An Air Quality Index for Auckland: Review of Some International Techniques and Example Data

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An Air Quality Index for Auckland:
Review of Some International Techniques and Example Data

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Executive summary

This report summarises several international approaches to reporting ambient air quality by Air Quality Index (AQI). AQI is a simple method of communicating ambient air quality data to end users, usually the public. AQIs have been used globally since the 1970s and were pioneered by the United States Environmental Protection Agency (USEPA). Their primary purpose is to report ambient air quality data and its health effects to people with little or no understanding of the many ambient air quality guidelines and standards. AQI usually use the familiar 'traffic light' colour scale to convey health effects to users. AQI allows the public to adjust their behaviours in times of poor ambient air quality. AQIs are usually reported in real-time, online and increasingly, on smart phone applications.

Various kinds of AQI are used globally. Two broad kinds exist, firstly those which assess performance against ambient air quality guidelines or standards and ascribe health effects to them, and secondly those where classifications are based on health effects.

Auckland (and New Zealand) does not currently have an AQI, which represents a significant gap in the ambient air quality monitoring programme. Auckland Council should look to implement an AQI, in order to remain up to date with international best practice, and to provide meaningful reporting of ambient air quality to the public. There is potential, for an AQI to be developed in Auckland, which has national relevance and could potentially be rolled out nationwide.

This report aims to:

- Summarise various AQI globally and briefly asses their strengths
- Summarise benefits of an AQI
- Present example AQI for Auckland using 2013 monitoring data
- Present recommendations for establishing an AQI in Auckland

Contents

List of Figures

List of Tables

1.0 Introduction

1.1 How are air quality data communicated (Auckland, New Zealand and globally)

In New Zealand, regional councils are tasked with monitoring ambient air quality under the Resource Management Act 1991 (RMA, 1991), and reporting compliance of gazetted airsheds with the National Environmental Standards for Air Quality (NES-AQ) (MfE, 2014). These ambient air quality data collected by regional councils is reported in several ways. The majority of regional councils have the data they collect available on their websites. In practice, this is done in several ways, and with little standardisation. Regional councils may choose to make raw data available, or to make technical reports available as summary documents. Often, data reporting is geared largely toward tracking compliance with the National Environmental Standards for Air Quality (NES-AQ) (MfE, 2014). Making raw data and reports available online are great tools; however whether they are understood by end users is another question. Understanding other environmental datasets held by regional councils (e.g. rainfall, river level) is easier for the general public, as this data is more tangible, and for example, the public are used to thinking in terms of mm of rainfall and adjusting their activities accordingly. A challenge therefore exists to report ambient air quality data in a meaningful way, which highlights the health risks that the population are exposed to, rather than focussing on compliance with a standard. An Air Quality Index (AQI) is therefore potentially a useful tool for reporting of ambient air quality, both in real time, and for annual compliance and state of the environment reporting, as this report will demonstrate.

Currently ambient air quality data in Auckland are only reported yearly, in the State of Environment report cards. These cards provide simple and easy to understand analysis of ambient air quality, intended for public audience. However, this is currently the only routine reporting of ambient air quality data in Auckland. This has several limitations, in that the public are not aware of either the data held by council, or the potential health effects. Furthermore, it does not represent value for ratepayers.

Globally, the vast majority of countries that conduct ambient air quality monitoring, report the data to the public via an AQI (in addition to making raw data available). Countries currently operating an AQI include Canada (Ménard, 2014; Stevens, 2014), China (including Hong Kong), Mexico, Singapore, UK and USA (Mintz, 2009). A Europe–wide index also operates, managed by the European Union (Van den Elshout, 2008; 2012). Generally, this data is then available online, or via smartphone applications. Usually, the AQI is developed by a central government agency (e.g. United States Environmental Protection Agency (USEPA) in the USA, or Department for Environment, Food and Rural Affairs (DEFRA) in the UK. AQI are then reported through either local government websites, or national websites, or both in some cases. In the late 1990s Ministry for the Environment (MfE) began a project around environmental performance indicators (EPI) (MfE, 1998) which was similar to an AQI. This project failed to gain traction and was not widely used.

1.2 What is an AQI?

An Air Quality index (AQI) is an indicator of air quality, based on air pollutants that have adverse effects on human health and the environment. AQI may consist of an individual pollutant, or a suite of pollutants, depending on the dominance of various emissions sources in the area concerned.

AQIs take pollutant concentrations from ambient air quality monitoring sites, and convert these data to a single figure. Usually, these numbers are colour – coded against a scale relating to relative health impacts. The nature of the figure and the scale are flexible, with many different AQI in use globally. Usually, the scales range from something approximating ‘safe’ to ‘hazardous’. These classifications are then further described to give guidance around their health effects on specific groups of the population. In some cases, epidemiological experts develop the bands based on health effects at different ambient concentrations.

Often AQI report a single pollutant from a monitoring site. The usual approach is to calculate AQI for all pollutants and report the highest value (Mintz, 2009). New approaches use methods to calculate an AQI using a range of pollutants from ambient air quality monitoring sites (Cheng et al. 2003; Cheng et al. 2007; Hasselback and Taylor, 2010) are being developed as ‘next generation’ AQI. These approaches do however assume a degree of standardisation of pollutants measured by ambient air quality monitoring sites.

AQIs are primarily a tool for communicating air quality to the public. Whilst people globally are generally concerned about ambient air quality (Evans et al. 1988, Bickerstaff and Walker, 1999; Johnson, 2002) the complex nature of monitoring data, and constantly evolving national and international standards, guidelines and exceedence values mean that deciphering data is often too difficult for the casual observer. Simply making ambient air quality data available online is no longer enough – this assumes that the public have both the inclination and skill to translate data to meaningful risk for their health (Steib, 1996; Johnson, 2003). An AQI distils data to a single, transferable number. Furthermore, an AQI appropriately codes the AQI value against risk and health effects. The public can therefore quickly understand ambient air quality in their area, and adjust their activities accordingly.

AQI are used extensively internationally, and have long been recognised as an effective method of translating the complexities and eccentricities of ambient air quality to the public, as well as ascribing meaningful health effects to ambient air quality.

This report aims to:

- Summarise various AQI globally and briefly asses their strengths
- Summarise benefits of an AQI
- Present example AQI for Auckland using 2013 monitoring data
- Present recommendations for establishing an AQI in Auckland

2.0 Benefits of Air Quality Index

2.1 Communication to stakeholders

Communication of ambient air quality data to the public presents significant challenges. In order to engage with the public in a meaningful manner, ambient air quality data needs to be presented in both an accessible format, and in a manner which translates data into tangible results. Given the regulatory landscape of ambient air quality, with consistently evolving guidelines, standards and recommendations, agencies have a responsibility to stakeholders (e.g. ratepayers) to translate this relatively complex world into an output which has real meaning for users. Presentation of graphs and standards is no longer enough, and may serve to disengage the public. AQI address these issues in several ways.

Firstly, AQI remove the requirement for a user to understand what a given ambient concentration of a pollutant really means. Ambient air quality professionals generally understand the data, in terms of units, ambient concentrations and values of concern, but the public may not necessarily have the ability or inclination to make informed judgements about implications of given values. AQI distil this data into a single figure, and add a colour code, meaning that a tangible assessment of ambient air quality is provided quickly. The familiar green – red colour scale assists here too.

AQI allow the public to make meaningful comparisons between sites, areas and even internationally. The universal score and colour code means that the comparisons can be easily made. In the USEPA and DEFRA examples, the comparisons are provided through maps and other graphics available online.

Thirdly, AQI generally have health effects associated with their various index bands. In many examples, two groups are provided, for general public, and more sensitive groups. The public therefore, are able to associate given AQI values with tangible effects on their health, allowing modification of behaviour where possible. In the AQHI and DEFRA examples, this is more explicit, as the other AQI described in this report ascribe the health effects to their bands, rather than using the health effects in the development of their bands.

2.2 Assisting compliance reporting

In the New Zealand context, considerable effort is spent on reporting compliance of gazetted airsheds with the NES-AQ (MfE, 2014). This reporting is important, as this can be an indicator of public exposure to pollutants. The reporting can track long term trends in ambient air quality. However, the link between this and health effects is not overtly stated. An AQI approach, targeting towards health effects, may allow organisations to track trends in health effects on the population. Potentially, organisations may prefer to report statistics around reduced activity days, or days with higher health effects rather than the concentrations and exceedances that are traditionally reported.

2.3 Real-time reporting

As described in section 3, one of the strengths of AQIs is the ability to report large amounts of data, often from multiple ambient air quality sites, easily in real time. The relatively simple calculations mean that an entire monitoring network can be reported on a single web page, in a meaningful way. The colour coding of the AQI bands translate well to spatial representations such as maps, contouring and animation of changes through time. The DEFRA website, for example, summarises the entire United Kingdom in an easy to understand manner.

2.4 Smartphone connectivity

The popularity of smartphones represents an opportunity for mobile access to AQI. Internationally, many agencies make their AQI and ambient air quality data available through smartphone apps. These apps allow truly mobile access to AQI, which increases the importance of AQI to the public. Many apps also feature notification services to allow users to be updated of changes in ambient air quality in real time. Smartphone apps are available for many cities in Asia, USA and Canada. As the world becomes increasingly connected, smartphone apps are increasingly regarded as necessities.

2.5 Tracking delivery on Auckland Council strategic objectives

Strategic Direction 7 of the Auckland Plan (Auckland Council, 2012), "*Acknowledge that nature and people are inseparable"* is relevant in terms of the AQI. Ambient air quality has effects on both people and nature, and a meaningful way of communicating ambient air quality to the public is essential to deliver this. Furthermore, AQI allow the public to begin to understand how their daily activities both affect and are affected by ambient air quality. AQI allow the public to make an informed judgement about altering their daily activities in response to ambient air quality.

Directive 7.7 "*Minimise reverse sensitivity and exposure associated with emissions"* is also applicable. Currently, the public has access to very limited information about ambient air quality, and accordingly there is little public knowledge around ambient air quality, specifically concentrations which people are exposed to daily. An AQI would allow the public to make informed decisions in real time, to self-regulate their exposure to reduced ambient air quality. An AQI would also allow public to make decisions to positively alter ambient air quality, such as using public transport, installing compliant woodburner or operating existing ones at higher efficiency.

Section 5.1 of the Proposed Unitary Plan (Auckland Council, 2012) has two major objectives relevant to an AQI. Firstly, *"Air quality is maintained in those parts of Auckland that have excellent or good air quality, and air quality is enhanced in those parts of Auckland where it is poor"* relates well to the ability of AQI to track trends in ambient air quality. For instance, if there is an increase in number of days falling in a given AQI band, then it's easy to assess the success of this objective. An AQI would allow the result to be communicated in an easily understandable manner.

Secondly, *"Land use is managed to avoid or mitigate the adverse effects of motor vehicle emissions on people, especially in respect of children's health"* also has relevance here, in that any changes in land use can be assessed by changes in AQI, and then reported in a meaningful way to the public. If a health-effects bases AQI is selected, then any changes seen are easily converted into real – world health effects.

An AQI could also be used for tracking of compliance with the AAAQS, required under the PAUP (Auckland Council, 2013). This would allow Auckland Council to meaningfully report on the trends in health effects, based on the AAAQS. For instance, annual reporting could report the number or percentage of days in each band, and thus report the number of days with increased risk of health effects. Potentially, this could be translated into a cost to the Auckland economy.

3.0 Examples of Air Quality Indexes

3.1 USEPA AQI

Pollution indexes have been used by the United States Environmental Protection Agency (USEPA) since the 1970's. In 1976, the USEPA released the Pollutant Standard Index (PSI). The PSI rated ambient air quality from 0-500, with 100 equal to the National Ambient Air Quality Standard (NAAQS). The PSI was calculated for every pollutant with a NAAQS at an individual monitoring site, but only the highest exceeding pollutant was reported. The PSI also had descriptors intended to convey the potential health effects. The PSI was revised in 1979 and used for the next 20 years (Johnson, 2003).

In 1998, the USEPA began to look at revising the PSI. The USEPA was concerned that health effects could occur at ambient concentrations below the NAAQS (e.g. 100 on the PSI) for sensitive people (e.g. those with asthma), but probably would not affect the majority of people. Accordingly the USEPA embarked on a programme of focus groups and conducted an exploratory study to assess how to adjust the PSI to include 'sensitive groups' and redevelop the risk categories (Johnson, 2003). The revised PSI was adopted as the Air Quality Index in 1999, and was effective from August the same year (Johnson, 2003; Mintz, 2009; USEPA, 2012). In 2012, the USEPA revised the NAAQS, for $PM_{2.5}$ and accordingly altered the bands for $PM_{2.5}$. This reflects international concern around the health effects of $PM_{2.5}$ (WHO, 2013A, B)

The AQI is based on the five pollutants regulated by the Clean Air Act: ground-level ozone, particulate matter, carbon monoxide, sulphur dioxide, and nitrogen dioxide. These pollutants all have NAAQS, which translate to roughly 100 on the AQI (USEPA, 2009B)

The air quality index is a piecewise linear function of the pollutant concentration. At the boundary between AQI categories, there is a discontinuous jump of one AQI unit. To convert from concentration to AQI this equation is used:

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{HI} - BP_{Lo}}(C_p - BP_{Lo}) + I_{Lo}.$$

Where:

I_p = the index for pollutant p
C_p = the rounded concentration of pollutant p
BP_{Hi} = the breakpoint that is ≤ C_p
BP_{Lo} = the breakpoint that is ≥ C_p
I_{lhi} = the AQI value corresponding to BP_{Hi}
I_{lo}= the AQI value corresponding to BP_{Lo}
(Johnson, 2003; Mintz, 2009)

Each AQI pollutant has a specific breakpoint, which determine based on the concentration, what classification the concentration falls in (figure 1).

This Breakpoint...						...equal this AQI		…and this category
O_3 (ppm) 8-hour	O_3 (ppm) 1-hour1	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	AQI	
0.000 - 0.059	-	0 - 54	0.0 - 15.4	0.0 - 4.4	0.000 - 0.034	(2)	0 - 50	Good
0.060 - 0.075	-	55 - 154	15.5 -40.4	4.5 - 9.4	0.035 - 0.144	(2)	51 - 100	Moderate
0.076 - 0.095	0.125 - 0.164	155 - 254	40.5 - 65.4	9.5 - 12.4	0.145 - 0.224	(2)	101 - 150	Unhealthy for Sensitive Groups
0.096 - 0.115	0.165 - 0.204	255 - 354	65.5 - 150.4	12.5 - 15.4	0.225 - 0.304	(2)	151 - 200	Unhealthy
0.116 - 0.374 (0.155 - 0.404)[4]	0.205 - 0.404	355 - 424	150.5 - 250.4	15.5 - 30.4	0.305 - 0.604	0.65 - 1.24	201 - 300	Very unhealthy
(3)	0.405 - 0.504	425 - 504	250.5 - 350.4	30.5 - 40.4	0.605 - 0.804	1.25 - 1.64	301 - 400	Hazardous
(3)	0.505 - 0.604	505 - 604	350.5 - 500.4	40.5 - 50.4	0.805 - 1.004	1.65 - 2.04	401 - 500	Hazardous

[1] Areas are required to report the AQI based on 8-hour ozone values. However, there are areas where an AQI based on 1-hour ozone values would be more protective. In these cases the index for both the 8-hour and the 1-hour ozone values may be calculated and the maximum AQI reported.

[2] NO_2 has no short-term NAAQS and can generate an AQI only above a value of 200.

[3] 8-hour O_3 values do not define higher AQI values ($\geq$ 301). AQI values of 301 or higher are calculated with 1-hour O_3 concentrations.

[4] The numbers in parentheses are associated 1-hour values to be used in this overlapping category only.

Figure 1 USEPA AQI breakpoints (from Mintz, 2009)

Suppose a site records a 24hr average PM_{10} value of 70 $\mu g/m^3$, then the equation to calculate the AQI is:

$$AQI = \frac{100 - 51}{154 - 55}(70 - 55) + 51 = 58.3$$

The AQI value for the 24hr average therefore corresponds to the moderate category (figure 2). In the case of a site with multiple pollutants being measured, the AQI should be calculated for all pollutants, and the highest AQI value reported as the AQI for the site (Mintz, 2009). In this situation the USEPA recommends reporting the AQI and saying what pollutant is responsible for the AQI value (Mintz, 2009). It should be noted that the best ambient air quality rating is 'Good', rather than 'excellent' or similarly emotive words. This reflects international best practice around guidelines and standards, which generally states that there is no 'safe' concentration of pollutants, rather, below the standard there is an acceptable level of risk for the majority of the population exposed to a given concentration (WHO, 2005; Mintz, 2009, WHO, 2013A, B)

Due to the structure of ambient air quality monitoring in the USA, with all data collected on behalf of the USEPA by State environmental protection authorities, the USEPA is able to report the AQI at a national scale, and forecast AQI in near – real time. Local data are also reported online by state authorities. The spatial coverage of ambient air quality sites in the United States allows the USEPA to provide real time access to national scale AQI information through their website, www.airnow.gov. An example of a nationwide AQI is shown in figure 3.

Air Quality Index Levels of Health Concern	Numerical Value	Meaning
Good	0 to 50	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	51 to 100	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy	151 to 200	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	201 to 300	Health warnings of emergency conditions. The entire population is more likely to be affected.
Hazardous	301 to 500	Health alert: everyone may experience more serious health effects

Figure 2 USEPA AQI classes and meanings (Johnson, 2003; USEPA, 2009A; 2009B)

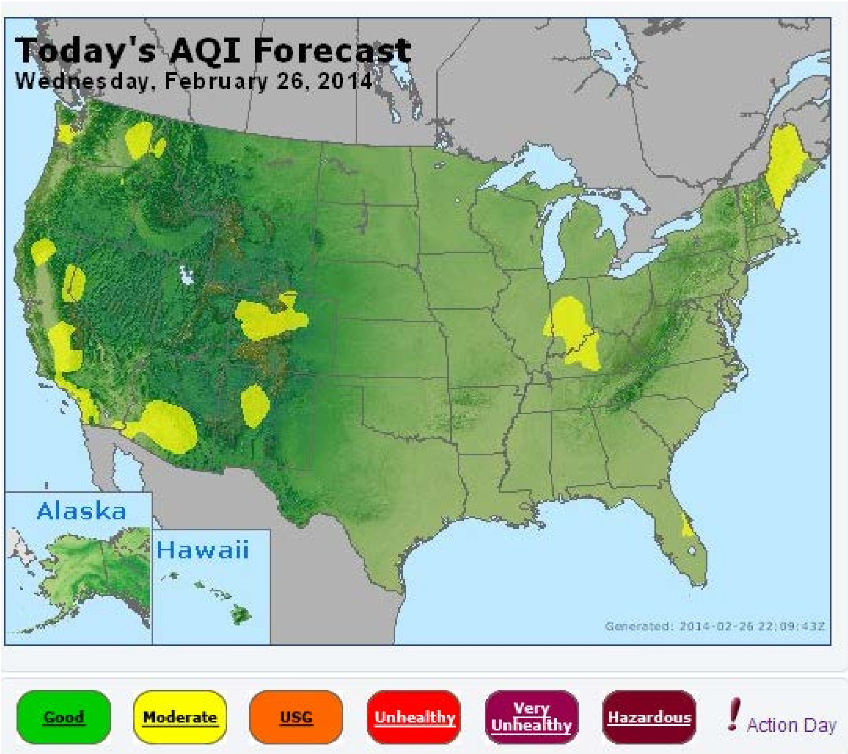


Figure 3 USEPA AQI for Wednesday 27th February 2014, from the USEPA AIRNOW website.

3.2 British Columbia, Canada

British Columbia uses the Air Quality Health Index (AQHI), developed by Environment Canada. The AQHI was developed using data and existing research from Canadian epidemiological studies, and this specifically estimates the short term health risks caused by degraded ambient air quality, rather than the USEPA AQI which ascribes risk as a function of the exceedence of the NAAQS. Thus the AQHI assesses relative health risks, rather than assessing a management guideline (Hasselback and Taylor, 2010). Higher AQHI values thus have higher health risks. The AQHI also recognises the 'no safe level' concept, and accordingly splits the health advice for the index into 2 categories 'at risk' (for those with existing health issues, e.g. Asthma, Cardiopulmonary issues) and 'general population' for those with better health. Modifications to behaviour are therefore suggested lower down the scale for those in the 'at risk' group.

The AQHI differs from the USEPA AQI in a few major ways. Firstly, the AQHI uses multiple pollutants from ambient air quality monitoring sites, specifically nitrogen dioxide (NO_2), ozone (O_3), and particulate matter ($PM_{2.5}$). Each of these pollutants has specific health effects, they also provide useful proxies for pollutants not included in the AQHI, such as PM_{10}, and also cover the major sources of pollutants (Hasselback and Taylor, 2010).Secondly, the scaling of the index is slightly different, in that the AQHI ranges from 1 to 10 (low-high risk). Values over 10 are reported as 10+, and are seldom seen in Canada, apart from in unusual conditions such as forest fires (Hasselback and Taylor, 2010).Thirdly, the equations for calculation of the AQHI are much different to the USEPA AQI. However, there is no need for the breakpoints to be known as in the USEPA AQI. The AQHI function is:

$$\boldsymbol{AQHI} = \frac{10}{10.4} \times (100 \times \left(e^{(0.000871 \times N)} - 1 + e^{(0.000537 \times O)} - 1 + e^{(0.000487 \times PM)} - 1\right))$$

Where:

AQHI = the AQHI value
N = nitrogen dioxide (ppb)
O = Ozone (ppb)
PM = $PM_{2.5}$ ($\mu g/m^3$)
(Hasselback and Taylor, 2010)

The result of the equation is therefore the AQHI value. Results are rounded up to the nearest positive integer. Results less than 0.5 are rounded up to one. The AQHI values are then categorised using the 2 groups method, as shown in figure 4.

As is common internationally, the AQHI values are then posted online (see figure 5).

Health Risk	Air Quality Health Index	Health Messages	
		At Risk Population*	General Population
Low	1 - 3	Enjoy your usual outdoor activities.	Ideal air quality for outdoor activities.
Moderate	4 - 6	Consider reducing or rescheduling strenuous activities outdoors if you are experiencing symptoms.	No need to modify your usual outdoor activities unless you experience symptoms such as coughing and throat irritation.
High	7 - 10	Reduce or reschedule strenuous activities outdoors. Children and the elderly should also take it easy.	Consider reducing or rescheduling strenuous activities outdoors if you experience symptoms such as coughing and throat irritation.
Very High	Above 10	Avoid strenuous activities outdoors. Children and the elderly should also avoid outdoor physical exertion.	Reduce or reschedule strenuous activities outdoors, especially if you experience symptoms such as coughing and throat irritation.

Figure 4 Canada AQHI codes and health messages (Hasselback and Taylor, 2010)

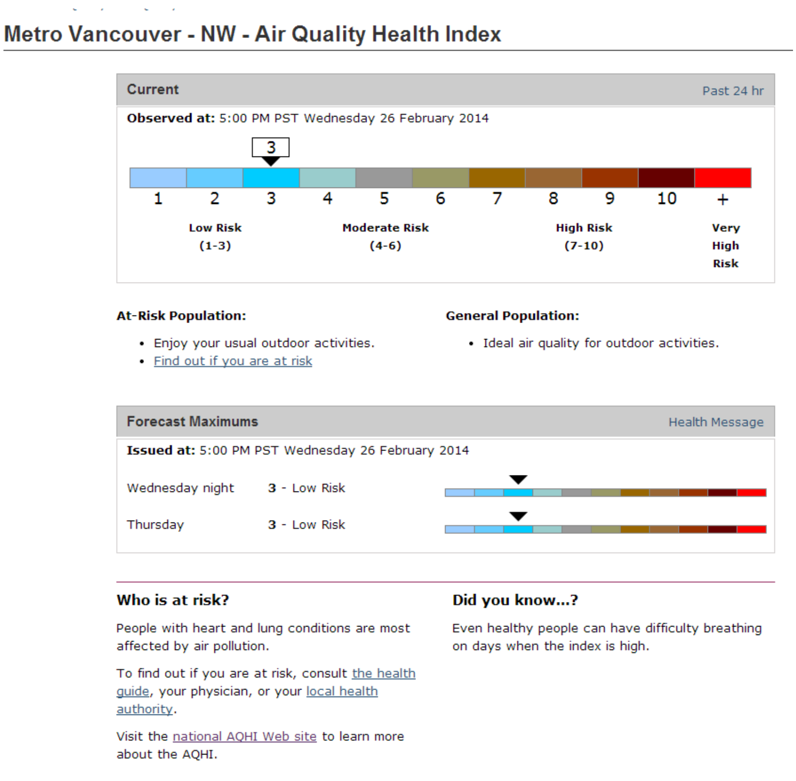


Figure 5 Canada AQHI for Metro Vancouver (27/02/2014) (Source http://weather.gc.ca/airquality/pages/bcaq-001_e.html

3.3 Australian examples

3.3.1 New South Wales (NSW) and Victoria

The NSW Government and Victoria EPA administer publish an AQI for their respective state. NSW and Victoria use the same AQI, but the results are reported through their respective websites. The NSW/VIC AQI uses the simplest arithmetic of the AQI covered in this report. As per the USEPA AQI, the AQI is calculated for all pollutants at a site, and then the highest AQI value is reported. Pollutants used are ozone (O_3), nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), particulates (either PM_{10} or $PM_{2.5}$) and visibility (as B_{sp}). The NSW AQI is calculated using this formula:

$$AQI = \frac{Pollutant\ concentration}{Standard} \times 100$$

As shown in the formula, the NSW/VIC AQI is largely based on the relationship between the pollutant concentration and the standard for that pollutant, in the case of Australia this is the National Environmental Protection Measures (NEPM) which in practice are similar to the National Environmental Standards for Air Quality (NES-AQ). The relationship between the index and health effects is less overt than the Canadian AQHI.

A potential benefit of the NSW AQI is the ease of calculation. Suppose a monitoring site records a 24hr average PM_{10} value of 60 µg/m^3. The AQI calculation is therefore:

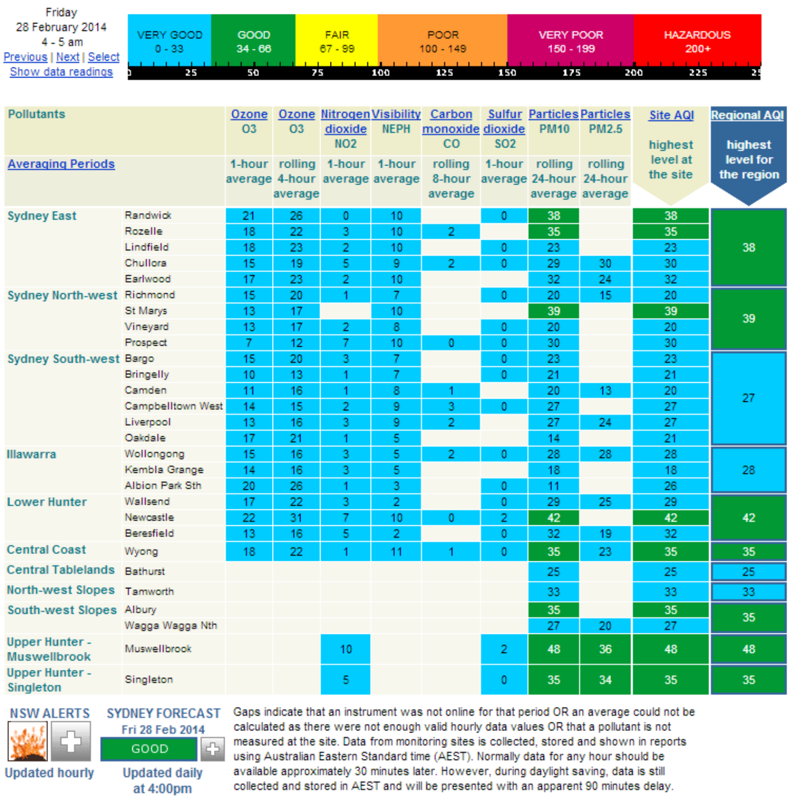
$$AQI = \frac{60}{50} \times 100 = 120$$

The AQI value of 120 corresponds to an AQI rating of poor (see figure 6, below).

Category	Index range
Very good air quality	0–33
Good air quality	34–66
Fair air quality	67–99
Poor air quality	100–149
Very poor air quality	150 or greater

Figure 6 NSW AQI classes (top) and Victoria AQI classes (http://www.epa.vic.gov.au/Our-work/Monitoring-the-environment/Air-quality-bulletins/Hourly-air-quality-interactive-map)

As is international best practice, the AQI values are reported online at www.envrionment.nsw.gov.au and www.epa.vic.gov.au. The example AQI Values are summarised in a table, shown in figure 7.



Pollutants		Ozone O3	Ozone O3	Nitrogen dioxide NO2	Visibility NEPH	Carbon monoxide CO	Sulfur dioxide SO2	Particles PM10	Particles PM2.5	Site AQI highest level at the site	Regional AQI highest level for the region
Averaging Periods		1-hour average	rolling 4-hour average	1-hour average	1-hour average	rolling 8-hour average	1-hour average	rolling 24-hour average	rolling 24-hour average		
Sydney East	Randwick	21	26	0	10		0	38		38	38
	Rozelle	18	22	3	10	2		35		35	
	Lindfield	18	23	2	10		0	23		23	
	Chullora	15	19	5	9	2	0	29	30	30	
	Earlwood	17	23	2	10			32	24	32	
Sydney North-west	Richmond	15	20	1	7		0	20	15	20	39
	St Marys	13	17		10			39		39	
	Vineyard	13	17	2	8		0	20		20	
	Prospect	7	12	7	10	0	0	30		30	
Sydney South-west	Bargo	15	20	3	7		0	23		23	27
	Bringelly	10	13	1	7		0	21		21	
	Camden	11	16	1	8	1		20	13	20	
	Campbelltown West	14	15	2	9	3	0	27		27	
	Liverpool	13	16	3	9	2		27	24	27	
	Oakdale	17	21	1	5			14		21	
Illawarra	Wollongong	15	16	3	5	2	0	28	28	28	28
	Kembla Grange	14	16	3	5			18		18	
	Albion Park Sth	20	26	1	3		0	11		26	
Lower Hunter	Wallsend	17	22	3	2		0	29	25	29	42
	Newcastle	22	31	7	10	0	2	42		42	
	Beresfield	13	16	5	2		0	32	19	32	
Central Coast	Wyong	18	22	1	11	1	0	35	23	35	35
Central Tablelands	Bathurst							25		25	25
North-west Slopes	Tamworth							33		33	33
South-west Slopes	Albury							35		35	35
	Wagga Wagga Nth							27	20	27	
Upper Hunter - Muswellbrook	Muswellbrook			10			2	48	36	48	48
Upper Hunter - Singleton	Singleton			5			0	35	34	35	35

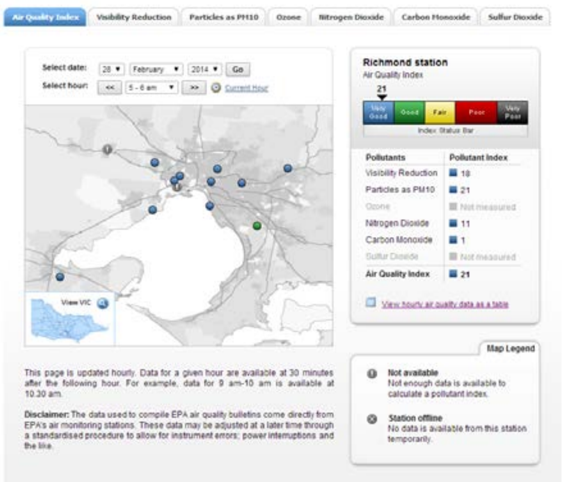


Figure 7 NSW AQI values (top) and Victoria AQI values (bottom), as published online (http://www.epa.vic.gov.au/Our-work/Monitoring-the-environment/Air-quality-bulletins/Hourly-air-quality-interactive-map)

3.4 UK example

In the UK, the Department for Environment, Food and Rural Affairs (DEFRA) publishes an AQI called the Daily Air Quality Index (DAQI). The DAQI differs to all other AQI reviewed here in that there is no calculation required to derive the index value. Rather, the DAQI uses a set of breakpoints to classify ambient concentrations pollutants on a colour – coded scale for each pollutant, ranging from Low to very high. Pollutants used are ozone (O_3) nitrogen dioxide (NO_2), carbon monoxide (CO), sulphur dioxide (SO_2), PM_{10} and $PM_{2.5}$. Like the AQHI, the DAQI is concerned with health effects rather than assessing concentrations related to an ambient air quality standard. The classification was developed by a group of health experts, Committee on Medical Effects of Air Pollutants (COMEAP).The boundaries between index classes are (figure 8):

Nitrogen Dioxide

Based on the hourly mean concentration.

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
µg/m³	0-67	68-134	135-200	201-267	268-334	335-400	401-467	468-534	535-600	601 or more

Ozone

Based on the running 8-hourly mean.

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
µg/m³	0-33	34-66	67-100	101-120	121-140	141-160	161-187	188-213	214-240	241 or more

Sulphur Dioxide

Based on the 15-minute mean concentration.

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
µg/m³	0-88	89-177	178-266	267-354	355-443	444-532	533-710	711-887	888-1064	1065 or more

$PM_{2.5}$ Particles

Based on the daily mean concentration for historical data, latest 24 hour running mean for the current day.

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
µg/m³	0-11	12-23	24-35	36-41	42-47	48-53	54-58	59-64	65-70	71 or more

PM_{10} Particles

Based on the daily mean concentration for historical data, latest 24 hour running mean for the current day.

Index	1	2	3	4	5	6	7	8	9	10
Band	Low	Low	Low	Moderate	Moderate	Moderate	High	High	High	Very High
µg/m³	0-16	17-33	34-50	51-58	59-66	67-75	76-83	84-91	92-100	101 or more

Figure 8 DAQI Classes and breakpoints for target pollutants http://uk-air.defra.gov.uk/air-pollution/daqi

DEFRA reports the DAQI online (figure 9), and also forecasts ambient air quality as the DAQI.

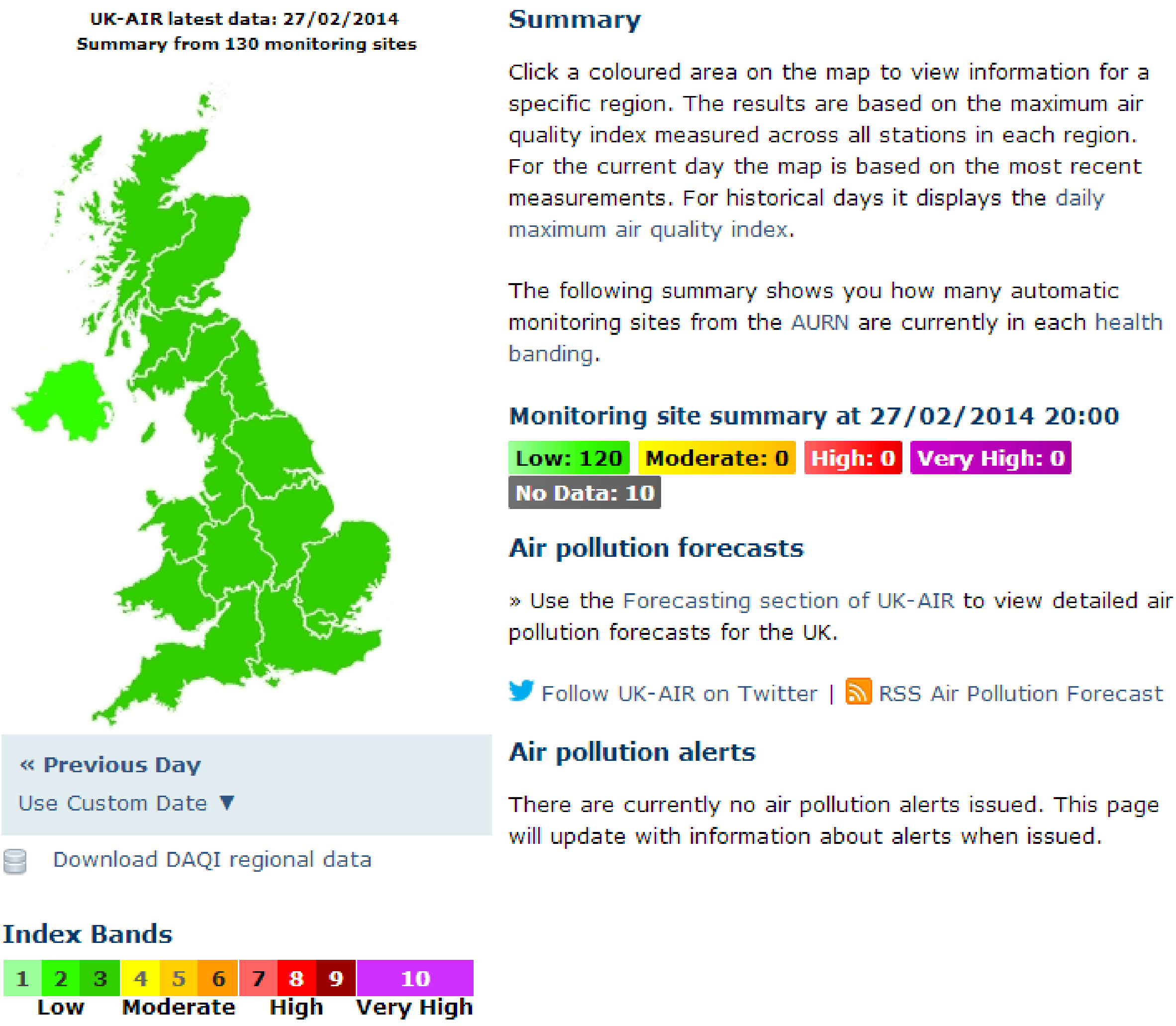


Figure 9 DAQI summary from www.uk-air.defra.gov.uk

3.5 Summary of AQI techniques

As outlined in this section, there are several key differences in AQI used globally (table 1). The key difference is whether the AQI was calculated based on known health effects, or whether the health effects are ascribed to the AQI bands. The number of bands also has a bearing on the end resolution of the AQI, directly influencing its usefulness. In the Auckland context, the Canada AQHI, whilst useful, may not applicable as current Auckland Council sites do not monitor the required group of pollutants at all ambient air quality monitoring sites, as shown in table 1.Table 1 Summary of key descriptors of AQI presented.

AQI	*Health effects based*	*Compliance based*	*Calculation Difficulty*	*Multiple pollutants used?*	*Number of bands*	*Currently reported on line*	*Applicable for Auckland?*
USEPA AQI	Ascribes risk to bands	Yes, NAAQS standards based	Simple	Highest AQI reported	6	Yes	Yes
Canada AQHI	Yes, splits population into 2 groups	No, purely health effects based	Medium	Yes, NO_2, O_3, $PM_{2.5}$	11	Yes	No – no Auckland Council sites measure the required combination of pollutants
NSW / Victoria AQI	Ascribes risk to bands	Yes, NEPM standards based	Simple	Highest AQI reported	6	Yes	Yes
DEFRA DAQI	Yes, bands were developed based on health effects	No, purely health effects based	No calculation – bands are based on ambient concentrations	Highest AQI reported	10	Yes	Yes

	Key strengths	*Key weaknesses*
USEPA AQI	• Proven technique with long history of use • Simple outputs • Backed by USEPA • Reports highest pollutant result as AQI	• Fiddly calculation
Canada AQHI	• Strong basis in health effects • High resolution scale	• Requires specific pollutants at sites for calculation
NSW / Victoria AQI	• Simple outputs	• Lower resolution scale
DEFRA DAQI	• High resolution scale • Health effects based • No calculation – based on classification of concentration	• Higher resolution potentially confusing for public

4.0 An AQI for Auckland – example data

This section presents 2013 PM_{10} data (24hr average, from Beta Attenuation Monitor sites (BAM)), using the DEFRA AQI and the NSW/Victoria AQI. These two methods were chosen as they represent two fairly different methods of AQI calculation. The NSW/Victoria AQI is based around compliance against ambient air quality standards, and thus the relevant standard drives the AQI value. This is a similar approach to the New Zealand EPI (MfE, 1998). The DEFRA method differs in that the index bounds are defined by acceptable health risk factors, published by the COMEAP group. Ideally, an AQI is reported in real-time, online or by smartphone apps. This section attempts to show how AQI data can be manually reported.

4.1 Reporting annual AQI data

Index values were calculated for all daily averages for PM_{10} for 2013. PM_{10} was chosen as it is a good indicator of ambient air quality, and is currently the focus of monitoring efforts in Auckland and New Zealand. The daily AQI for each site was calculated using the formula in section 2.3.1 (NSW/VIC AQI) and section 2.4 for the DEFRA method. The resulting index values were then converted to a percentage of days, and plotted (figures 10 and 11). Daily index values were also plotted on a calendar grid for each method, using data from Khyber Pass (figures 12 and 13). This site was chosen as in 2013 there were a good range of daily averages, from well under the NES-AQ to exceeding the NES-AQ.

Figures 10 and 11 highlight the differences between the two AQI methods used here. Given that the DEFRA AQI had more index bands, figure 5.2 shows the actual AQI values in greater detail, which potentially conveys more information to the user. For example, the Khyber Pass bar in the DEFRA example uses 5 different bands to cover the low to moderate range, where the NSW / Victoria example uses only 2 bands to cover the same range. Given the recent assertions in literature around no safe levels for pollutants (WHO, 2013A,B), it makes sense for AQIs to convey as much information, even at low AQI values as possible.

Figures 12 and 13 show a similar pattern. The calendar plot method is an extension of a method used by Mintz et al (1994), who asserted that when constructed carefully similar plots conveyed temporal patterns in an easy to understand manner. Again, the resolution of the DEFRA method allows more detail to be shown in the plot. The NSW / Victoria method again appears to present an overly simplified representation. The calendar plot however, is a powerful tool for summarising yearly data in a meaningful manner. The public can easily assess ambient air quality through time, without understanding of guidelines and standards. Days of high AQI (as thus concentrations) are obvious, such as those seen on March 7 and October 28th, both exceedances of the NES-AQ (MfE, 2014).

Both graphical approaches presented provide meaningful reporting of AQI. The percentage of days (figure 10 and 11) perhaps provide a good way of summarising the entire network, as sites can be directly compared, useful for annual reporting and tracking trends. The calendar plot, whilst designed to report annual scale data, could be used in real time, updated daily on a website. For annual reporting, it also conveys higher resolution data, in that daily values are presented through time.

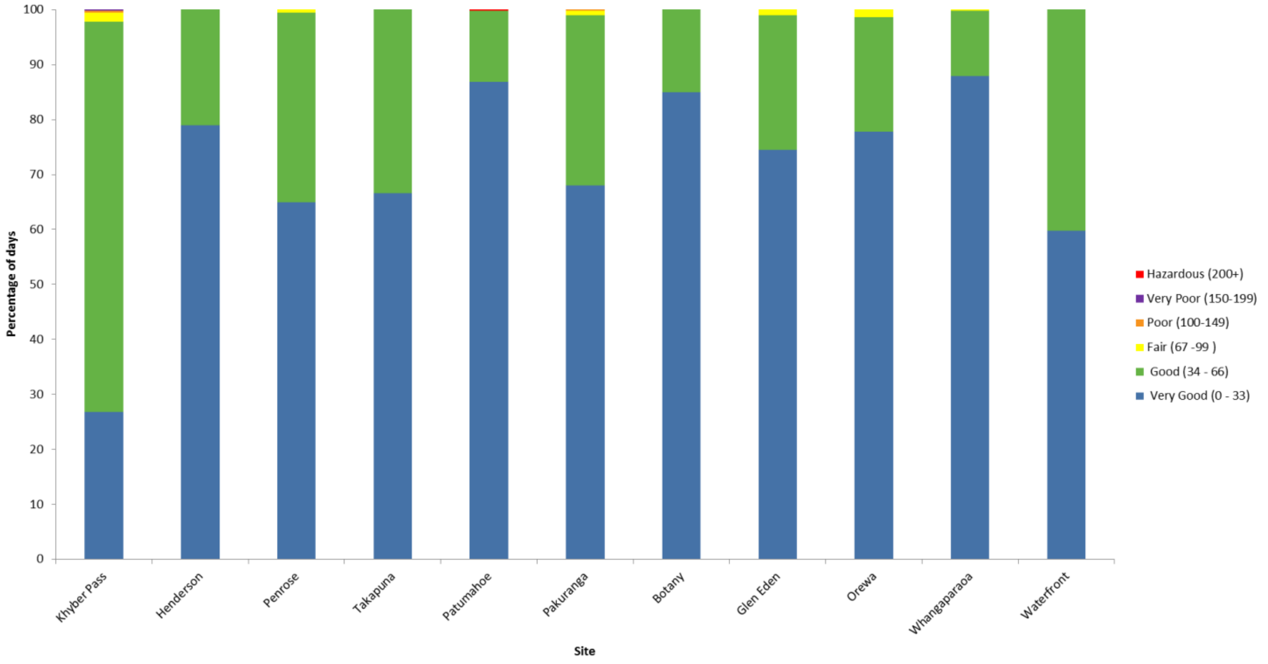


Figure 10 2013 PM_{10} AQI for Auckland ambient air quality sites (NSW/Victoria method)

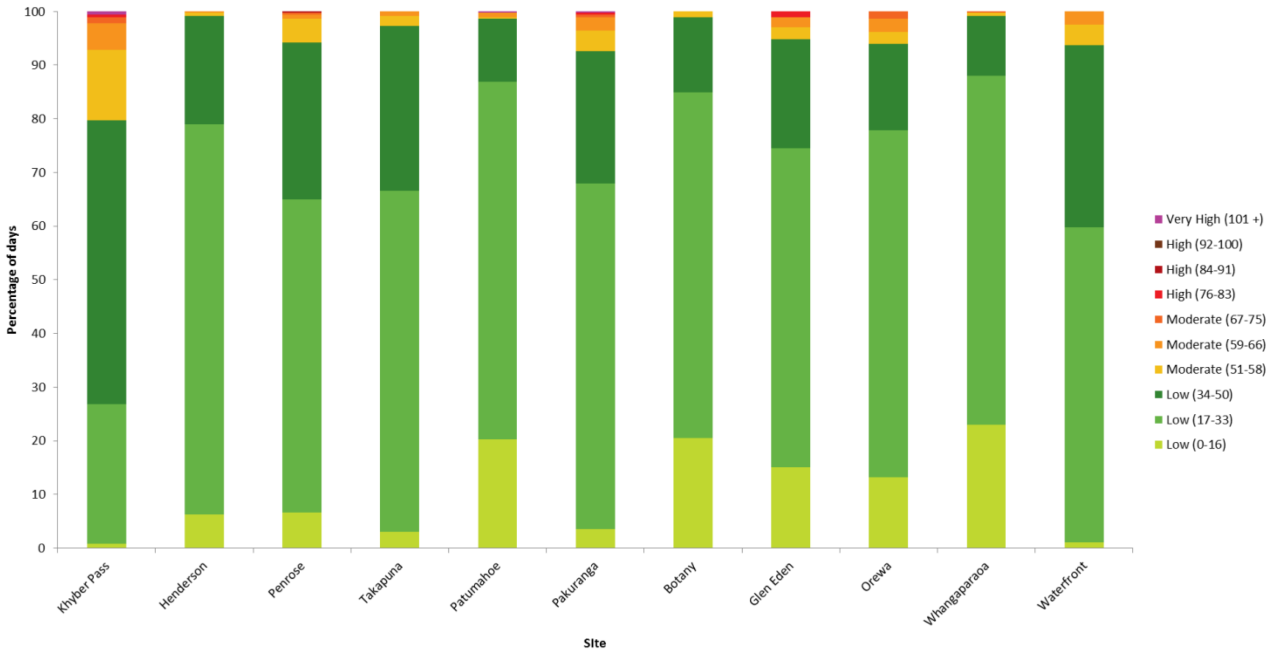


Figure 11 2013 PM_{10} AQI for Auckland ambient air quality sites (DEFRA method)

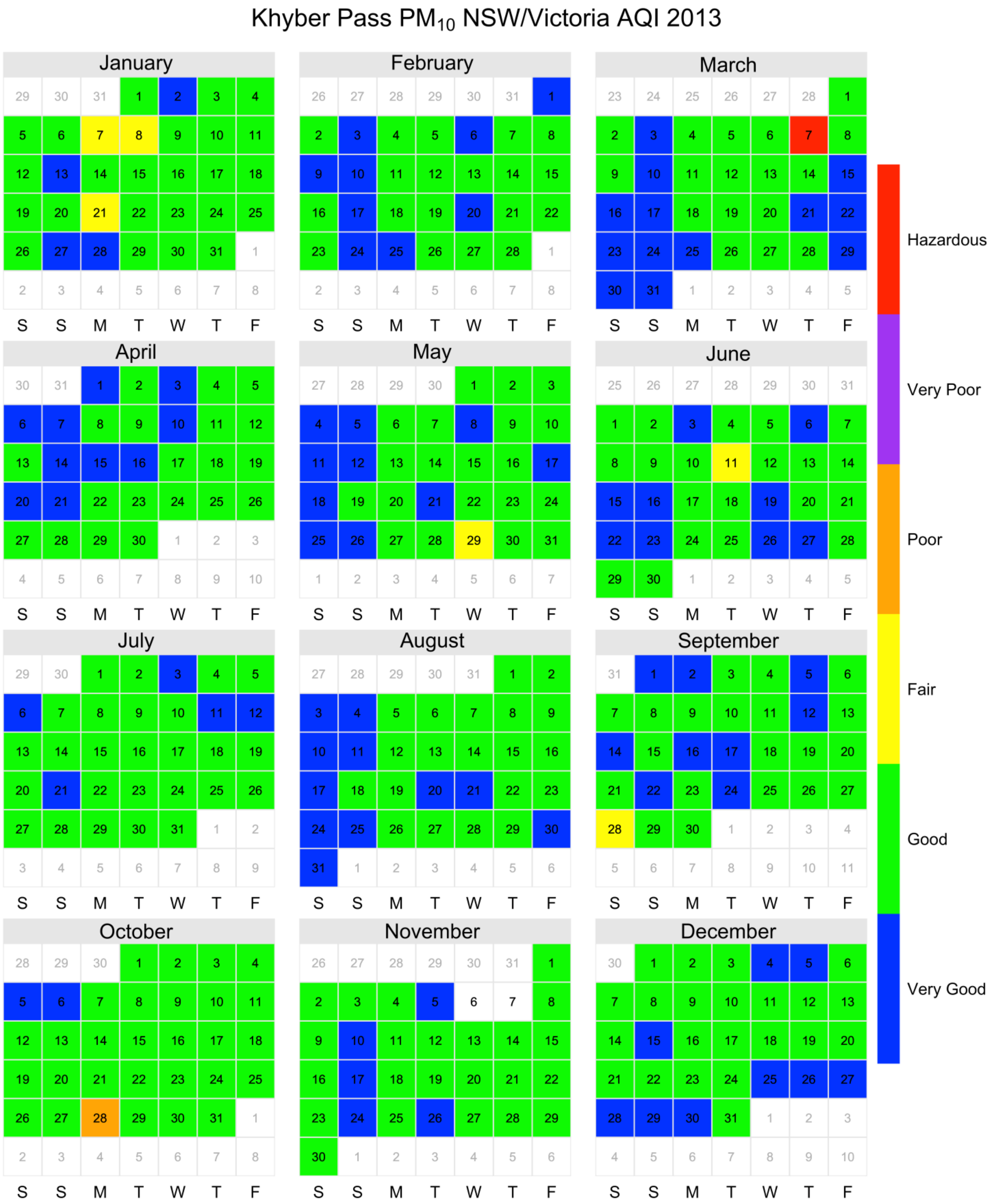


Figure 12 2013 PM_{10} AQI for Khyber Pass ambient air quality site (NSW / Victoria method)

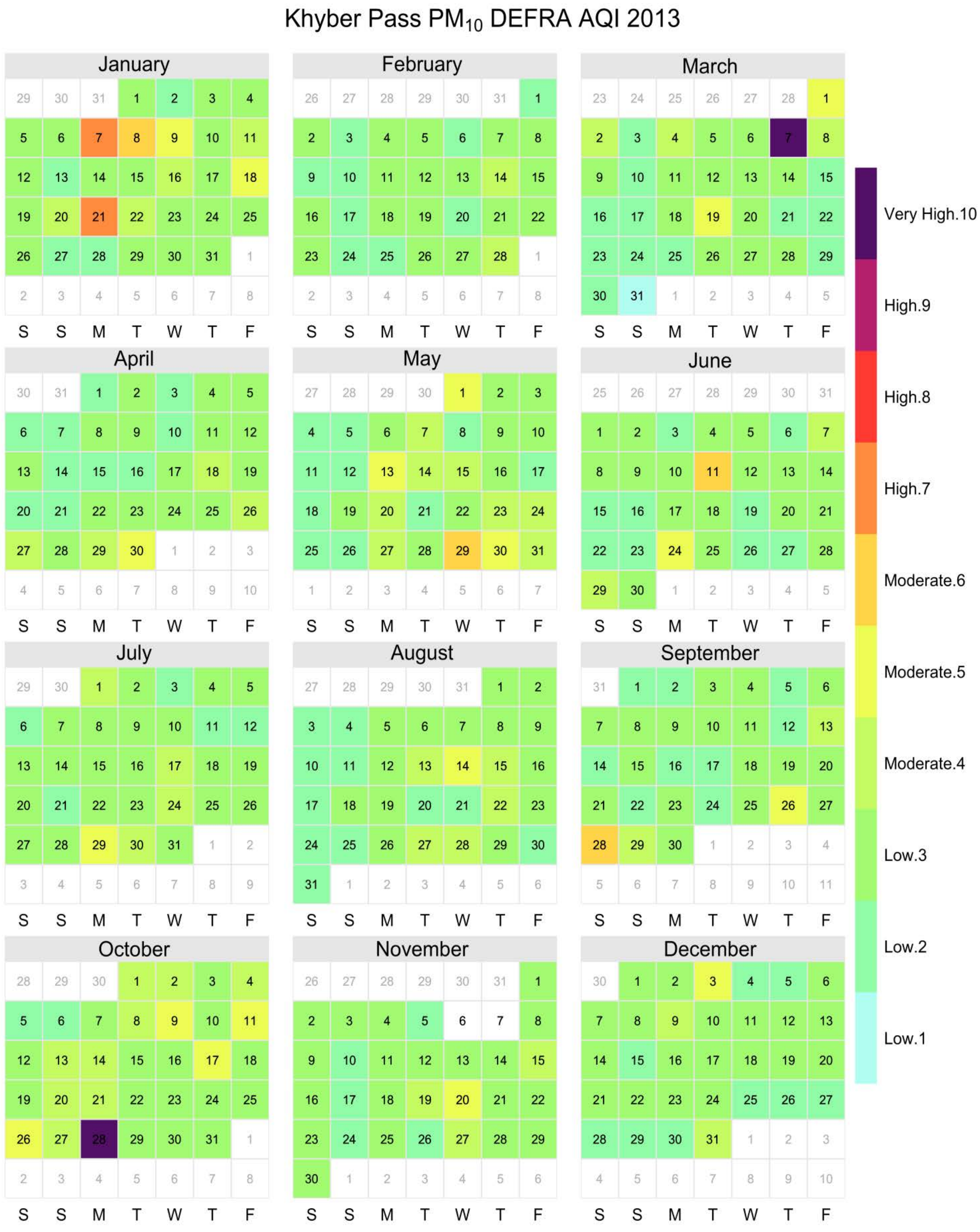


Figure 13 2013 PM_{10} AQI for Khyber Pass ambient air quality site (DEFRA Method)

4.2 Reporting AQI Trends

AQI can be used for reporting annual trends to the public. Whilst these outputs are perhaps not sufficient for long term trend analysis, they provide a quick summary for the public of differences between years. Figures 14 and 15 present both 2012 and 2013 daily average PM_{10} AQI using the DEFRA method.

Figure 15 allows comparison between years, and sites. This allows quick assessment of differences between years. The plot is however rather busy. In figure 14, AQI data from Khyber Pass and Takapuna have been separated. At the percentage of days falling in each AQI band remains fairly steady between 2012 and 2013. In 2013 however, there were exceedances of the NES-AQ for PM_{10}, and accordingly there is a small 'very high' percentage shown on the plot. Broadly speaking, 2013 had generally higher AQI values, and thus lower ambient air quality. At Takapuna, 2012 was a much better year than 2013, with a high percentage of Low AQI values. Again, a very broad comment can be made that 2012 was a better ambient air quality year at Takapuna.

There are obvious differences in the AQI results for Takapuna and Khyber Pass. At Takapuna, the vast majority of daily AQI values fall within the low bands, with a small proportion of Moderate days (0.5 – 1 %). At Khyber Pass however, the AQI falls into the moderate band between 10-15% of the time.

This approach allows the public to make informed decisions about ambient air quality in different parts of Auckland. For example, at a glance in figure 15, the lower AQI values recorded at Whangaparoa and Patumahoe (rural background sites) show the influence of the city and people's daily activities on ambient air quality well.

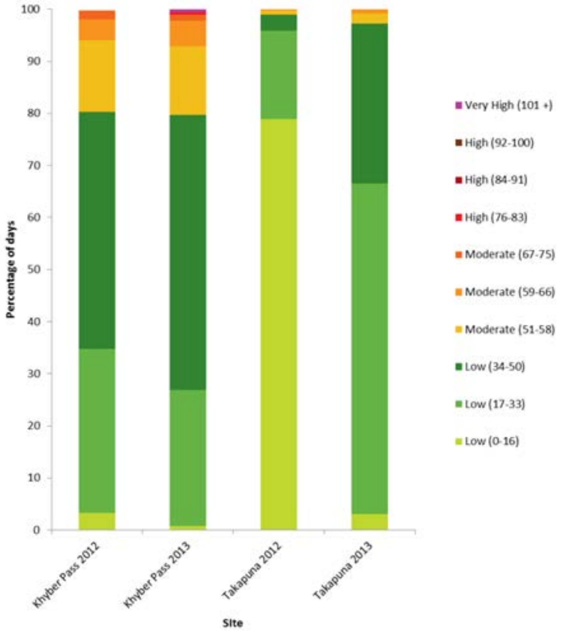


Figure 14 2012 and 2013 PM_{10} AQI for Khyber Pass and Takapuna ambient air quality sites (DEFRA method)

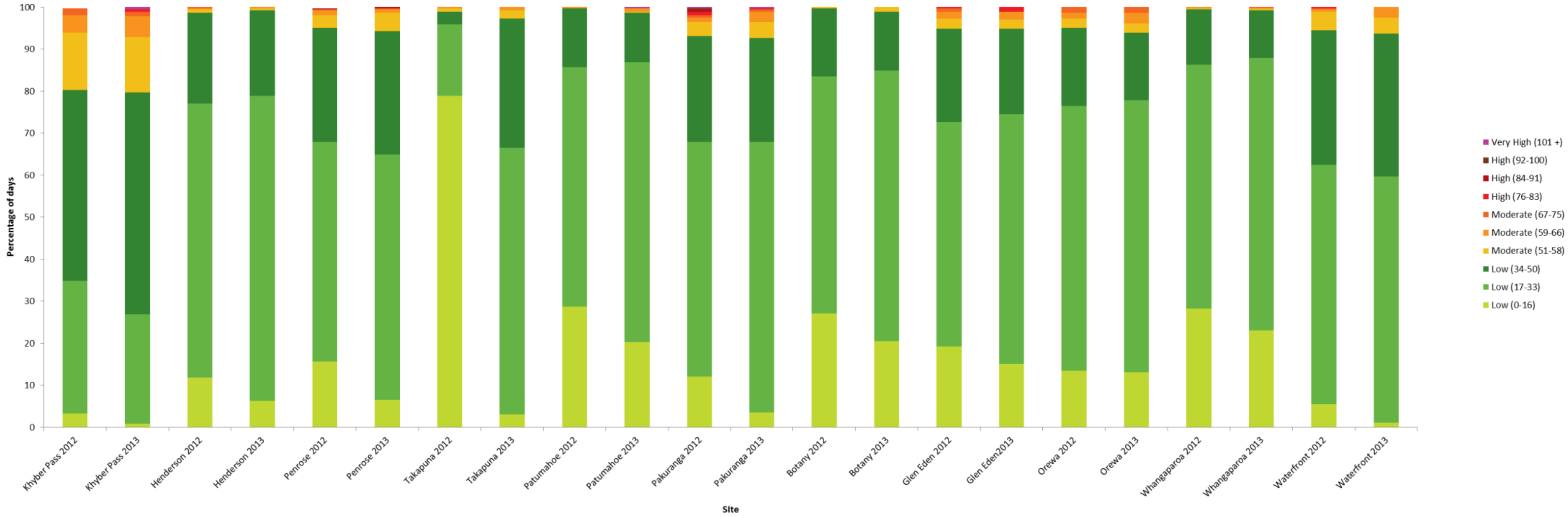


Figure 15 2012 and 2013 PM_{10} AQI for Auckland ambient air quality sites (DEFRA method

5.0 Recommendations for Auckland

Internationally, AQI are regarded as best practice for reporting ambient air quality data to the public (Van den Elshout, 2014). A commitment to reporting a meaningful AQI to the public will assist Auckland to achieve the 'world's most liveable city' vision, and deliver on objectives and strategies outlined in the Auckland Plan and PAUP (Auckland Council, 2013A,B).

Current reporting of ambient air quality data is not sufficient to allow the public to make informed decisions on health effects and risks of reduced ambient air quality, due to frequency and content of reporting. Reporting a dynamic problem through a static medium is not appropriate. A meaningful, real-time AQI, which is easily accessible, represents an agile and dynamic solution.

Providing access to an AQI will potentially allow the public to make changes to their activities to both positively impact ambient air quality, and to minimise the risks to their health.

This report recommends:

- Auckland Council begin a process to establish an AQI
- Auckland Council form an interdisciplinary project team (including external parties such as NIWA, universities) to begin developing an AQI for Auckland
- Future air quality strategy should include a means of reporting ambient air quality using an AQI to augment existing activities
- Report AQI in an easily understandable manner, suitable for public use
- Health effect based AQI is recommended as tools are already in place for tracking progress around NES-AQ compliance
- Make AQI information available through Auckland Council websites and on a smartphone app
- Consider a 'tool' approach – e.g. the final AQI has meaning nationally, and can be used by other regional councils, with a view to a national AQI. Potentially funded by Envirolink
- Investigate whether a national AQI could be endorsed by MfE, and centrally reported

6.0 Acknowledgements

The authors would like to thank the reviewers for their helpful comments which greatly strengthened this report.

7.0 Glossary

List of Abbreviations

AP	Auckland Plan
AQI	Air Quality Index
AAAQS	Ambient Air Quality Standards
AC	Auckland Council
BAM	Beta particle attenuation monitor
CO	carbon monoxide
EPI	Environmental Performance indicators
MfE	Ministry for the Environment
NAAQS	National Ambient Air Quality Standards
NES	New Zealand National Environmental Standard
NES-AQ	National Environmental Standards for Air Quality
NO_X	nitrogen oxides
NO_2	nitrogen dioxide
NSW	New South Wales
PAUP	Proposed Auckland Unitary Plan
PSI	Pollutant Standard Index
PM	particulate matter
PM_{10}	particulate matter less than 10 microns
$PM_{2.5}$	particulate matter less than 2.5 microns
O_3	ozone
RAQT	Auckland Regional Air Quality Target
RMA	Resource Management Act (1991)
SO_2	sulphur dioxide
UK	United Kingdom
USA	United States of America
USEPA	United States Environment Protection Agency
VIC	Victoria (Australian state)
WHO	World Health Organisation

8.0 References

Auckland Council, 2013A. The Proposed Auckland Unitary Plan (notified 30th September 2013).

Auckland Council, 2012. The Auckland Plan.

Bickerstaff, K., and Walker, G., 1999. Clearing the smog? Public responses to air quality information. *Local Environment, 4,* 279-294.

Cheng, W., Chena, Y., Zhang, J., Lyons, T., Paid, T. and Chang, S. 2007. Comparison of the Revised Air Quality Index with the PSI and AQI indices. *Science of The Total Environment, 382,* 191-198.

Cheng, W., Kuo, Y., Lin, P., Chang, K., Chen, Y., Lin, T. and Huang, P. 2003. Revised air quality index derived from an entropy function. *Atmospheric Environment, 38,* 383-391.

Evans, G., Colome, D., and Shearer, D. 1988. Psychological reactions to air pollution. *Environmental Research, 45* 1-15.

Johnson, B, 2002. Gender and race in beliefs about outdoor air pollution. *Risk Analysis, 22,* 725-738.

Johnson, B, 2003. Communicating air quality information: Experimental evaluation of alternative formats. *Risk Analysis 23, 91-103.*

Ménard, S., Gravel, S., Moran, M., Landry, H., Kallaur, A., Pavlovic, R., Makar, P., Stroud, C., Gong, W., Chen, J., Anselmo, D., and Cousineau, S. 2014. Current and Future Developments in Numerical Air Quality Forecasting in Canada. *Air Pollution Modelling and its Application XXIII Springer Proceedings in Complexity*, 629-633

MfE, 1998. Environmental performance indicators: Confirmed indicators for air, fresh water and land. MfE report.

MfE, 2014. Users Guide to the National Environmental Standards for Air Quality 2011: 2014 update. *Ministry for the Environment, report number 1141*.

Mintz, D., Fitz-Simons, T., and Wayland, M. 1994. Tracking Air Quality Trends with SAS/GRAPH. *USEPA Report.*

Mintz, D. 2009. Technical assistance document for the reporting of daily air quality –the Air Quality Index (AQI). *USEPA Office of Air Quality Planning and Standards Report,* EPA-454/B-09-001

Resource Management Act 1991.

Steib, D., Paola, J., and Neuman, K. 1996. Do Smog advisories work?: Results of an evaluation of the Canadian Smog Advisory Program. *Canadian Journal of Public Health, 87*, 166-169.

Stevens, S. 2014. Communicating About Air Quality—Lessons From Canada's AQHI. *Air Quality Management.* Springer, pp 365-377.

Taylor, E., and Hasselback, P., 2010. Air Quality Health Index variation across British Colombia. *British Colombia and Interior Health report.*

USEPA, 2012. The National Ambient Air Quality Standards for Particle Pollution: Revised air quality standards for particle pollution and updates to the Air Quality Index (AQI)*. USEPA Technical bulletin.*

Van den Elshout, S. 2008. Comparing urban air quality in Europe in real time: A review of existing air quality indices and the proposal of a common alternative. *Environment International* 34(5) 720-726.

Van den Elshout, S. 2012. CAQI index: Comparing Urban Air Quality across Borders. CITEAIRII report, European Union.

Van den Elshout, S., Légerb, K., and Heichc, H. 2014. CAQI Common Air Quality Index — Update with PM2.5 and sensitivity analysis. *Science of The Total Environment* 488-489 461-468.

WHO, 2005. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide Global update 2005: Summary of risk assessment. *WHO/SDE/PHE/OEH/06.02*

WHO, 2013A. Review of evidence on health aspects of air pollution (REVIHAPP): First Results. *WHO Report.*

WHO, 2013B. Health risks or air pollution in Europe – HRAPIE project: New emerging risks to health from air pollution – results from the survey of experts