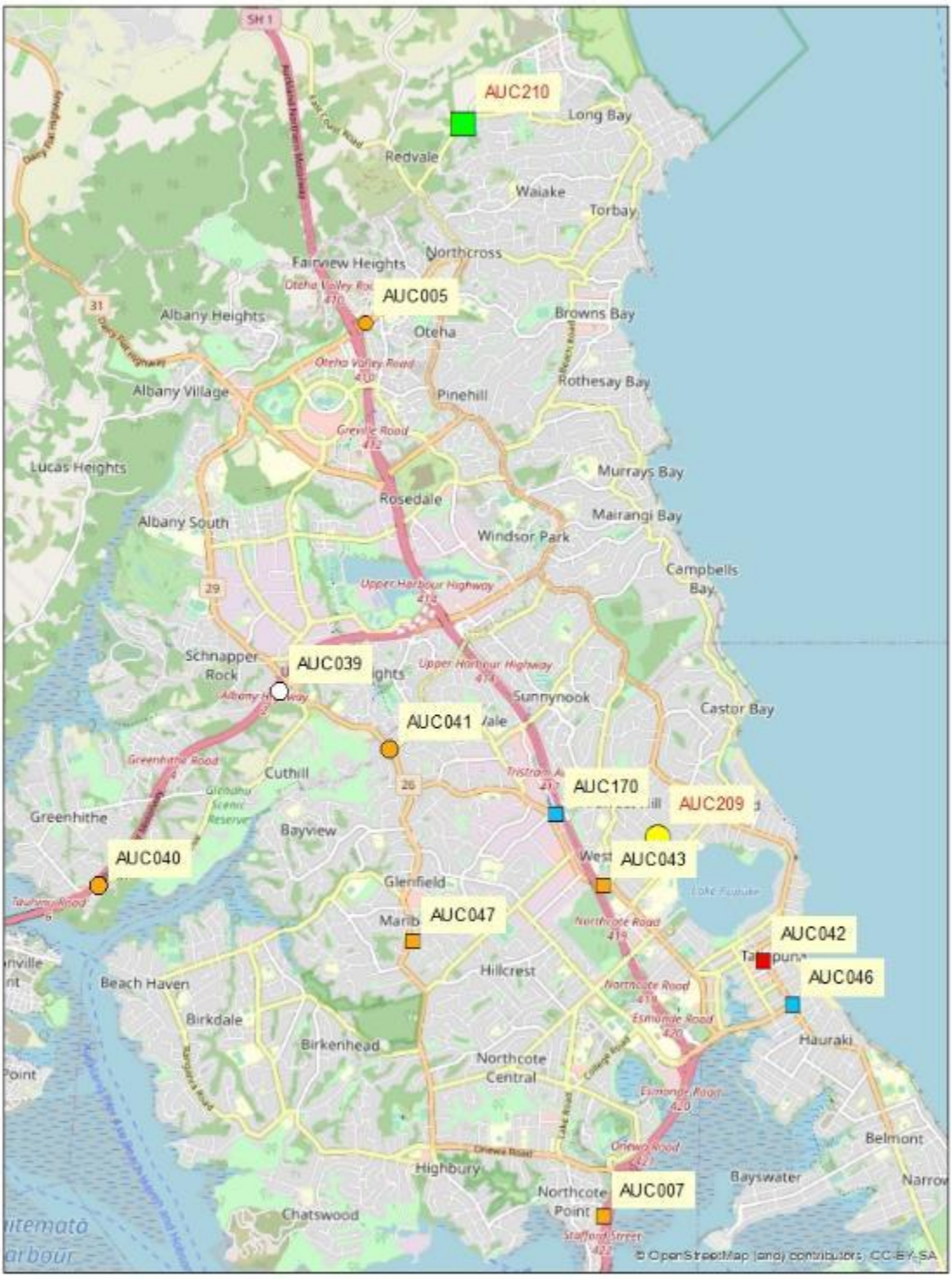


Figure C3 Proposed Network for Auckland - Northern.

Auckland – Southern

Network	Sub-Class	Sites	comments
Regional	Urban Background	AUC073	
	Roadside	AUC027 AUC190 AUC019 AUC072 AUC018	
Local	Urban Background (local traffic trend)	Min 1 new site needed	Suggest ~12 Desmond Pl, Otara (AUC211)
	Roadside (local traffic trend)	AUC067	Rising traffic trend
	Intersection	AUC069 AUC070	
	CBD/canyons		
	Port, industry, etc	New site(s) recommended at Airport	Screening campaign recommended at Airport to aid selection of representative site(s). Alternatively,site on Laurence Stevens Drive is recommended (AUC212)
	Growth	New site(s) recommended	Roads serving Drury-Opaheke growth areas
Sites that could be removed		AUC018 AUC026	Duplicates AUC019

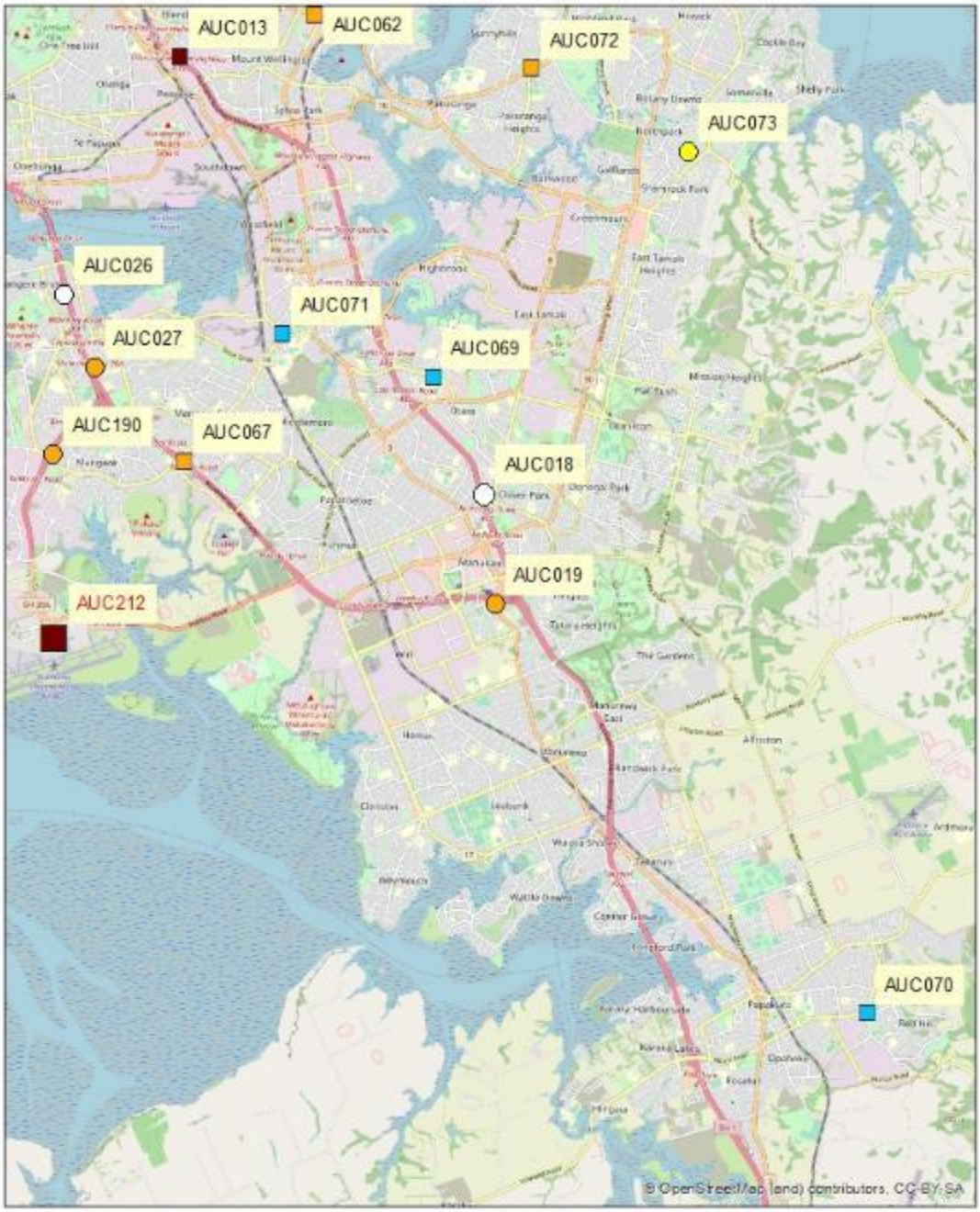


Figure C-4: Proposed Network for Auckland - Southern.

Auckland – Western

Network	Sub-Class	Sites	comments
Regional	Urban Background	AUC057 Min 1 new site recommended due to topographical variation	Suggest 6 Cole Pl, Te Atatu (AUC214)
	Roadside	AUC051 AUC053 AUC115	
Local	Urban Background (local traffic trend)	AUC049	Consider future move to Mapou Str
	Roadside (local traffic trend)	AUC050 AUC054	Rising traffic Falling traffic
	Intersection	AUC063	
	CBD/canyons	New Lynn	Suggest Memorial Drive (AUC215)
	Port, industry, etc		
	Growth	Suggest site(s) in Westgate	Suggest Maki Street, Westgate (AUC216)
Sites that could be removed		AUC020 AUC052	Duplicates AUC051 Duplicates AUC054

Figure C-5: Proposed Network for Auckland - Western.

Blenheim

Network	Sub-Class	Sites	comments
Regional	Urban Background	1 new site needed	Suggest Newbourne Cres (WEL201)
	Roadside	WEL012	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	Optional new site	Suggest SH1/SH6 (WEL202)
	CBD/canyons	Optional new site	Suggest nr 5, Maxwell Rd (WEL215)
	Port, industry, etc		
	Growth		
Sites that could be removed			

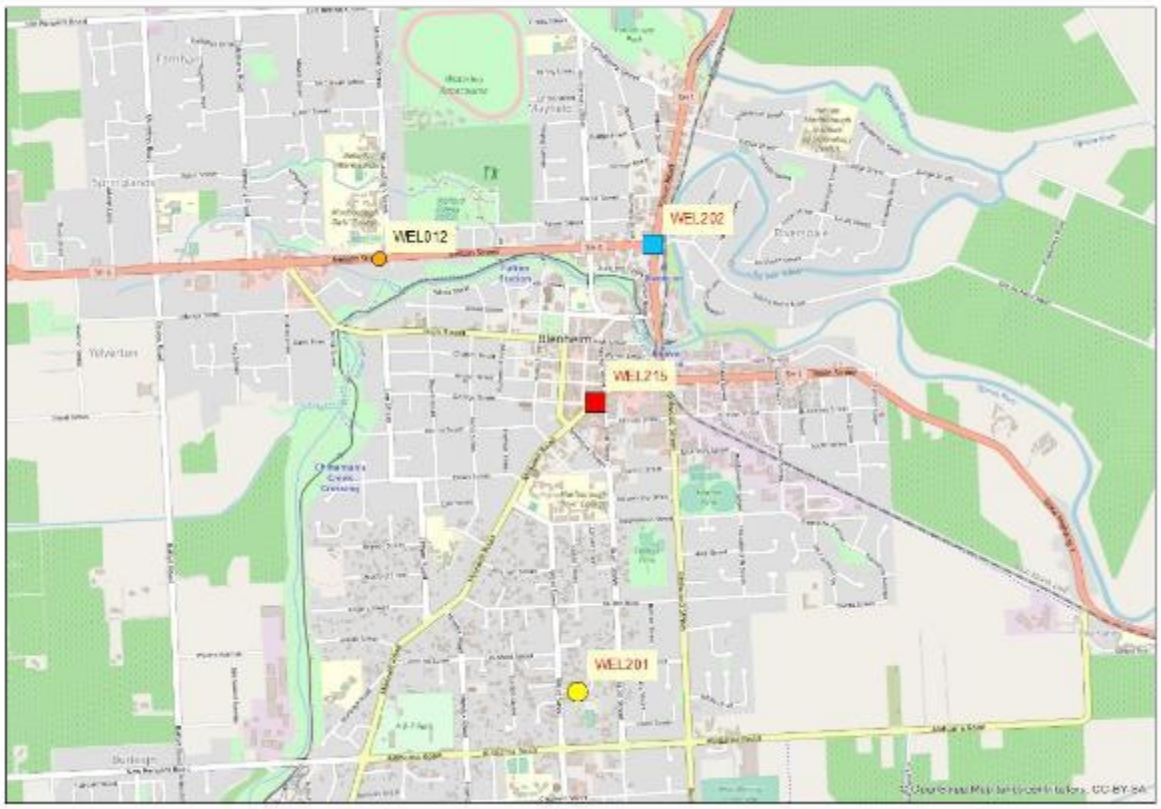


Figure C-6: Proposed Network for Blenheim.

Cambridge

Network	Sub-Class	Sites	comments
Regional	Urban Background	1 new site needed	Suggest Mason Place (HAM201)
	Roadside	1 new site needed	Suggest nr 161 Victoria Str (HAM202)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	HAM004	
	CBD/canyons	Optional new site	Suggest near 65 Victoria Str (HAM203)
	Port, industry, etc		
	Growth		
Sites that could be removed			

Figure C-7: Proposed Network for Cambridge.

Christchurch

Network	Sub-Class	Sites	comments
Regional	Urban Background	CHR004 CHR020	
	Roadside	Min 1 new site needed	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	CHR002 CHR003 CHR006 CHR012 CHR013 CHR014 CHR017	
	CBD/canyons	CHR016 Add min 1 site CBD	
	Port, industry, etc		
	Growth		
Sites that could be removed		CHR011 CHR015	

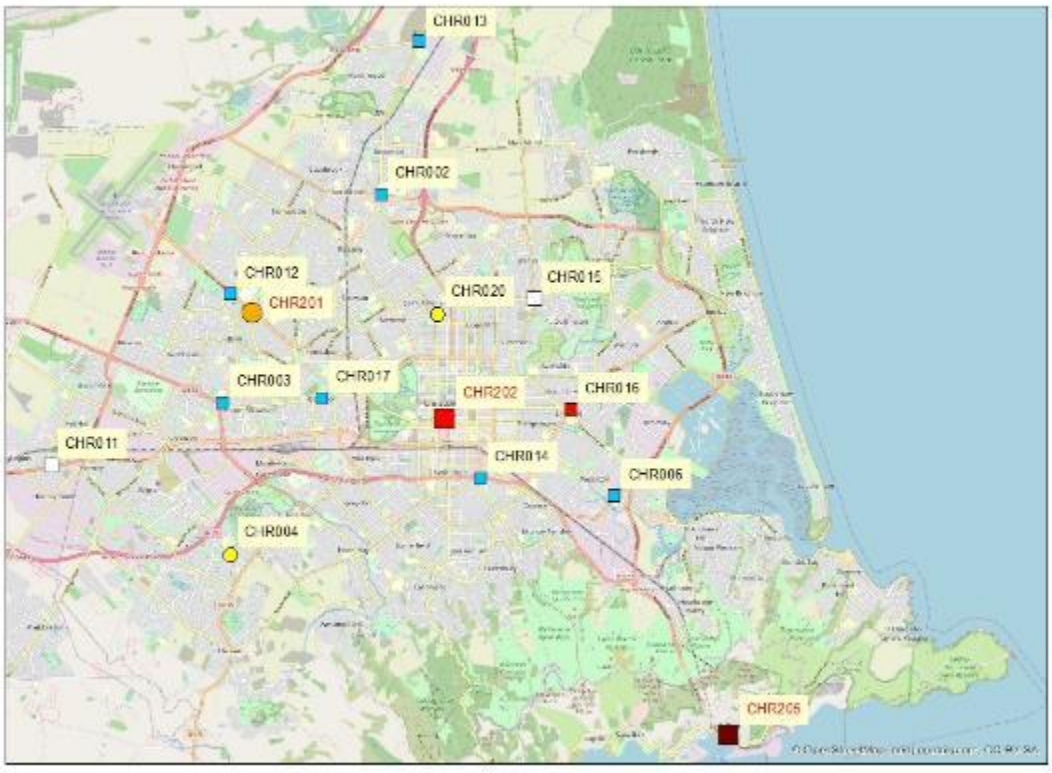


Figure C-8: Proposed Network for Christchurch.

Dunedin

Network	Sub-Class	Sites	comments
Regional	Urban Background	Add 3 new sites	Suggest Bridger Str (DUN213), Crammond Ave (DUN210) and Ardern Str (DUN212)
	Roadside	DUN002 Add new site to cover lowland areas	Suggest Castle Str or Cumberland Str, north of Dundas Str (DUN211)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)	DUN008	Steep gradient
	Intersection	DUN001 DUN006 DUN009	DUN006 is in Mosgiel
	CBD/canyons	Add min 1 site CBD	Suggest George Str (between Hannover and St Andrews) (DUN201)
	Port, industry, etc		
	Growth		
Sites that could be removed		DUN007 DUN011	If replaced by DUN213 Unrepresentative

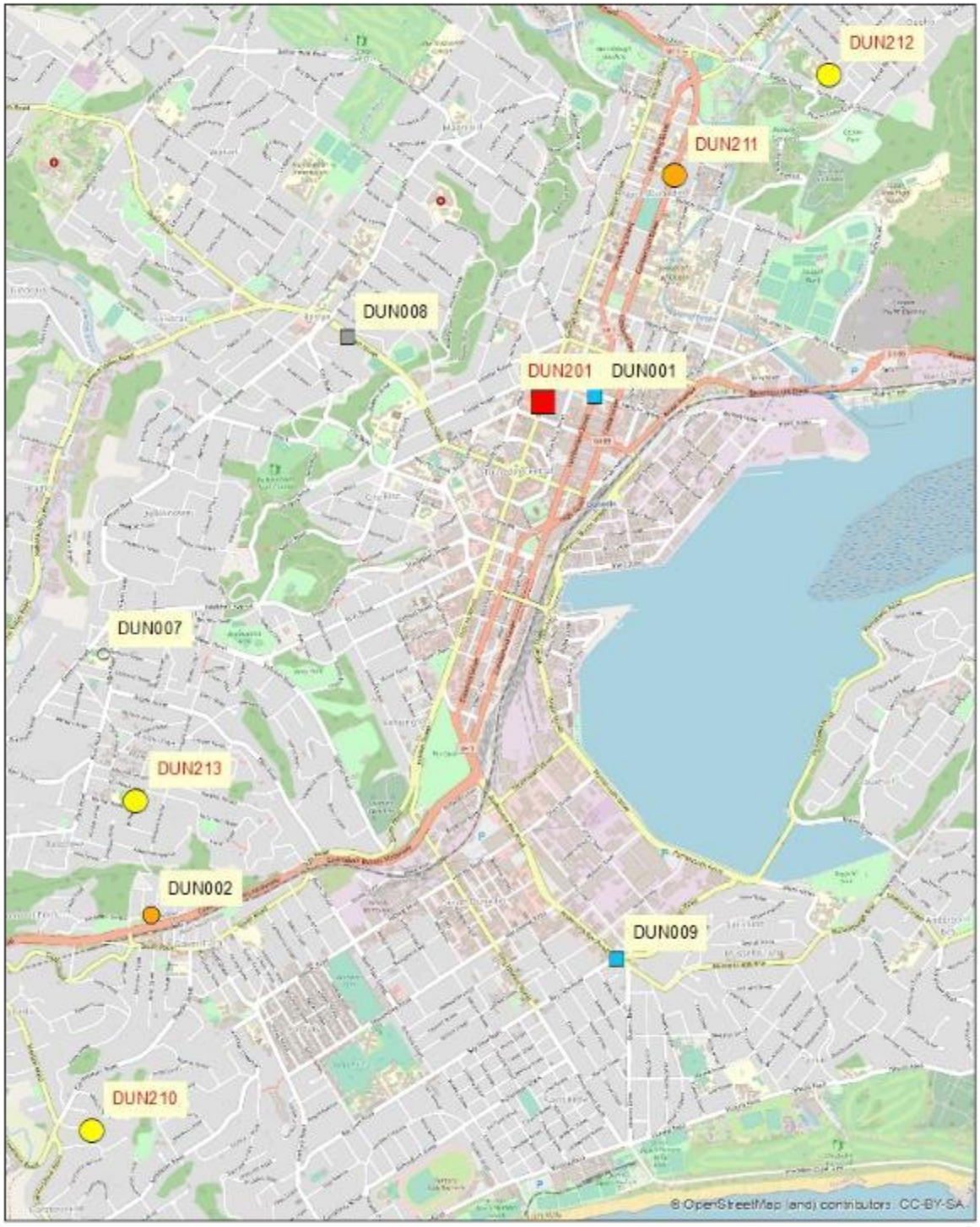


Figure C-9: Proposed Network for Dunedin.

Gisborne

Network	Sub-Class	Sites	comments
Regional	Urban Background	1 new site needed	Suggest Fergusson Dr (NAP201)
	Roadside	1 new site needed	Suggest Gladstone Rd, E of Lytton Rd (NAP202)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)	NAP001	Impacted by car parking?
	Intersection	Optional 1 new site	Suggest Gladstone Rd/Lytton Rd (NAP203)
	CBD/canyons	Optional new site	Suggest Gladstone Rd, nr. Peel Str (NAP204)
	Port, industry, etc	Optional new site at port	Suggest The Esplanade or Rakaiatane Rd (NAP205)
	Growth		
Sites that could be removed		NAP001	If replaced by NAP202

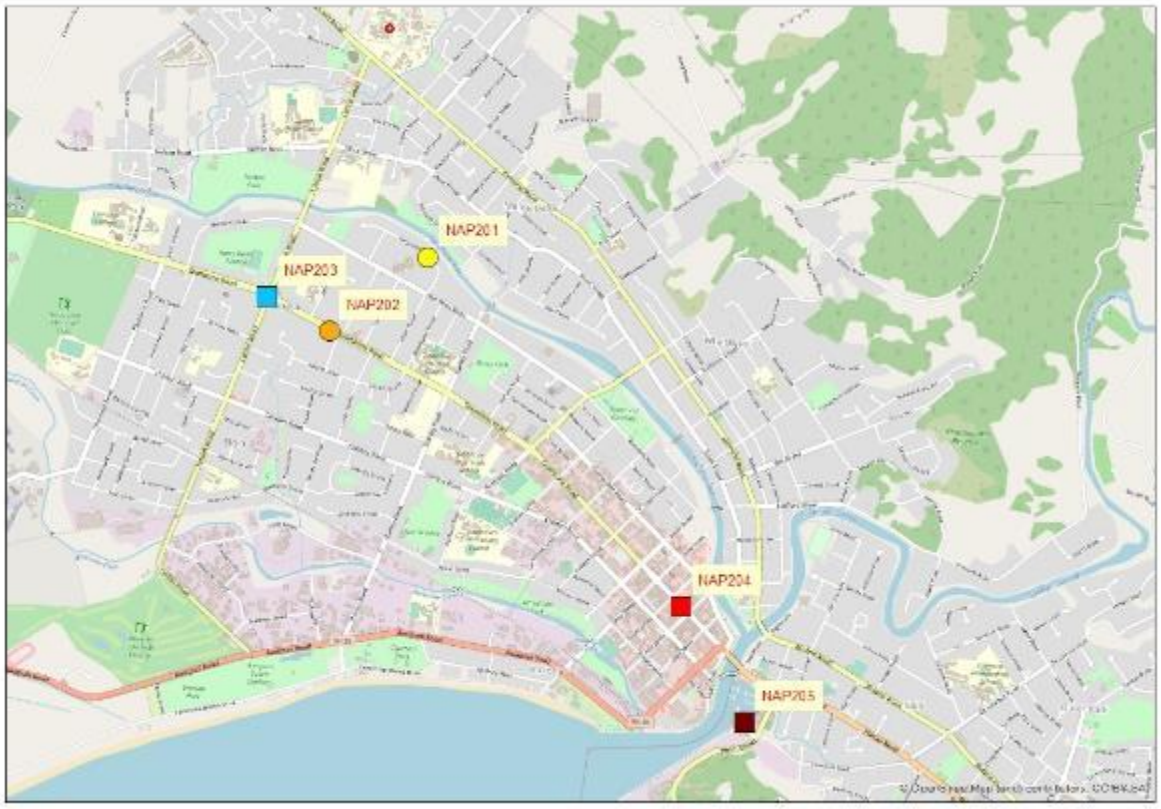


Figure C-10: Proposed Network for Gisborne.

Greymouth

Network	Sub-Class	Sites	comments
Regional	Urban Background	1 new site needed	Suggest Joyce Cres (CHR203)
	Roadside	CHR001	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	Optional 1 new site	Suggest SH6/Tainui Str (CHR204)
	CBD/canyons		
	Port, industry, etc		
	Growth		
Sites that could be removed			

Figure C-11: Proposed Network for Greymouth.

Hamilton

Network	Sub-Class	Sites	comments
Regional	Urban Background	HAM017	
	Roadside	1 new site needed	Suggest Te Rapa Rd nr Vercoe Rd (HAM204)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	HAM001 HAM003 HAM013 HAM014	HAM014 and HAM015 roughly correlated HAM003 and HAM013 roughly correlated
	CBD/canyons	Min 1 new site needed	Suggest Victoria Str nr Alma Str (HAM205)
	Port, industry, etc	HAM002 HAM012	Suspect impacted by rail yard Suggest screening survey campaign of whole Te Rapa area
	Growth	Waikato Expressway	Suggest Pardoa Blvd (HAM206)
Sites that could be removed		HAM002 HAM015 HAM016	If replaced by HAM204 Duplicates HAM014 Duplicates HAM001

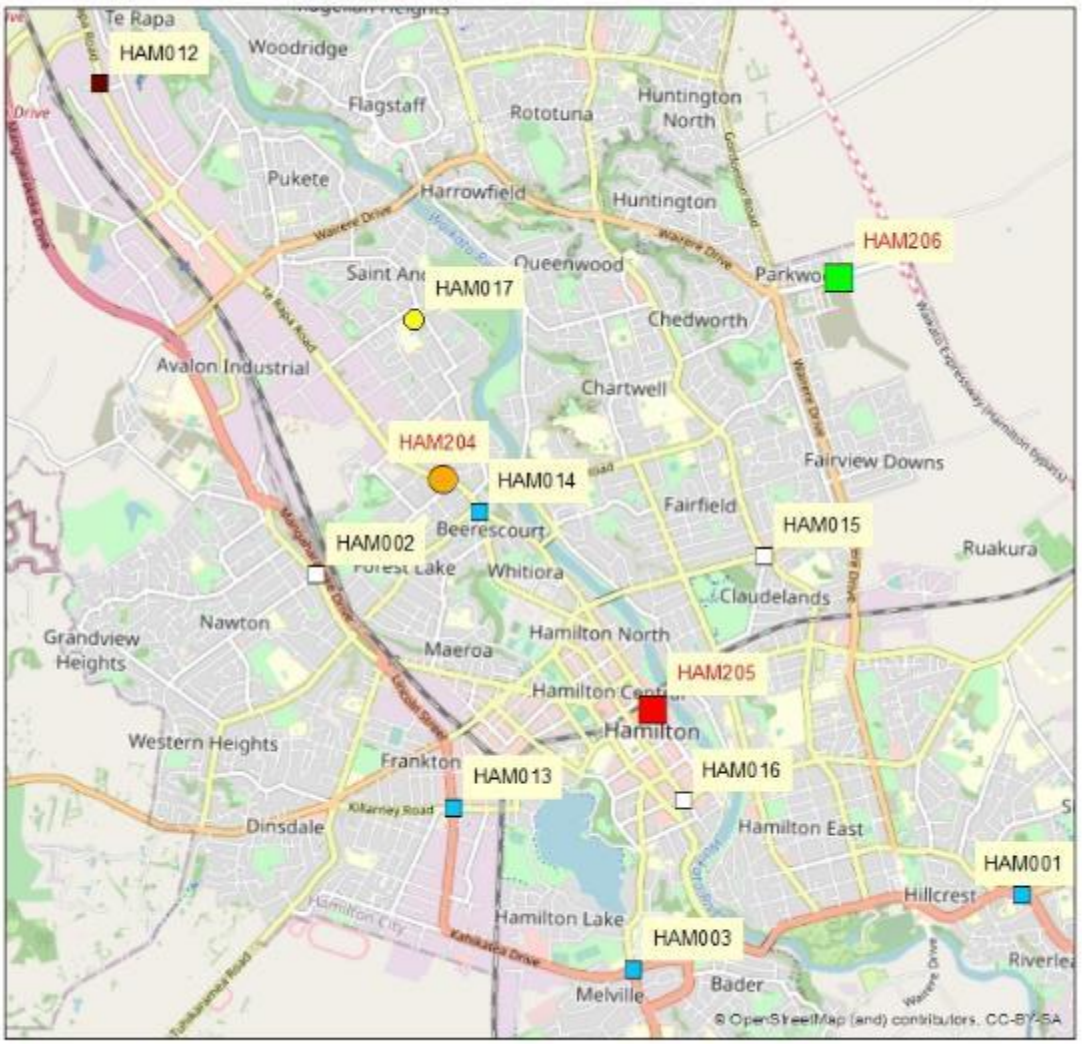


Figure C-12: Proposed Network for Hamilton.

Hastings

Network	Sub-Class	Sites	comments
Regional	Urban Background	NAP005	Consider future relocation to Fenwick Str/Willowpark
	Roadside	1 new site needed	Suggest Karamu Rd North, nr. Mayfair Ave (NAP206)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	NAP004	
	CBD/canyons	1 new site needed	Suggest Heretaunga Str W, between Neilson and King (NAP207)
	Port, industry, etc		
	Growth		
Sites that could be removed			

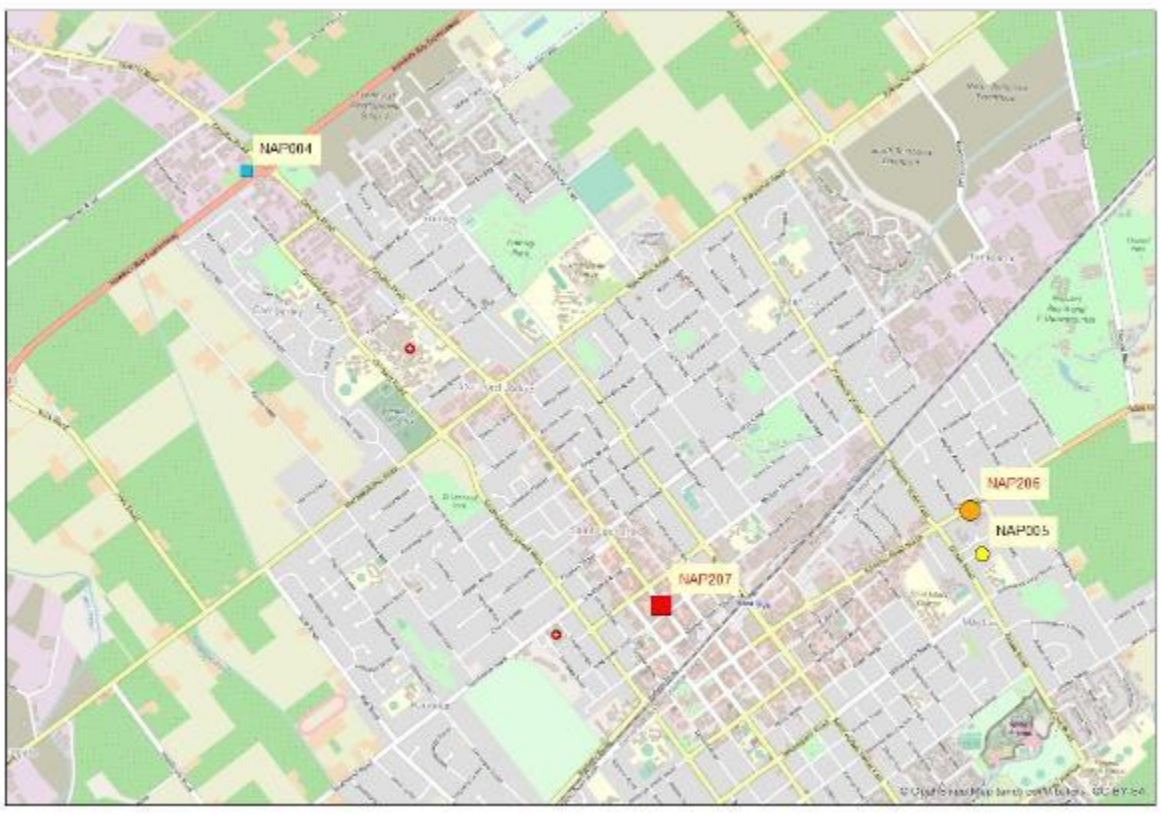


Figure C-13: Proposed Network for Hastings.

Hibiscus Coast

Network	Sub-Class	Sites	comments
Regional	Urban Background	Recommend 2 new sites	Recommend Polkinghorne Dr (Whangaparaoa, AUC221) and Denham Way (Orewa, AUC223)
	Roadside	AUC004 Recommend 2 new sites	NO2 is high at AUC004 relative to model – reason unknown Eg 699 Whangaparaoa Rd (AUC222) Eg 10 Twin Coast Discovery Hwy (AUC226)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection		
	CBD/canyons	Recommend 1 new site	Eg 324 Hibiscus Coast Hwy (AUC224)
	Port, industry, etc		
	Growth		Recommend Dairy Flat Highway (AUC225).
Sites that could be removed		AUC004	Once new sites (AUC222 and AUC226) are established

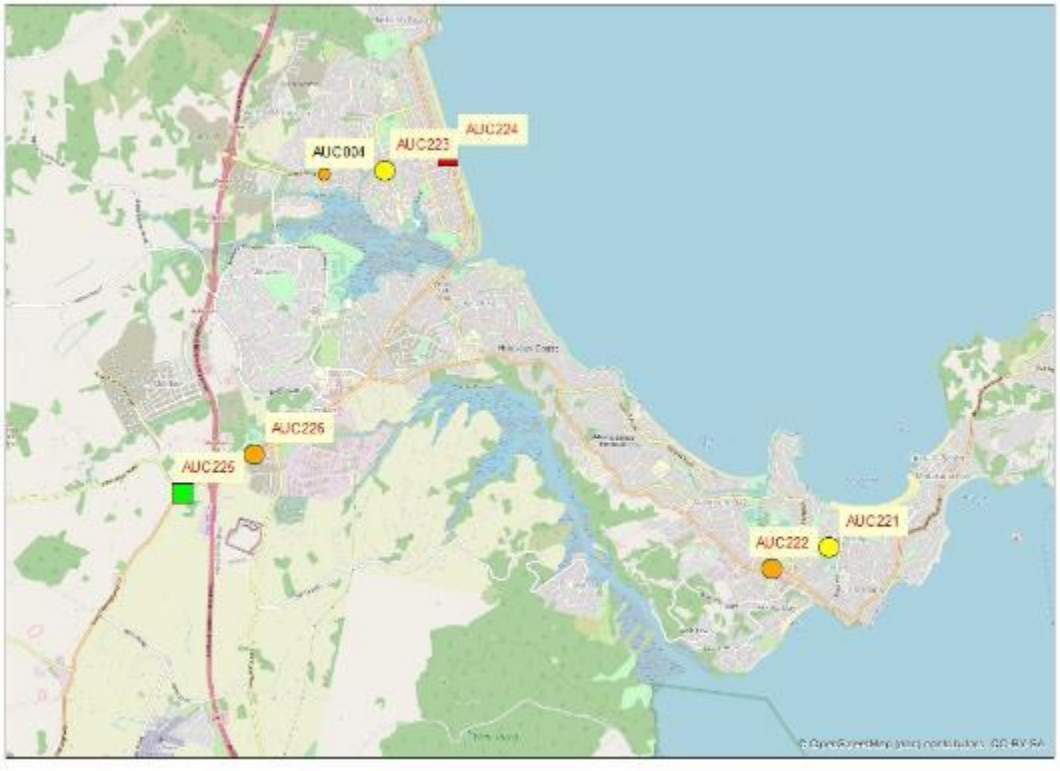


Figure C14 Proposed Network for Hibiscus Coast.

Invercargill

Network	Sub-Class	Sites	comments
Regional	Urban Background	1 new site needed	Suggest Grey Str (DUN202)
	Roadside	DUN010 1 new site needed	Non-ideal site (too far setback) Suggest Dee Str (SH6) nr Arthur Str (DUN214)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	Optional 1 new site	Suggest SH1/Elles Rd (DUN203)
	CBD/canyons	DUN005	
	Port, industry, etc		
	Growth		
Sites that could be removed		DUN010	Once replaced by DUN214

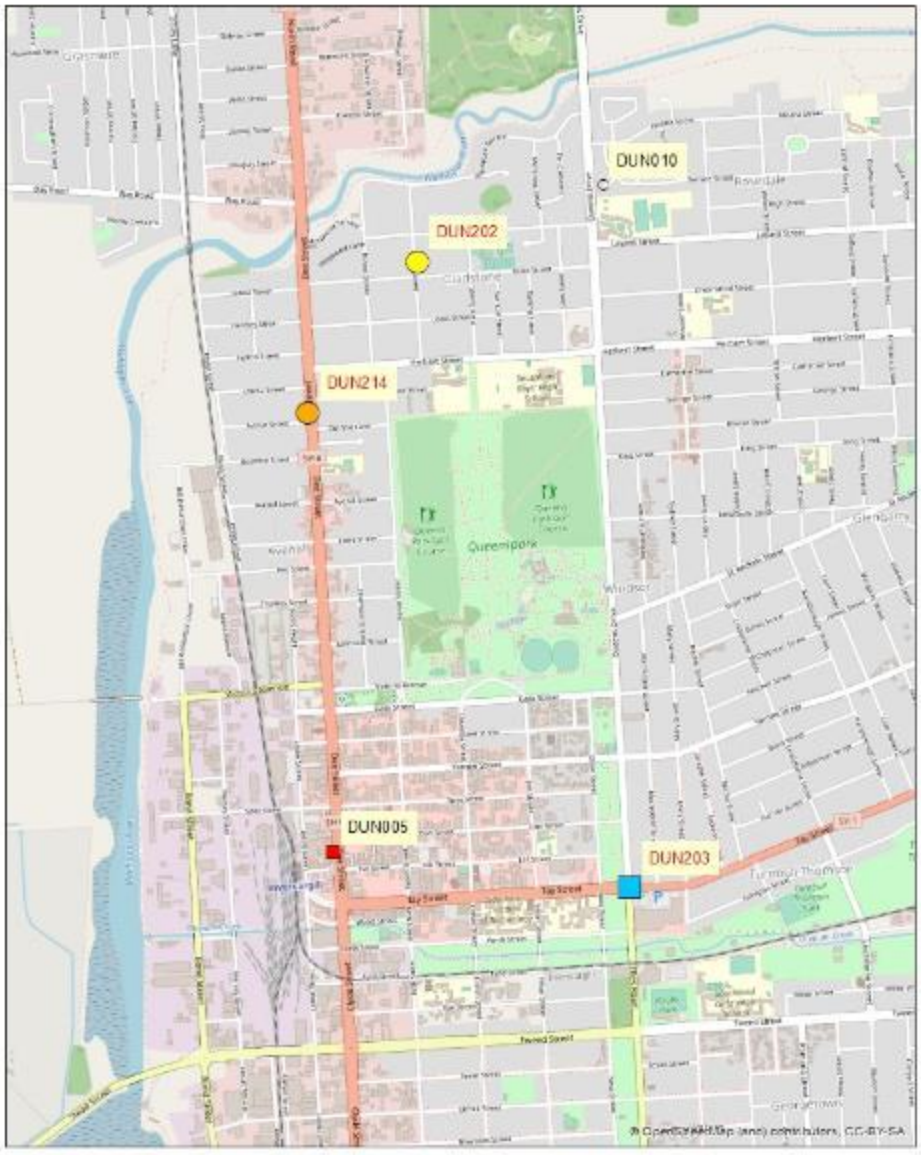


Figure C-15: Proposed Network for Invercargill.

Kāpiti Coast

Network	Sub-Class	Sites	comments
Regional	Urban Background	WEL103 (GWRC)	
	Roadside	WEL102 (GWRC)	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)	WEL063	Consider relocating to straight section
	Intersection	Optional 1 new site	Suggest Kāpiti Rd/Amohia Str (WEL113)
	CBD/canyons		
	Port, industry, etc		
	Growth		
Sites that could be removed			

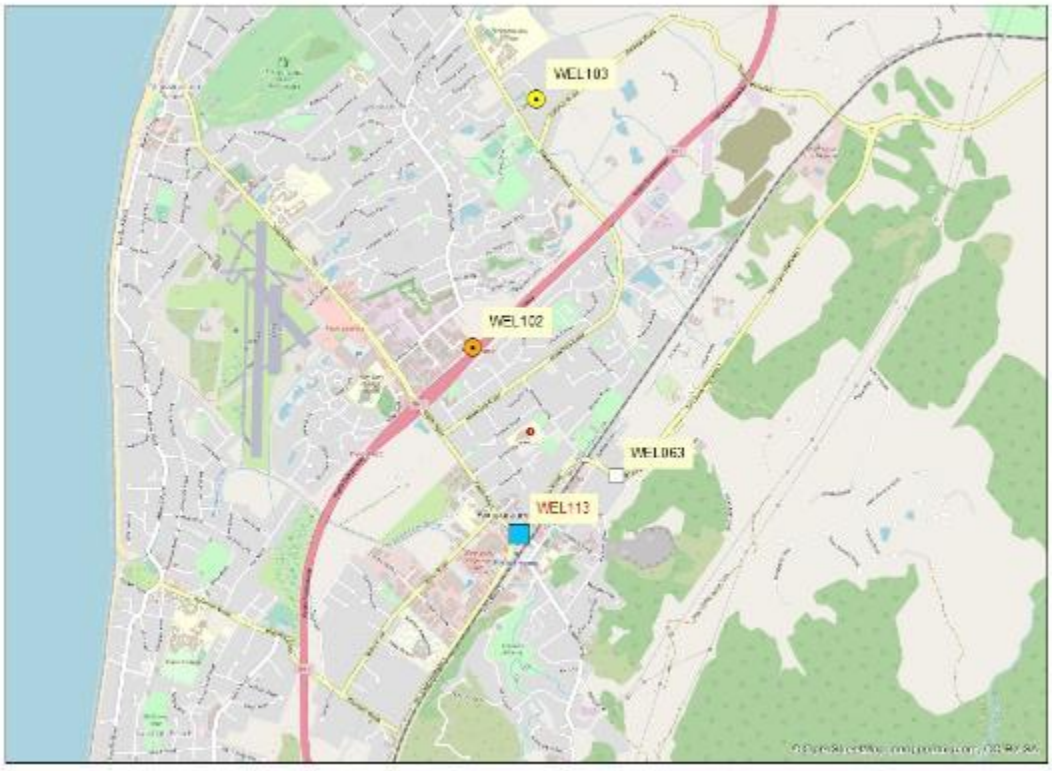


Figure C-16: Proposed Network for Kāpiti Coast.

Lower Hutt

Network	Sub-Class	Sites	comments
Regional	Urban Background	WEL054 WEL091	
	Roadside	WEL003 WEL052 WEL078	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	WEL053 *WEL090 (GWRC)*	
	CBD/canyons	Optional new CBD site	Suggest ~186 High Str (WEL116)
	Port, industry, etc		
	Growth		
Sites that could be removed			

Figure C-17: Proposed Network for Lower Hutt.

Masterton

Network	Sub-Class	Sites	comments
Regional	Urban Background	WEL096	
	Roadside	WEL089	Outlier – worth further investigation – could relocate
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	Optional 1 new site	Suggest Chapel Str/Lincoln Rd (WEL114)
	CBD/canyons	*WEL095 (GWRC)*	
	Port, industry, etc		
	Growth		
Sites that could be removed			

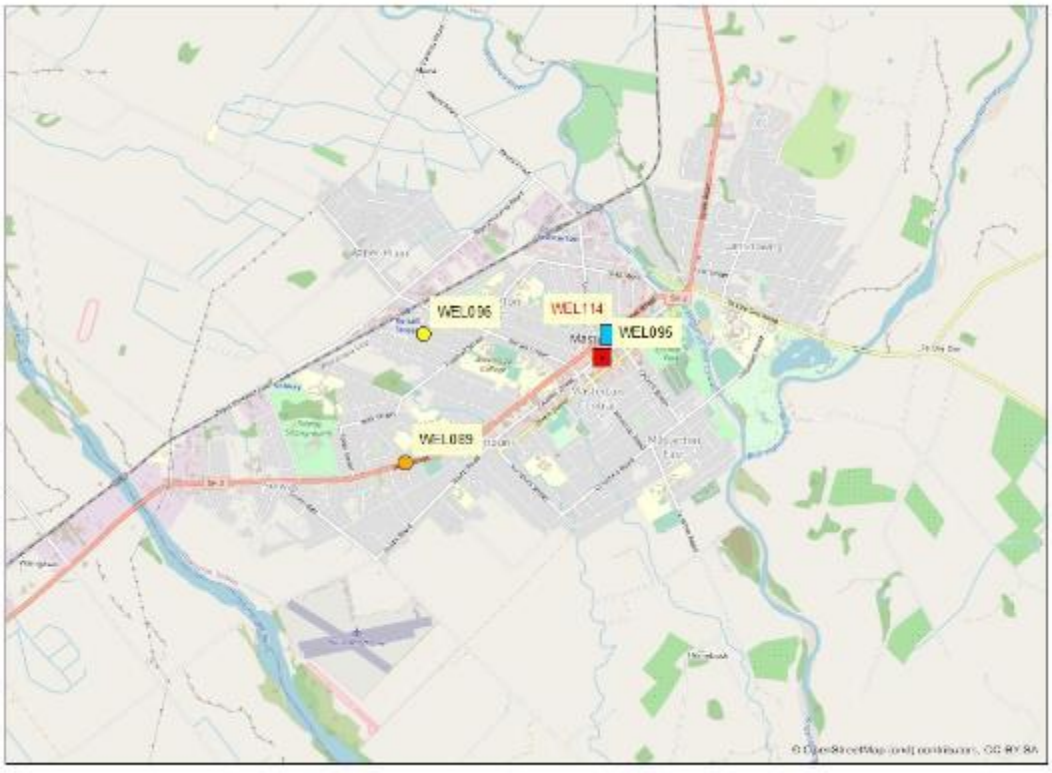


Figure C-18: Proposed Network for Masterton.

Napier

Network	Sub-Class	Sites	comments
Regional	Urban Background	NAP006	
	Roadside	1 new site needed	Suggest Hyderabad Rd between Taradale Rd and Georges Rd (NAP208)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	NAP003	
	CBD/canyons	Optional new site	Suggest nr 150 Hastings Str (NAP209)
	Port, industry, etc	Optional new sites at Port	Suggest Ahuriri Bypass (NAP210)
	Growth		
Sites that could be removed		NAP002	Difference in grade and trees make representativeness of this site ambiguous

Figure C-19: Proposed Network for Napier.

Nelson

Network	Sub-Class	Sites	comments
Regional	Urban Background	Min 1 new site needed	Suggest Hereford Str
	Roadside	WEL010 WEL011 WEL062	Designation is uncertain due to uncertainties in model for Nelson
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	WEL009	
	CBD/canyons	Optional new site	Suggest ~111 Trafalgar Str
	Port, industry, etc	Optional new sites at Port	
	Growth		
Sites that could be removed			

Figure C-20: Proposed Network for Nelson.

New Plymouth

Network	Sub-Class	Sites	comments
Regional	Urban Background	WAN009	
	Roadside	WAN011	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	Optional new site	Suggest Courtenay Str/Eliot Str (WAN201)
	CBD/canyons	Optional new site	Suggest Devon Str E (WAN202)
	Port, industry, etc	Optional new site at Port	Suggest Breakwater Rd (WAN203)
	Growth		
Sites that could be removed			

Figure C-21: Proposed Network for New Plymouth.

Ōtaki

Network	Sub-Class	Sites	comments
Regional	Urban Background	Min 1 new site	Suggest McLaren Pl (WEL117)
	Roadside	Min 1 new site	Suggest approx. 200 Main Hwy (WEL111)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	WEL087	
	CBD/canyons		
	Port, industry, etc		
	Growth		
Sites that could be removed		WEL061	Duplicates WEL087

Figure C-22: Proposed Network for Ōtaki.

Palmerston North

Network	Sub-Class	Sites	comments
Regional	Urban Background	new site needed	Suggest Masonic Close (WAN204)
	Roadside	WAN007	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	WAN006	
	CBD/canyons	Optional new site	Suggest Broadway Ave (WAN205)
	Port, industry, etc	WAN008	Suspected impact from rail yard
	Growth		
Sites that could be removed		WAN004 WAN005 WAN008	Duplicates WAN006 Duplicates WAN007 Once replaced by WAN204

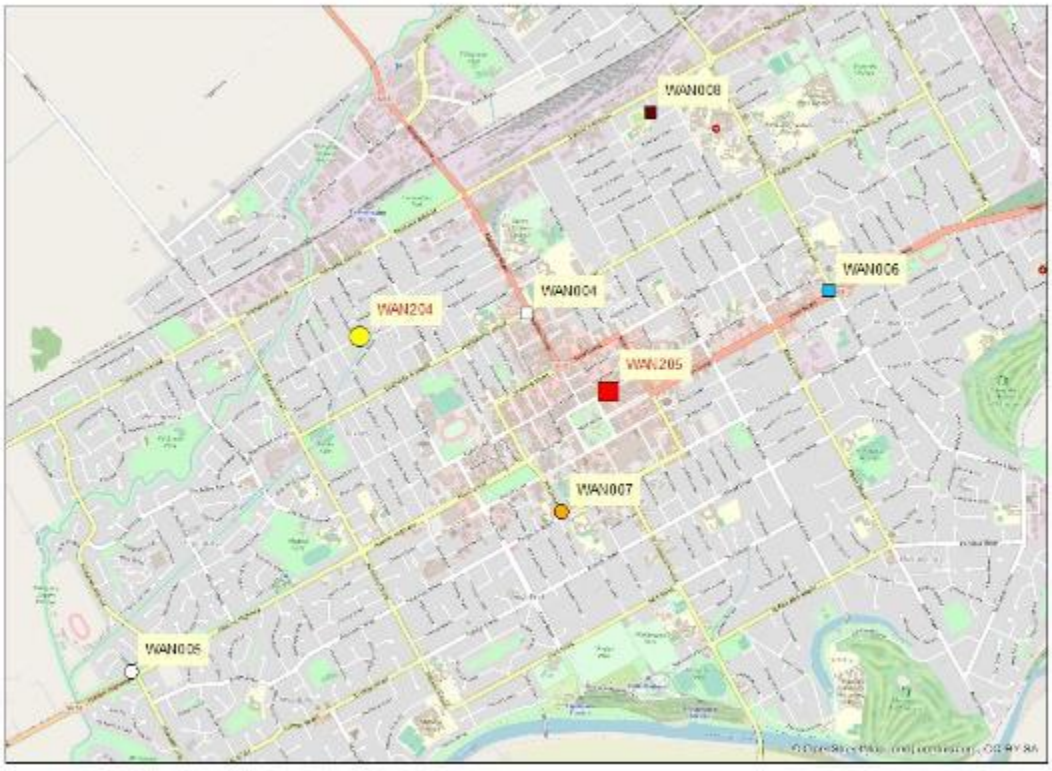


Figure C-23: Proposed Network for Palmerston North.

Porirua

Network	Sub-Class	Sites	comments
Regional	Urban Background	WEL072 1 new site recommended in Whitby/Aotea	(WEL110)
	Roadside	WEL100 (GWRC) WEL101 (GWRC)	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)	WEL005 WEL088	
	Intersection	Optional new site	Suggest Titahi Bay Rd/Kenepuru Dr (WEL216)
	CBD/canyons		Suggest Cobham Court (WEL115)
	Port, industry, etc	WEL080	
	Growth		
Sites that could be removed			

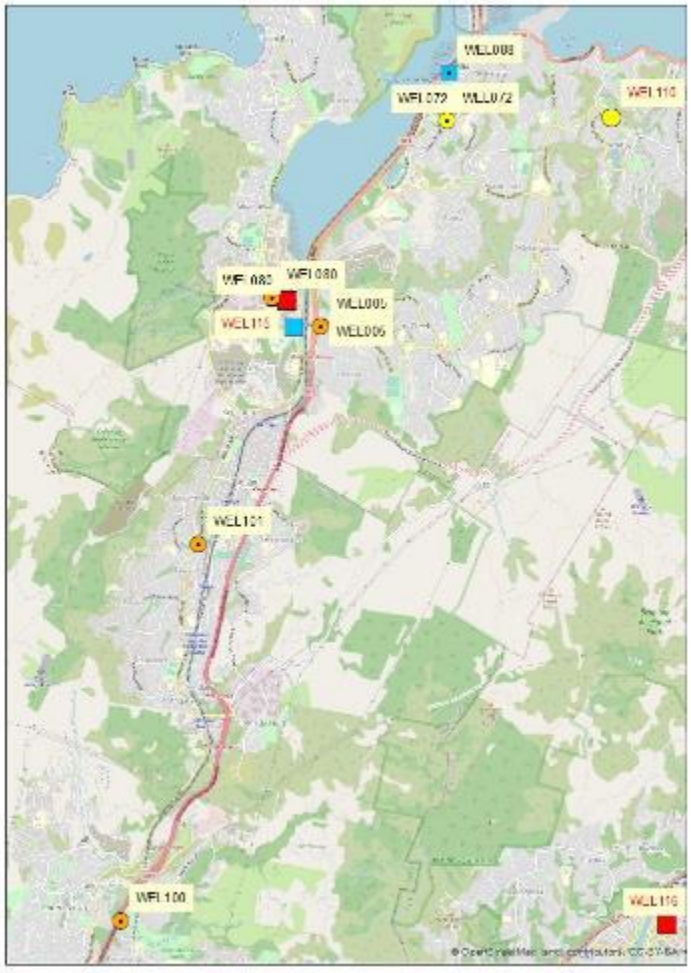


Figure C-24: Proposed Network for Porirua.

Queenstown

Network	Sub-Class	Sites	comments
Regional	Urban Background	new site needed	Suggest Suburb Str (DUN204)
	Roadside	new site needed	Suggest Frankton Rd, E of Suburb Str (DUN205)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	Optional new site	Suggest Shotover Str/Stanley Str (DUN206)
	CBD/canyons	Optional new site	Suggest ~35 Shotover Str (DUN207)
	Port, industry, etc	Optional new site at Airport	Suggest Lucas Pl (DUN208)
	Growth	Optional new site at Frankton	Suggest Frankton-Ladies Mile Hwy, E of Hardware Lane (DUN209)
Sites that could be removed		DUN004	Steep gradient

Figure C-25: Proposed Network for Queenstown.

Rotorua

Network	Sub-Class	Sites	comments
Regional	Urban Background	HAM023	
	Roadside	new site needed	Suggest Te Ngae Rd (HAM208)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	HAM006 Optional new site	Suggest Amohau Str/Fenton Str (HAM209)
	CBD/canyons	Optional new site	Suggest nr 1155 Pukuatua Str (HAM210)
	Port, industry, etc		
	Growth		
Sites that could be removed			

Figure C-26: Proposed Network for Rotorua.

Taupō

Network	Sub-Class	Sites	comments
Regional	Urban Background	new site needed	Suggest Kapua Pl (HAM211)
	Roadside	new site needed	Suggest Tongariro Str (HAM212)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	HAM005	
	CBD/canyons	Optional new site	Suggest nr 32 Heuheu Str (HAM213)
	Port, industry, etc		
	Growth		
Sites that could be removed			

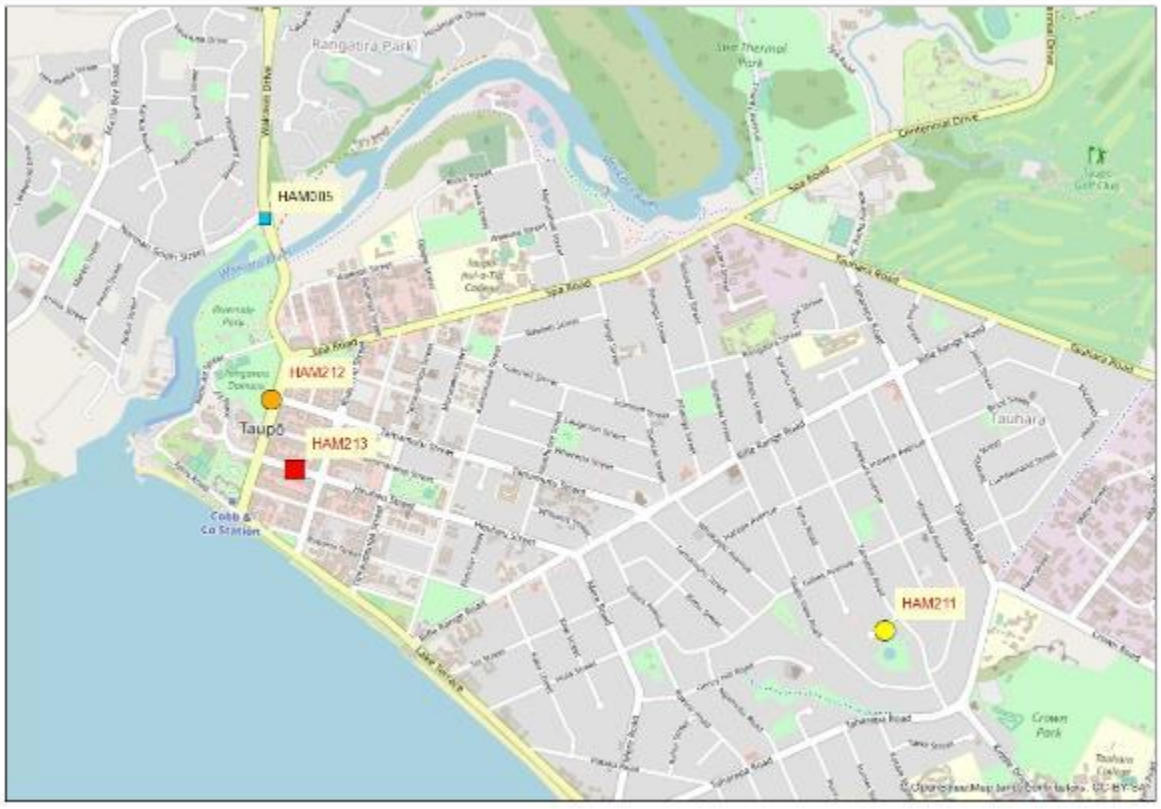


Figure C-27: Proposed Network for Taupō.

Tauranga

Network	Sub-Class	Sites	comments
Regional	Urban Background	HAM021	
	Roadside	HAM019	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	HAM007 HAM008 HAM018 HAM020	
	CBD/canyons	Optional new site	Suggest ~79 Grey Str
	Port, industry, etc	Optional new sites at Port	
	Growth		
Sites that could be removed		HAM010	Duplicates HAM007

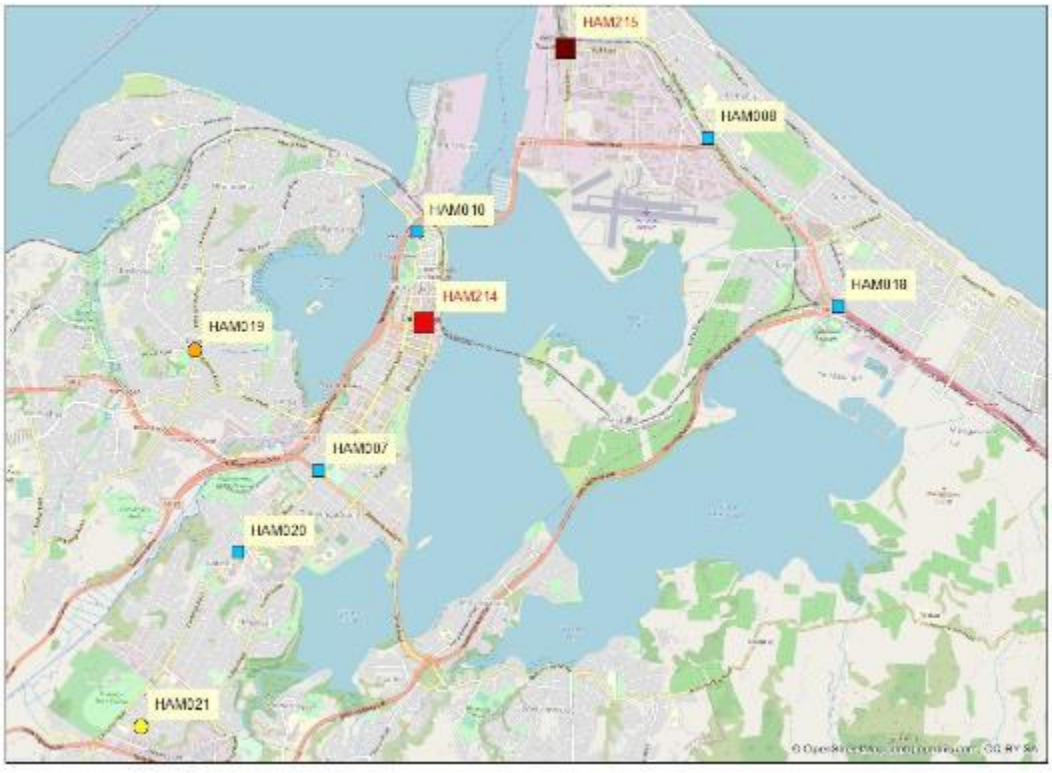


Figure C-28: Proposed Network for Tauranga.

Te Awamutu

Network	Sub-Class	Sites	comments
Regional	Urban Background	New site needed	Suggest Finch Str (HAM216)
	Roadside	New site needed	Suggest Ohaupo Rd (HAM217)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	HAM022	
	CBD/canyons		
	Port, industry, etc		
	Growth		
Sites that could be removed			

Figure C-29: Proposed Network for Te Awamutu.

Upper Hutt

Network	Sub-Class	Sites	comments
Regional	Urban Background	WEL092 WEL109 *(GWRC)*	
	Roadside	WEL105 *(GWRC)*	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	WEL057	
	CBD/canyons	*WEL093 (GWRC)*	
	Port, industry, etc		
	Growth		
Sites that could be removed			

Figure C-30: Proposed Network for Upper Hutt.

Wellington

Network	Sub-Class	Sites	comments
Regional	Urban Background	WEL048 WEL094 WEL106 (GWRC)	
	Roadside	WEL047 WEL051 *WEL085 (GWRC)* *WEL104 (GWRC)*	
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)	WEL008	
	Intersection	WEL049 WEL050 WEL073	
	CBD/canyons	*WEL081 (GWRC)* *WEL082 (GWRC)* *WEL083 (GWRC)* *WEL084 (GWRC)* *WEL086 (GWRC)*	
	Port, industry, etc	*WEL097 (GWRC)* *WEL098 (GWRC)*	
	Growth		
Sites that could be removed		WEL007 WEL064	Grade Grade

Figure C-31: Proposed Network for Wellington.

Figure C-32: Proposed Network for Wellington - CBD detail.

Whanganui

Network	Sub-Class	Sites	comments
Regional	Urban Background	New site needed	Suggest Exeter Cres (WAN206)
	Roadside	New site needed	Suggest Carlton Ave (WAN207)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection		
	CBD/canyons	Optional new site	Suggest Victoria Ave (WAN209)
	Port, industry, etc	WAN010	
	Growth		
Sites that could be removed			

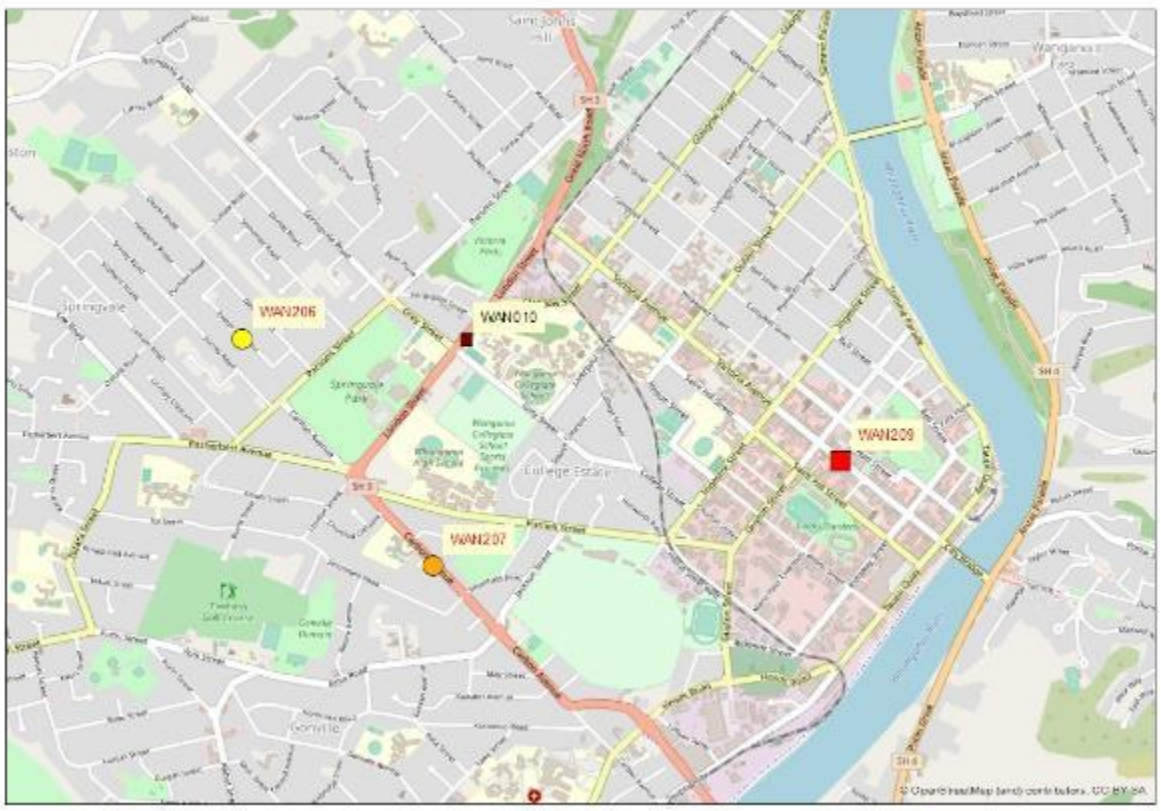


Figure C-33: Proposed Network for Whanganui.

Whangarei

Network	Sub-Class	Sites	comments
Regional	Urban Background	New site needed Use AUC 171 for now	Difficult to find non-power pole sites!
	Roadside	New site needed	Suggest Western Hills Dr (or Otaika Rd) (AUC220)
Local	Urban Background (local traffic trend)		
	Roadside (local traffic trend)		
	Intersection	AUC187	
	CBD/canyons	Optional new site	Suggest ~24 Cameron Str (AUC219)
	Port, industry, etc		
	Growth		
Sites that could be removed			

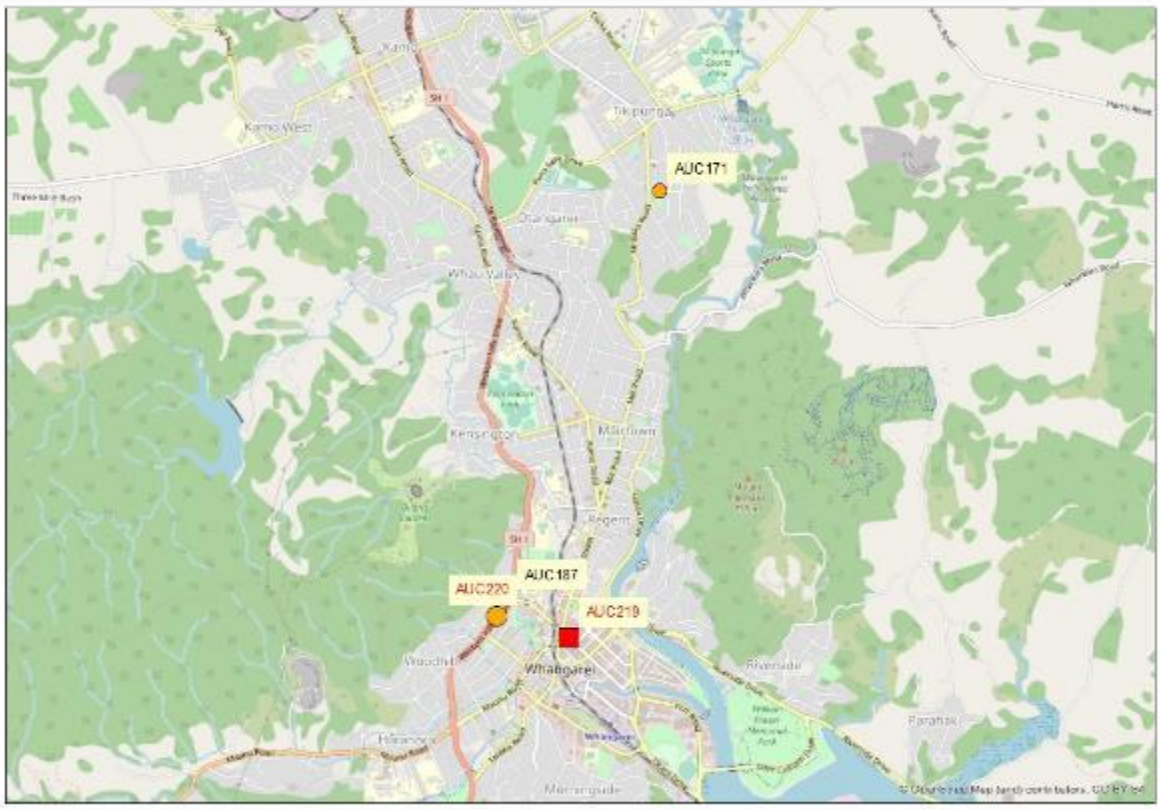


Figure C-34: Proposed Network for Whangarei.