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REGIONAL COUNCIL
Te Pane Matua Taiao

Traffic-related air quality monitoring in the Wellington Region

2016/17

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Executive summary

A regional network of low cost monitoring sites has been established to measure trends in traffic-related air pollutants. The indicator is based on levels of nitrogen dioxide (a harmful pollutant arising from vehicle emissions) and is designed to allow reporting against the Regional Land Transport Plan 2015 (RLTP) outcome of reduced harmful emissions from transport.

A challenge for regional reporting is ensuring that monitoring data represent wider trends across the region and not an atypical local impact. A monitoring site classification system, developed by National Institute of Atmosphere and Water (NIWA), has been used to select monitoring sites that represent "peak", "roadside" and "urban background" concentrations of traffic-related air pollutants. The regional network also includes some NZ Transport Agency (NZTA) monitoring sites that fit the NIWA site classification system.

In 2016 the annual average concentration of nitrogen dioxide measured at peak sites was approximately three times greater than that measured at the urban background sites and about one and half times higher than the roadside sites. The monitoring method was shown to have good consistency and is therefore suitable for determining trends over time and between sites. However, nitrogen dioxide measurements by passive diffusion tubes overestimate concentrations relative to the reference method used for compliance monitoring. Therefore concentrations from the network should not be compared to the World Health Organization guideline.

Additional sites are being added to the network in 2017/18 to improve geographic coverage and site classification representativeness. A regional baseline for concentrations of harmful transport generated pollutants will be available for reporting in 2018/19.

Between 2010 and 2016, NZTA's monitoring sites show a statistically significant downward trend in nitrogen dioxide concentrations. Most of the downward trend occurred between 2010 and 2013, with the last three year period (2014 to 2016) showing a plateauing trend. The GWRC continuous monitoring site in Upper Hutt (urban background) showed a decreasing trend. These trends do not appear to be due to meteorological effects.

It is recommended that the feasibility of measuring other transport generated pollutants such as ultrafine or fine particles, black carbon and nitrogen oxides (NOx) be investigated as suitable sensor technology becomes available. It is also recommended to develop a 'traffic indicator' that can be measured at key sites to assist validation and interpretation of future spatial and time series trends in traffic generated pollutants.

Contents

1. Introduction

A new air quality indicator has been developed to track trends in traffic-related air pollution across the region. The indicator has been designed to enable annual reporting on the new outcome in the Regional Land Transport Plan 2015 for reduced harmful emissions from transport using a measure of *Concentrations of harmful transport generated pollutants* (Appendix 1).

Previous reporting on traffic-related air pollution was not necessarily representative of regional trends as it was based on one fixed GWRC air quality monitoring site in central Wellington and more recently the New Zealand Transport Agency (NZTA) passive nitrogen dioxide monitoring network which is biased towards sites influenced by state highway traffic.

The design and implementation of a monitoring network for the new air quality indicator began in 2016/17 and the purpose of this report is to document the methodology, the monitoring network design and report on the first years' worth of results for the 2016 calendar year. Some preliminary findings on seven year trends (from 2010 to 2016) in traffic-related air pollutants at existing NZTA monitoring sites and at one GWRC continuous monitoring site are presented.

2. Background

2.1 Indicator measure for harmful transport generated pollutants

Nitrogen dioxide (NO_2) was chosen as the primary measure of harmful traffic generated pollutants for the RLTP indicator because at roadside locations it is:

a) Highly specific to local traffic emissions and therefore can be used as a proxy for the complex mixture of harmful traffic-related air pollution that also contains fine and ultrafine particles, including diesel particulate (World Health Organization 2006, p375)

b) A recognised and regulated harmful air pollutant that is linked to increases in asthma symptoms, reduced lung development and function in children and reduced life expectancy (COMEAP 2015). The World Health Organization guideline is an annual limit of 40µg/m^3 and the NES-AQ[1] is a 1-hour limit of 200 µg/m^3

c) Relatively inexpensive to measure using passive diffusion tubes which have a well-established methodology and QA/QC procedure

d) An established national environmental reporting indicator (Ministry for the Environment and Statistics NZ 2014) used by other regional councils and unitary authorities for regional state of the environment monitoring and local studies; both by diffusion tubes and reference monitoring instrument.

2.2 Vehicle emissions and harmful pollutants

Emissions from the combustion of fossil fuels include particulate matter ($PM_{2.5}$ and ultrafine $PM_{0.1}$), carbon monoxide, hydrocarbons including volatile organic compounds (VOC), and nitrogen oxides (NOx). The greenhouse gas, carbon dioxide (CO_2) is reported on under a separate measure for transport generated emissions. Black carbon emitted by vehicle exhausts is both a harmful pollutant and a short-lived climate warming pollutant.

Nitrogen dioxide (NO_2) is a secondary pollutant formed when nitric oxide (NO) emitted from combustion of fuel reacts with ground-level ozone (O_3) according to the simplified reaction equation:

$$NO + O_3 \rightarrow NO_2 + O_2$$

The amount of NO_2 formed near the roadside where NO is emitted by passing vehicles is limited by the availability of ozone for the reaction. Once all the ozone is depleted by the reaction, no further NO_2 is produced until the emitted NO is dispersed further afield where it can react with air containing higher levels of ozone. The mixture of NO and NO_2 (as well as other species) in the air is collectively known as nitrogen oxides (NOx)[2]. Nitrogen dioxide is, therefore, a measure of the harmful impact of traffic emissions on air quality, whilst NOx is a more direct measure of vehicle emissions. Diesel engines typically produce more NOx compared to petrol engines and a greater

[1] Resource Management (National Environmental Standards for Air Quality) Regulations 2004. Available at http://www.legislation.govt.nz/regulation/public/2004/0309/latest/DLM286835.html?search=ta_regulation_R_rc%40rinf%40rnif_an%40bn%40rn_25_a&p=3

[2] NOx = NO + NO_2

proportion of the NOx produced by diesel engines is directly emitted as NO_2. (Carslaw et al. 2011).

PM_{10} is also produced by non-combustion processes associated with road transport. Particles are generated from the mechanical abrasion of vehicle tyres, brake and clutch wear and general road surface wear. Vehicle turbulence and wind causes these particles to become airborne where they contribute to measured particle levels. The settled 'road dust' contains transitional metals such as zinc and copper and other hydrocarbons. When it rains these contaminants enter the storm water system where they are discharged into waterbodies (Gardiner et al. 2016). PM_{10} and $PM_{2.5}$ are also produced by non-traffic sources, such as crustal matter, dust from road works and naturally occurring marine aerosol. These sources contribute to measured levels of PM mass at roadsides and therefore PM_{10} is not always a useful indicator of traffic-related air pollutants. Black carbon is generated solely from combustion sources and therefore is a better marker of traffic emissions than PM_{10}.

The degree to which vehicle emissions result in elevated levels of NO_2 at the roadside depends on many factors. At the daily scale, different levels of traffic intensity throughout the day due to commuter travel patterns lead to a distinct diurnal pattern, with highest concentrations in the am peak, a lower inter-peak and a second evening peak. Typically the am peak in air pollution is higher than the pm peak due to differences in meteorology rather than traffic intensity. Morning meteorological conditions are generally more stable with lower wind speeds less favourable for dispersion of emissions. Higher emissions due to 'cold start' vehicle engines may also contribute to elevated air pollution levels during the early morning period.

At the seasonal scale, NO_2 concentrations are typically elevated in winter relative to other times of the year. This seasonal pattern is thought to be mainly due to meteorology, with winter conditions being less favourable for dispersion of air pollutants and possibly influence of naturally occurring higher levels of background ozone (Longley et al. 2016).

Nitrogen dioxide measurements typically show strong spatial gradients in built-up urban areas. Measurements can vary markedly across quite small distances, eg, on the same street. An observational study in Auckland CBD using locally developed land use regression modelling found that distance to an intersection with traffic lights, proximity to a bus stop and street width were the most significant determinants of NO_2 concentrations (Miskell et al. 2015).

2.3 Long term trends in harmful pollutant concentrations

2.3.1 Relating trends in pollutant concentrations to trends in emissions

The RLTP outcome expects harmful pollutant concentrations to decrease as vehicle standards improve and cleaner engine technologies that focus on removing harmful particulates from emissions penetrate the vehicle fleet. A challenge for reporting on this outcome is interpreting trends in roadside NO_2 concentrations at specific monitoring locations in terms of trends in national or regional vehicle fleet emissions. Individual roadside sites may be influenced by fleet profile characteristics that differ from the national or regional average or

experience changes in driving conditions such as increased congestion. Therefore in designing the indicator measure selecting monitoring site locations that are broadly representative of regional trends, not just local influences or non-road emission sources is critical. Additional finer scale traffic information may be required to explain trends at particular sites particularly if this is needed to evaluate impacts of policies and interventions designed to reduce emissions.

Reconciling trends in observed NO_2 concentrations with emission inventories is not straightforward, as emission inventories are typically based on NOx emissions and do not take into account the effect of photochemical reactions which mean that the relationship between NOx emissions and measured NO_2 concentrations are not necessarily linear.

2.3.2 Trends in the national emission inventory

A vehicle emissions prediction model VEPM (developed by Auckland Council and NZTA) is used to quantify national vehicle emissions (tonnes per square km per year) and predict how these are likely to change over time including the impact of new technology, improved fuel, fleet profile, average speeds and VKT (NZ Transport Agency, 2013A). VEPM uses emission factors from the European *COmputer Programme to Calculate Emissions from Road Transport*, known as COPERT. Annual emissions estimates from VEPM for CO, VOC, NOx, CO_2, PM_{10} and $PM_{2.5}$ are available through the Ministry for the Environment's Data Service[3] and are used as a 'pressure indicator' of on-road vehicle emissions for national environmental reporting on the air domain.

Reduced emissions of CO, NOx, VOC and PM_{10} from on-road vehicles between 2001 and 2012, due to improvements in vehicle fleet and fuel quality, were reported in the 2014 Air Domain Report (Ministry for the Environment & Statistics New Zealand, 2014). Data from the national emissions inventory can be disaggregated by region. In the Wellington region from 2009 to 2013, NOx was predicted to decrease by 16%. Emissions predictions for 2014 onwards were not available at the time of writing and it is not known whether this emissions inventory will be updated for future national Air Domain reports.

2.3.3 Trends in on-road vehicle emissions

A recognised issue with emission inventories is emission factors used in the model do not necessarily accurately reflect on-road operating conditions. Additionally the in-service vehicle fleet may differ from the registered fleet. Remote sensing campaigns to establish the emissions profile for on-road vehicle fleet under real-world driving conditions were carried out in Auckland during 2003, 2005, 2009, 2011 and 2015 (Bluett et al. 2013, 2016) and in Wellington during 2006 (Bluett & Dey 2007).

The method uses monitoring equipment on the roadside to pass a detector beam through the exhaust plume of a passing single vehicle to measure carbon monoxide (%), carbon dioxide, hydrocarbons (ppm), nitric oxide (NO ppm) and uvSmoke (as an indicator of particulate matter). At the same time a photo of the vehicle's license plate is taken which is later matched with data on year

[3] http://www.mfe.govt.nz/more/data/mfe-data-service#air

of manufacture, fuel type, engine capacity, vehicle type, country of first registration, gross vehicle mass and odometer reading. A large number of vehicles are sampled at a number of testing sites over a 10 day period to provide disaggregated emissions estimates, ie, by vehicle type, vehicle age, fuel type and vehicle mileage. Approximately 125,000 Auckland vehicles were sampled, with the following trends identified:

- Reduced average emissions of CO and NO from the Light Duty Vehicle (LDV) petrol fleet (downward pressure)
- Increased average NO emissions from the LDV diesel fleet (upward pressure)
- Steady average emissions from the Heavy Duty Vehicle (HDV) fleet (neutral pressure)
- Increasing proportion of diesel vehicles within the LDV fleet (upward pressure)
- Increasing effect of older and gross emitting LDV petrol vehicles (upward pressure)
- Steady traffic numbers (neutral pressure)

Trends in roadside air quality at two regional council continuous monitoring sites in Auckland and Christchurch were found to be consistent with the above trends in on-road emissions (Bluett et al. 2016). The significant decline in measured CO roadside concentrations at both sites matches the observed reduction in emissions of CO from the LDV and HDV fleet. NOx levels also declined at both sites, however most of the reduction was between 2006 and 2010 with concentrations stabilising after this period. The flat trend in recent years was not predicted by VEPM and has been attributed to the upward and downward pressures being balanced (Bluett et al. 2016).

Although there is no reason to suspect that like-for-like Auckland's vehicles perform differently in their emissions than Wellington vehicles, there could be a difference in the fleet profile between the two regions. Therefore as a separate analysis it may be possible to estimate trends in Wellington's fleet emissions using the Ministry of Transport's Motor Vehicle Register.

2.4 Future enhancements to indicator measure

The RLTP target (Appendix 1) was developed on the basis that monitored NO_2 provides a proxy for the impact of other harmful pollutants from traffic. However, the aim during the course of the RLTP is to improve the reporting and monitoring framework so that levels of other pollutants might be measured, for example particles and NOx. From 2017/18 onwards various low cost particle sensors will be tested and relationships with other pollutants from traffic emissions established. Based on these trials it may be possible to include a cost-effective and meaningful indicator for traffic-generated particle emissions. Another useful indicator is black carbon which is directly emitted by vehicle exhausts. Studies of short-term health effects suggest that BC is a

better indicator of harmful particulate substances from combustion sources (especially traffic) than undifferentiated particulate matter (PM) mass (World Health Organization 2012). Low-cost sensors for black carbon are not yet available.

3. Objectives

The objective of the monitoring programme is to determine trends in space and time of traffic-related air pollutants in a cost effective manner using a distributed network of nitrogen dioxide passive diffusion tubes.

This is a multi-year monitoring programme staged as follows:

- Year 1 (2015/16) – Programme design and first NO_2 spatial survey (Longley et al. 2016)
- Year 2 (2016/17) – Commission first tranche of sites based on results of Year 1 spatial survey to establish interim baseline and undertake second NO_2 spatial survey (Longley 2017).
- Year 3 (2017/18) – Commission second tranche of sites based on results of Year 2 NO_2 spatial survey to establish full network for representative baseline.
- Year 4 (2018/19) – Baseline data available for RLPT reporting. Install particle monitoring and more finely resolved nitrogen dioxide monitoring sensors at key sites if suitable technology available.
- Year 5 (2019/20) – Review network for possible rationalisation.

4. Methodology

4.1 Network design

4.1.1 Approach

In 2016, GWRC engaged NIWA to design a region-wide monitoring network suitable for assessing trends in traffic-related air pollution within a limited budget. The Wellington region has strong spatial gradients in nitrogen dioxide due to complex terrain, strong variations in elevation, a geographically constrained road network and higher than average winds in exposed areas. An indicator based on aggregating results from all monitoring sites would obscure valuable information about the different types of impact traffic-related air pollution is having. Therefore, the indicator has three components representing different types of impact:

- Urban background
- Roadside
- Peak.

Table 4.1 shows the traffic thresholds and other features that define the categories which are based on NIWA's expert opinion, empirical modelling of NO_2 (Longley et al. 2015) and dispersion modelling in Wellington CDB (Uhrner et al. 2015). This approach is consistent with the method recommended by NIWA Statistics NZ national air domain reporting (Longley & Somervell 2016), but does not consider population exposure.

Table 4.1: Site classifications for traffic-related air quality monitoring network (Longley et al. 2016)

Site classification	Description
Urban background	Site located within an urban area that is more than 400 m from any road with Annual Average Daily Traffic (AADT) > 10,000
Inner urban background	Sites that are setback from major roads in inner city areas can experience elevated concentrations. This may be due to a higher density of road traffic or a higher density of buildings, or taller buildings. A site located on a city centre street with AADT < 5,000 and building heights > 8m on both sides.
Roadside	Site located within 200 m of the centreline of any road with AADT > 10,000
Peak	A site that is: – multiple roadside (a site located within 200 m of the centreline of more than one road with AADT > 10,000) AND/OR – located within 100 m of the centre of any roundabout or signalised intersection AND/OR – located in a street with AADT > 5,000 and building heights > 8 m on both sides (therefore in a street canyon) AND/OR – suspected to be influenced by atypically high volumes of diesel exhausts (from buses, trucks, rail, aviation, maritime or industrial sources.

For reporting on the indicator to be unbiased it is critical that the locations selected for monitoring within each site category broadly represent what could be expected across the region and not an atypical local impact. Due to the potential for high spatial variability in NO_2 concentration across the region, the methodology for site selection for the different site types included short duration initial screening surveys carried out by NIWA covering a large number of sites. The purpose of these screening surveys was to identify the variability in concentrations measured within and between site categories so that a small set of representative sites could then be selected for inclusion in the network. The geographical range of the region is also represented by splitting the region into zones to further distinguish differences or similarities in trends. NIWA also reviewed existing NZTA sites in the region to determine which ones met the siting criteria and therefore could be included into the new network.

NIWA reviewed existing regional modelled and traffic flow data to identify general long-term trends and any localised deviations from those trends. Ultimately the results of this traffic pattern analysis were not useful for identifying monitoring locations due to data limitations.

NIWA carried out two short-term screening surveys during the summer months with three tube deployments over a period of three to four months at a range of sites. The first survey was undertaken in 2015/16 focusing on characterising the spatial variability in the Wellington CBD (Longley et al. 2016). NIWA undertook the second survey during 2016/17 focussed on identifying urban background sites and peak sites in other centres, such as Upper Hutt and Masterton (Longley 2017).

4.1.2 Year 1 sites

The results of the first NIWA survey were used to identify monitoring locations for first tranche of sites established in 2016/17. For data analysis and reporting a further category of site was introduced by GWRC called “special character” to represent sites that may be reporting more localised influences or particular sources of emissions and therefore should not be included in the regional indicator, for example, the bus-only lane in Manners Street, Wellington CBD (WEL082). The network configuration for Year 1 is shown in Table 4.2.

Table 4.2: Configuration of monitoring sites in Year 1 (2016/17) (NZTA site identification numbers are in black and GWRC site identification numbers are in red)

Area	Urban background	Roadside	Peak	Special Character	Total
Wellington	048	084 085 086	050 008 049 073[4] 081 083	082	**11**
Hutt Valley & Masterton	054[5]	078 003 052 079 089	053		**7**
Porirua & Kāpiti Coast	072	063 080 088	087		**5**
Total	**3**	**11**	**8**	**1**	**23**

4.1.3 Year 2 sites

The results of the second NIWA survey were used to identify monitoring locations for second tranche of sites established in 2017/18. NIWA recommended adding up to 13 new sites including one site to represent the inner urban background for Wellington City. NIWA also recommended splitting Wellington into two zones (inner and outer) due to significant differences in concentrations in the two zones. Concentrations in Kāpiti and Ōtaki appeared to show only minor differences and therefore these two zones could be combined. At this stage it is not proposed to install an urban background site in Kāpiti/Ōtaki due to large travel distances involved in servicing this area. Concentrations in Upper Hutt are only slightly lower than comparable locations in Lower Hutt and therefore these two zones could be combined. At this stage GWRC has not included an inner urban background site for Wellington city due to difficulties in locating suitable site that meets siting criteria.

Two new special character sites to screen the impact of NOx emissions from aircraft (at take-off and landing) at Wellington Airport relative to a nearby traffic-site will also be identified and then installed during 2017/18. These sites will not be reported on as part of the RLTP indicator. The network configuration for Year 2 and Year 3 is shown in Table 4.3.

[4] Co-located at GWRC air quality monitoring station (Willis Street/Urban Motorway, Wellington CBD)
[5] Co-located GWRC air quality monitoring station (Phil Evans Reserve, Waterloo, Lower Hutt)

Table 4.3: Configuration of monitoring sites in Years 2 and 3 (2017/18) (NZTA site identification numbers are in black and GWRC site identification numbers are in red)

Sites	Urban background	Roadside	Peak	Special Character	Total
Wellington (central)	NA	084 086	050 008 049 073[6] 081 083	082	**9**
Wellington (outer)	048 094*	085		Airport #1* Airport #2*	**5**
Lower Hutt	091* 054[7]	079 078 003 052	090* 053		**8**
Upper Hutt	092*		093*		**2**
Kāpiti Coast/Ōtaki	NA	063	087		**2**
Porirua	072	080 088			**3**
Masterton	096*	089	095*		**3**
Total	**7**	**11**	**11**	**3**	**32**

*Additional sites

4.2 Monitoring nitrogen dioxide using passive diffusion tubes

4.2.1 Sampling device

Diffusion tubes were originally developed for indoor air monitoring at workplaces. They are now commonly used as a low-cost method for mapping spatial variation in nitrogen dioxide concentrations and for measuring long term trends.

The tubes contain stainless steel mesh at the closed end that has been soaked in a solution of a chemical reagent, triethanolamine (TEA). NO_2 in ambient air is converted to nitrite anions (NO_2-) when absorbed onto the substrate containing TEA. The concentration of nitrite is subsequently determined in the laboratory and is used to calculate NO_2 concentration based on tube length, the internal cross sectional area of the tube, the diffusion coefficient for NO_2 in air and the exposure duration.

The tubes are attached to 'street furniture' such as street lights adjacent to road sides. Since the diffusion rate of air is quite slow this method requires long exposure periods, eg, one to four weeks. Therefore it is not possible to measure short term peaks, such as hourly averages. However, the method is well suited

[6] Co-located at GWRC air quality monitoring station (Willis Street/Urban Motorway, Wellington CBD)
[7] Co-located GWRC air quality monitoring station (Phil Evans Reserve, Waterloo, Lower Hutt)

for assessing long-term concentration trends (eg, annual averages based on monthly averages).

4.2.2 Measurement bias

Diffusion tubes are affected by several sources of interference which can cause substantial under or overestimation (referred to as "bias") compared to the NO_2 chemiluminescent analyser (defined within New Zealand as the reference method by the National Environment Standards for Air Quality).

The bias calculated for co-located passive tubes (triplicate) and the chemiluminescent analyser central Wellington monitoring site during 2016 was quite high, ie, +49% (Table A2.1, Appendix 2) meaning that at this site, passive tubes over estimate relative to the chemiluminescent reference method, ie, the reference method measures on average concentrations that are about 33% lower than the passive tube method.

A bias correction will not be applied to passive tube measurements made at the other passive tube monitoring sites as the co-location relationship is site-specific and may not be applicable at other sites where relative concentrations of NO, NO_2 and O_3 in air may be different due to local characteristics (eg, exposure to wind, traffic intensity and profile and distance to roadside).

The high level of measurement bias at central Wellington monitoring site means that results of passive NO_2 monitoring should not be directly compared with the World Health Organization guideline which is based on measurements undertaken using the reference method.

4.2.3 Measurement precision

In the context of environmental monitoring, precision is the closeness of agreement between mutually independent test results obtained by repeating a measurement several times under stipulated conditions. The precision of diffusion tube measurements is typically evaluated from the results of triplicate tubes co-located at the same site exposed for the same length of time.

Good precision is important because it means that tubes located at different sites will be internally consistency and therefore we can be confident that results from the network will be useful for showing the relative differences between concentrations at all sites. The precision measure recommended for diffusion tubes is the coefficient of variation (CV) which is calculated monthly by:

CV% = standard deviation of triplicate results * 100 / mean of triplicate results

Tubes are considered to have "good" precision where the coefficient of variation (CV) of duplicate or triplicate diffusion tubes for eight or more periods during the year is less than 20%, and the average CV of all monitoring periods is less than 10%. (DEFRA, 2016).

Calculated CVs for 1-month triplicate observations at GWRC central Wellington air quality monitoring site are presented in Table A2.2, Appendix

A2. During 2016, the average CV was 5.2% and the CV was less than 20% for each month, indicating that the precision of the passive samplers is satisfactory.

The precision of the UK laboratory Staffordshire Scientific Services (2014-2016) where the tubes are analysed was assessed as "good"[8].

4.2.4 Monitoring protocols, operation and data reporting

GWRC uses the same monitoring method as the New Zealand Transport Agency (NZTA). In 2016, NZTA's national monitoring network consists of 120 plus NO_2 diffusion tube sites throughout the country which are managed and operated in accordance with an operating manual (NZ Transport Agency 2013B). The NZTA monitoring procedures follow the United Kingdom's technical guidance document (DEFRA, 2009). NZTA contracts Watercare Services Ltd to manage their network, including engaging Scientific Services Laboratory of Staffordshire County Council, UK, to supply and analyse the passive samplers deployed in NZ.

With the approval of NZTA, Watercare Services Ltd. supplies diffusion tubes for the GWRC operated sites and arranges the UK laboratory analysis and reporting of monitoring results of these 'project sites' under the umbrella of NZTA's National Network. GWRC staff or their contractor is responsible for commissioning the GWRC sites and arranging the monthly tube exchanges.

The GWRC tubes are mounted on street poles at approximately 3m above ground level and are exposed for one month before being exchanged with a new tube. The tubes are exchanged on the same schedule as NZTA tubes, ie, on the first Wednesday of each calendar month, plus or minus two days. Results are typically available three months after deployment. Annual monitoring results and metadata for all NZTA sites and GWRC sites that meet NZTA siting criteria are published each year on NZTA's website on the TRAMS (Transport related air quality monitoring system)[9]. Sites to be reported on TRAMS are identified in Appendix 3.

[8] https://laqm.defra.gov.uk/assets/tubeprecision2016version0317finalreducedv2

[9] https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/air-quality-climate/monitoring/transport-related-air-quality-monitoring-system/

Figure 4.1: Passive diffusion tube mounted on street pole adjacent to Titahi Bay Road, Porirua (WEL080)

4.3 GWRC NO_2 reference monitoring sites

GWRC operates three air quality monitoring stations that include nitrogen dioxide and carbon monoxide (using standard reference equipment) to provide short term values (ie, 1-hour averages) that can be used for compliance reporting against the NES-AQ and for long term trend analysis for state of the environment reporting. These stations are located in Upper Hutt (Savage Park), Masterton West (Wairarapa College) and Wellington central (Corner of Willis Street and the Urban Motorway). Details of the monitoring methods and site metadata are outlined in Mitchell (2017). Meteorological sensors (wind, temperature, relative humidity) are located at each GWRC site to help with the interpretation of air quality trends.

The Wellington central monitoring site (Figure 4.2) is critical to the traffic-related air quality network for:

- Providing highly resolved and accurate data that can be used to analyse diurnal and weekday/weekend air quality variation that can be matched with traffic data (if available)

- Establishing the relationship between different markers of traffic-related air pollution (eg, how closely different particle measurements correlate with oxides of nitrogen)

- Providing a testing environment for comparing the performance of low-cost new technology particle sensors, specifically how these sensors compare to each other and to reference equipment

- Co-locating passive nitrogen dioxide tubes to assess the relationship between the reference method and the passive tube method to calculate the precision of the tube method.

Figure 4.2: GWRC Wellington central air quality monitoring reference site

4.4 Data analysis

4.4.1 Calculating annual average nitrogen dioxide concentration

Typically air quality concentrations are reported by calendar year rather than financial year as many commonly monitored air pollutants in NZ show seasonal variation, eg, winter exceedances of PM_{10} in wood smoke environments, therefore reporting by calendar year includes the entire winter period enabling year-to-year comparisons. The NZTA national monitoring reports annual averages of NO_2 on a calendar year basis. In order to report a valid annual average 75% data capture is required, equivalent to at least nine months in each calendar year. Because the GWRC monitoring programme commenced at the start of the financial year (June or July 2016) the 75% data capture criteria was not achieved. However, a seasonal adjustment factor was derived in order to report 2016 annual concentrations based on five to six months of results.

NO_2 monthly concentrations measured at 15 Wellington NZTA sites from 2010 to 2016 were used to investigate the relationship between each month of the year and the corresponding annual mean. Simple linear regression plots for each calendar month and annual means are shown in Figure A4.1, Appendix 4). These regression plots were fitted without an intercept.

The 12 linear regression slope coefficients (one for each month of the year) were fitted with a second order orthogonal polynomial curve. The fitted values for the 12 coefficients (Table A4.1, Appendix 4) were then used to adjust each 1-month observation in the 2016 dataset for each site where up to six months

are missing (ie, ≥ 50% annual data capture). The adjusted monthly values were then averaged to provide an estimate of the annual mean for a site.

4.4.2 Time trends in pollutant concentrations

It takes several years of data collection before time trends can be established for the regional traffic-related air pollution indicator. However, data from seven NZTA passive nitrogen dioxide monitoring sites established in 2010 (that are now also included in the GWRC network) were analysed for site-specific trends.

To calculate whether there is a statistically significant trend at these sites, the non-parametric Theil-Sen method was used as implemented by the R package *openair* version 2.1-0 (Carslaw & Ropkins, 2012). Given a set of n x, y pairs, the slopes between all pairs of points are calculated. The Theil-Sen estimate of the slope is the median of all these slopes. Bootstrap resampling provides the estimate of p for the slope. Prior to calculating a linear trend, these data were de-seasonalised by seasonal trend decomposition using loess and any missing data points were linearly interpolated (as implemented in *openair*).

Percentage change over the time series was calculated as this is useful for comparing slopes for sites with very different concentration levels and for comparison with emission inventories. The percentage change uses the concentration at the beginning and end months to express the mean slope.

The trend, T is defined as:

$$T[\%.yr^{-1}] = 100.\left(\frac{C_{End}}{C_{Start}} - 1\right)/N_{years}$$

where C_{End} and C_{Start} are the mean concentrations for the end and start date, respectfully. N_{years} is the number of years (or fractions of) the time series spans.

A second method used to look at time trends was seasonal decomposition by moving averages as implemented by the R package *stats* (version 3.4.1). This is a relatively simple method that decomposes the time series into a seasonal, secular trend and random component. In this case an additive seasonal model was assumed. Any missing values in the time series were imputed using the R package *imputeTS* (version 2.5) using spline interpolation.

5. Results and discussion

5.1 Spatial variation in NO_2 passive diffusion tube results 2016

Monthly averages and annual averages for each site are presented in Table A5.1, Appendix 5. The regional averages by monitoring zone and site type are shown in Table 5.1. The average of the peak sites (29.2 µg/m^3) was approximately three times greater than the urban background (8.7 µg/m^3) and about one and half times higher than the roadside sites (18.2 µg/m^3). Maps showing the annual average for each site as a concentration band are presented in Appendix 6.

Table 5.1: Annual average NO_2 (µg/m^3) by site type and zone (2016)

Zone	Urban background	Roadside	Peak	Average
Wellington	7.8 (n=1)	17.1 (n=3)	30.9 (n=6)	24.5 (n=10)
Hutt Valley & Masterton	10.7 (n=1)	16.3 (n=5)	23.1 (n=1)	20.0 (n=7)
Porirua & Kāpiti	7.7 (n=1)	22.7 (n=3)	24.2 (n=1)	16.4 (n=5)
Average	8.7 (n=3)	18.2 (n=11)	29.2 (n=8)	

Figure 5.1 shows the annual averages for each monitoring site by site type coloured by zone. Four peak sites in the Wellington (WEL081, WEL082, WEL008 and WEL049) show elevated concentrations relative to the other sites in the network. WEL081 (Lambton Quay) and WEL082 (Courtney Place) represent inner CBD traffic and some canyon effect with tall buildings either side of the roadway restricting dispersion of pollutants. WEL008 (Basin Reserve) and WEL049 (Newtown) are busy arterials with stop start traffic and congestion at times next to the monitoring sites. The other peak sites in Wellington WEL050 (Kilbirnie) and WEL073 (GWRC Wellington central monitoring station) had concentrations at the low end of range for peak sites possibly because they are more exposed sites where air pollutants are more readily dispersed.

Of the roadside sites, WEL088 (next to Johnsonville-Porirua SH1) had a high annual average (31.5 µg/m^3) relative to the other roadside sites in the network. The reasons for the elevated concentration need to be investigated but may be due to congestion effects arising from the Paramata Esplanade roundabout 300m north of this monitoring site or there may be additional influence from a nearby local road (Papakowhai Road). The roadside site with relatively low concentration was WEL085 (Johnsonville). Results at this site will be compared against the new outer Wellington background site in Johnsonville (WEL094) established in 2017/18.

The urban background site in Hutt Valley zone (WEL054) had a higher annual average (10.7 µg/m3) relative to the other background site suggesting it may be influenced by local effects, such as the nearby Waterloo train station and bus interchange. Results at this site will be compared against the new Lower Hutt background site (WEL091) established in 2017/18.

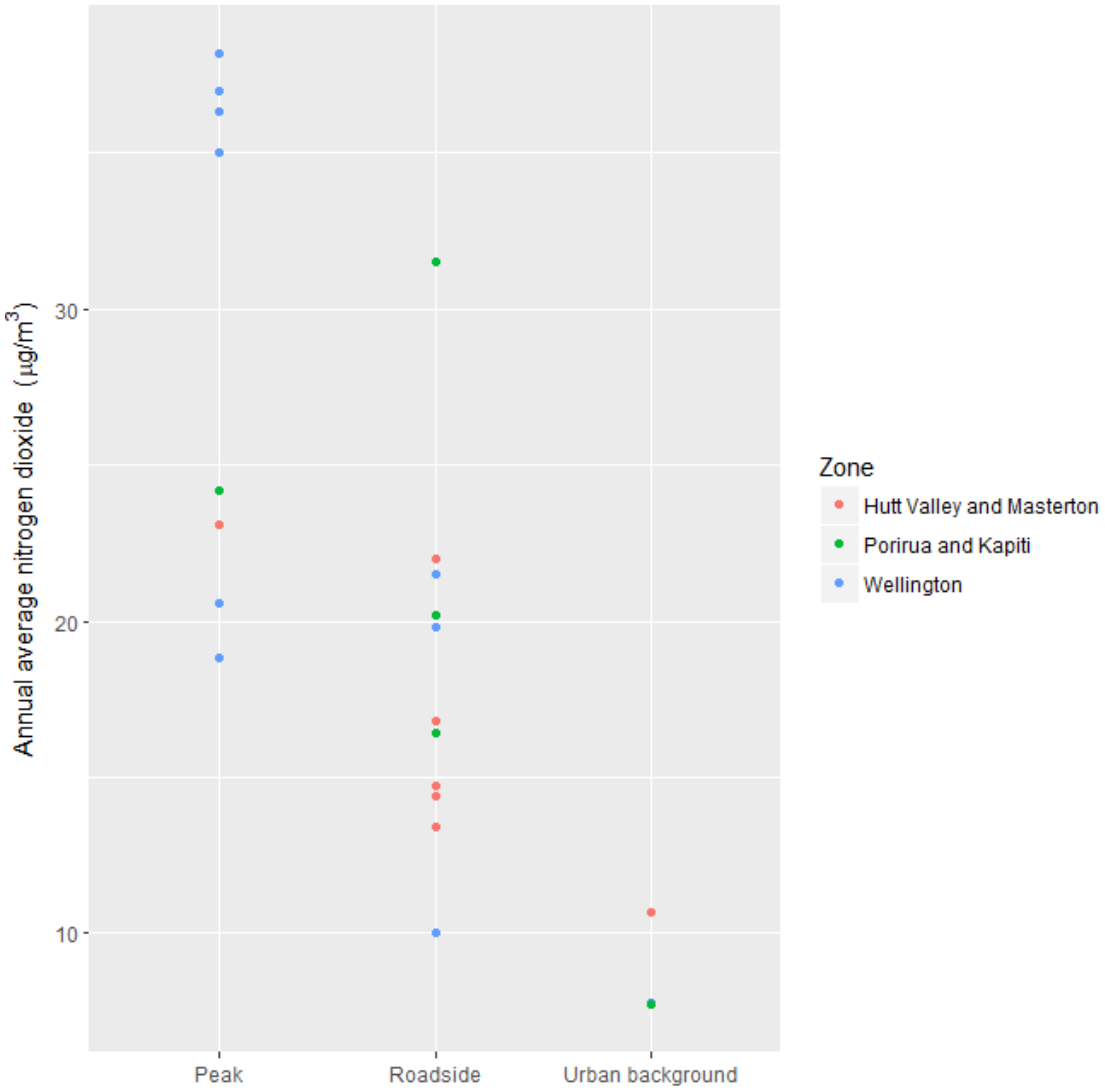

Figure 5.1: 2016 annual average NO_2 (µg/m³) by site type and zone

5.2 Time trends at NO_2 sites with long term data

5.2.1 Trends at selected long term NZTA passive NO_2 monitoring sites

Current annual reporting on the RLTP target for harmful traffic generated pollutants is based on all the available sites in the NZTA passive NO_2 monitoring network in the Wellington region. The five year annual average for all these sites (2011 to 2015) shows a downward trend (GWRC, 2016).

Thiel-Sen linear trend estimates for existing NZTA sites that are also part of the GWRC network and where data are available for seven consecutive years are shown in Table 5.2. The trend is shown as per cent change per year with the 95% confidence interval in brackets. Four sites showed a statistically significant downward trend, one site showed an increase and two sites showed no trend. Trend graphs for these sites are shown in Appendix 7. It appears that most of the drop in concentrations of NO_2 occurred between 2010 and 2013, with a much flatter trend observed between 2014 and 2016.

Table 5.2: Theil-Sen trend (per cent change per year with 95% confidence interval) in passive NO_2 annual averages at selected sites from 2010 to 2016

Location	Site type	Site ID	% change per year	Significance
Knights Rd, Lower Hutt	Peak	WEL053	-4.21 [-5.24, -3.07]	p<0.001
Basin Reserve, Wellington	Peak	WEL008	2.3 [0.97, 3.44]	p<0.001
Newtown, Wellington	Peak	WEL049	No change	NA
Kilbirnie, Wellington	Peak	WEL050	-3.39 [-4.46, -2.09]	p<0.001
Boulcott, Lower Hutt	Roadside	WEL052	No change	NA
Island Bay, Wellington	Urban background	WEL048	-4.59 [-5.70, -3.50]	p<0.001
GWRC air quality station, Waterloo	Urban background	WEL054	-2.92 [-4.42, -1.65]	p<0.05

The decreasing trends found at most sites are consistent with predictions made by VEPM (between 2010 and 2013) for reduced NOx emissions for the Wellington region. The flattening of the trend between 2014 and 2016 may reflect on-road emissions trends in the Auckland fleet for increasing average emissions from the LDV diesel fleet and increasing proportion of diesel vehicles in the fleet (Bluett et al. 2016).

The increasing trend in NO_2 concentrations at WEL008 (Basin Reserve) may be due to increasing congestion levels close to the monitoring site but this cannot be verified without obtaining local data on congestion levels. The static trend at WEL049 (Newtown) and the relatively high concentrations recorded at this site may be due to its proximity to a bus stop and intersection.

At the GWRC continuous monitoring site (urban background) in Upper Hutt NO_2 declined between 2006 and 2016 (-4.13 [-4.71, -3.56], percentage change per year, $p<0.001$ with 95% confidence interval) (Figure A8.1, Appendix 8). This trend follows the regional emissions inventory trend for NOx (only available till 2013).

Although more data are needed it is possible that the urban background sites are most sensitive to showing the impact of regional emissions reductions as they are not influenced by the roadside increment. However as concentrations are already quite low at the urban background sites determining this effect at decreasing concentrations overtime may require more sensitive monitoring methods than passive tubes. Therefore, roadside sites may be more useful for detecting regional trends.

5.2.2 Impact of meteorology on long term NO_2 trends

Meteorology affects day-to-day air pollution concentrations, with stable atmospheric conditions promoting higher concentrations and unstable leading to better dispersion and hence lower concentrations. At the seasonal level

higher concentrations during winter attributed to on average lower wind speeds and possibly the increased availability of ozone (Longley et al. 2016).

Figure 5.3 shows the distribution of monthly NO_2 concentration at all sites in Table 5.2 between 2010 and 2016 by month of the year. NO_2 concentrations are typically elevated during the winter months. Figure 5.4 shows the distribution of monthly average wind speed for measurements made at GWRC air quality stations (Upper Hutt, Lower Hutt and Wainuiomata). From spring through to early summer (September to January) monthly wind speeds are higher than the rest of the year. A similar pattern, but with higher average wind speed, is observed at the MetService Wellington Airport and Kelburn met sites (not shown).

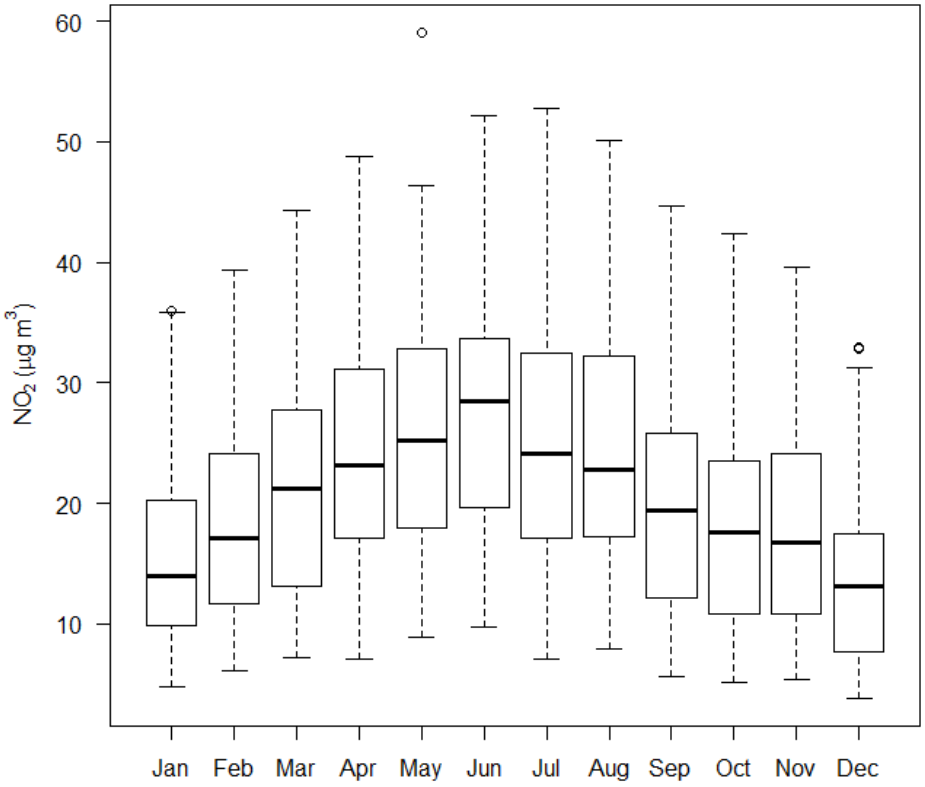

Figure 5.2: Box plots of monthly average NO_2 between 2010 and 2016 for sites in Table 5.2

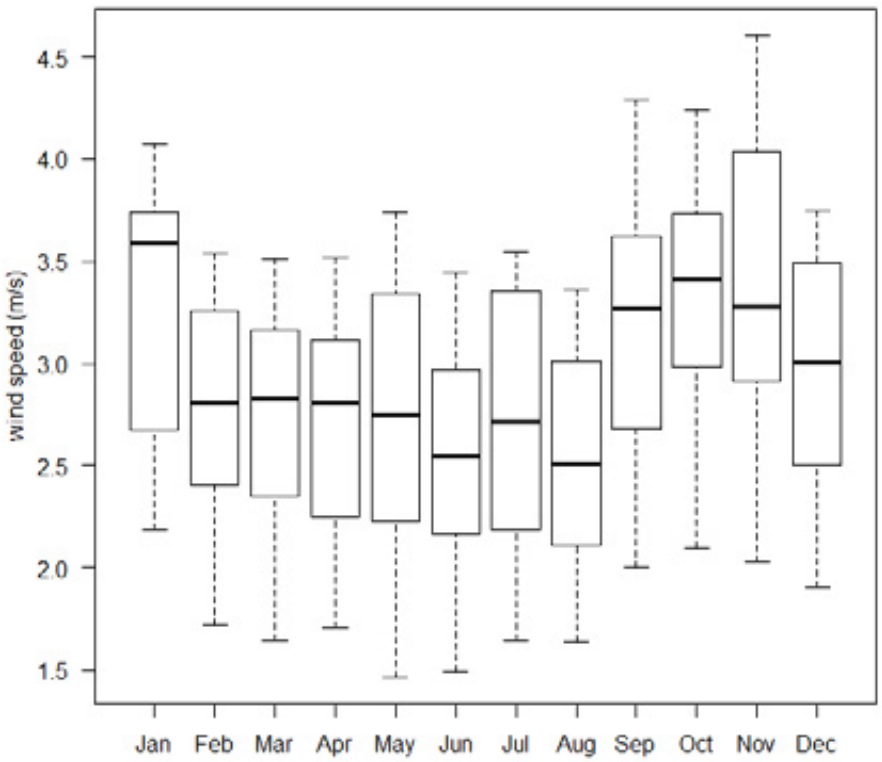

Figure 5.3: Box plots of monthly average wind speed between 2010 and 2016 for GWRC air quality monitoring sites

The relationship between monthly average wind speed and monthly concentrations of NO_2 was examined using data from the GWRC monitoring station (Phil Evans Reserve, Waterloo, Lower Hutt) where WEL054 is co-located with wind measurements. Monthly wind speed and NO_2 concentrations measured at GWRC monitoring station between 2010 and 2016 were moderately negatively correlated, r = -0.59 [-0.72, -0.43][10], that is, as wind speed increases NO_2 concentration decreases. Expressed as linear regression, this could be interpreted that 35% of variation in NO_2 is explained by wind speed. This correlation is likely to be due to both of the time series having a time trend, ie NO_2 appears to be decreasing from 2012, whilst wind speed increased from 2012 (over the duration of the time frame 2010 to 2016). There is also correlation in the seasonal trends, ie, wind speeds generally lower in winter and NO_2 concentrations higher in winter.

If we remove the time trend and seasonal trend from each series, then regress de-trended and de-seasonalised NO_2 on de-trended and de-seasonalised wind speed then the correlation relationship disappears. De-trended series of NO_2 and wind speed are shown in Figures A8.2 and A8.3 (Appendix 8).

Therefore, meteorology is correlated with inter-annual or seasonal variation in NO_2 but, in this case, not the seven year trend.

[10] 95% confidence interval

6. Recommendations

- Investigate the usefulness and feasibility of adding a 'traffic indicator' to key sites. This additional information could assist validation and interpretation of spatial and time series trends in traffic generated pollutants. This traffic indicator could include data on the main drivers of pollutant concentrations, ie, traffic intensity, fleet profile, driving conditions (congestion versus free-flowing) complemented by wind speed and direction measurements.

- Evaluate other instruments and low-cost sensors designed to measure direct markers of traffic related emissions such as nitrogen oxides (NOx), black carbon and ultrafine particles.

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Appendix 1: RLPT (2015) outcome and measures

'An efficient and optimised transport system that minimises the impact on the environment'				
Outcome	**Measure**	**Baseline**	**2025 Target**	**Comment/Rationale**
Reduced harmful emissions from transport	Transport generated emissions (per capita)	2.31 tonnes transport generated CO_2 per capita in 2013 13% reduction in per capita CO_2 emissions from 2005 - 2013	**15% reduction** in annual per capita CO_2 emissions	• Targets are based upon an 'expected future' scenario[1] where future growth in vehicle trips is broadly linked to population growth • Government policies are targeted at regulating emissions and providing incentives for people who drive cleaner, more fuel efficient vehicles • Assumes vehicle efficiency improvements of up to 20% over the 10 year period to 2025 • Policies to encourage more public transport use and seeking a low emission public transport fleet will contribute to these targets • Projections suggest a decrease in transport-generated CO_2 emissions, expressed in both per capita and absolute terms
	Transport generated emissions (absolute)	1,061 kilotonnes transport generated CO_2 in 2013. 7% reduction in total annual transported-generated CO_2 in Wellington region 2005 - 2013	**10% reduction** in total annual CO_2 emissions	
	Concentrations of harmful transport generated pollutants	5 year rolling average (2009 to 2013) for NO_2 across the regional automatic monitoring stations. 23.5 (µg/m3) at GWRC's Wellington central monitoring station	**A reduction** in the average concentration (measured as a 5 year rolling average) of harmful transport-generated emissions (NO_2 + others) at automatic monitoring stations	• Harmful pollutant emissions generated by transport are likely to decrease as vehicle standards improve and cleaner engine technologies focus on removing harmful particulates from emissions • GWRC will continually improve its monitoring framework to allow monitoring of the pollutants CO, PM_{10} and $PM_{2.5}$
Increased private vehicle occupancy	Peak period private vehicle occupancy.	1.39 people per vehicle in 2013 (Wellington CBD cordon)	Gradual increase in private vehicle occupancy to **1.45**	• Assumes increases in parking costs above inflation rates, as has historically been the case • Incentives and initiatives to promote car sharing/carpooling along with increasing fuel and parking costs are likely to have some small positive influence on this target

Appendix 2: Passive NO_2 tube measurement bias and precision

Table A2.1: Triplicate tubes deployed at GWRC central Wellington monitoring station for 2016

Period	Start Date	End Date	Tube 1 µg/m³	Tube 2 µg/m³	Tube 3 µg/m³	Triplicate Mean	Standard Deviation	95% CI of mean
Jan	5/01/2016	5/02/2016	14.8	14.5	15.2	15	0.4	0.9
Feb	5/02/2016	2/03/2016	18.2	18.5	15	17	1.9	4.8
Mar	2/03/2016	5/04/2016	20.1	20.9	20.9	21	0.5	1.1
Apr	5/04/2016	3/05/2016	26.6	24.8	24.2	25	1.2	3.1
May	3/05/2016	7/06/2016	22.4	25.4	25.9	25	1.9	4.7
Jun	7/06/2016	4/07/2016	29	29.6	29.8	29	0.4	1.0
Jul	4/07/2016	3/08/2016	20.7	20.1	19.9	20	0.4	1.0
Aug	3/08/2016	7/09/2016	21.6	24.2	24.8	24	1.7	4.2
Sep	7/09/2016	5/10/2016	23.2	21.9	23.1	23	0.7	1.8
Oct	5/10/2016	1/11/2016	17.1	15.5	19.8	17	2.2	5.4
Nov	1/11/2016	5/12/2016	16.9	18.8	19.3	18	1.3	3.1
Dec	5/12/2016	9/01/2017	13.2	13	13.2	13	0.1	0.3

Measurement bias was calculated using the spreadsheet tool recommended by DEFRA (2016) available at http://laqm.defra.gov.uk/documents/AEA_DifTPAB_v04.xls

Bias factor A	0.67 (0.63 - 0.72)
Bias B	49% (39% - 58%)
Diffusion Tubes Mean:	21 µg/m³
Mean CV (Precision):	5 µg/m³
Automatic Mean:	14 µg/m³
	Data Capture for periods used: 100%
Adjusted Tubes Mean:	14 (13 - 15) µg/m³

Therefore the reference method is about 33% lower than the diffusion tube method with the adjustment factor for estimating reference method (y) equivalent from passive tube results (s): y=0.67x (Bias adjustment factor)

Table A2.2: Coefficient of variation (CV) for triplicate tubes deployed at GWRC central Wellington monitoring station for 2016 (annual average CV 5.2%)

Month	CV%	Month	CV%
Jan	2.4	Jul	2.1
Feb	11.3	Aug	7.2
Mar	2.2	Sep	3.2
Apr	5	Oct	12.4
May	7.7	Nov	6.9
Jun	1.4	Dec	0.9

Appendix 3: Passive NO_2 monitoring sites 2016

NZTA Identifier	Area	Location	GWRC classification	Site sponsor	NZTM E	NZTM N
WEL053*	Lower Hutt	Knights Road	Peak	NZTA	1759934	5436058
WEL087*	Ōtaki	Rahui Road/SH intersection, Otaki	Peak	GWRC	1782151	5485622
WEL008*	Wellington	Basin Reserve	Peak	NZTA	1748917	5426328
WEL049*	Wellington	Riddiford/Mein Street	Peak	NZTA	1748907	5425194
WEL050*	Wellington	Kilbirnie (on SH1)	Peak	NZTA	1750102	5425039
WEL073,074,075*	Wellington	Willis Street/urban motorway	Peak	NZTA	1748360	5427134
WEL081	Wellington	Lambton Quay, CBD	Peak	GWRC	1748671	5428257
WEL082	Wellington	Manners Street, CBD	Special character	GWRC	1748752	5427413
WEL083	Wellington	Courtney Place, CBD	Peak	GWRC	1748971	5427223
WEL063*	Kāpiti	Paraparaumu	Roadside	NZTA	1769627	5469035
WEL078*	Lower Hutt	Manor Park	Roadside	NZTA	1766009	5441920
WEL003*	Lower Hutt	Petone	Roadside	NZTA	1757206	5435187
WEL052*	Lower Hutt	Boulcott	Roadside	NZTA	1759667	5436831
WEL079	Lower Hutt	Cuba Street, Petone	Roadside	GWRC	1758286	5434987
WEL089*	Masterton	High Street, Masterton	Roadside	GWRC	1822056	5462296
WEL080*	Porirua	Titahi Bay Rd	Roadside	GWRC	1754261	5444566
WEL088*	Porirua	Johnsonville-Porirua motorway (SH1)	Roadside	GWRC	1756620	5447614
WEL084	Wellington	Thorndon Quay, Pipitea	Roadside	GWRC	1749266	5429488
WEL085	Wellington	Morefield Rd, Johnsonville	Roadside	GWRC	1751000	5434368
WEL086	Wellington	Wakefield St, CBD	Roadside	GWRC	1748788	5427570
WEL054*	Lower Hutt	Birch Lane, GWRC site	Urban background	NZTA	1761034	5435864
WEL072*	Porirua	Papakowhai, Porirua	Urban background	NZTA	1756584	5446972
WEL048*	Wellington	Island Bay	Urban background	NZTA	1748544	5422507

*Annual averages and metadata reported on NZTA TRAMS website

Appendix 4: Seasonal adjustment method

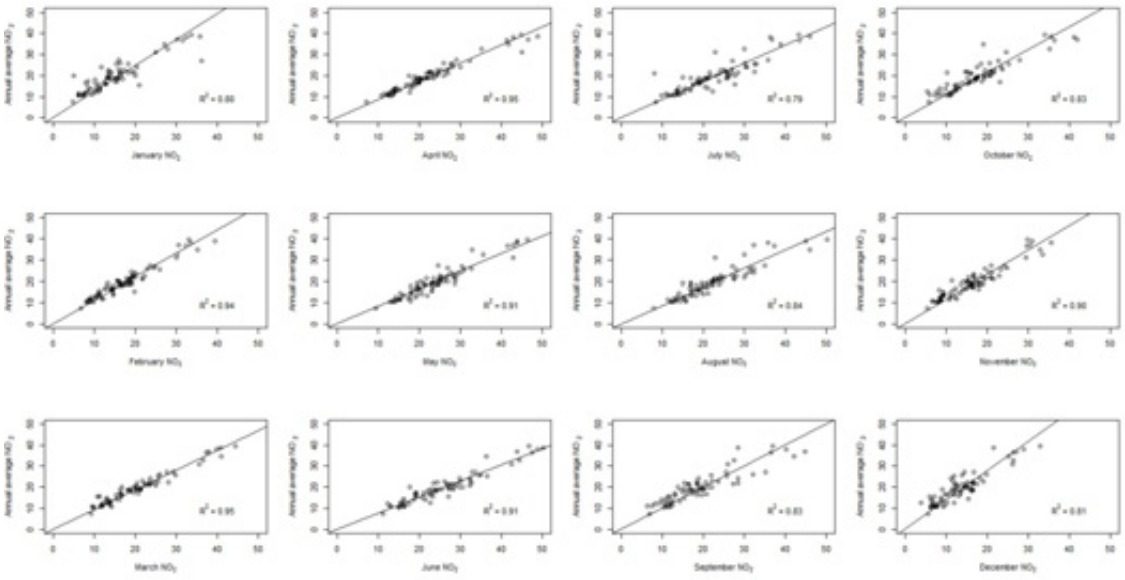


Figure A4.1: Regression plots of annual mean against 1-month NO_2 concentrations at 15 sites (n=74) in Wellington operated between 2010 and 2016 (fitted without an intercept)

Table A4.1: Adjustment factors (polynomial coefficient) for monthly averages used to estimate annual mean concentrations

Month	Adjustment factor	Month	Adjustment factor
January	1.232	July	0.828
February	1.083	August	0.875
March	0.967	September	0.955
April	0.883	October	1.068
May	0.832	November	1.213
June	0.814	December	1.391

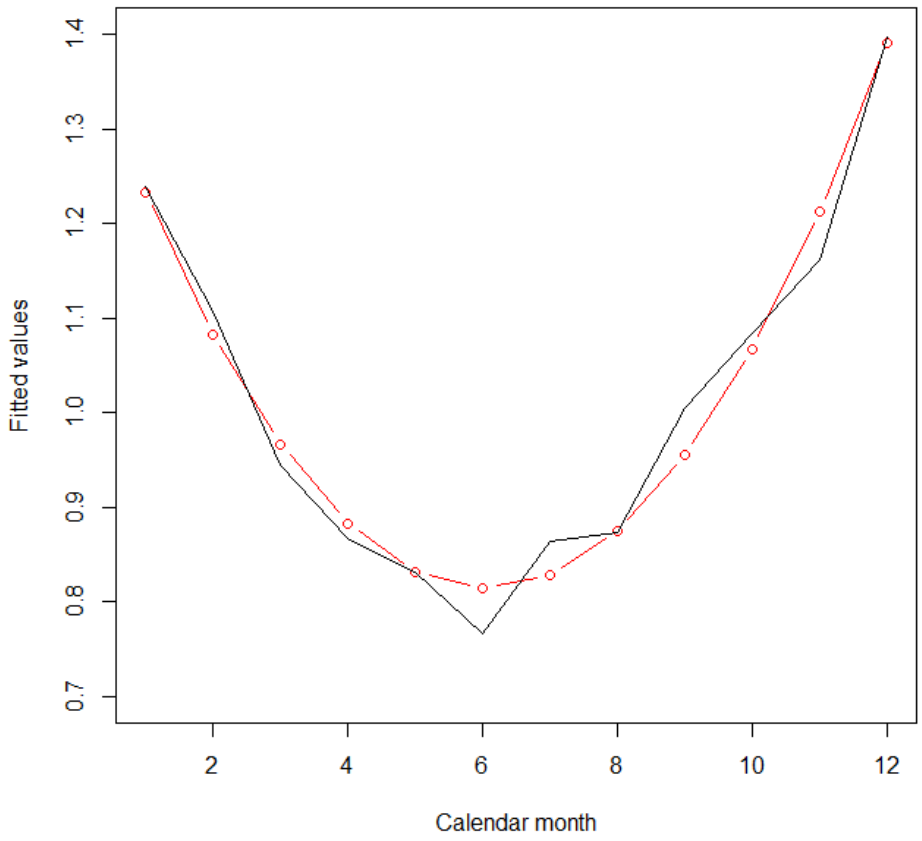


Figure A4.2: Polynomial fit (red) of NO_2 monthly slope coefficients (black) from linear regression of annual mean on monthly mean.

Appendix 5: Passive NO_2 monitoring results 2016

Table A5.1: Passive NO2 monitoring results 2016, with estimated annual averages* where data capture below 75%.

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
WEL053	16.0	20.2	21.7	26.8	29.4	32.4	26.9	30.3	22.0	23.7	16.7	11.5	**23.1**
WEL087								22.1	23.9	28.1	18.7	18.9	**24.2***
WEL008	32.5	33.5	39.7	42.8	43.7	48.8	36.2	35.7	40.2	41.1	35.5	28.9	**38.2**
WEL049	30.1	30.5	37.8	46.5	42.9	43.8	36.6	32.2	44.7	41.9	30.3	27.1	**37.0**
WEL050	13.6	17.0	20.2	22.0	21.2	24.5	20.4	23.8	19.8	17.3	13.7	12.3	**18.8**
WEL073,074,075	14.8	17.2	20.6	25.2	24.6	29.5	20.2	23.5	22.7	17.5	18.3	13.1	**20.6**
WEL081							37.4	35.6	41.0		30	27	**35.0***
WEL082							43.7	30.3	42.0	42.9	37.3	32.4	**39.7***
WEL083							33.9		39.1	38.4	32	26	**36.3***
WEL063	7.8	12.5	15.4	19.7	20.6	19.0	18.7	18.3	19.6	15.5	17.8	12	**16.4**
WEL078			10.8	16.8	18.0	23.2	17.4	19.2	11.5	12.2	9.2	6	**14.4**
WEL003	8.4	11.1	13.1	18.4	15.4	20.7	20.4	21.1	15.4	12.3	11.0	8.6	**14.7**
WEL052	13.9	12.1	21.5	25.5	28.1	30.1	29.2	24.3	23.4	16.8	17.4		**22.0**
WEL079							18.5	23.2	17.8	16.7	14.8	9.2	**16.8***
WEL089								16.9	18.2	9.7	10.1	9	**13.4***
WEL080							21.7	22.7	24.6	22.3	14.7	13.4	**20.2***
WEL088								31.8	29.9	34.8	24.9	24.4	**31.5***
WEL084							23.1	25.5	25.9	21.2	17.5	14	**21.5***
WEL085							10.4	15.7	10.6	8.4	8.1	6.2	**10.0***
WEL086							21.3	25.4	24.4	19.7	13.9	12.9	**19.8***
WEL054	7.0	8.3	9.4	12.9	14.2	16.2	12.8	15.8	11.6	7.3	7.0	6.3	**10.7**
WEL072	10.0	5.8	7.4	12.2	8.1	9.8	7.4	9.0	6.8	5.7	4.6	5.4	**7.7**
WEL048	5.0	6.1	7.2	10.1	8.9	12.1	8.6	8.8	6.9			4.5	**7.8**

Appendix 6: Maps of annual average NO_2 for sites in 2016

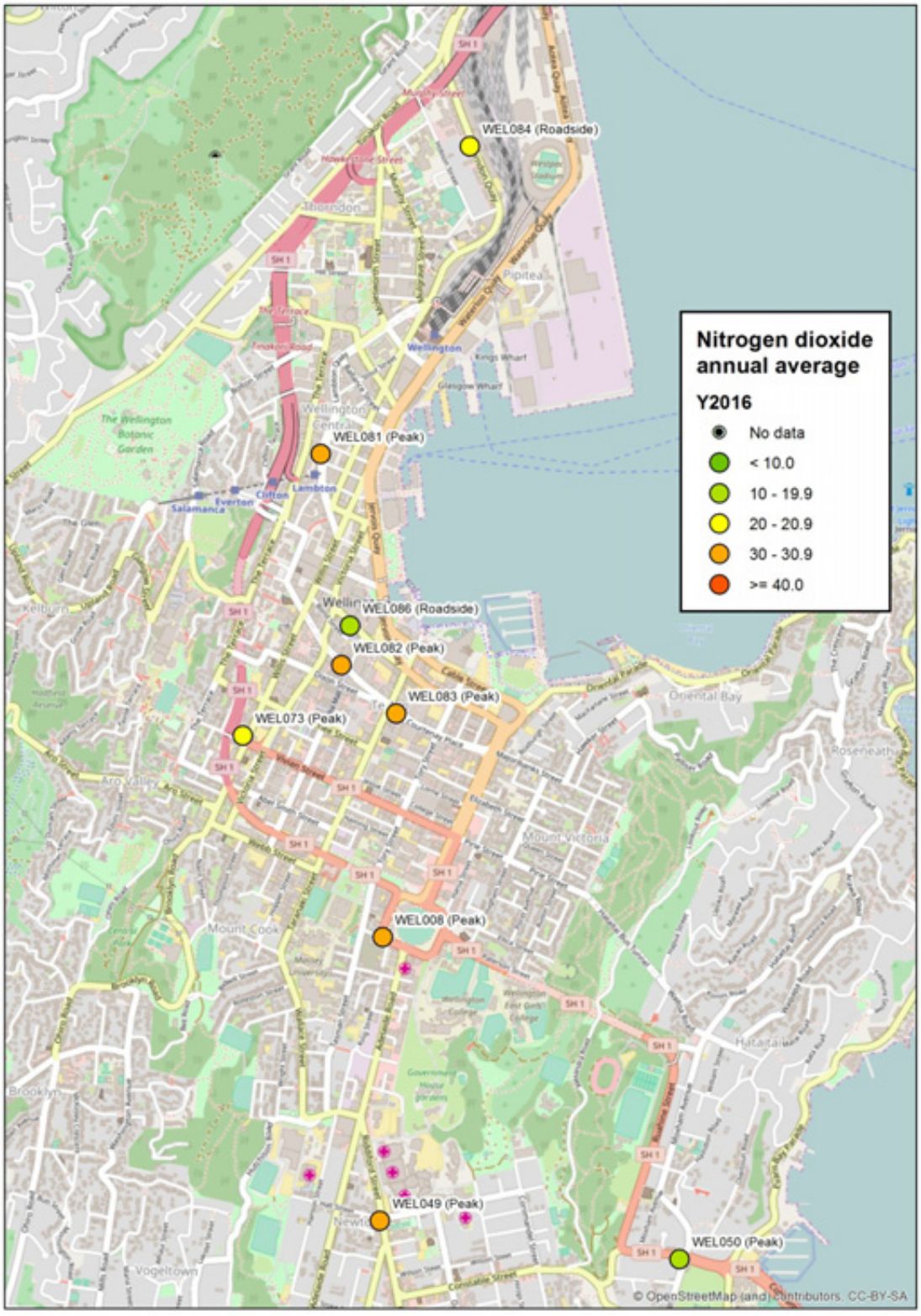


Figure A6.1: Map of Wellington City sites

Figure A6.2: Map of Johnsonville and Porirua sites

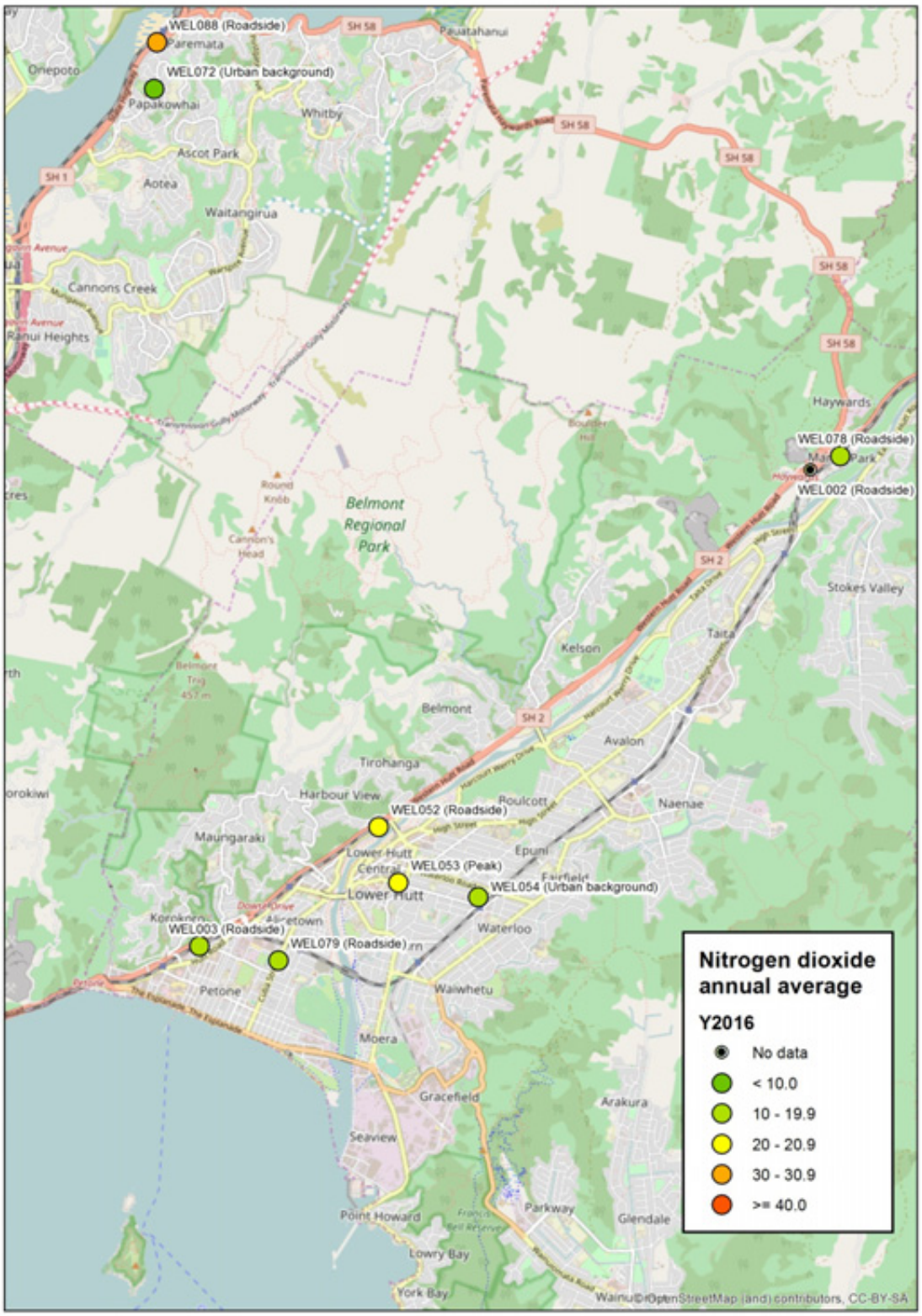


Figure A6.3: Map of Lower Hutt and Porirua sites

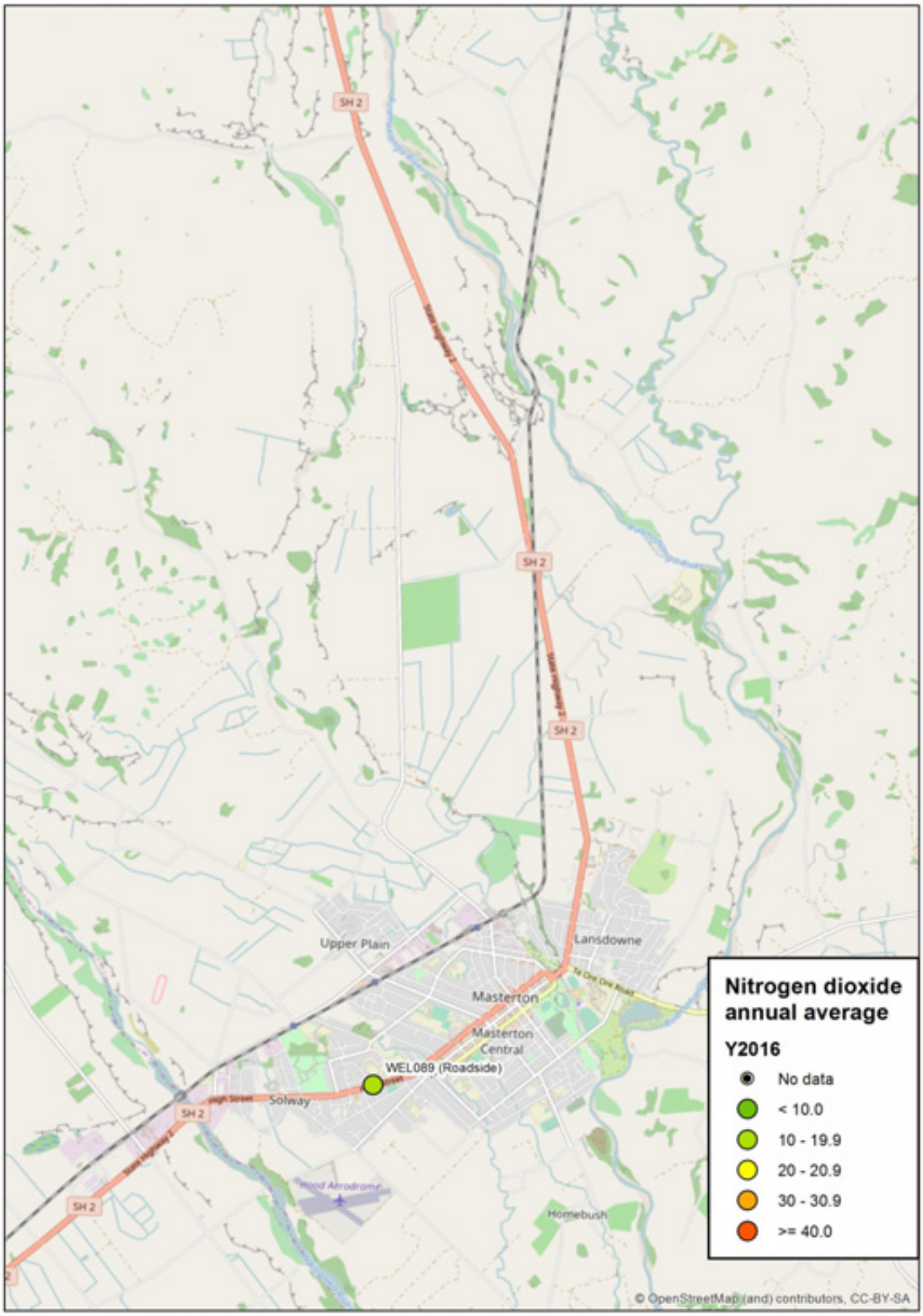
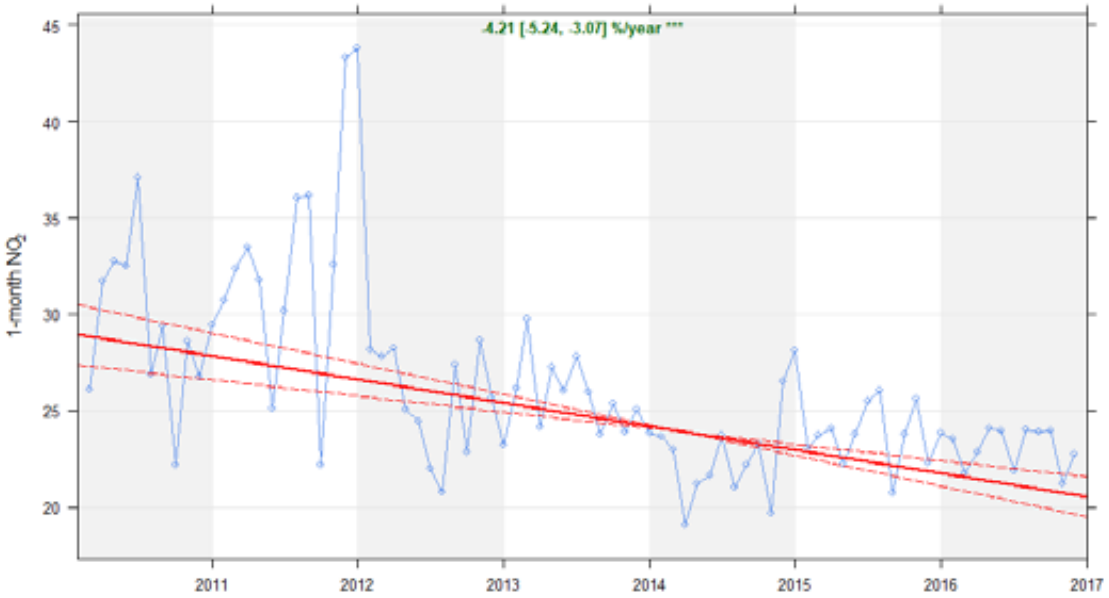


Figure A6.4: Map of Masterton sites

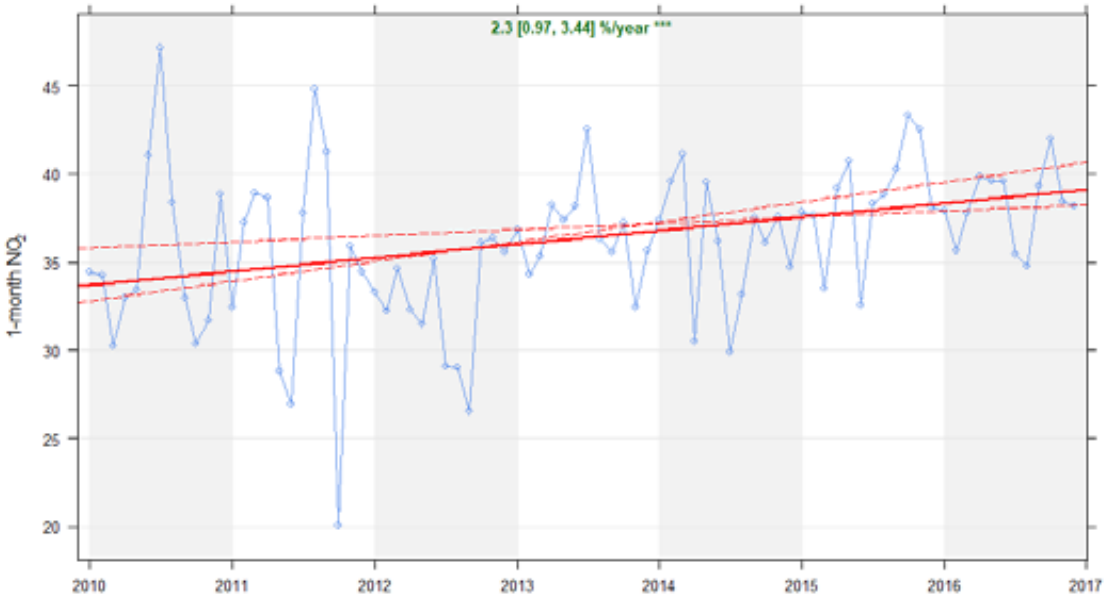
Figure A6.5: Map of Kapiti sites

Appendix 7: Time trends NZTA passive NO_2 sites

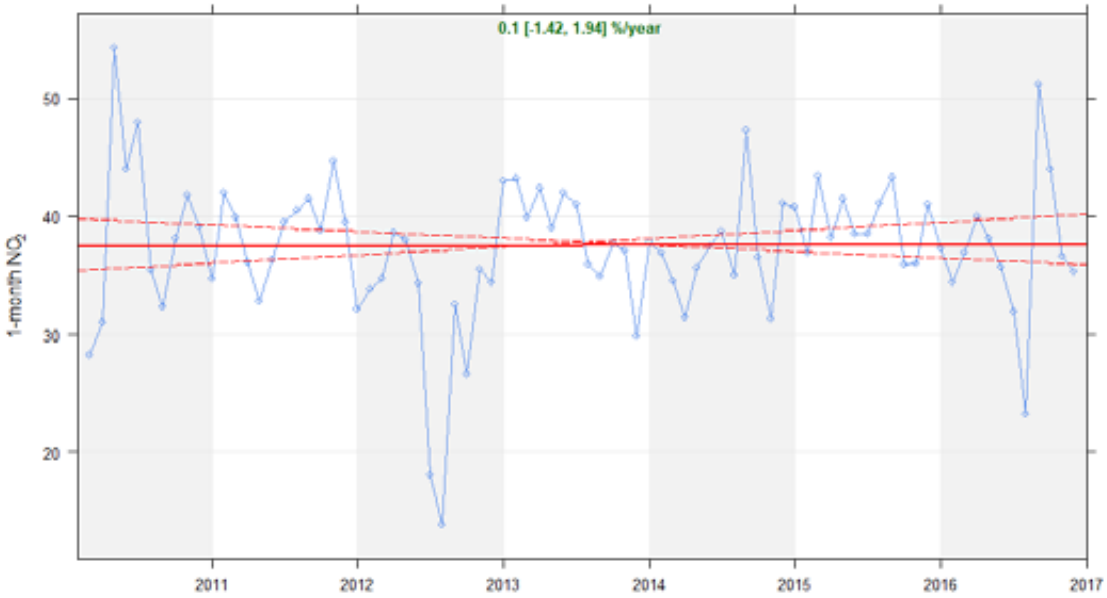
A7.1: WEL053 Knights Road, Lower Hutt



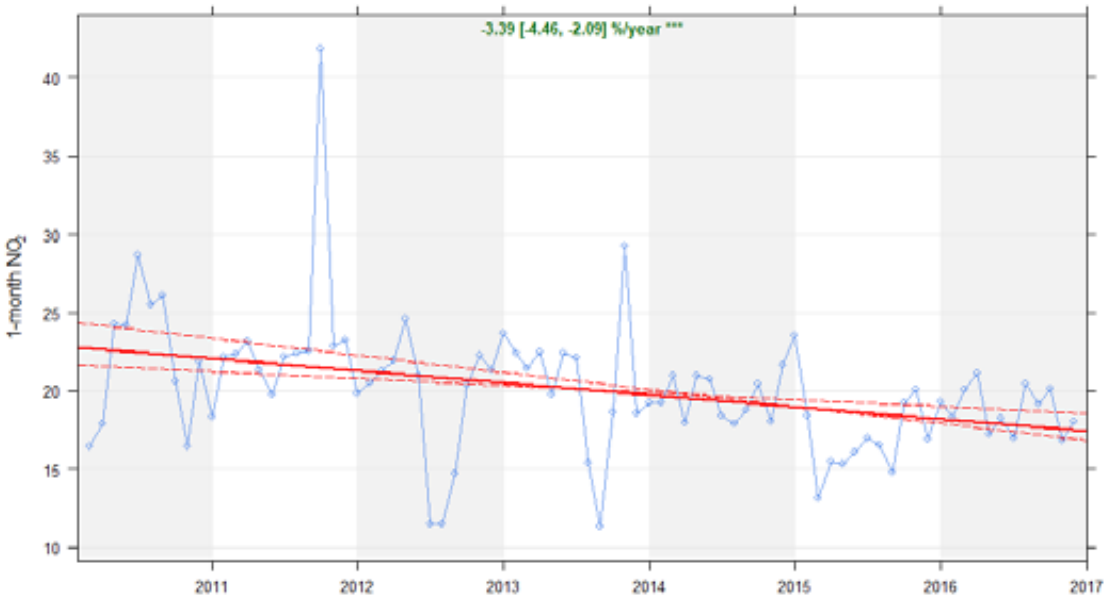
A7.2: WEL008 Basin Reserve, Wellington



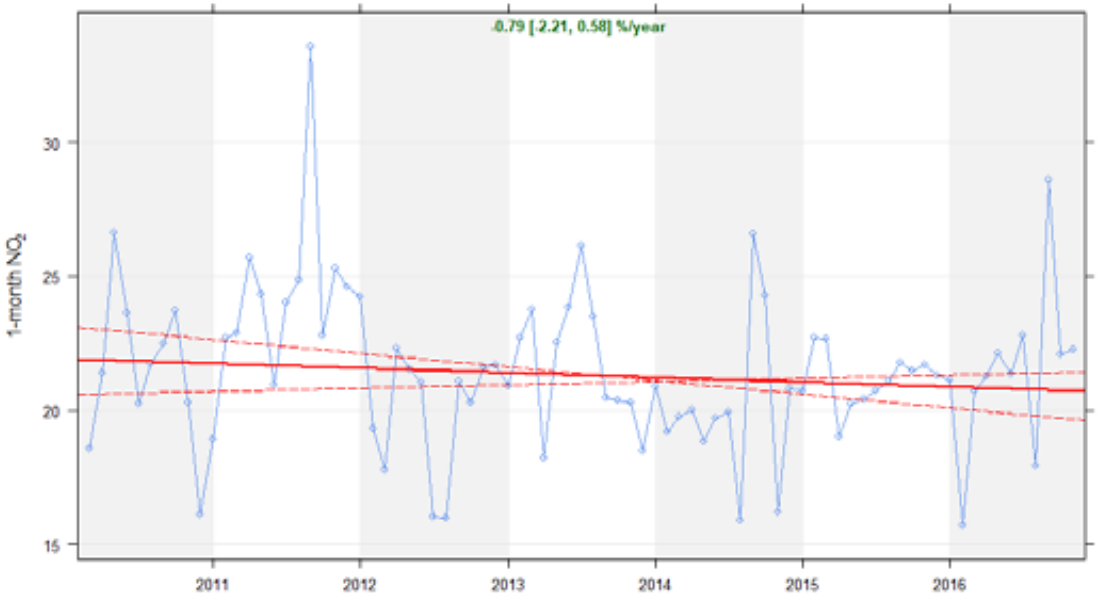
A7.3: WEL049 Newtown, Wellington



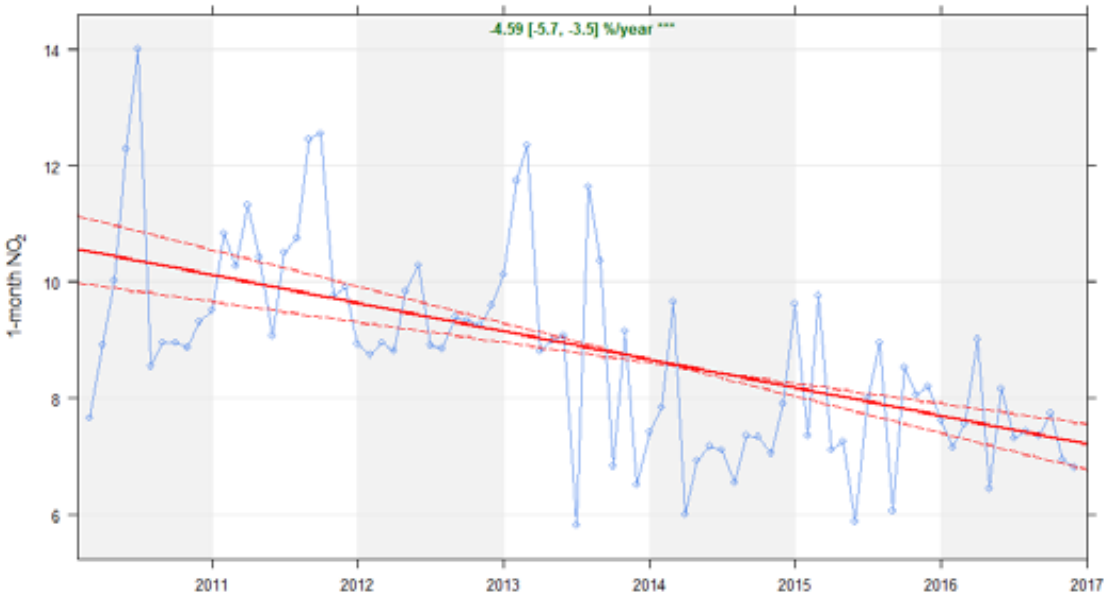
A7.4: WEL050 Kilbirnie, Wellington



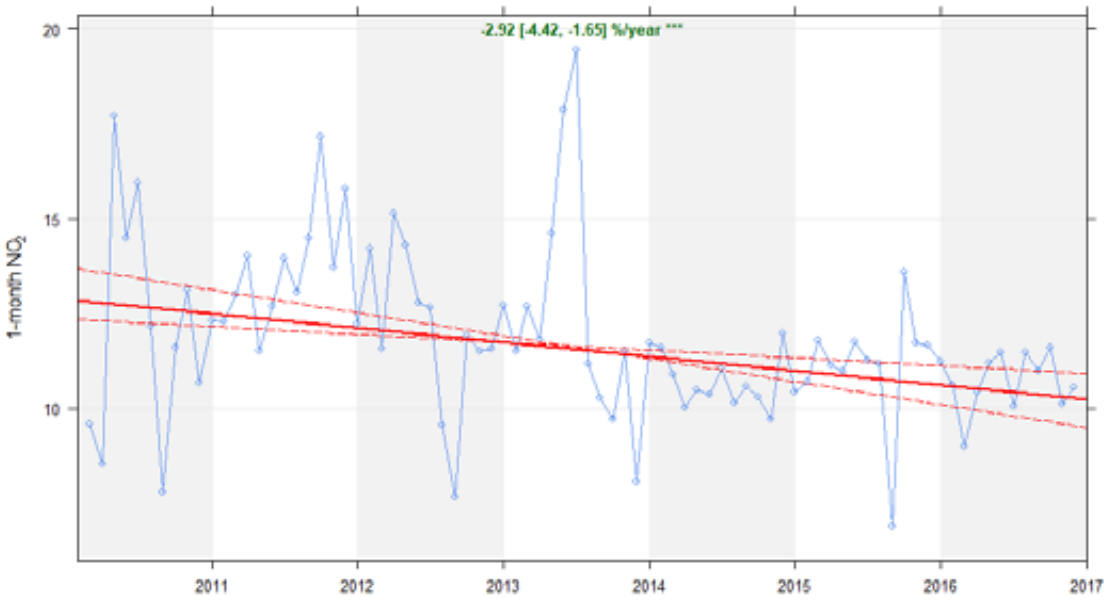
A7.5: WEL052 Boulcott, Lower Hutt



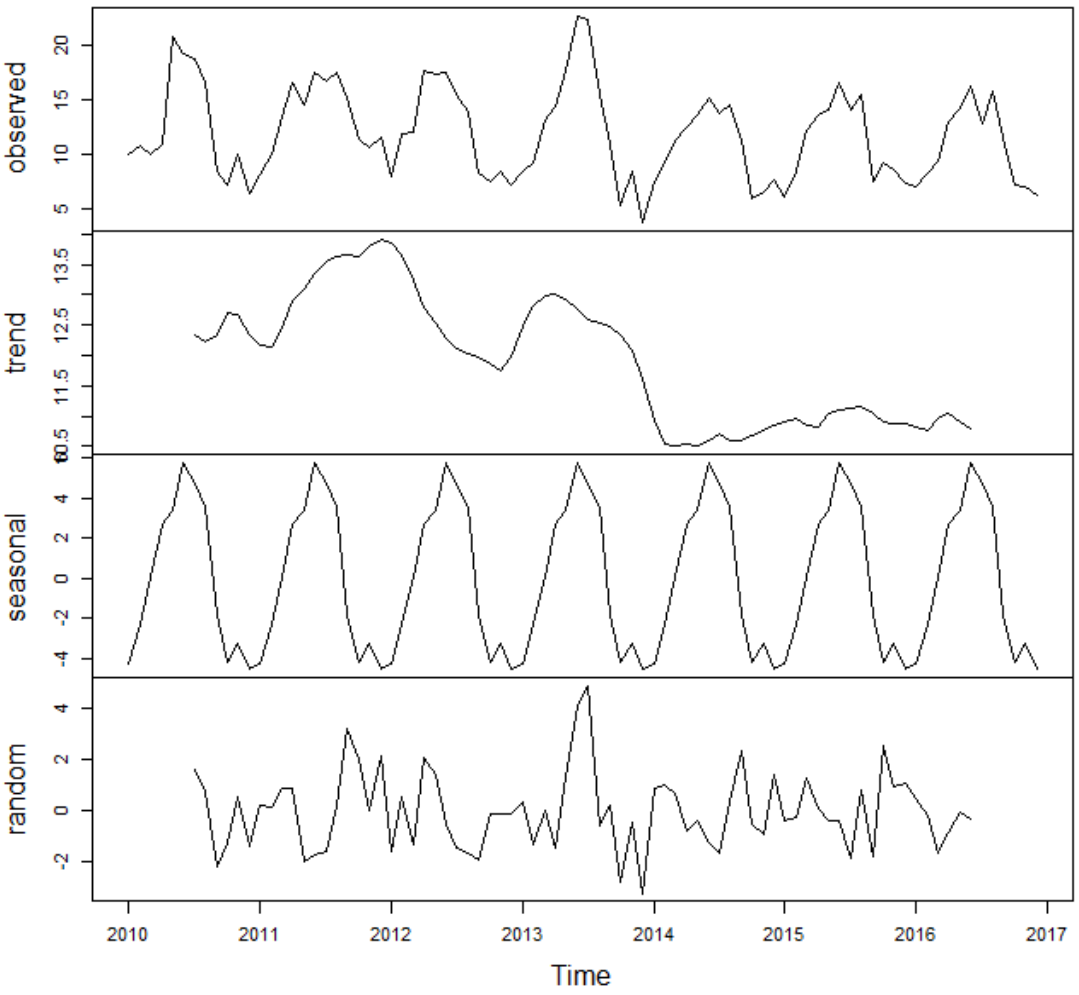
A7.6: WEL048 Island Bay, Wellington



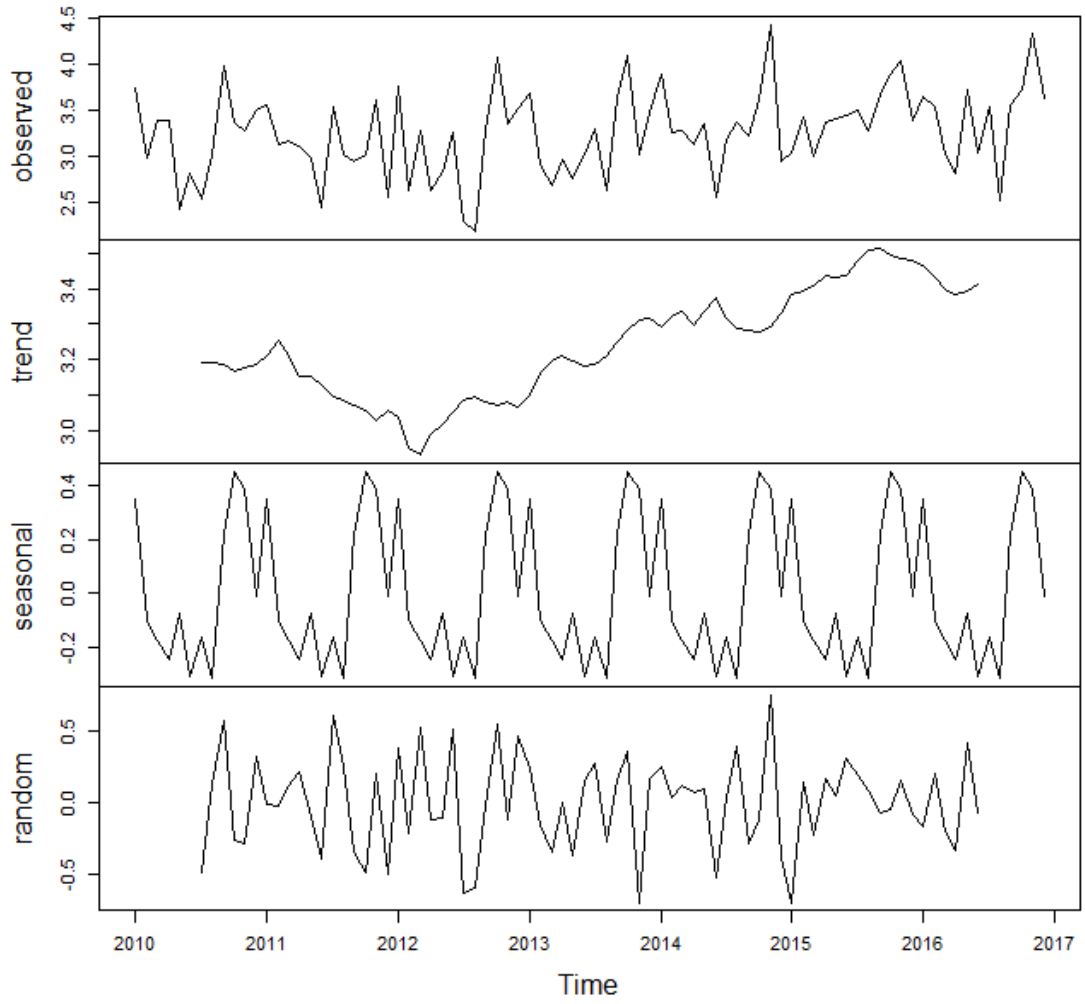
A7.7: WEL054 GWRC air quality station, Waterloo, Lower Hutt



A7.8: NO_2 decomposed time series WEL054 GWRC air quality station, Waterloo, Lower Hutt

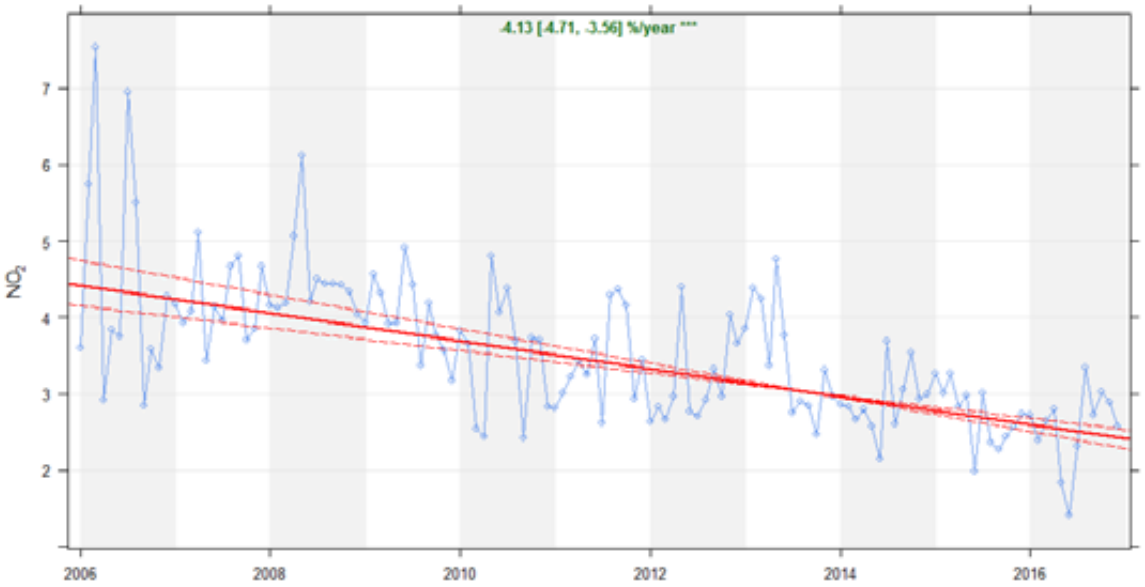


A7.9: Wind speed decomposed time series GWRC air quality station, Waterloo, Lower Hutt

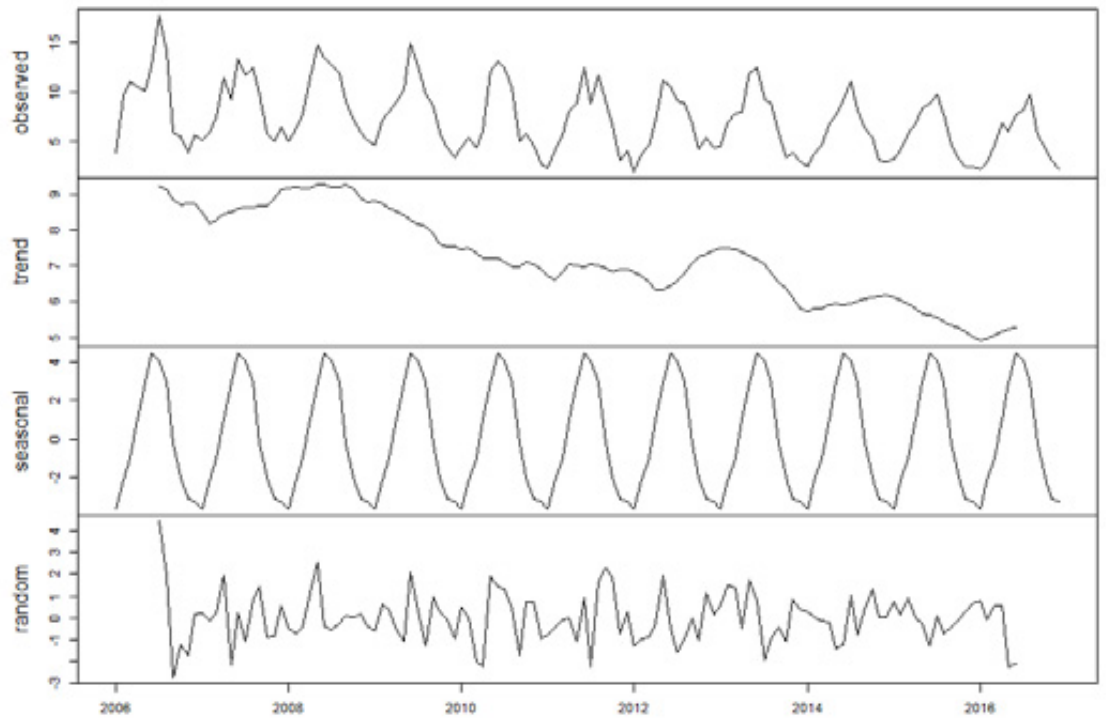


Appendix 8: Time trends GWRC continuous NO_2 site

A8.1: Upper Hutt (Savage Park) 2006 to 2016 nitrogen dioxide



A8.2: Upper Hutt (Savage Park) 2006 to 2016 seasonal decomposition NO_2



A8.3: Upper Hutt (Savage Park) 2006 to 2016 seasonal decomposition wind speed