Auckland
Regional Council
TE RAUHITANGA TAIAO

Nitrogen Dioxide in air in the Auckland Region:

Passive Sampling Results

December 2007 TP346

Auckland Regional Council
Technical Publication No. 346, 2007
ISSN 1175-205X
ISBN -13: 978-1-877416-86-6
ISBN -10: 1-877416-86-X
Printed on recycled paper

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Acknowledgements

This report has been prepared by Shanju Xie, Kevin Mahon and Janet Petersen of the Auckland Regional Council.

The cover image, courtesy of Watercare Services Limited, shows the Britomart site at the corner of Customs Street East and Commerce Street in central Auckland. The red circle indicates the passive sampler which is attached to the street light pole.

Executive Summary

Nitrogen dioxide (NO_2) is a major air pollutant in the Auckland region. The National Environmental Standards* (NES) for NO_2 is breached regularly along busy roadsides. NO_2 can irritate the lungs, increase susceptibility and severity of asthma, and lower resistance to infections such as flu. The transport sector is the predominant contributor to Auckland's NO_2 problem, but there is also a contribution from industrial discharges.

In order to gain an understanding of NO_2 concentrations in the Auckland region, monitoring programmes using passive samplers were started in 1994. Summer surveys were carried out from 1994 to 1998, and winter surveys from 2002 to 2004 and 2006. Two long-term sites at Pitt Street (Pitt St), an urban traffic site and Mt Eden - Kelly Street (Mt Eden), an urban residential site, were established in 1995 with continuous monthly measurements until 2006. In 1997-1998 and 2006, samplers were placed along the roadsides near motorways to measure the spatial variation of concentrations close to the motorways. The results provide important information about the temporal and spatial variations of NO_2.

Key results about the temporal variations are that:

- Month-to-month and year-to-year variations are quite site specific,
- Concentrations in winter are about two times of those in summer,
- The lowest monthly concentrations are usually in December - January, and
- Concentrations show a downward trend at Pitt St but remain stable at Mt Eden.

Key results about the regional spatial variations are that:

- Relatively high concentrations generally align to the southeast-northwest direction (Manukau→central Auckland→North Shore) of State Highway 1, and
- The highest concentrations are in the CBD-Newmarket areas.

Key results about the spatial variations close to motorways are that:

- There is a generally downward trend of NO_2 concentrations with increasing distances from the roadside,
- On average concentrations are higher on the downwind side of the motorway, and
- The contributions from the motorway can remain elevated up to at least 300m away from the roadside.

* Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins and Other Toxics) Regulations 2004 (Including Amendments 2005)

These results can be used for identifying pollution hotspots; independently validating emissions inventories, and urban airshed and roadside dispersion modelling; population exposure analysis; and improving future air quality monitoring.

1 Introduction

Nitrogen dioxide (NO_2) is a major air pollutant in the Auckland region. The National Environmental Standards for Air Quality* (NES) set out the ambient NO_2 1-hour concentration limit (200 µg m^{-3}) (MfE, 2005). In Auckland, the limit is regularly exceeded along busy roadsides. NO_2 can irritate the lungs, increase susceptibility and severity of asthma, and lower resistance to infections such as flu. The transport sector is the predominant contributor to Auckland's NO_2 levels, but there is also a contribution from industrial discharges.

Combustion sources, including vehicle emissions and discharges from power stations, emit nitrogen oxides (NO_x), mainly in the form of nitric oxide (NO) with a small proportion of NO_2. In the atmosphere NO is oxidised to NO_2 by ozone. This contributes to the major part of NO_2 in urban air. The concentration of NO_2 is therefore controlled by the NO_x level, the availability of oxidants, mainly ozone, from the upwind rural and coastal environment and the proportion of NO_2 in NO_x emissions. Mitigation policies are developed to limit NO_x emissions with the aim to reduce ambient NO_2 concentrations because the NO component is converted to NO_2 in the air.

1.1 Passive Sampling

Ambient NO_2 concentrations in the Auckland region are measured by continuous analysers or passive samplers. The continuous monitoring uses the regulatory chemiluminescence method to measure short-term concentrations (e.g. 1-hour and 24-hour means), and monitors compliance with the NES. Passive sampling, a less accurate, non-regulatory method, is a relatively cost effective means for general assessment of NO_2 levels at many sites, but it will not show short-term peaks. The results from the two methods can be compared using co-located measurements.

The passive samplers in these studies were basically an activated filter paper contained inside a small plastic holder. After exposure to the air for a period of time, usually two to four weeks for typical ambient concentrations, the sample (filter paper) is analysed using ion chromatography in the laboratory to determine the concentration of NO_2. In general passive samplers are deployed in pairs for each period at each site, to identify any unusual results and to give a measure of quality control. The averaged value from the two samples, if consistent, is used as the measurement at the site.

* Resource Management (National Environmental Standards Relating to Certain Air Pollutants, Dioxins and Other Toxics) Regulations 2004 (Including Amendments 2005)

1.2 Monitoring Programmes

In order to gain an understanding of NO_2 concentrations in the Auckland region, in particular their spatial distributions, monitoring programmes using passive samplers were started in 1994. The passive sampling campaigns in the Auckland region are summarised in Table 1.1. They can be grouped into four categories: summer surveys, winter surveys, long-term monitoring and roadside profiles. Benzene, Toluene, Ethylbenzene and Xylene (BTEX) passive sampling has also been undertaken in Auckland, but those results are not reported here.

Table 1.1
Summary of NO_2 passive sampling campaigns in the Auckland region*

Year	Number of sites	Duration	Reference
Summer survey – results are summarised in Table A1.1 (Appendix 1)			
1994-1995	12	Mid-December to mid-March	NIWA (1995)
1995-1996	12	Mid-December to mid-March	NIWA (1997)
1996-1997	15	Mid-December to mid-March	NIWA (1997)
1997-1998	15	Mid-November to mid-February	NIWA (1998)
Winter survey - results are summarised in Tables A1.2 (Appendix 1) and A2.1 (Appendix 2)			
2002	21	June, July and August	WSL (2003a)
2003	26	June, July and August	WSL (2003b)
2004	10	June, July and August	WSL (2005a)
2006	60	July, August and September	WSL (2006a)
Long-term sites - results are summarised in Table A3.1 (Appendix 3)			
1995-2006	2	Monthly	NIWA (1998), WSL (2003a, 2003b, 2005b, 2006b, 2006c)
Special studies - results are summarised in Tables A1.3 and A1.4 (Appendix 1), and A2.2 and A2.3 (Appendix 2)			
1997-1998	4 (roadside)	Mid-November to mid-February	NIWA (1998)
1999	6 (intersection)	May and June	NIWA (1999)
2006	16 (roadside)	July, August and September	WSL (2006d)

*Based on the ARC summary report (ARC, 2006a). The two long-term sites are also counted as summer or winter survey sites. In 2006, Gavin St was listed as both a regional and a roadside site.

The summer surveys were carried out in summer months, usually in a three-month period with measurements of monthly concentrations, from 1994 to 1998 to assess general concentrations at typical rural, suburban, urban and roadside locations (for the description of the types of sampling sites, see Table A1.7 in Appendix 1). Later, the survey campaign was carried out in winter. In 2006, a comprehensive survey was designed with an increased sampling size of 60 to improve the picture of the spatial distribution of NO_2 concentrations on a regional scale. Sampling sites for summer or winter surveys usually varied from year to year. In order to allow comparison between months, years and sites, and because of growing health concerns, two long-term sites at Pitt Street (Pitt St), an urban traffic site and Mt Eden - Kelly Street (Mt Eden), an urban residential site, were established in 1995 with continuous monthly measurements.

Some sampling campaigns were carried out for special studies. During the 1997-1998 survey, four sampling sites were placed along Avenue Road East at different distances from State Highway 1 (SH1) in Otahuhu to measure the variation of concentrations with distance from the motorway. To investigate the variation of NO_2 concentrations around the intersection of Khyber Pass Road and Mountain Road, a survey of NO_2 concentrations (two-week-mean) at six locations around the intersection was carried out in May and June 1999. In 2006, in addition to the 60 regional sites, 16 roadside sites were placed at different distances from State Highway 20 (SH20) at Mangere and SH1 at Penrose to measure the spatial variation of concentrations close to the two motorways.

Monitoring was performed by contractors, specifically the National Institute of Water and Atmospheric Research Ltd (NIWA) (1994 - 1999), and the Watercare Services Ltd (WSL) (2000 - 2006). Passive samplers used were supplied and analysed by the CSIRO Marine and Atmospheric Research in Australia. In the 2004 survey, samplers from the Staffordshire County Council (SCC) in the United Kingdom (UK) were placed alongside the CSIRO samplers as a comparison. The results of CSIRO and SCC passive samplers and continuous analysers at the continuous sites are listed in Table A1.8 (Appendix A). It appeared that the correlation coefficient between the CSIRO and the analyser results was higher than between the SCC and the analyser results (WSL, 2005a). Therefore, CSIRO samplers were continued to be used in 2005 and 2006, as the results might be slightly better and to maintain consistency in the sampling programmes.

The results of individual sampling programmes were presented in the reports by NIWA or WSL, which are also listed in Table 1.1. The data from 1994 to 2004 have been summarised and analysed in a recent internal ARC report (ARC, 2006a). Analysis of the data collected in 2006 is the focus of this report, which also integrates the results of previous years.

1.3 Sampling in 2006

There was insufficient information about NO_2 spatial distributions in the region from the passive data gathered before 2006 due to limited numbers of sampling sites. Therefore, in 2006, the number of sites was increased to 60 and 16 for region-wide and roadside-scale spatial variations, respectively. The locations of the sampling sites are shown in Chapters 3 and 4 for regional and roadside sites, respectively.

In previous passive sampling studies, representative sites were selected for typical rural, suburban, urban and roadside locations. 43 of these previous sites were used in 2006. Measurements at these repeated sites could be used for analysis of temporal variations. The sampling network in 2006 was extended with further 17 sites in rural, suburban, urban and roadside areas.

Roadside-scale sites were near SH20 (Mangere) and SH1 (Penrose). The Mangere section of SH20 was selected since NO_x emissions from vehicles travelling along the motorway are the dominant source in the area and there are few other major roads nearby. In addition, measurements on the western and eastern sides of the motorway would provide upwind and downwind data under the prevailing south-westerly wind.

The Penrose section of SH1 was chosen so that the passive results could be used with other measurements in future studies. The Penrose permanent site at Gavin Street (Gavin St) was set up in 1987. Various pollutants, e.g.: NO_x, fine particles (PM_{10} - particulate matter less than 10 microns in diameter) and sulphur dioxide (SO_2), are monitored there, together with meteorological parameters (i.e. wind speed, wind direction, ambient temperature, relative humidity and solar radiation) (ARC, 2006b). From 2004 to 2006, a mobile trailer was placed at four locations close to the Gavin St site at varying distances from the motorway, with continuous measurements of carbon monoxide (CO), NO_x , PM_{10} and meteorological parameters. Vehicles emissions and discharges from industrial sources are the dominant NO_x source in the area.

In 2006, the measurements from the pairs at each site (samples A and B) are generally consistent across all the sites and months, therefore, are averaged to represent the concentration at the site. However, for regional sites there was only one valid sample at Greenlane in July and at Chapel Downs in August because the other samples were vandalised. For roadside sites, the value of a sample at Site 3 (150 m away from the SH1 roadside) in July was too high (57.0 µg m^{-3}, compared to 31.3 µg m^{-3} of another sample), and was not used to calculate the average. The relationship between NO_2 concentrations from paired samples is shown in Figures A2.1 and A2.2 (Appendix 2) for regional and roadside sites, respectively.

As a means of estimating uncertainties in passive sampling, the difference between the measurements of paired samples is analysed. In 2006, 93 per cent of all sample pairs were within 10 per cent of the pair mean, as shown by the histogram plot in Figure A2.3 (Appendix 2). On average, the difference between the individual samples and their pair means was 3.0 per cent. This demonstrates a good agreement between the measurements of paired samples.

Due to the differences in monitoring technique, results from passive samplers and chemiluminescence analysers are not always comparable. Overseas, passive measurements are often adjusted to the equivalent values from the chemiluminescence method before comparison to regulated limits (e.g., UKDEFRA, 2003). There was a close relationship between the co-located NO_2 data in 2006 from the two methods, with a correlation coefficient R^2 of 0.82. However, the passive results were usually lower than the corresponding continuous data, on average 17 per cent lower with an average of 25.7 µg m^{-3} from the passive and 31.0 µg m^{-3} from the continuous measurements. The co-located data in 2006 are shown in Table A2.4 and Figure A2.4 (Appendix 2). The data points are scattered around the regression line. It is obvious that the adjustment of passive results at non-co-located sites will introduce uncertainties. This is also the case for the measurements in previous years.

In this study, the values from the passive samplers in all our campaigns listed in Table 1.1 are reported without any adjustment in order to maintain the consistency among the passive data. It is probable that the passive results are lower than those which would be measured using a chemiluminescence analyser. However, data from both methods are expected to demonstrate a similar pattern of the temporal and spatial distributions.

1.4 Purpose of Study

The purpose of this study is to summarise and present information from the passive monitoring programmes, by analysing the 2006 data and integrating results of previous years. This report is divided into two parts. Part I (Chapter 2) presents the temporal distribution in terms of monthly and yearly variations. Part II (Chapters 3 and 4) focuses on the spatial distribution, on the regional and local scales. The results can be used for identifying pollution hotspots; independently validating emissions inventories, urban airshed and roadside dispersion modelling; population exposure analysis; and improving future air quality monitoring.

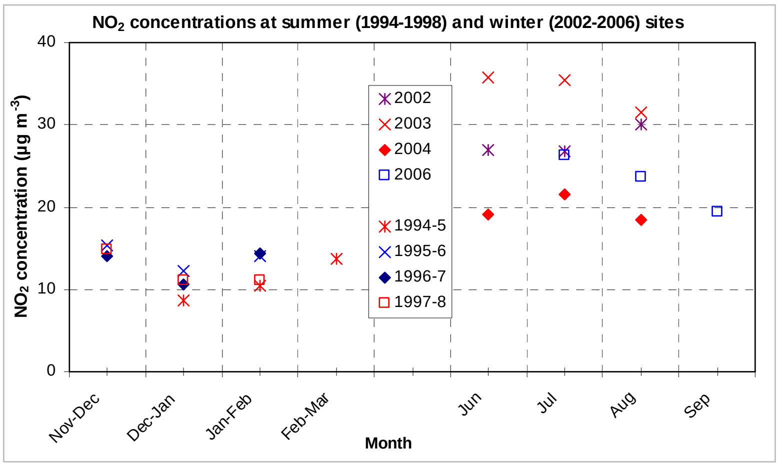
2 Temporal Variations

Two datasets, one from the summer and winter survey sites, and one from the long-term sites, are used to analyse month-to-month and year-to-year variations of nitrogen dioxide (NO_2) concentrations. As a comparison, continuous data from the monitoring network are also analysed.

2.1 Results from Survey Sites

Monthly NO_2 concentrations at summer (1994-1998) and winter (2002-2006) survey sites are shown in Figure 2.1. Although summer and winter surveys were carried out at various sites in different years, the measurements were considered representative of regional NO_2 levels. The concentrations in winter were consistently higher than in summer. The lowest concentrations were observed in the month of December-January. This is likely due to less traffic on the road during the Christmas–New Year holiday period. In winter, the highest monthly concentrations appeared in various months in different years, i.e. in August in 2002, June in 2003, and July in 2004 and 2006.

Figure 2.1
Average NO_2 concentrations during summer (1994-1998) and winter (2002-2006) surveys. The data are listed in Tables A1.5 and A1.6 (Appendix 1).



2.2 Results from Long-term Sites

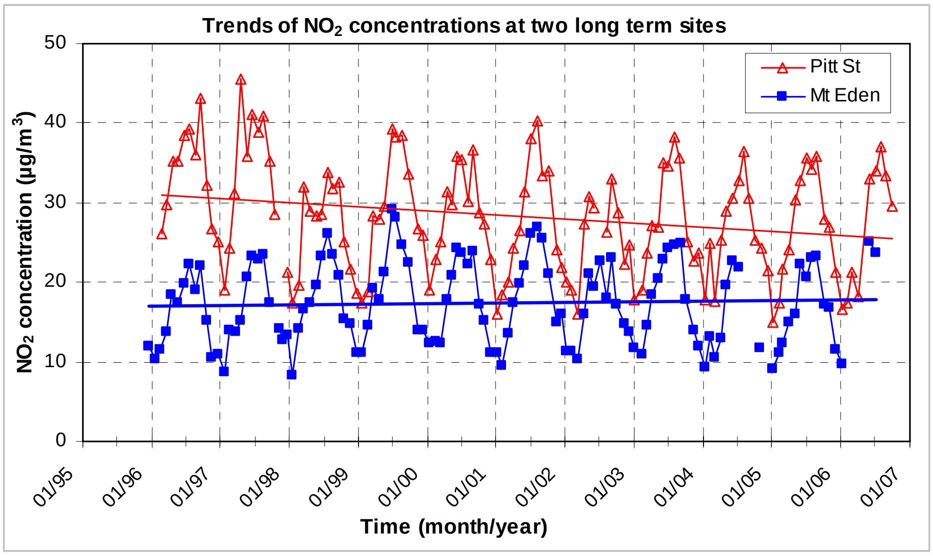
Passive sampling results at two long-term sites from December 1995 to September 2006 are shown in Figure 2.2. Concentrations at Pitt St were consistently higher than those at Mt Eden. Both sites demonstrated a strong seasonal variation with higher concentrations in winter than in summer, and the lowest concentrations in December-January. This is consistent with the results from the survey sites. Over the sampling period, the average NO_2 concentrations in summer (December, January and February) and winter (June, July and August) were 20.2 and 35.3 µg m^{-3} respectively at Pitt St, 11.5 and 23.5 µg m^{-3} respectively at Mt Eden. The ratios of concentrations in winter compared to summer were 1.8 and 2.0 at Pitt St and Mt Eden, respectively. The concentrations in winter and in summer and their ratios for each year of sampling are listed in Table A3.2 (Appendix 3).

There is a generally downward trend at Pitt St. However, NO_2 concentrations at Mt Eden remain relatively constant over the monitoring period. The Pitt St site is heavily affected by traffic emissions from Pitt St and the Hobson Street south-bound on-ramp to SH1. The Mt Eden site is located in the urban residential area. The effects of direct vehicle emissions from nearby roads are more significant at Pitt St than at Mt Eden on the measured NO_2 concentrations. The decline of NO_2 concentrations at Pitt St is possibly due to a reduction of direct NO_2 emissions from nearby roads. It is also suggested that encroaching vegetation at the Pitt St site may contribute to this decline since the sampler was attached to a pergola off the side of Vodafone House, immediately above planter beds (ARC, 2006a).

A study of urban airshed modelling in Auckland (Gimson, 2005) suggests that regional NO_2 levels are ozone-limited, leading to a seasonal trend in regional NO_2 dependent on natural ozone levels, but not local NO_x emissions. NO_2 concentrations at Mt Eden are considered to be largely controlled by the natural background ozone levels, therefore, do not show a significant year-to-year variation. Background ozone levels in New Zealand are higher in winter than in summer (MfE, 2004). The higher winter NO_2 concentrations at both sites, and across the region, are considered to be a result of higher background ozone levels and poor dispersion conditions in winter, rather than an increase in NO_x emissions during that period.

Figure 2.2

NO_2 concentrations from December 1995 to September 2006 at Pitt Street and Mt Eden Road), based on the ARC report (ARC, 2006). The data are listed in Table A3.1 (Appendix 3).



2.3 Comparison with Continuous Measurements

As a comparison to the passive results in Sections 2.1 and 2.2, data from the continuous method are analysed. Details about the continuous monitoring sites can be found in the ARC technical publication, TP296 (ARC, 2006b).

Consistent with the passive measurements, the continuous data also demonstrate higher NO_2 concentrations in winter than in summer. This is illustrated in Figures 2.3 and 2.4 for the monthly concentrations at the roadside and other sites in 2006, respectively. Generally, the concentrations at the roadside sites (Queen St and Khyber Pass) were higher than at other sites. All the sites showed a very similar seasonal variation. The ratios of the concentrations in winter (June, July and August 2006) compared to summer (December 2006, January and February 2007) were calculated for all the continuous monitoring sites, except for Queen St due to missing data at the site in July 2006. The ratios of winter to summer were (respectively) 2.0, 2.0, 2.2, 2.3, 2.4, 2.6, and 4.0 for Khyber Pass, Henderson (suburban site), Kingsland (urban site), Takapuna (suburban site), Glen Eden (suburban site), Gavin St (urban site), and Musick Point (rural site), with an average of 2.5 across all the sites.

Figure 2.3

Monthly NO_2 concentrations from continuous measurements at the roadside sites in 2006.

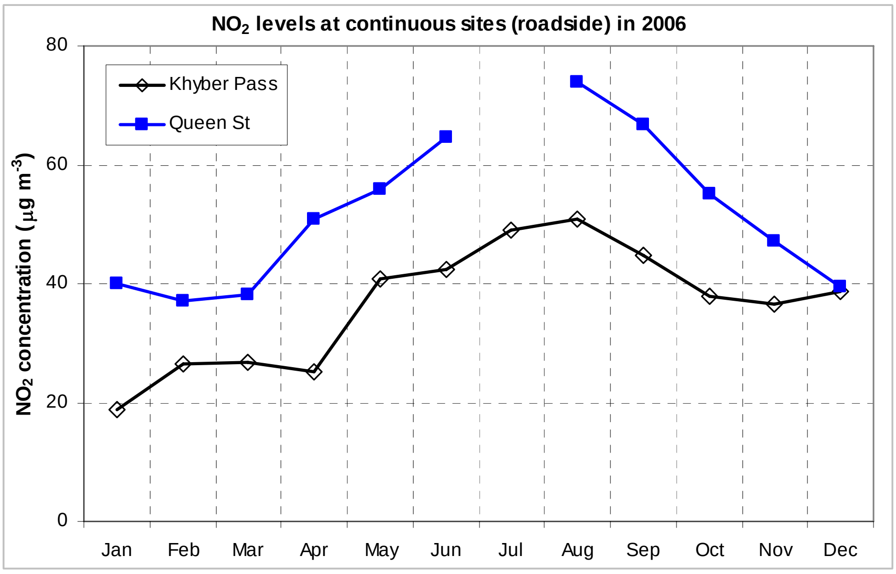
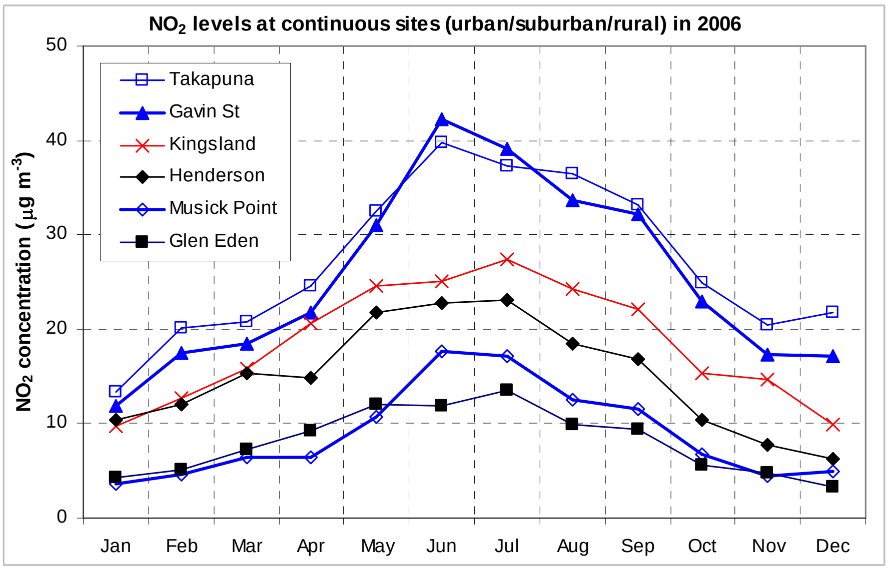
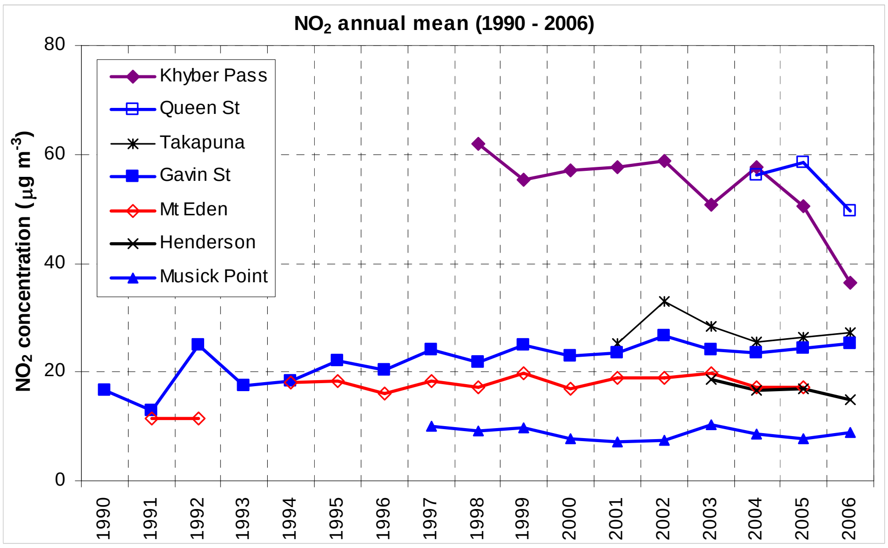


Figure 2.4
Monthly NO_2 concentrations from continuous measurements at the urban, suburban or rural sites in 2006.



Annual average NO_2 concentrations from continuous measurements in 1990 - 2006 are shown in Figure 2.5. There appeared to be a downward trend at Khyber Pass, a slightly upward trend at Gavin St, but no obvious upward or downward trends at Takapuna, Mt Eden (urban site) and Musick Point. By comparison, the passive results also showed a stable year-to-year variation at Mt Eden, and a decline at Pitt St (roadside site). Generally the trends from passive results are consistent with those from continuous measurements. However, with more sites and longer data records, continuous measurements provide more information about trends of NO_2 concentrations than passive data.

Figure 2.5
Annual NO_2 concentrations from continuous measurements in 1990-2006.



3 Spatial Distributions - Regional

This chapter presents the spatial distribution of nitrogen dioxide (NO_2) concentrations on the regional scale, and Chapter 4 on the local (roadside) scale. NO_2 concentrations vary on a small scale, particularly near roadsides, due to effects of local emissions, dispersion conditions and chemical processes. A case study has been carried out around the intersection of Khyber Pass Road and Mountain Road, to assess how representative the regional sites are for the areas measured. Section 3.1 summarises the results of the case study. Sections 3.2 and 3.3 present the results of the sampling campaign in 2006.

3.1 Intersection of Khyber Pass Road and Mountain Road

To investigate the variation of NO_2 concentrations around the intersection of Khyber Pass Road and Mountain Road, a survey of NO_2 concentrations at six locations around the intersection was carried out in May and June 1999 (NIWA, 1999). The locations of six sites are shown in Figure 3.1. Average fortnightly concentrations were measured using passive samplers. The survey lasted for six weeks with three measurements at each site. The results, shown in Table A1.4 (Appendix 1), demonstrated that concentrations along Khyber Pass Road (the busiest road in the intersection) were generally higher than along Mountain Road and Park Road. Overall, the measured values were reasonably comparable in the surrounding area near the Khyber Pass Road monitoring site.

In 2006, two sites were placed adjacent to the NIWA office, one on Khyber Pass Road (Khyber Pass) and one on Mountain Road (Mountain Rd). The site locations are also shown in Figure 3.1. The results, shown in Table 3.1, are consistent with those of the intersection survey in 1999.

Therefore, the regional sampling sites are considered fairly representative of the areas measured.

Table 3.1

NO_2 concentrations (μg m^{-3}) at Khyber Pass and Mountain Rd in 2006

Site	July	August	September	Mean
Khyber Pass (site 1 in Figure 3.1)	50.5	47.4	45.9	47.9
Mountain Rd (site 7 in Figure 3.1)	40.8	38.7	34.1	37.9

Figure 3.1
Sampling sites around the intersection of Khyber Pass Road and Mountain Road. In 1999, sites 1-6 were used. Site descriptions and the results are listed in Table A1.4 (Appendix 1). In 2006, sites 1 (Khyber Pass) and 7 (Mountain Rd) were used.

3.2 Sampling in 2006

The sampling sites in 2006 are plotted in Figures 3.2 (region-wide) and 3.3 (close-up of the CBD area), respectively. The size of the symbol (•, indicating the locations of samplers) corresponds to the concentration measurements averaged over three months from July to September 2006. Figure 3.2 shows that relatively high concentrations generally locate along the major roads and in residential areas. The highest measurement (three-month-mean 51.3 µg m^{-3}) was from the busy roadside near Britomart.

The Auckland airport also showed a moderate level of NO_2 (three-month-mean 24.9 µg m^{-3}). The airport is away from main arterial routes and the main source of pollution in the area is likely to be from aircraft and local traffic associated with the airport.

Plots of the sampling sites in 2006 using the monthly concentrations from July to September, shown in Figures A2.5 to A2.7 (Appendix 2), demonstrate a very similar pattern to Figures 3.2 and 3.3 of three month average concentrations. Results from previous surveys, although with fewer sites, also demonstrated higher concentrations along major roads and in populated residential areas than in other locations (ARC, 2006).

Figure 3.2

Region-wide sampling sites in 2006. The size of the symbol (•) corresponds to the NO_2 measurements which are listed in Table A2.1 (Appendix 2).

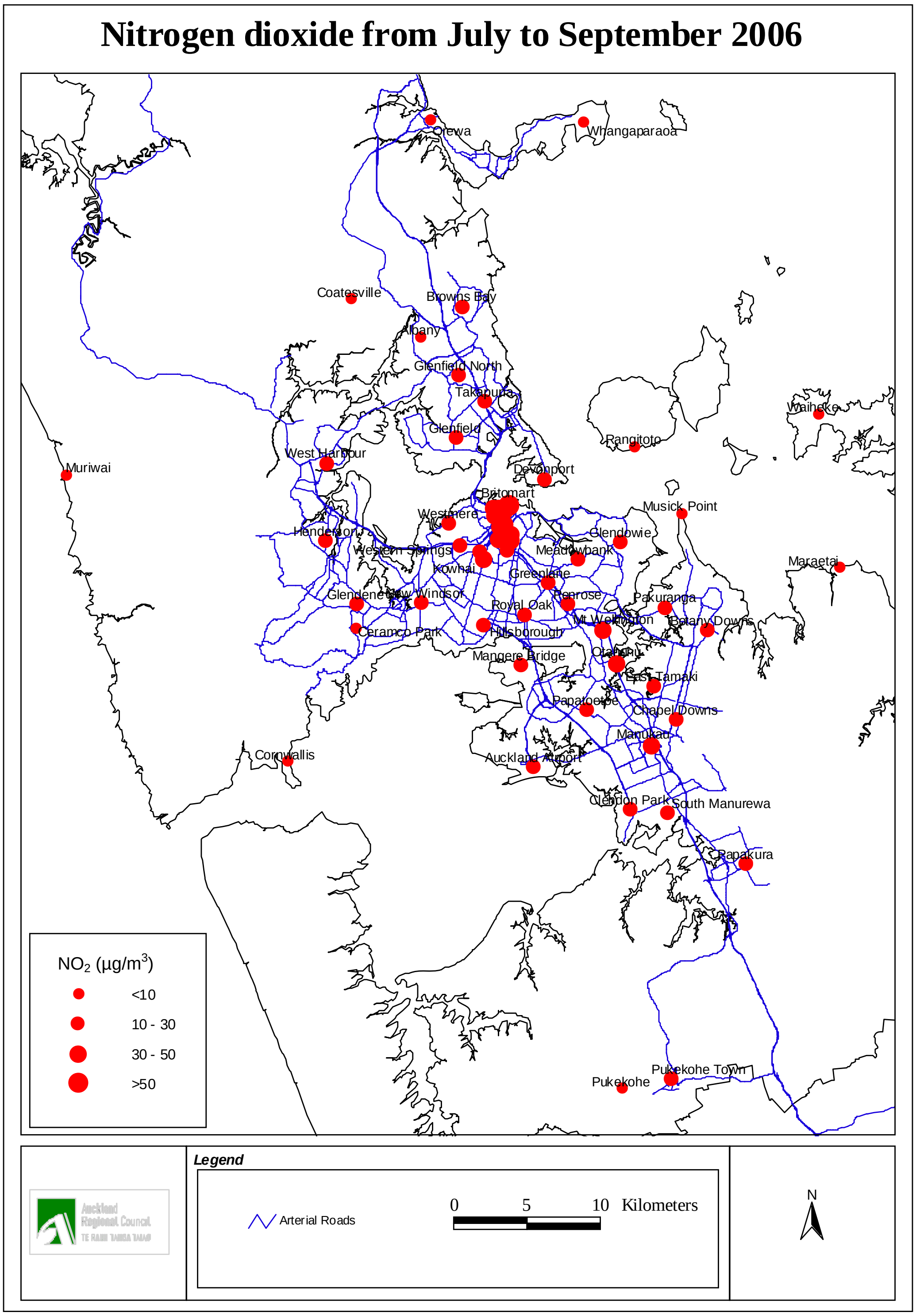
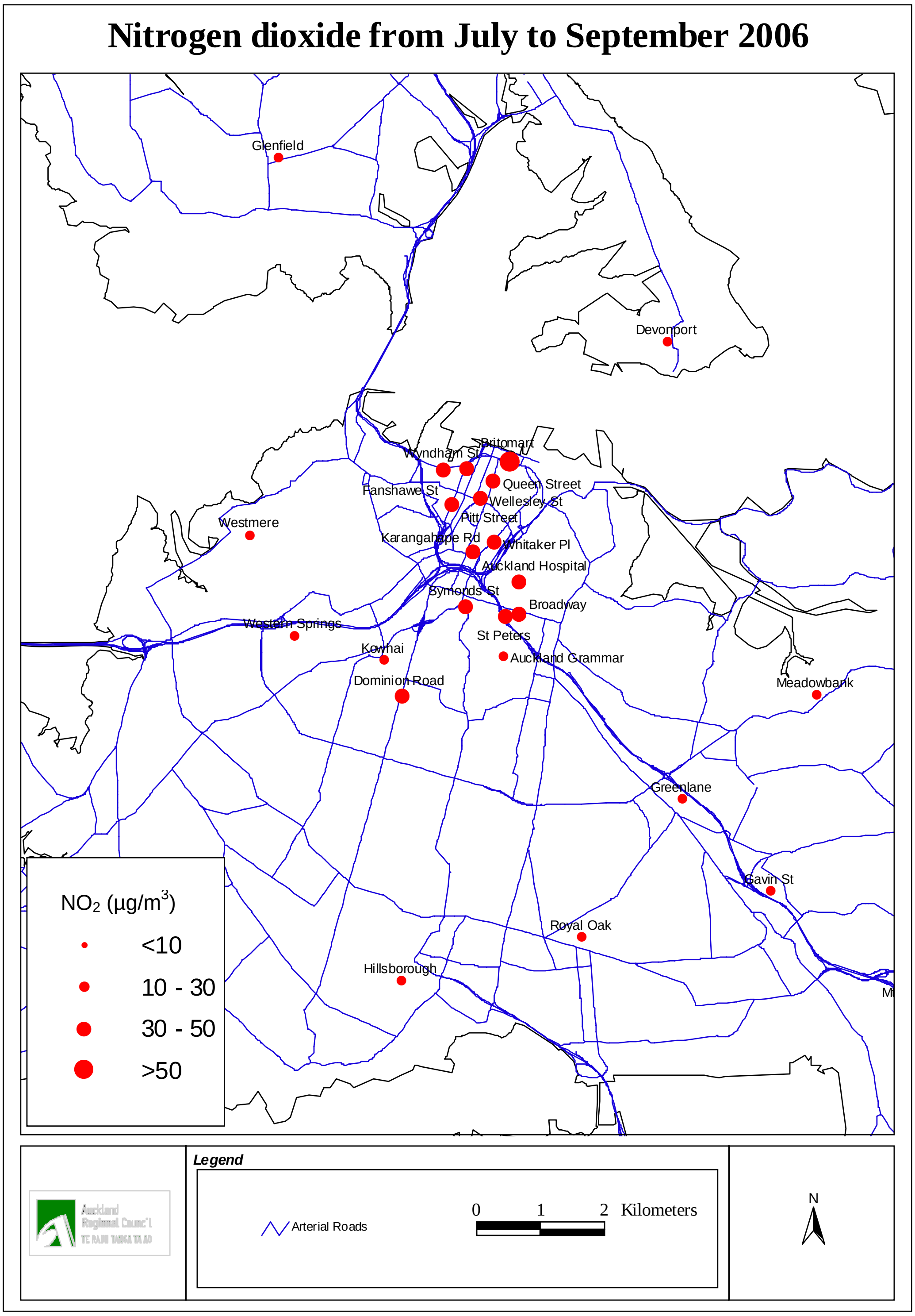


Figure 3.3

CBD-wide sampling sites in 2006. The size of the symbol (•) corresponds to the NO_2 measurements which are listed in Table A2.1 (Appendix 2).



3.3 Concentration Contours in 2006

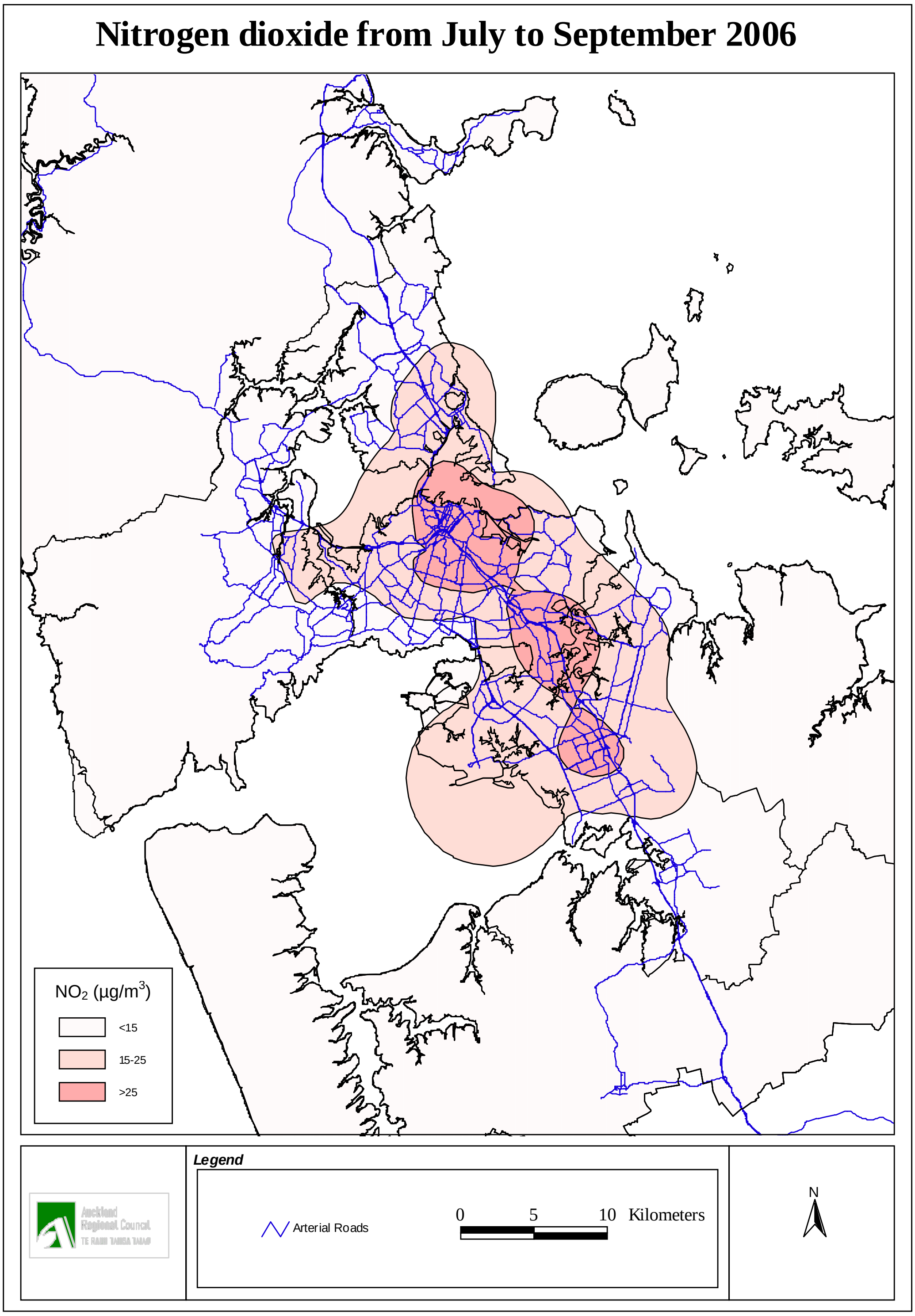
The contours of three-month-mean NO_2 concentrations for the regional sites in 2006 are plotted in Figure 3.4. The figure demonstrates that relatively high concentrations generally align to the southeast-northwest direction of SH1 (Manukau-central Auckland-North Shore), with the highest in the CBD-Newmarket areas. Two areas around the Auckland airport and Henderson show moderate concentrations. The contours of the monthly concentrations in July, August and September, shown in Figures A2.5-A2.7 (Appendix 2), demonstrated a very similar pattern to the three-month concentrations. More detailed contour plots are presented in Appendix 2 (Figures A2.8 to A2.11)

The sampling in 2006 is the most comprehensive survey to date. It provides a better overall picture of spatial distributions on the regional scale than those using previous measurements (ARC, 2006), due to the limited numbers of sites in previous surveys.

In a study of air pollution and health risks near roadways in Auckland ("Mrs Smith Study"), a logarithmic relationship between concentrations and distances from roadsides was used to calculate maximum 1-hour and 24-hour NO_2 and annual average NO_x concentrations at a distance from roadsides (NIWA, 2004). In the study, an air pollution exposure map was presented using annual NO_X emissions as a proxy for ambient air pollution levels (NIWA, 2004). Our 2006 passive sampling survey improves the knowledge of NO_2 exposure and will help future studies about air pollution and health risks in Auckland.

Figure 3.4

Spatial distribution of NO_2 concentrations in Auckland (three-month-means)



4 Spatial Distributions - Roadside

As in many other cities in the world, Auckland's nitrogen dioxide (NO_2) problem is mainly due to vehicle emissions. High concentrations usually occur at the roadsides of major roads. This is of particular concern due to the high asthmatic population and increasing population density around major road corridors in Auckland. Understanding how NO_2 concentrations decline away from roads is critical for population exposure analysis. For this reason, passive samplers were placed at different distances from SH20 at Mangere (12 sites), SH1 at Penrose (4 sites) and SH1 at Otahuhu (4 sites). The measurements are analysed and presented in this chapter.

4.1 Results at Mangere

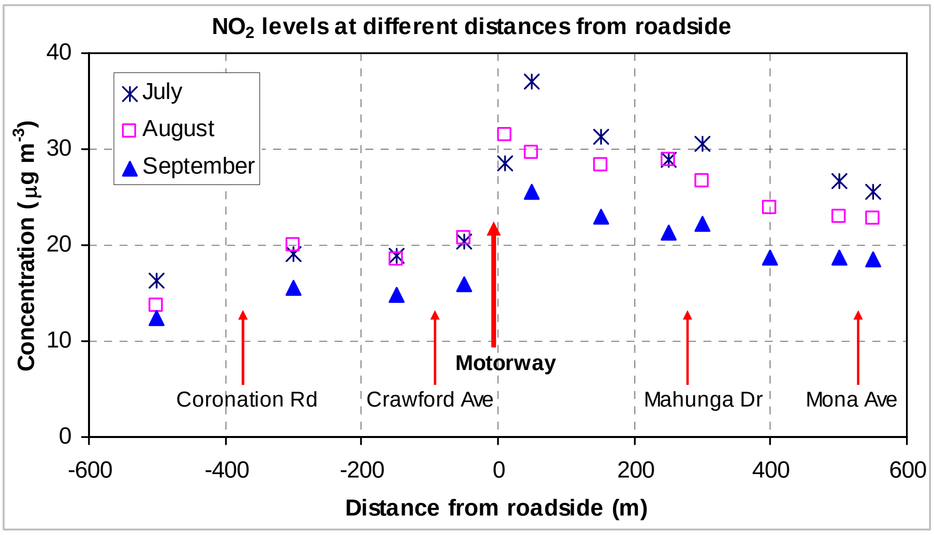
The site locations are shown in Figures 4.1. Monthly NO_2 concentrations at different distances from the roadside of SH20 are shown in Figure 4.2. Concentrations on the eastern side of the road (positive distance in Figure 4.2) were generally higher than on the western side (negative distance in Figure 4.2). This is because the eastern sites are downwind of SH20, while the western sites are upwind. The wind roses demonstrating the prevailing south-westerly wind during the sampling period are shown in Figures A2.12 and A2.13 (Appendix 2).

Figure 4.1
Roadside sites at Mangere (from 1 to 12) in 2006

On the eastern side, there was generally a downward trend of NO_2 concentrations with increasing distances from the roadside due to reducing effects from vehicle emissions. Slightly elevated concentrations at a greater distance from the motorway may be caused by local sources, for example, in July and September a higher concentration at 300 m (Site 5) than at 250 m (Site 4) was most likely due to vehicle emissions from Mahunga Drive as the only other local source. However, it is not clear why in July the concentration at Site 1 (10 m) is lower than at Site 2 (50 m). Generally measurements in July were the highest, followed by values in August and those in September the lowest.

On the western side, NO_2 concentrations within 400 m from the roadside (Sites 9, 10 and 11) were similar and did not show an obvious downward trend with increasing distances from the roadside. NO_2 concentrations at Site 12 (at 500 m) were lower than at other sites.

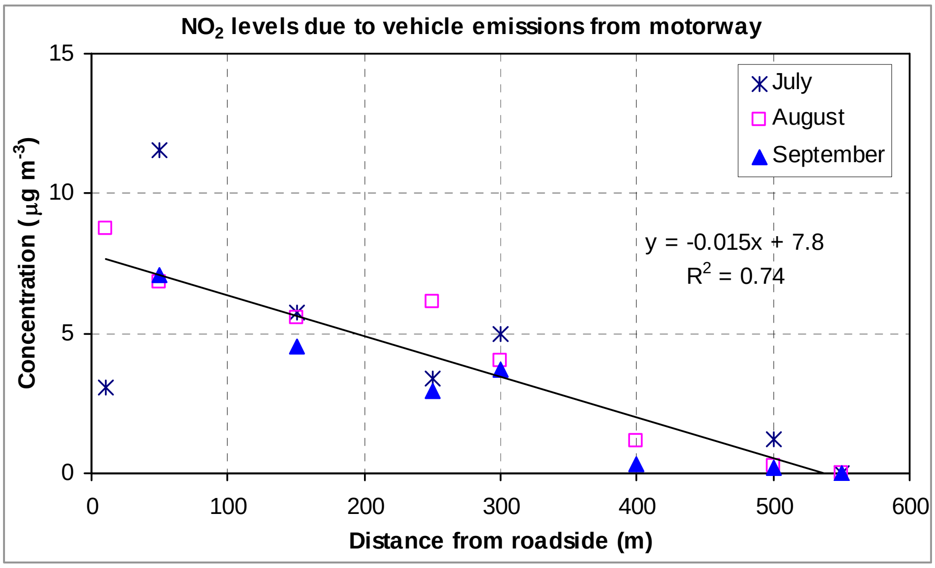
Figure 4.2
Monthly NO_2 concentrations at the roadside of SH20 at Mangere (the positive distance indicates the eastern side, negative the western side). The arrow (↑) indicates the position of the motorway and local roads. Data are listed in Table A2.2 (Appendix 2)



Measured NO_2 concentrations consist of contributions from vehicle emissions along the motorway and local roads, and from other sources (the urban background). On the western side, the urban background is the biggest contributor, closely followed by the motorway, whereas contributions from local roads are relatively minor. The significant contribution from the motorway on the eastern side resulted in higher concentrations at locations closer to the roadside. In order to estimate the contribution from the motorway, the measured concentrations are subtracted by the values at the furthest site (Site 8, 550 m away from the roadside) which are taken to be the urban background. The resultant concentrations are mainly due to the contribution from the motorway with some contribution from local roads, but without the contribution of the assumed urban background. The motorway makes a much greater contribution to the observed concentrations than local roads, as illustrated in Figure 4.2. The subtracted results may possibly underestimate the contribution of the motorway since it may still contribute to the measurements at the furthest eastern site. This appears to be the case given the much lower concentrations to the west of the motorway. However, this will not affect the conclusion that there is a declining trend of concentrations with greater distances from the roadside. Overall, the subtracted results are considered representative of the contribution of the motorway to the elevated concentrations close to the roadside, in particular the declining trend.

The subtracted NO_2 concentrations on the eastern side of the motorway are plotted in Figure 4.3. Similar to Figure 4.2 (total measurements), Figure 4.3 shows a general downward trend of NO_2 concentrations with increasing distances from the roadside. However, Figure 4.3 does not show obvious monthly variations as Figure 4.2. The best-fit line for data in July, August and September is also shown in Figure 4.3, as an indication of the overall trend.

Figure 4.3
Roadside NO_2 concentrations due to vehicle emissions from the motorway (east of SH20 at Mangere)

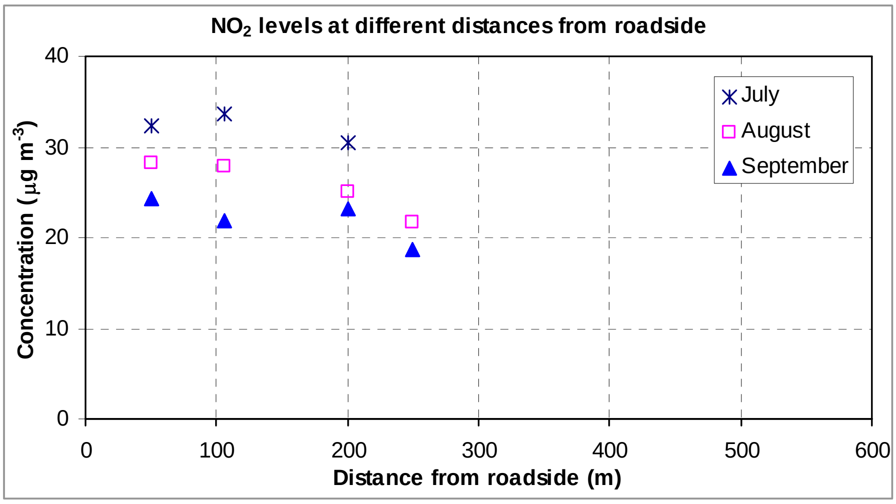


4.2 Results at Penrose

The site locations are shown in Figures 4.4. Monthly NO_2 concentrations at different distances from the roadside of SH1 are shown in Figure 4.5. Similar to the measurements on the eastern side of SH20 (Figure 4.2), there was generally a downward trend of NO_2 concentrations with increasing distances from the roadside due to reducing effects from vehicle emissions from the motorway. Measurements in July were the highest, followed by values in August and those in September the lowest. The NO_2 concentrations at Penrose are comparable to those on the eastern side of SH20.

Figure 4.4
Roadside sites at Penrose (1, 2 and 3) in 2006 (x: the Gavin St site)

Figure 4.5
Monthly NO_2 concentrations at the roadside of SH1 at Penrose. Data are listed in Table A2.3 (Appendix 2)



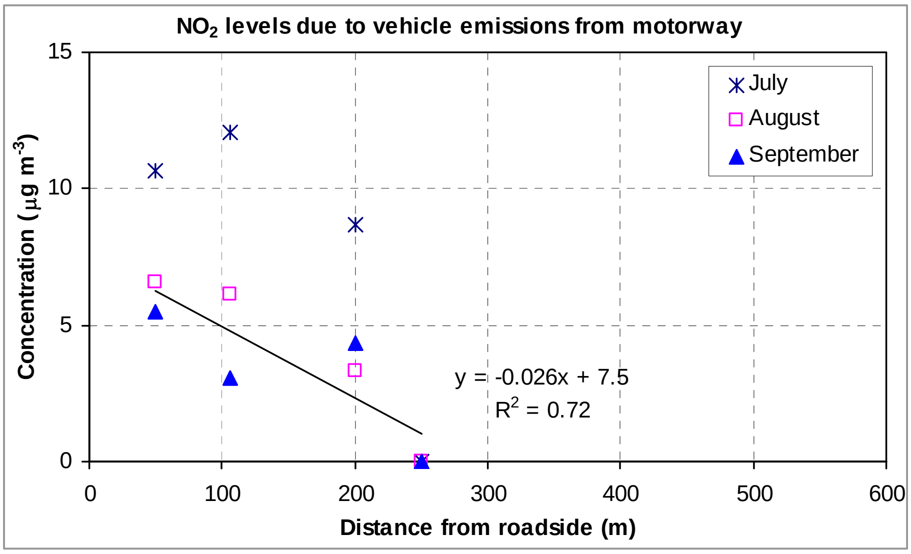
As in Section 4.1, the contribution from the motorway is estimated by subtracting the measurements by the values at the furthest site (Site 3, 250 m away from the roadside) which are taken to be the urban background. The subtracted concentrations are shown in Figure 4.6. At Site 3 the value in July is not available, and the value in August is used. Therefore, the estimate for July is indicative only, and not used to plot the best-fit line.

Similar to Figure 4.5 (total measurements), Figure 4.6 shows a general downward trend of NO_2 concentrations with increasing distances from the roadside. However, Figure 4.6 does not show obvious monthly variations as in Figure 4.5. The best-fit line for data in August and September is also shown in Figure 4.6. Although there were only eight data points available to generate the trend line, it indicated a generally linear reduction of concentrations with increasing distances from the roadside.

The Ellerslie-Panmure Highway is about 350 m to the northwest of the sampling sites. It contributes to the urban background component of the measured concentrations. However, the contribution is considered to be less significant than from the motorway which is upwind of the sampling sites. The wind rose demonstrating the prevailing south-westerly wind during the sampling period is shown in Figure A2.9 (Appendix 2).

Figure 4.6

Roadside NO_2 concentrations due to vehicle emissions from the motorway (SH1 at Penrose)

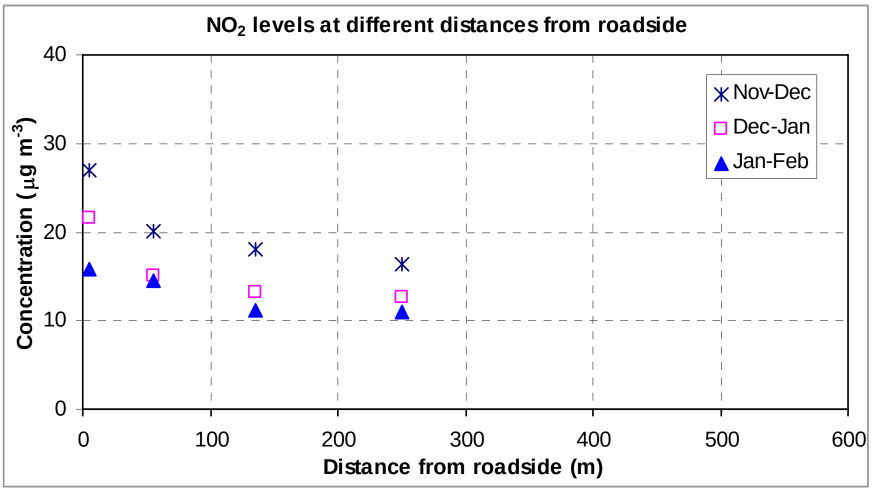


4.3 Results at Otahuhu

The site locations are shown in Figures 4.7. Monthly NO_2 concentrations at different distances from the roadside of SH1 at Otahuhu are shown in Figure 4.8. There was a generally downward trend of NO_2 concentrations with increasing distances from the roadside due to reducing effects from vehicle emissions along the motorway. Measurements in November-December were the highest, followed by values in December-January and those in January-February the lowest.

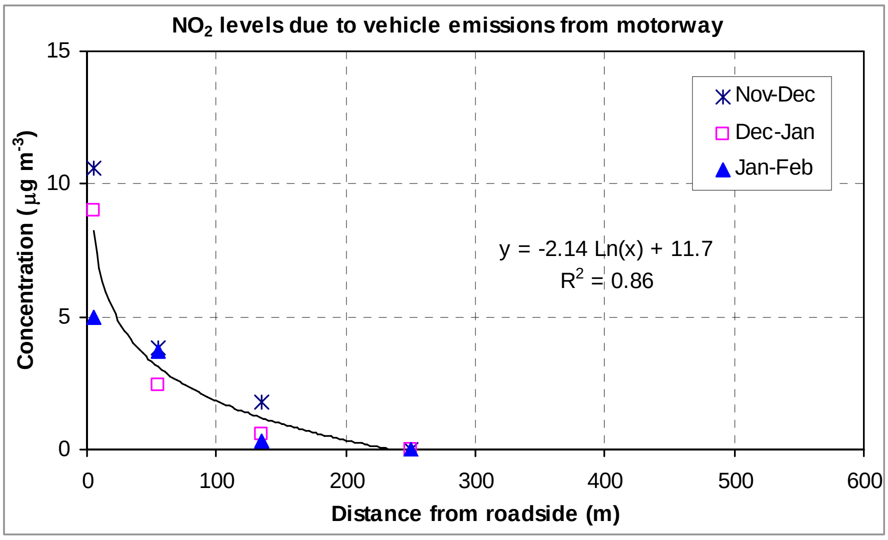
Figure 4.7
Roadside sites at Otahuhu (A, B, C and D) in 1997-1998

Figure 4.8
Monthly NO_2 concentrations at the roadside of SH1 at Otahuhu. Data are listed in Table A1.3 (Appendix 1).



As discussed in Section 4.1, the contribution from the motorway is estimated by subtracting the measurements by the values at the furthest site (Site D, 250 m away from the roadside) which are considered as the urban background. The subtracted concentrations are shown in Figure 4.9. Similar to Figure 4.8 (total measurements), Figure 4.9 shows a generally downward trend of NO_2 concentrations with increasing distances from the roadside. However, Figure 4.9 does not show obvious monthly variations as Figure 4.8. The best-fit curve for all the data is also shown in Figure 4.9. Compared to the linear best-fits at Mangere and Penrose, the logarithmic function at Otahuhu represents a faster reduction of concentrations with increasing distance from the roadside. This difference may be related to the site location or the sampling season (i.e., summer at Mangere and Penrose, but winter at Otahuhu).

Figure 4.9
Roadside NO_2 concentrations due to vehicle emissions from the motorway (SH1 at Otahuhu)



4.4 Discussion

Local exposure to traffic on motorways has adverse effects on people's health. A recent study, which tracked over 3,600 children in 12 communities in southern California over a period of eight years showed a significant reduction in lung function for children living within 500 m of a motorway (Gauderman, *et al.*, 2007).

Few studies to measure the decline of NO_2 concentrations away from roads have been reported in the literature. In the UK, limited roadside measurements, using passive or continuous methods alongside motorways or busy urban roads, have been carried out. The results suggested that concentrations beyond about 20-50 m from the edge of the road will be essentially similar to the local background (AQEG, 2004). This did not appear to be the case in the passive sampling surveys reported here.

Monthly NO_2 concentrations at roadsides of SH20 at Mangere, SH1 at Penrose and SH1 at Otahuhu are plotted together in Figure 4.10. Estimated traffic volumes at the three motorway sections are listed in Table 4.1. Traffic volumes at Penrose and Otahuhu are much higher than at Mangere. However, the concentrations at Mangere were generally similar to those at Penrose and higher than those at Otahuhu (due to different sampling seasons). This demonstrates that roadside concentrations are dependent on other factors as well, including emission characteristics, dispersion conditions and chemical processes. It appears that the NO_2 concentrations generally decreased away from roads in the form of linear functions at Mangere and Penrose (sampling in winter), and logarithmic at Otahuhu (sampling in summer).

Figure 4.10

Monthly NO_2 concentrations at roadsides of SH20 at Mangere, SH1 at Penrose and SH1 at Otahuhu. Monitoring was carried out from July to September 2006 at Mangere and Penrose, and from mid-November 1997 to mid-February 1998 at Otahuhu.

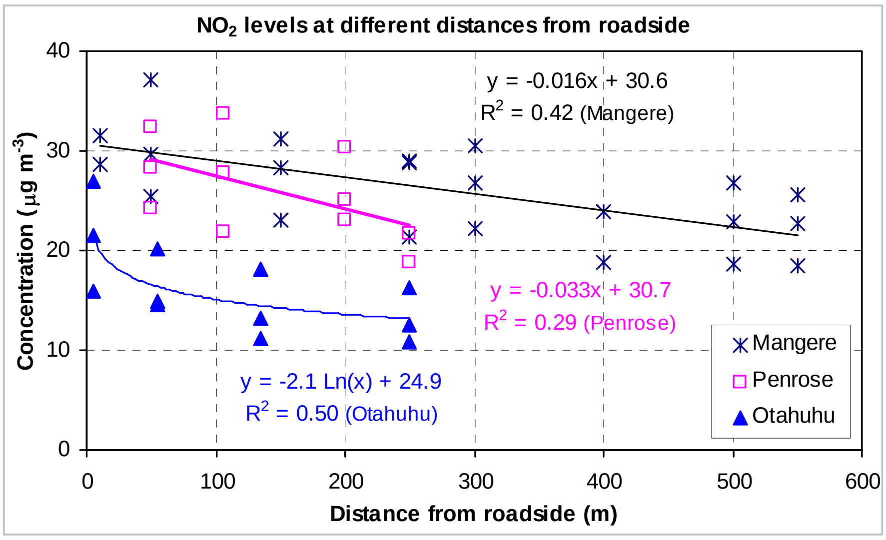


Table 4.1

Traffic volumes at the motorway sections where passive sampling was undertaken*

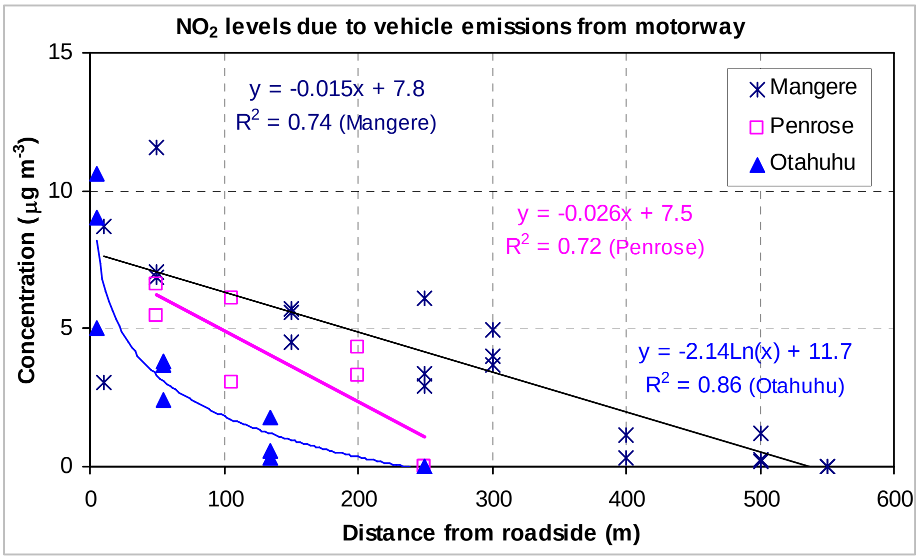
Traffic Volume	SH20 at Mangere	SH1 at Penrose	SH1 at Otahuhu
Annual average daily traffic (year)	69,020 (2005)	140,380 (2005)	109,000 (1997) 100,950 (1998) 113,210 (2005)

* Data source: State highway traffic volume reports (http://www.transit.govt.nz). Traffic volumes in 2005 were the most recent data when this report was prepared. For comparison, data for SH1 at Otahuhu in 1997 and 1998 are also listed.

In our study, to estimate the contribution of the motorway, the measured concentrations are subtracted by the values at the furthest site which are taken to be the urban background. The resultant concentrations are mainly due to the contribution from the motorway with possible minor contribution from local roads, but without the contribution of the urban background. The subtracted results may possibly under-estimate the contribution of the motorway since the motorway may still contribute to the measurements at the furthest site. Overall, the subtracted results are considered representative of the contribution of the motorway to the elevated concentrations close to the roadside, in particular the declining trend of concentrations away from the roadside.

Roadside NO_2 concentrations due to vehicle emissions from SH20 at Mangere, SH1 at Penrose and SH1 at Otahuhu are plotted together in Figure 4.11. Compared to the total measurements (Figure 4.10), Figure 4.11 shows a similar downward trend of concentrations with increasing distances from the roadside, but the correlation coefficients for the best-fit equations are higher. At about 5 m away from the motorways, the subtracted concentrations at Otahuhu were similar to at Mangere.

Figure 4.11
Roadside NO_2 concentrations due to vehicle emissions from the motorways (SH20 at Mangere, SH1 at Penrose and SH1 at Otahuhu).



In the Mangere study, the subtracted concentrations are elevated to approximately 300 m away from the roadside, at further distances than suggested in the UK studies (AQEG, 2004). This provides important information in assessing NO_2 exposure close to busy roadsides in Auckland. In the Penrose and Otahuhu studies, the furthest site is only 250 m away from the motorway. The estimate of the elevated concentrations due to the motorway using the subtraction method is therefore inconclusive. However, the method will not affect the conclusion about the trend of decreased concentrations away from the motorway.

In the Mrs Smith Study, a logarithmic relationship between concentrations and distances from roadsides was used to calculate maximum 1-hour and 24-hour NO_2 and annual average NO_x concentrations at a distance from roadsides (NIWA, 2004). An empirical relationship between the ratio NO_2/NO_x and NO_x concentrations was then applied to obtain annual average NO_2 concentrations. The passive sampling in this report measured monthly average concentrations. This makes difficult the direct comparison between passive results and the above calculations. However, our study demonstrates that the relationship between NO_2 concentrations and distances from roadsides could be linear or logarithmic. The relationship may be location or season dependent.

The falloff of NO_2 concentrations away from roads is associated with emission characteristics, dispersion conditions and chemical processes. Further research is needed to understand the relationship between the measured concentrations and these factors, to understand the different spatial variations between UK and Auckland studies, and between various Auckland sites, and to understand how far the influence of emissions from a motorway can extend.

5 Summary

The passive monitoring programmes from 1994 to 2006 provide important information about NO_2 concentrations in the Auckland region, particularly the temporal and spatial variations.

The analysis of measurements at the summer and winter survey sites, and long-term sites demonstrates that:

- Month-to-month and year-to-year variations are quite site specific.
- Concentrations in winter are about two times of those in summer.
- The lowest monthly concentrations are usually in December-January.
- Concentrations at Pitt St showed a downward trend while concentrations at Mt Eden remain stable.

Analysis of the regional spatial variations shows that:

- Relatively high concentrations generally align to the southeast-northwest direction of SH1 (Manukau→central Auckland→North Shore).
- The highest concentrations are recorded in the CBD-Newmarket areas.

Surveys were carried out to investigate the decline of NO_2 concentrations away from roadsides of motorways. The results show that downwind of the prevailing wind:

- There is a general downward trend of NO_2 concentrations with increasing distances from the roadside.
- On average concentrations are higher on the downwind side of the motorway.
- The contributions from the motorway can remain elevated up to at least 300 m away from the roadside.

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Appendix 1: Monitoring Results from 1994 to 2004

Table A1.1

Average NO_2 concentrations (µg m^{-3}) at summer survey sites from 1994 to 1998*

Site	Type	Easting	Northing	1994-1995	1995-1996	1996-1997	1997-1998
Albany	Suburban	1751200	5934406			7.5	
Auckland Airport	Suburban	1759889	5903647	9.7			
Britomart	Road	1757517	5921000		19.6		
Broadway	Road	1758448	5918363			21.8	
Browns Bay	Suburban	1756010	5935270		8.1		
Coatesville	Rural	1744765	5930577	3.1			
Devonport	Suburban	1760213	5922272			13.2	
Drury	Suburban	1772969	5891681				14.1
Gavin St	Suburban	1761751	5913995				14.9
Greenlane	Suburban	1760210	5916067		18.3		
Henderson	Suburban	1747174	5916302	8.4			
Howick	Suburban	1771086	5914700	11.3			
Kingseat	Rural	1759599	5888413				25.5
Manukau	Suburban	1767504	5904440		22.9	23.2	
Manurewa	Suburban	1769727	5902125	13.2			
Maraetai	Rural	1781127	5916794				3.0
Massey	Suburban	1742061	5920532	4.0			
Mission Bay	Urban	1763329	5920332			16.2	
Mountain Rd	Roadside	1757814	5918505				4.0
Mt Eden	Urban	1756894	5918019	11.9			12.0
Mt Wellington	Suburban	1764156	5912342		24.4	24.8	
Muriwai	Rural	1727232	5922985		1.9	1.3	
Musick Point	Rural	1769512	5920277				6.4
New Lynn	Suburban	1750050	5913978			13.8	
Northcote	Suburban	1756108	5924151		17.3		
Otahuhu A	Roadside	1765118	5910068				21.5
Otahuhu B	Roadside	1765172	5910075				16.6
Otahuhu C	Roadside	1765259	5910094				14.2
Otahuhu D	Roadside	1765366	5910119				13.3
Pakuranga	Suburban	1766960	5913007			12.1	
Pitt St	Roadside	1756758	5919683		26.0	22.8	19.4
Rangitoto	Rural	1766328	5924960		3.5	3.7	
St Mary's Bay	Suburban	1755633	5921120			20.9	
Tamaki	Suburban	1764732	5916727	10.7			
Titirangi	Suburban	1746898	5911596	6.9			
Volcanic St (Mt Eden)	Suburban	1755426	5916135		11.3	11.2	
Waiheke	Suburban	1778955	5927200				3.1
Waikaraka Park	Suburban	1760381	5911709	10.7			
Wairau Valley	Suburban	1756165	5928083	16.5	16.9	17.9	15.6
Western Springs	Suburban	1754310	5918423			18.9	
Whangaparaoa	Rural	1762959	5946471				2.0
Wyndham St (CBD)	Roadside	1757018	5920781	25.2	19.0		
Number of sites				**12**	**12**	**15**	**15**

*Taken from the ARC summary report (ARC, 2006). See Table A1.7 for the description of types of sites. Eastings and northings are in New Zealand Transverse Mercator coordinates (NZTM). Some sites with the same name in Tables A1.1, A1.2 and A2.1 display different coordinates due to different siting of the samplers. See Table 1.1 for sampling periods.

Table A1.2

Average NO_2 concentrations (µg m^{-3}) at winter survey sites from 2002 to 2004*

Site	Type	Easting (m)	Northing (m)	2002	2003	2004
Auckland Grammar	Urban	1757505	5918013		25.5	
Auckland Hospital	Urban	1757680	5919106		30.0	
Britomart	Roadside	1757846	5920786		36.9	
Broadway	Roadside	1758448	5918363	41.2	56.0	
Dominion Rd	Roadside	1755961	5917162	36.1	27.6	
East Tamaki	Suburban	1768610	5909765		29.2	
Fanshawe St	Roadside	1756626	5920726		36.6	
Gavin St	Suburban	1761751	5913995			28.4
Glendene	Suburban	1747211	5914929	10.7		
Grafton	Urban	1757440	5919614		37.7	
Greenlane	Suburban	1760415	5915587		29.8	
Haslett St (Eden Terrace)	Urban	1756155	5918718	28.0		
Henderson	Suburban	1745139	5918533			14.9
Karanghape Rd	Roadside	1757047	5919458		52.0	
Kowhai School	Urban	1755691	5917772			20.5
Mangere Bridge	Suburban	1759131	5910178		24.8	
Manukau	Suburban	1767549	5904435	33.8	34.9	
Mountain Rd	Roadside	1757814	5918505	35.4	42.1	34.7
Mt Eden	Urban	1756894	5918019	19.9	30.6	19.7
Mt Wellington	Suburban	1764156	5912342	32.1	36.7	
Musick Point	Rural	1769512	5920277			10.7
Otahuhu	Suburban	1765118	5910068	35.7	35.3	
Pakuranga	Suburban	1768407	5913944	19.7		
Pitt St	Roadside	1756758	5919683	27.8	44.5	
Pukekohe	Rural	1765440	5880819	4.2	5.2	4.9
Queen St	Roadside	1757416	5920572	44.0	40.0	42.6
South Manurewa	Suburban	1768598	5899826	12.0		
St Peters School	Urban	1757629	5918475	35.6	33.7	
Symonds St lower	Roadside	1757408	5919571	33.0		
Symonds St upper	Roadside	1756940	5918729	38.3	42.1	
Takapuna	Suburban	1756059	5928077			25.9
Waima St	Urban	1756107	5918776	27.5		
Wairau Valley	Suburban	1756165	5928083	25.1	31.4	
Wellesley St	Roadside	1757168	5920284		37.4	
Whangaparaoa	Rural	1762823	5947226	2.4	4.3	3.1
Whitaker Pl (CBD)	Roadside	1757435	5919610		38.8	
Wyndham St (CBD)	Roadside	1757018	5920781	35.6	36.4	
Number of sites				**21**	**26**	**10**

*Taken from the ARC summary report (ARC, 2006). See Table A1.7 for the description of types of sites. Eastings and northings are in NZTM. See Table 1.1 for sampling periods.

Table A1.3

Monthly NO_2 concentrations (μg m^{-3}) at the roadside of SH1 at Otahuhu along Avenue Road East in 1997-1998*

Site	Distance from motorway (m)	November-December	December-January	January-February	Mean
Otahuhu A	5	26.9	21.6	15.9	21.5
Otahuhu B	55	20.1	15.0	14.6	16.6
Otahuhu C	135	18.1	13.2	11.2	14.2
Otahuhu D	250	16.3	12.6	10.9	13.3

*Taken from the ARC summary report (ARC, 2006), the sites are also listed in Table A1.1. See Figure 4.7 for detailed locations.

Table A1.4

Average NO_2 concentrations (μg m^{-3}) around the intersection of Khyber Pass Road and Mountain Road*

Site	Sampling period	Concentration	Mean
1 - NIWA building on Khyber Pass Road	10 May – 24 May 1999 24 May – 6 June 1999 6 June – 22 June 1999	46.9 49.5 49.5	48.7
2 - Opposite Lion Place on Mountain Road	10 May – 24 May 1999 24 May – 6 June 1999 6 June – 22 June 1999	38.0 38.3 38.9	38.4
3 - Adjacent to St Peters College on Mountain Road	10 May – 24 May 1999 24 May – 6 June 1999 6 June – 22 June 1999	38.3 39.4 40.7	39.5
4- Adjacent to netball courts on Khyber Pass Road	10 May – 24 May 1999 24 May – 6 June 1999 6 June – 22 June 1999	52.1 52.3 52.3	52.2
5- Adjacent to railway on Park Road	10 May – 24 May 1999 24 May – 6 June 1999 6 June – 22 June 1999	40.4 41.2 41.2	41.2
6- Adjacent to Lion Breweries on Khyber Pass Road	10 May – 24 May 1999 24 May – 6 June 1999 6 June – 22 June 1999	43.1 45.5 44.6	44.4

*Taken from NIWA (1999). See Figure 3.1 for locations of sites.

Table A1.5

Monthly NO_2 concentrations (μg m^{-3}) at summer survey sites in 1994-1998*

Year	November-December	December-January	January-February	February-March	Total sites (same pattern)
1994-1995		8.6	10.4	13.7	11 (8)
1995-1996	15.3	12.3	14.0		12 (10)
1996-1997	14.1	10.6	14.4		7 (3)
1997-1998	14.9	11.1	11.1		15 (9)

*Based on the ARC summary report (ARC, 2006), only including the sites with data for the whole period (three months). The numbers in the parentheses are the numbers of sites showing the same pattern of monthly variations as the across-site-means.

Table A1.6

Monthly NO_2 concentrations (µg m^{-3}) at winter survey sites in 2002-2006*

Year	June	July	August	September	Total sites (same pattern)
2002	27.0	26.8	30.0		14 (8)
2003	35.7	35.5	31.5		22 (11)
2004	19.1	21.5	18.4		9 (5)
2006		24.2	21.7	18.7	55 (49)

*See the footnote of Table A1.5 for explanation.

Table A1.7

Description of the types of sampling sites*

Type	Description
Rural	Sites in the open countryside away from roads, industrial sources and residential areas. Measurements at these sites represent regional background pollution concentrations for most of the time.
Suburban	Sites in residential or industrial areas outside central Auckland.
Urban	Sites in central Auckland but away from the edge of busy roads.
Roadside	Sites close to the edge of a busy road. The dominant source of pollution at the sites is direct emissions from the vehicles moving along the road.

*Based on the UK definition (AQEG, 2004).

Table A1.8

Results of CSIRO and Staffordshire County Council (SCC) passive samplers and continuous analysers at the continuous sites in 2004

Site	CSIRO			SCC			Continuous		
	June	July	August	June	July	August	June	July	August
Gavin St	25.6	31.2		28.7	30.6	24.9	29.1	34.7	35.1
Henderson	12.9	18.5	13.2	14.5	22.1	13.4	17	24.8	19.6
Kowhai	20.2	22.9	18.1	23.6	18.3	22.0	23.4	24.9	25.6
Khyber Pass	33.4	36.7	35.1	38.5	30.6	34.8	58	72.8	80.1
Mt Eden	19.7	21.3	18.0	19.6	21.1	19.2	21.7	25	23.6
Musick Point	10.0	13.1	9.0	12.7	16.1	11.5	11.5	14.9	11.2
Queen St	42.6	43.3	41.3	54.6	46.1	52.2	68.2	65.8	70.3
Takapuna	24.9	28.2	25.4	32.0	31.4	29.9	28.9	35.7	35.3

*Taken from WSL (2005a).

Appendix 2: Monitoring Results in 2006

Figure A2.1

Relationship between monthly mean NO_2 concentrations from paired samples A and B at the regional sites in 2006. The values of samples A and B at each site are averaged to represent the concentration at the site, and the results are listed in Table A2.1.

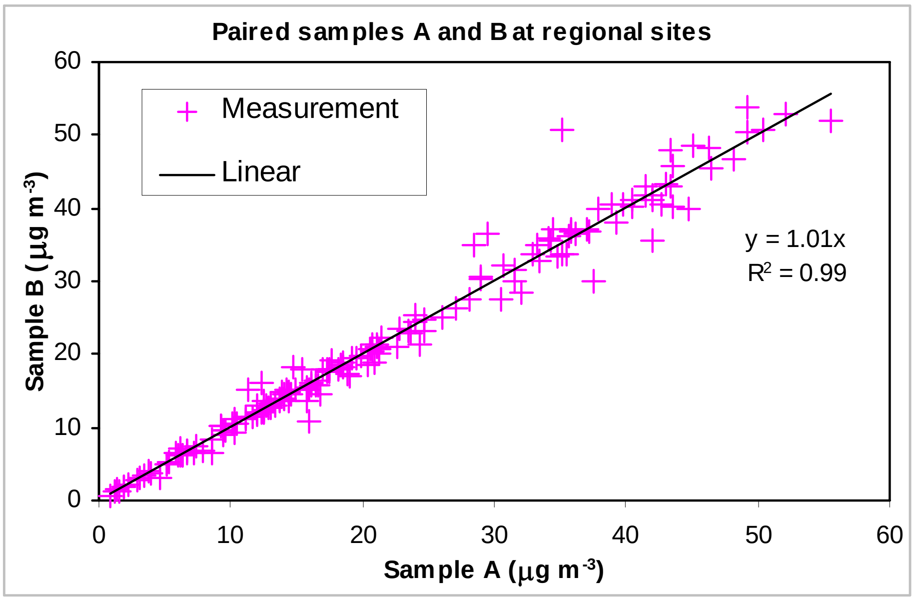


Figure A2.2

Relationship between monthly mean NO_2 concentrations from paired samples A and B at the roadside sites in 2006. The values of samples A and B at each site are averaged to represent the concentration at the site, and the results are listed in Tables A2.2 and A2.3.

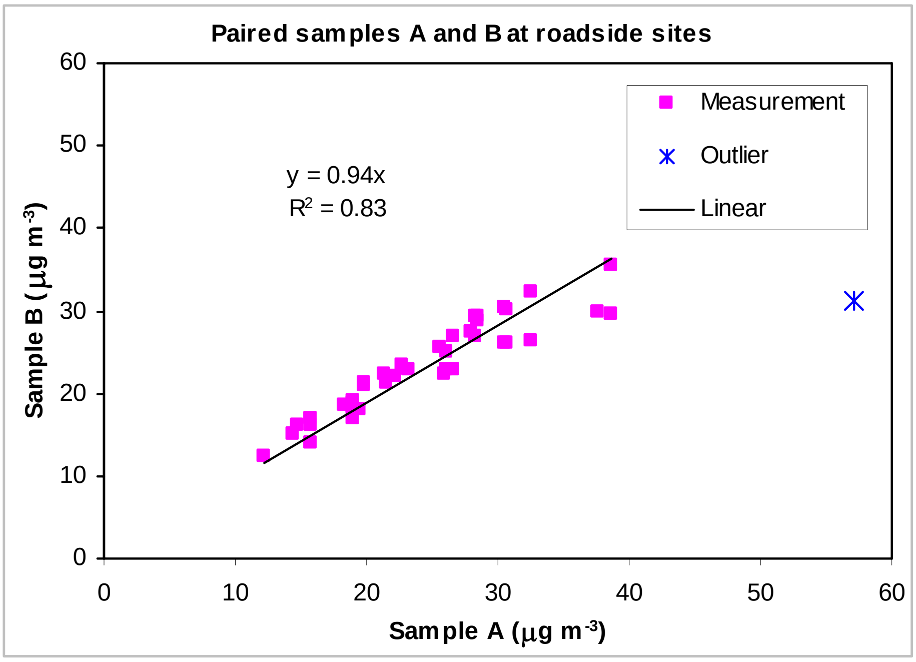


Figure A2.3

The distribution of the difference between the individual samples and their pair means for 2006 samples (213 pairs in total, 171 and 42 from regional and roadside sites, respectively). The difference is calculated as $|C_A-C_B|/(C_A+C_B)$, where C_A and C_B are the measurement of paired samples A and B, respectively (Petersen *et al.*, 1996).

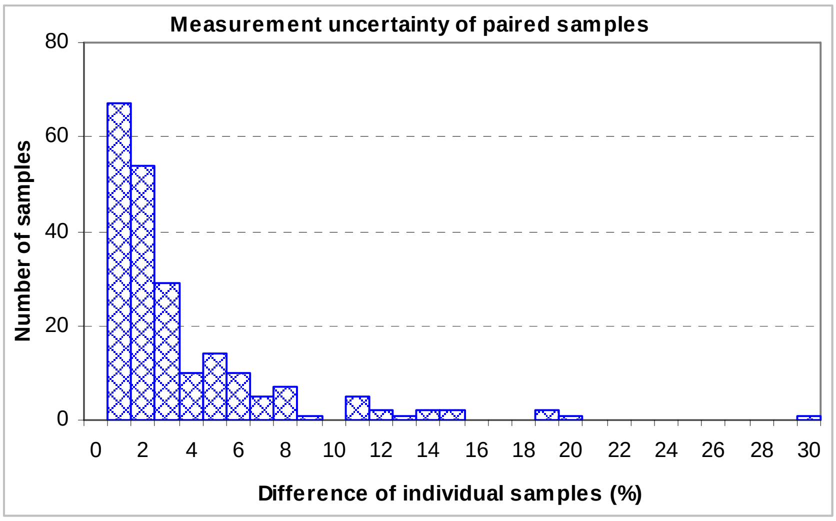


Figure A2.4

Relationship between monthly mean NO_2 concentrations from passive samplers (the average of the sample pairs) and from continuous monitors in 2006 (see also Table A2.4)

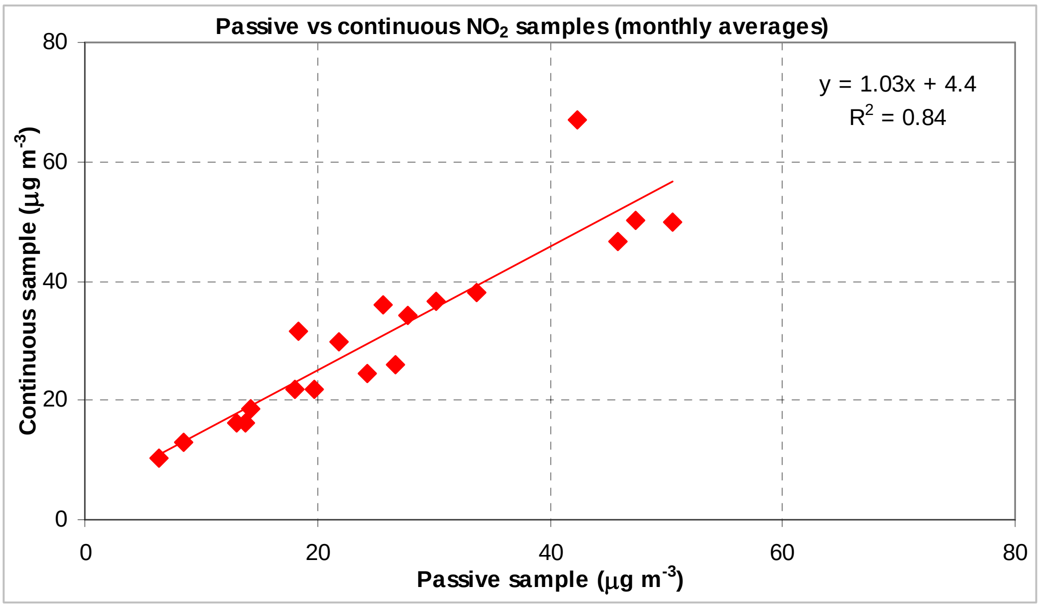


Table A2.1

Monthly mean NO_2 concentrations (μg m^{-3}) at regional sites in the 2006 winter survey*

Site	Location	Type**	Easting	Northing	Jul	Aug	Sep	Mean
Albany[r]	19 Columbia Pl	Suburban	1751656	5932492		7.4	6.6	7.0
Auckland Airport[r]	Andrew McKee Ave	Suburban	1759428	5902986	29.1	24.7	20.9	24.9
Auckland Grammar[r]	Mountain Rd	Urban	1757588	5917840	23.4		18.4	20.9
Auckland Hospital[r]	Cr Park Rd & Domain Dr	Urban	1757817	5919001	34.9	31.7	29.8	32.1
Blockhouse Bay (New Windsor)	End of Penbury Pl	Suburban	1751696	5914278	15.7	13.7	11.9	13.8
Botany Downs	14 Oakridge Way	Suburban	1771357	5912358	18.4	18.1	12.2	16.2
Britomart[r]	Cr Customs St E & Commerce St	Roadside	1757662	5920890	51.5	52.5	49.8	51.3
Broadway[r +]	444 Khyber Pass Rd	Roadside	1758435	5918363	143.9	129.4	67.2	113.5
Browns Bay[r]	48 Redwing St	Suburban	1754481	5934622	13.2	13.4	7.5	11.4
Ceramco Park	Near 50 Meadowvale Rise	Suburban	1747149	5912481	12.7	9.4	7.3	9.8
Chapel Downs	6 Gretton Ct	Suburban	1769232	5906244	21.7	16.0	13.9	17.2
Clendon Park	Mid of Robert Skelton Pl	Suburban	1766054	5900106	19.4	14.2	9.7	14.4
Coatesville[r]	24 Mahoenui Valley Rd	Rural	1746809	5935100	1.5	1.3	0.8	1.2
Cornwallis	Cr of Cornwallis Rd & Five Break Rd	Rural	1742428	5903287	3.1	1.3	1.9	2.1
Devonport[r]	12 High St	Suburban	1760144	5922752	20.6	14.0	10.5	15.0
Dominion Rd[r]	321 Dominion Rd	Roadside	1755981	5917215	38.6	36.4	34.6	36.5
East Tamaki[r]	4 Berrett Pl	Suburban	1767720	5908572	23.1	19.8	16.1	19.7
Fanshawe St[r]	Cr Halsey St	Roadside	1756628	5920747	42.0		34.4	38.2
Gavin St (Penrose)[r]	Air Quality Monitoring site	Urban	1761755	5914168	33.7	27.8	21.8	27.8
Glendene[r]	Great North Rd (Waikumete Cemetery)	Suburban	1747214	5914139	18.0	16.1	12.4	15.5
Glendowie	4 Helen Pl	Suburban	1765383	5918425	20.7	16.5	12.8	16.7
Glenfield	3 Bank St	Suburban	1754067	5925628	18.7	15.0	12.4	15.4
Glenfield North	8a Kupari Pl	Suburban	1754234	5929904	16.4	14.6	10.7	13.9
Greenlane[r]	15 Woodbine Ave	Suburban	1760386	5915596	28.2	23.3	21.1	24.2
Hillsborough	Mid of Fickling Ave	Suburban	1755988	5912753	16.0	14.7	11.3	14.0
Henderson[r]	70 Lincoln Rd	Suburban	1745144	5918549	18.1	14.2	13.1	15.1
Karangahape Rd[r]	Cr K Rd & Queen St	Roadside	1757090	5919464	42.3	42.9	41.7	42.3
Khyber Pass	269 Khyber Pass Rd	Roadside	1757823	5918503	50.5	47.4	45.9	47.9
Kowhai[r]	26 Onslow Rd	Urban	1755706	5917778	26.7	24.3	19.8	23.6
Mangere Bridge[r]	6 Tainui Tce	Suburban	1758508	5909959	14.7	12.9	9.8	12.5
Manukau[r]	Leyton Way (Shopping Centre)	Suburban	1767546	5904408	41.5	33.2	31.5	35.4

Table A2.1 (cont)

Site	Location	Type**	Easting	Northing	Jul	Aug	Sep	Mean
Maraetai[r]	Omana Esplanade (Regional Park)	Rural	1780424	5916641	6.5	5.0	3.8	5.1
Meadowbank	8 Keith Ave	Suburban	1762475	5917228	22.8	19.5	14.3	18.9
Mountain Rd[r]	Near 269 Khyber Pass Rd	Roadside	1757819	5918507	40.8	38.7	34.1	37.9
Mt Wellington[r]	Clemow Dr (motorway off-ramp)	Urban	1764155	5912340	39.7	35.8	34.0	36.5
Muriwai[r]	Motutara Rd (Regional Park)	Rural	1727263	5923002	3.8	2.8	2.3	3.0
Musick Point[r]	Air Quality Monitoring site	Rural	1769530	5920374	13.8	8.5	6.3	9.5
Orewa (Red Beach)	Halidene Tce	Suburban	1752268	5947462	12.4	9.6	6.2	9.4
Otahuhu[r]	Opposite 14 Avenue Rd E	Suburban	1765139	5910060	37.0	35.0	31.4	34.5
Pakuranga[r]	Air Quality Monitoring site	Suburban	1768417	5913955	21.1	17.7	16.8	18.5
Papakura[r]	21 George St	Suburban	1774012	5896342	16.1	14.0	11.1	13.7
Papatoetoe[r]	12 Beryl Pl	Suburban	1763041	5906915	21.3	17.5	12.5	17.1
Pitt St[r]	21 Pitt St	Roadside	1756765	5920210	37.1	33.4	29.6	33.3
Pukekohe[r]	Air Quality Monitoring site	Rural	1765421	5880812	6.2	5.3	3.4	5.0
Pukekohe Town	21 Albert Pl	Suburban	1768851	5881559	17.6	14.6	11.5	14.6
Queen St[r]	155 Queen St	Roadside	1757414	5920573	45.7	47.2	42.3	45.0
Rangitoto[r]	Visitor Info Centre	Rural	1766328	5924960	9.8	6.2	6.1	7.3
Royal Oak	Baker Pl	Suburban	1758816	5913442		15.4	13.2	14.3
South Manurewa[r]	39 Tawa Cr	Suburban	1768601	5899830	17.5	15.6	10.3	14.4
St Peters School[r]	Mountain Rd	Urban	1757602	5918466	43.2	40.1	38.9	40.7
Symonds St[r]	223 Symond St	Roadside	1756983	5918624	41.6	53.8	44.8	46.7
Takapuna[r]	Air Quality Monitoring site	Suburban	1756071	5928068	30.2	25.6	18.4	24.7
Waiheke[r]	Mako St	Suburban	1778942	5927191	6.8	6.7	5.1	6.2
Wellesley St[r]	Cr Albert St	Roadside	1757214	5920316	46.8	43.1	40.4	43.4
West Harbour	12a Crosby Rd	Suburban	1745215	5923865	13.1	11.9	9.2	11.4
Western Springs[r]	Derwent St	Suburban	1754307	5918153	24.7	23.9	19.5	22.7
Westmere	Dorsett Rd	Suburban	1753614	5919726	20.5	17.7	15.5	17.9
Whangaparaoa[r]	Regional Park	Rural	1762836	5947227	6.7	3.9	1.9	4.2
Whitaker Pl[r]	Cr Symond St	Roadside	1757431	5919624	41.8	36.4	35.9	38.0
Wyndham St[r]	Cr Nelson St	Roadside	1757008	5920767	36.5	33.0	30.8	33.4

* Based on WSL (2006a). Eastings and northings are metres in NZTM.

** See Table A1.7 for the description of types of sites.

[r] Repeated sites of previous years.

[+] The data at Broadway were affected by a nearby gas heater, therefore, were not used in the analysis in this report.

Figure A2.5

Spatial distribution of monthly NO_2 concentrations in Auckland (July 2006)

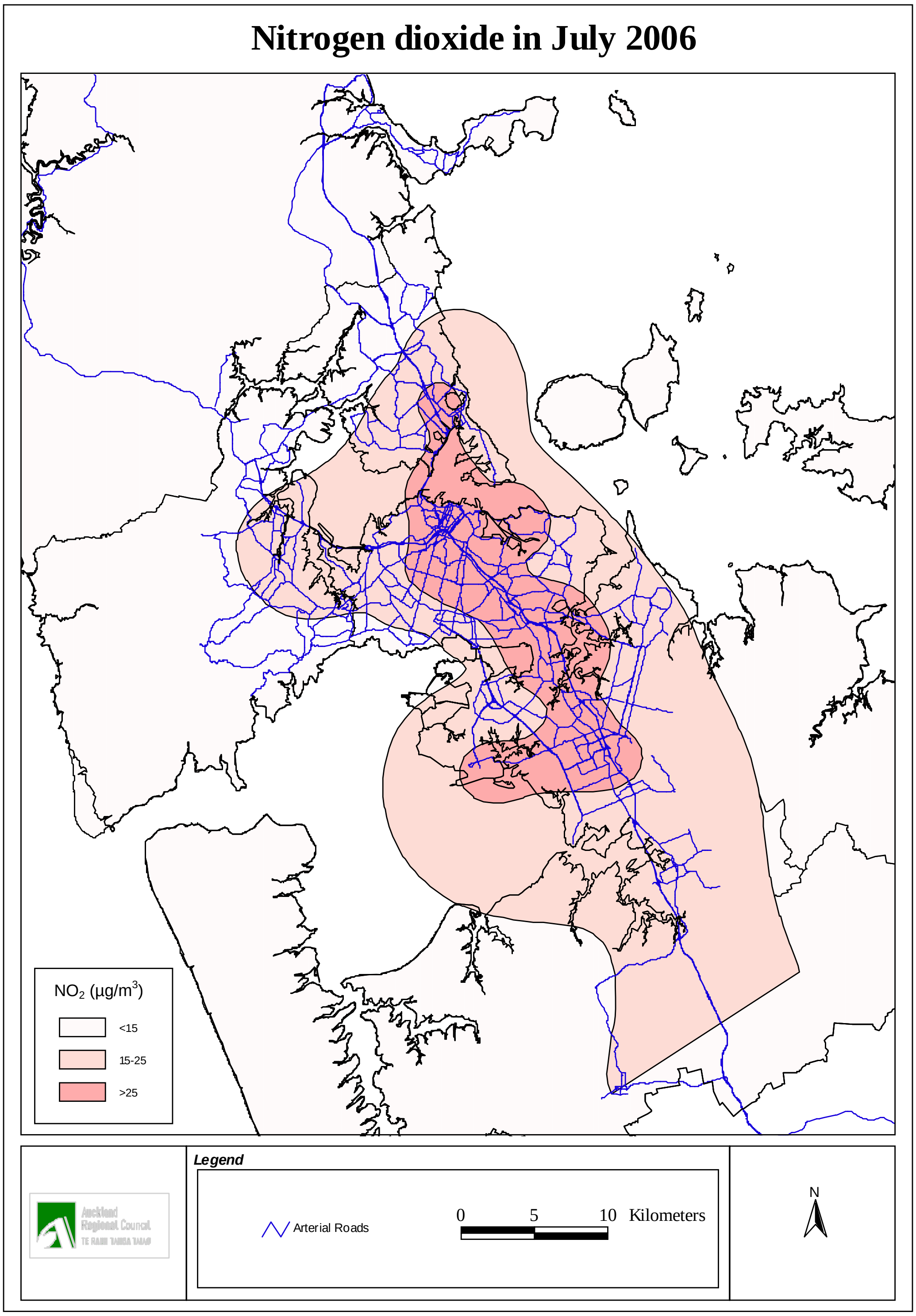


Figure A2.6

Spatial distribution of monthly NO_2 concentrations in Auckland (August 2006)

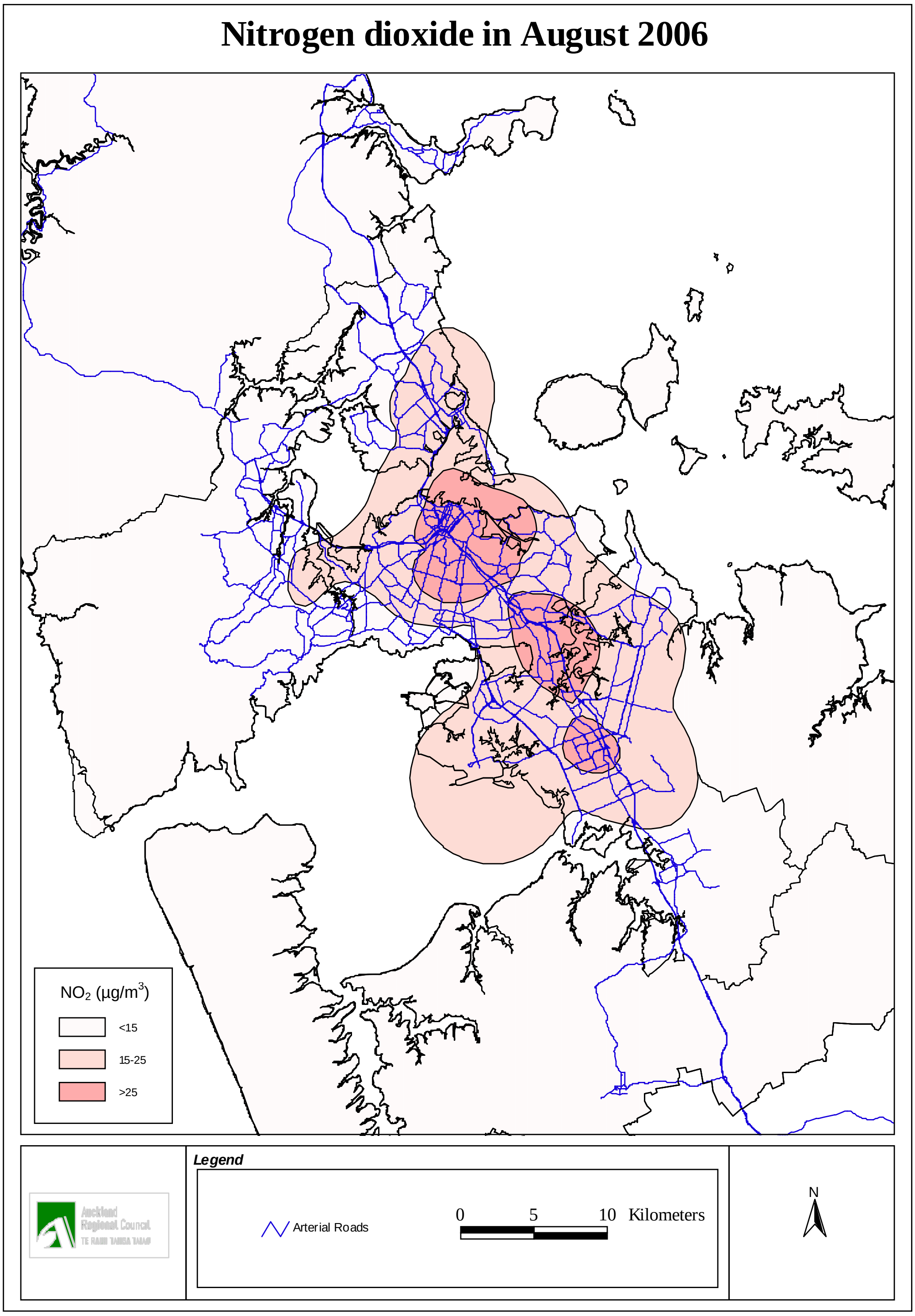


Figure A2.7

Spatial distribution of monthly NO_2 concentrations in Auckland (September 2006)

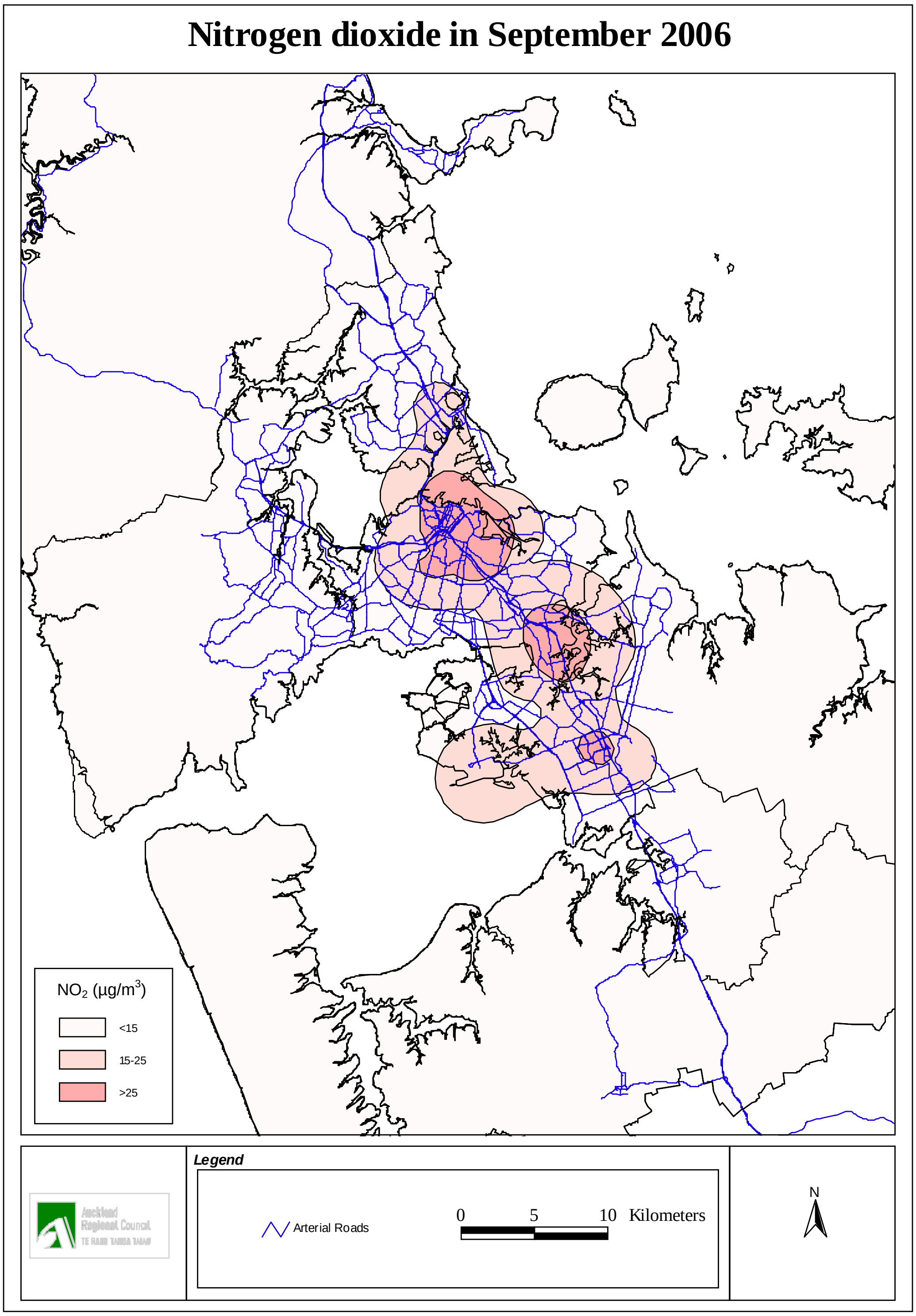


Figure A2.8

Spatial distribution of monthly NO_2 concentrations in Auckland (July 2006)

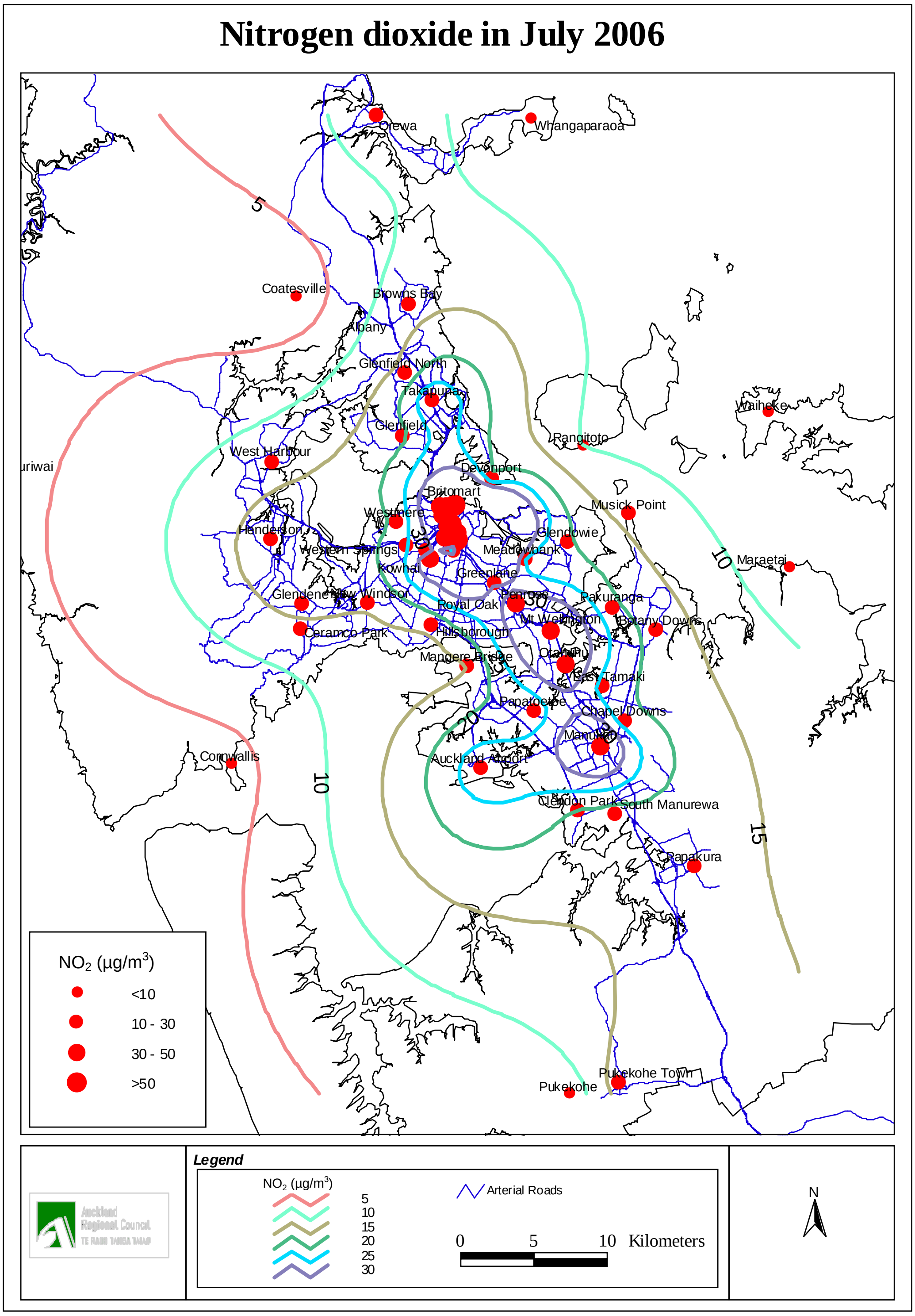


Figure A2.9

Spatial distribution of monthly NO_2 concentrations in Auckland (August 2006)

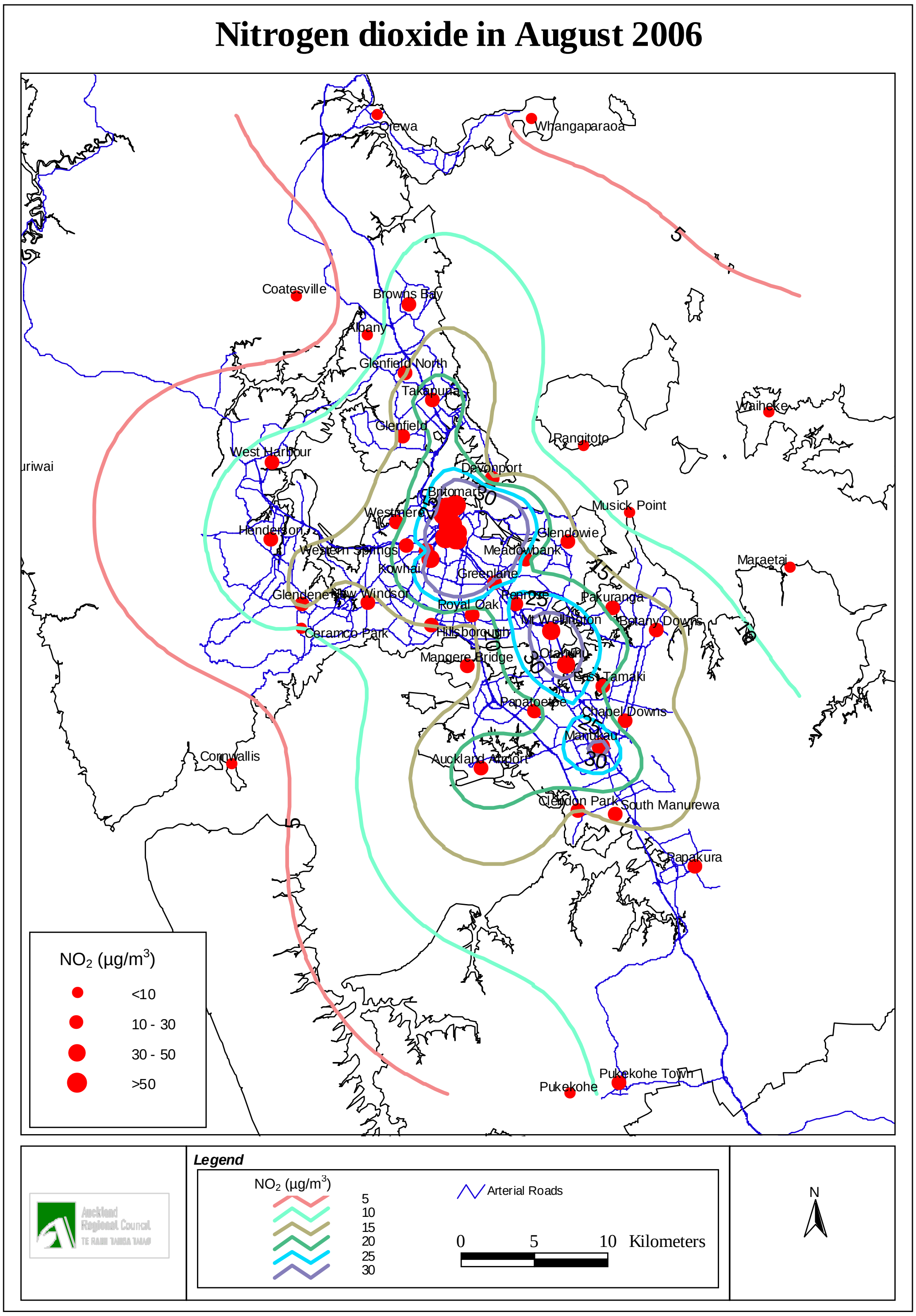


Figure A2.10

Spatial distribution of monthly NO_2 concentrations in Auckland (September 2006)

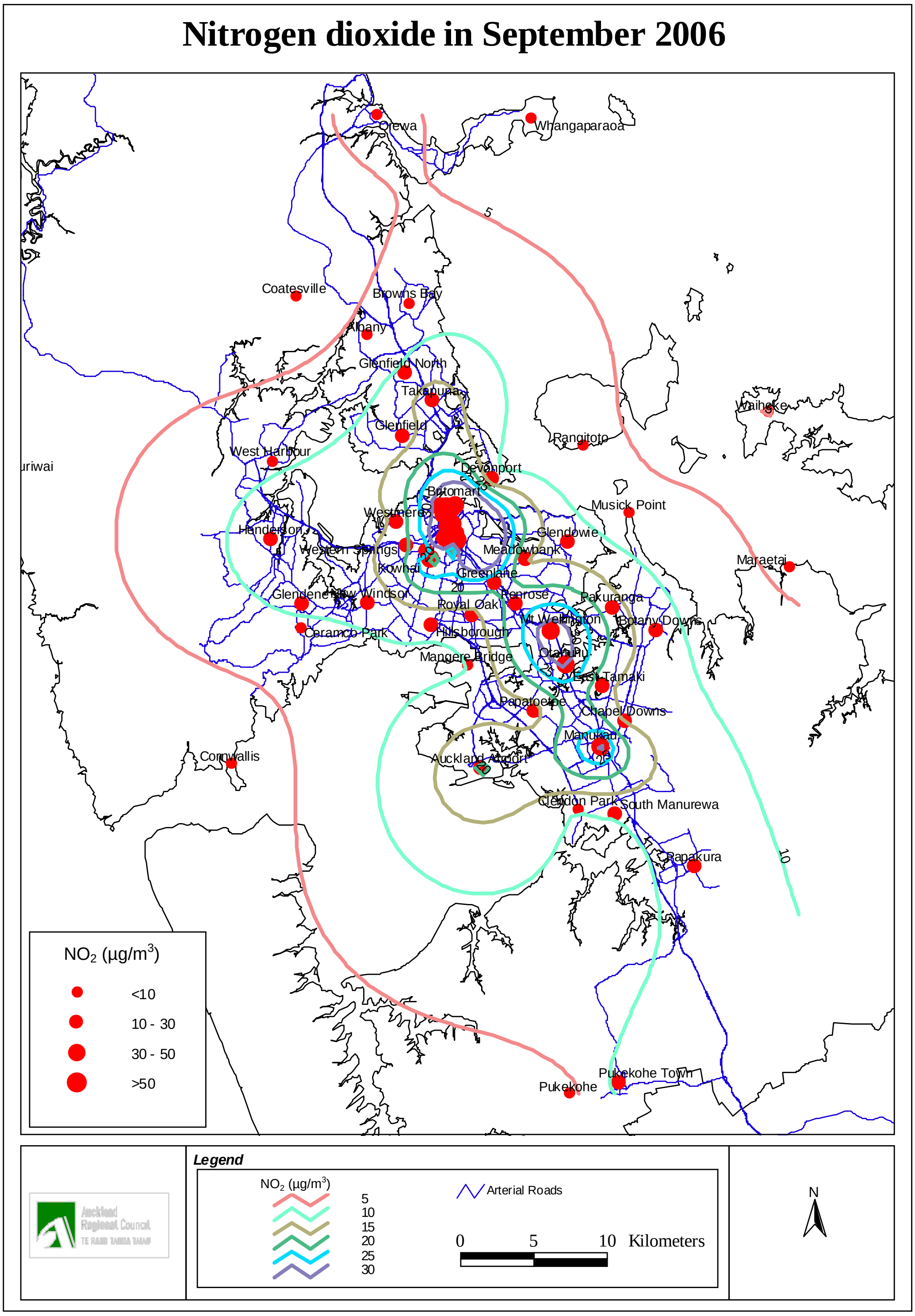


Figure A2.11

Spatial distribution of NO_2 concentrations in Auckland (three-month-means, July-September 2006)

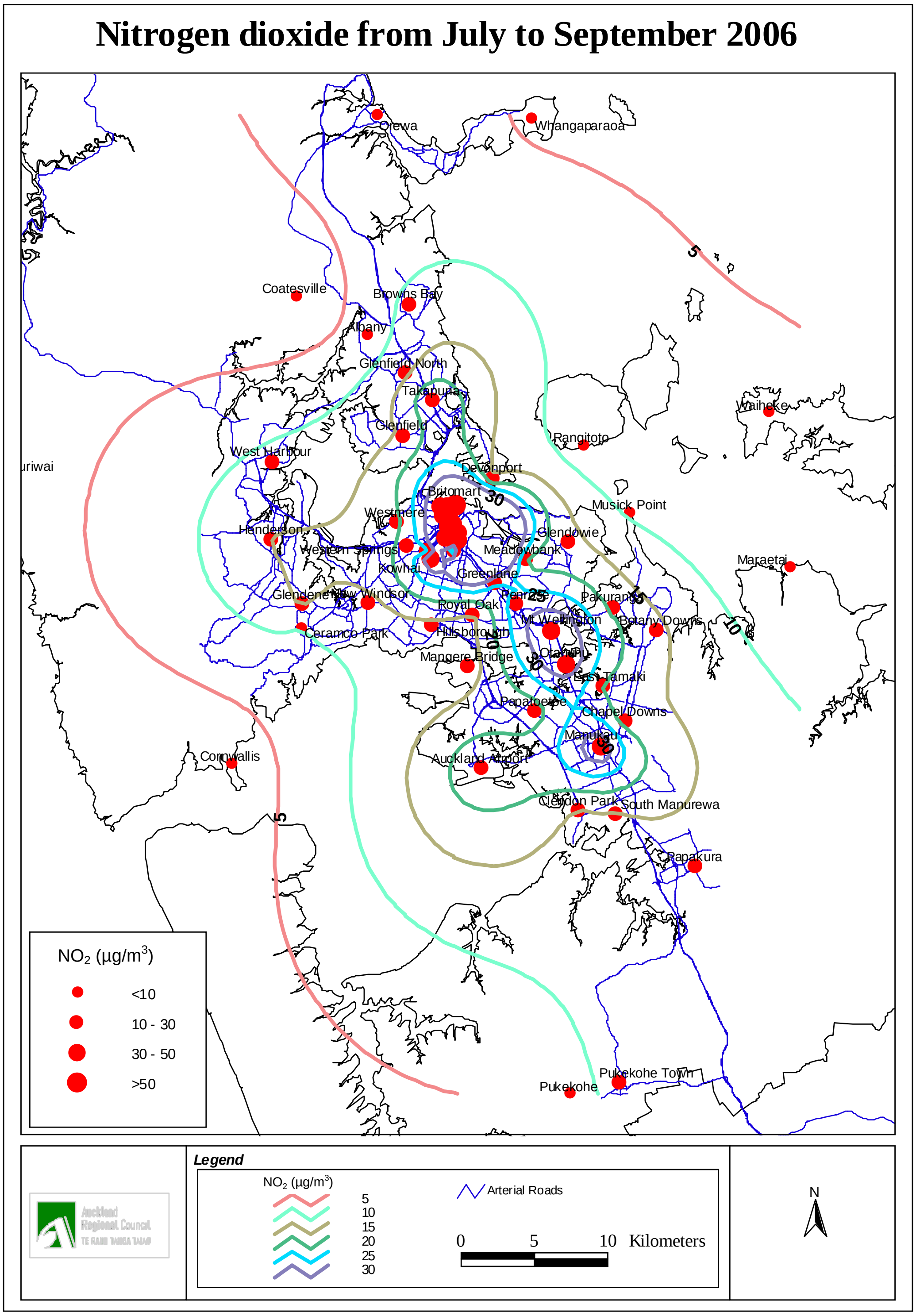


Table A2.2

Monthly NO_2 concentrations (µg m^{-3}) at the roadside of SH20 at Mangere in 2006*

Site	Distance from roadside (m)*	July	August	September
1	10	28.6	31.5	
2	50	37.1	29.6	25.5
3	150	31.3	28.3	23.0
4	250	28.9	28.8	21.4
5	300	30.5	26.7	22.2
6	400		23.9	18.8
7	500	26.7	23.0	18.7
8	550	25.5	22.7	18.5
9	-50	20.4	20.7	16.0
10	-150	18.9	18.4	14.8
11	-300	19.0	20.0	15.5
12	-500	16.4	13.6	12.3

*Positive distances indicate on the east of SH20, while negative on the west. The sites locate along Domain Road, Hastie Avenue and Mona Avenue (from west to east). See Figure 4.1 for detailed locations.

Table A2.3

Monthly NO_2 concentrations (µg m^{-3}) at the roadside of SH1 at Penrose in 2006*

Site	Distance from roadside (m)	July	August	September
1	50	32.4	28.3	24.2
Gavin St	106	33.7	27.8	21.8
2	200	30.4	25.0	23.1
3	250		21.7	18.8

*The Gavin St site (at 19 Gavin Street) is also listed in Table A2.1. Sites 1, 2 and 3 locate around the Gavin St site, but with various distances from the motorway. See Figure 4.4 for detailed locations.

Table A2.4

Mean NO_2 concentrations (µg m^{-3}) from passive samplers and from continuous monitors in 2006

Site	July		August		September	
	Passive	Continuous	Passive	Continuous	Passive	Continuous
Gavin St	33.7	38.0	27.8	34.1	21.8	29.9
Henderson	18.1	21.8	14.2	18.6	13.1	16.3
Kowhai	26.7	26.1	24.3	24.5	19.8	21.7
Khyber Pass	50.5	49.9	47.4	50.3	45.9	46.5
Musick Point	13.8	16.3	8.5	12.9	6.3	10.3
Queen St	45.7		47.2		42.3	67.0
Takapuna	30.2	36.7	25.6	35.9	18.4	31.7

*Continuous measurements listed are those with valid data > 75%.

Figure A2.12
Wind rose at Onehunga during the passive sampling period (July – September 2006)

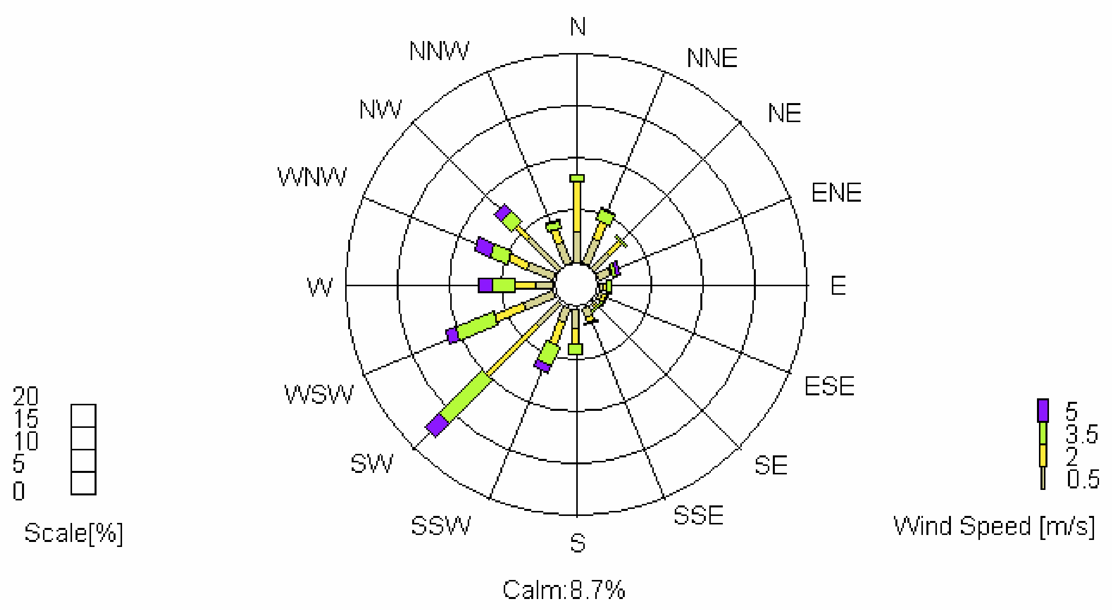
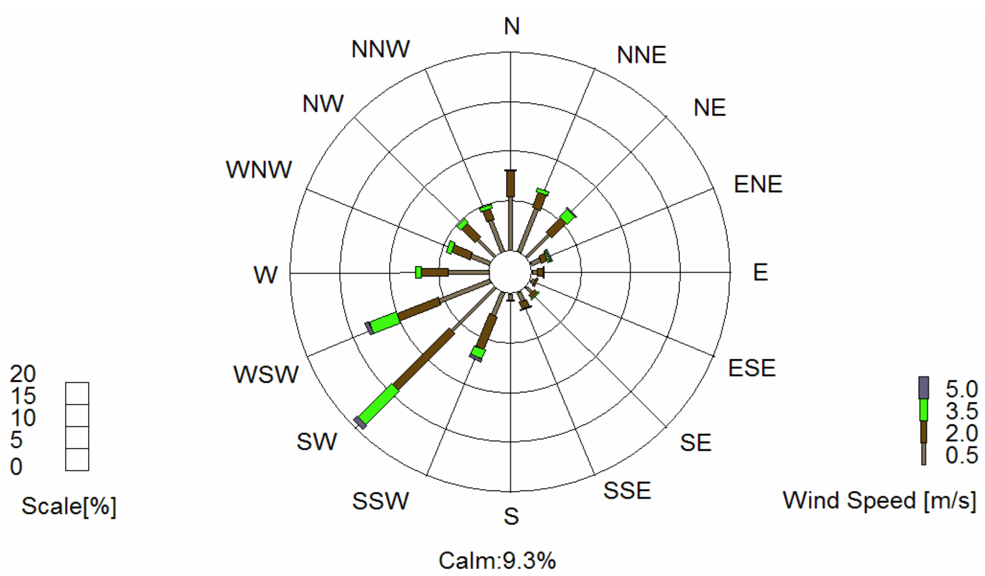


Figure A2.13
Wind rose at Penrose during the passive sampling period (July – September 2006)



Appendix 3: Monitoring Results at Long-term Sites

Table A3.1

Monthly NO_2 concentrations (µg m^{-3}) at long-term sites from 1995 to 2006*

Year	Month	Mt Eden	Pitt St
1995	December	11.9	
1996	January	10.3	
1996	February	11.6	26.0
1996	March	13.8	29.7
1996	April	18.5	35.2
1996	May	17.5	35.3
1996	June	19.8	38.5
1996	July	22.3	39.2
1996	August	19.0	36.1
1996	September	22.1	43.1
1996	October	15.1	32.1
1996	November	10.5	26.8
1996	December	11.0	25.1
1997	January	8.7	19.1
1997	February	13.9	24.2
1997	March	13.7	31.1
1997	April	15.1	45.6
1997	May	20.6	35.8
1997	June	23.3	41.0
1997	July	23.0	38.8
1997	August	23.5	40.9
1997	September	17.5	35.3
1997	October	14.2	28.5
1997	November	12.8	
1997	December	13.4	21.2
1998	January	8.2	17.4
1998	February	14.2	19.6
1998	March	16.6	32.0
1998	April	17.4	28.9
1998	May	19.7	28.3
1998	June	23.3	28.6
1998	July	26.1	33.9
1998	August	23.4	31.9
1998	September	20.8	32.7
1998	October	15.3	25.0
1998	November	14.7	21.6
1998	December	11.2	18.6
1999	January	11.2	17.4
1999	February	14.5	18.8
1999	March	19.3	28.4
1999	April	17.7	27.9
1999	May	21.2	29.6
1999	June	29.2	39.4
1999	July	28.1	38.3
1999	August	24.7	38.4
1999	September	22.4	33.6
1999	October	13.9	26.8
1999	November	14.0	26.0
1999	December	12.3	19.0
2000	January	12.6	22.9
2000	February	12.3	25.0
2000	March	17.9	31.4
2000	April	20.9	29.7

Table A3.1 (cont)

Year	Month	Mt Eden	Pitt St
2000	May	24.4	35.9
2000	June	23.7	35.3
2000	July	22.3	30.1
2000	August	23.8	36.7
2000	September	17.2	28.8
2000	October	15.2	27.4
2000	November	11.2	22.9
2000	December	11.2	15.9
2001	January	9.5	18.3
2001	February	13.6	20.0
2001	March	17.5	24.2
2001	April	19.8	26.5
2001	May	22.1	31.4
2001	June	26.1	38.1
2001	July	27.0	40.3
2001	August	25.5	33.4
2001	September	21.0	34.0
2001	October	15.0	24.1
2001	November	16.0	21.9
2001	December	11.4	20.0
2002	January	11.4	19.1
2002	February	10.3	16.1
2002	March	16.0	27.3
2002	April	21.1	30.7
2002	May	19.4	29.4
2002	June	22.7	
2002	July	18.0	26.4
2002	August	23.1	33.1
2002	September	17.3	28.7
2002	October	14.7	22.2
2002	November	13.8	24.7
2002	December	11.8	17.8
2003	January	10.9	19.1
2003	February	14.5	23.7
2003	March	18.3	27.0
2003	April	20.5	27.0
2003	May	22.9	35.1
2003	June	24.4	34.6
2003	July	24.7	38.3
2003	August	25.0	35.6
2003	September	17.7	25.1
2003	October	13.9	22.8
2003	November	11.9	23.8
2003	December	9.3	17.8
2004	January	13.2	24.8
2004	February	10.6	17.6
2004	March	12.9	25.3
2004	April	19.6	29.0
2004	May	22.7	30.6
2004	June	21.8	32.7
2004	July		36.4
2004	August		30.5
2004	September		25.3
2004	October	11.8	24.3
2004	November		21.4
2004	December	9.1	15.0
2005	January	11.1	17.4
2005	February	12.3	21.7
2005	March	14.9	24.2
2005	April	16.0	30.4
2005	May	22.2	32.7
2005	June	20.6	35.5
2005	July	23.0	34.1

Table A3.1 (cont)

Year	Month	Mt Eden	Pitt St
2005	August	23.3	35.9
2005	September	17.1	27.9
2005	October	16.8	27.0
2005	November	11.5	21.2
2005	December	9.8	16.5
2006	January		17.4
2006	February		21.2
2006	March		18.3
2006	April		
2006	May	25.2	33.0
2006	June	23.6	34.0
2006	July		37.1
2006	August		33.4
2006	September		29.6

*Based on the ARC summary report (ARC, 2006).

Table A3.2

Average NO_2 concentrations (µg m^{-3}) in summer and winter at long-term sites from 1995 to 2006*

Year	Mt Eden			Pitt St		
	Summer (Dec – Feb)	Winter (Jun – Aug)	Ratio**	Summer (Dec – Feb)	Winter (Jun – Aug)	Ratio**
1995 – 1996	11.3	20.3	1.8	26.0	37.9	
1996 – 1997	11.2	23.3	2.1	22.8	40.3	1.8
1997 – 1998	12.0	24.3	2.0	19.4	31.4	1.6
1998 – 1999	12.3	27.3	2.2	18.3	38.7	2.1
1999 – 2000	12.9	23.3	1.8	22.6	34.0	1.5
2000 – 2001	11.4	26.2	2.3	18.1	37.3	2.1
2001 – 2002	11.0	21.3	1.9	18.4	29.7	
2002 – 2003	12.4	24.7	2.0	20.2	36.2	1.8
2003 – 2004	11.0	21.8		20.1	33.2	1.7
2004 – 2005	10.8	22.3	2.1	18.0	35.2	1.9
2005 – 2006	9.8	23.6		18.4	34.8	1.9
Average	11.5	23.5	2.0	20.2	35.3	1.8

* Concentrations in summer and winter are calculated using monthly concentrations in Table A3.1.

** Ratio of concentrations in winter compared to summer when data for each month were available.