Review of Air Quality Index and Air Quality Health Index

Environmental and Occupational Health

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January 30, 2013

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Ontario Agency for Health Protection and Promotion (Public Health Ontario), Chen H, Copes R. Review of air quality index and air quality health index. Toronto, ON: Queen's Printer for Ontario; 2013.

ISBN 978-1-4606-0936-1 [PDF]
ISBN 978-1-4606-0934-1 [Print]

Executive Summary

Over the past 30 years, epidemiological research has demonstrated adverse health effects from short-term (i.e., day-to-day) fluctuations in ambient levels of air pollution. In addition, repeated exposures to ambient air pollution over a prolonged period of time (i.e., years) have been shown to increase the risk among healthy individuals of developing and dying from cardiovascular disease, respiratory disease, and lung cancer. To characterize ambient levels of air pollution present at a given time and location, and to serve as the basis for communicating the health significance of air pollution to the public, many countries including Canada have developed numerical indices of air quality. There are currently two indices in use in Ontario, Canada: the Air Quality Index (AQI) and the Air Quality Health Index (AQHI).

Given the need to provide best available evidence in supporting public health policy decision-making regarding the use of the AQI and the AQHI, and the continuous advances in knowledge on air health effects, we conducted a study to examine the strengths and limitations of the two indices.

We reviewed the formulations of the two indices. We searched the literature for studies associating the two indices with ambient air pollutants and adverse health outcomes. In addition, using hourly concentrations of six air pollutants (e.g., $PM_{2.5}$, NO_2) measured at 47 fixed-site stations in Ontario, 2003-2010, we assessed how the two indices may have performed with respect to identifying high air pollution days and with respect to the number of advisories that would be issued with current trigger levels. Furthermore, we reviewed possible modifications to the AQHI made by different provinces of Canada and their pilot studies of implementing this index.

The Air Quality Index is calculated by comparing the concentrations of selected air pollutants to their established air quality objectives and criteria, and is based on the concentration of a pollutant that is highest relative to its standard. The pollutants considered in the AQI are $PM_{2.5}$, O_3, NO_2, SO_2, CO, and total reduced sulphur compounds (TRS). The numeric AQI index is classified into five descriptive categories. The breakpoints between the AQI categories are derived from air quality standards or mathematical extrapolation. Currently, there is a lack of empirical evidence supporting a quantitative relationship between the AQI and known health effects.

The Air Quality Health Index directly makes use of the exposure-response relationship between air pollution and health from a time-series study of 12 major cities in Canada. Under an assumption of additive health effects of $PM_{2.5}$, NO_2, and O_3, the AQHI is calculated as the sum of excess mortality risk associated with the three pollutants, adjusted to a 1-10+ scale which is subdivided into four categories. The AQHI incorporates $PM_{2.5}$, O_3, and NO_2. The formulation of AQHI is derived from observed linkage between ambient air pollutants and short-term mortality.

Although we were not able to identify any published study in which the relationship between the AQHI and morbidity was assessed, there are some preliminary analyses suggesting that daily variation in AQHI may be associated with asthmatic- and cardiac-related morbidity.

From the quantitative comparison of the AQI and the AQHI, the AQHI was more closely related to the mixture of air pollutants than the AQI. The correlation between the two indices was stronger in the warm season than the cool season, and in rural than urban areas. As well, the AQHI was found to be a better predictor of AQI than vice versa. While AQI-based smog advisory days occurred mostly in warm season, high-risk days may also occur in cold seasons, according to the AQHI. From 2003-2006, the AQHI tended to trigger more advisory days than the AQI. In more recent years (2007-2010), absolute difference in the number of advisory days between both indices was no longer appreciable. In extreme air pollution episodes, the AQI was found to be more responsive to transient changes of O_3 and $PM_{2.5}$, whereas the AQHI was more responsive to NO_2, a marker for traffic-related air pollution.
An important limitation of both indices is their failure of recognizing possible health effects associated with chronic exposure to air pollution and the importance of spatial locations on increasing individuals' risk to ambient air pollution.

In making a choice between the AQI and AQHI, it is important to consider their strengths, limitations, as well as the intended use of the index, and the evidence supporting its effectiveness in this application.

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Acknowledgement

The authors thank Amira Aker (Environmental Health Analyst, Public Health Ontario) and Julia McIsaac (Occupational Medicine Resident, University of California, San Francisco) for their assistance in gathering information about possible modification to the AQHI and pilot implementation studies from other Canadian provinces. In addition, we would like to thank Dr. David Yap and Tony Munoz (Ontario Ministry of the Environment) for their assistance in providing air pollution datasets as well as background information regarding the AQI formulation. We further thank Dr. Teresa To (Sick Kids Hospital, Toronto) and Dr. Dave Stieb (Health Canada) for sharing preliminary results of their health studies relating to AQHI. Last but not the least, we thank Tonya Bruin (Health Canada) for providing additional AQHI-related documents.

Note to Readers

Due to limited air quality data, only selected rural communities such as Tiverton and Grand Bend were included in the analyses. As a result, the findings may not be generalizable to other rural communities with different mixes of air pollutants. In addition, we derived city-wide Air Quality Index (AQI) to allow direct comparison with the Air Quality Health Index (AQHI). In practice, the AQI levels are calculated for each monitoring site individually. The AQI levels estimated in the current analysis may not be the same as those published in the annual air quality reports by the Ontario Ministry of the Environment.

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Introduction

Over the past 30 years, considerable epidemiological research has demonstrated adverse health effects from short-term (i.e., day to day) fluctuations in ambient levels of air pollution. Associations have been found between exposures occurring on the day of the event or the preceding days and daily non-accidental mortality, cardio-respiratory deaths, hospitalizations, and emergency room visits.[1-19] There is also evidence that certain subgroups of the population are at higher risk.[20] The conclusion is clear: short-term elevations of ambient air pollution cause a variety of acute health events, especially in certain subgroups of the population, such as the elderly, children, and those who are impaired physiologically (e.g., congestive heart failure, diabetes, and cardiovascular disease).[13,21] More recently, several longitudinal studies[22-25] showed that repeated exposures to ambient air pollution over a prolonged period of time (i.e., years) increased the risk among healthy individuals of developing and dying from cardiovascular disease, respiratory disease, and lung cancer. Because of ubiquitous exposure to ambient air pollution in modern society, air pollution is now ranked as the eighth-leading cause of death among high-income countries.[26]

Present-day ambient air pollution is a complex mixture of hundreds of substances, including sulphur dioxide (SO_2), ozone (O_3), nitric oxide (NO), nitrogen dioxide (NO_2), carbon monoxide (CO), particulate matter (PM), rubber dust, polycyclic aromatic hydrocarbons (PAHs), and many different volatile organic compounds (VOCs). Particulate matter is also a heterogeneous mixture of solid and liquid droplets with wide distributions of size and mass. Coarse particles, greater than 2.5μm in median aerodynamic diameter, derive from a variety of sources including windblown dust and grinding operations, and fine particles (particles with diameter less than 2.5μm or $PM_{2.5}$) are primarily from the combustion of fossil fuel.[27] Common constituents of particulates include elemental and organic carbon, sulphates, nitrates, pollen, microbial contaminants, and metals.[27] Fine particles may also react with sulphur dioxide and oxides of nitrogen in the atmosphere to form strong acids, such as sulphuric acid, nitric acid, hydrochloric acid, and acid aerosols.[27] In addition, urban air also contains diesel exhaust, benzene and 1,3-butadiene that are considered carcinogenic.[28]

To characterize ambient levels of air pollution present at a given time and location, and to communicate the health significance of air pollution to the public, many countries including Canada and the USA have developed numerical indices of air quality. There are two types of indices of air quality: (1) the Air Quality Index or AQI that is calculated by comparing the concentrations of selected air pollutants to their established air quality objectives and criteria, and is based on the concentration of a pollutant that is highest relative to its standard [29-32] and (2) the Air Quality Health Index or AQHI that directly makes use of the exposure-response relationship between air pollution and health from a time-series study of 12 major cities in Canada.[33] Under an assumption of additive health effects of $PM_{2.5}$, NO_2, and O_3, the AQHI is calculated as the sum of excess mortality risk associated with the three pollutants, adjusting to a 1-10+ scale. The AQHI has been adopted by many provinces in Canada.[34] The AQI is still used in some parts of Canada such as Ontario and other countries such as the USA and UK.[29,31]

The indices of air quality have been used as a tool to communicate information about real-time and forecast levels of ambient air pollution to the public and to susceptible individuals.[29-32,34] However, there are concerns about the underlying formulations of these two indices. For example, one concern is that the AQI formula may fail to account for the health responses associated with the simultaneous exposure of multiple pollutants,[33] whereas the AQHI may not be generalizable to rural communities because its formula is based on data from selected large Canadian cities.[35] In addition, confusion has occurred among the public in some parts of Ontario where both indices are in use, because of conflicting information from these two indices with regard to high pollution days.[36] In light of continuous advances in knowledge on the effects of air pollution, and the need to provide best available evidence in supporting public health policy decision making regarding the use of the AQI and the AQHI, we conducted a study to assess the two indices.

Objectives

The objective of the study is to examine the strengths and limitations of the AQI and the AQHI. One may argue that the two indices may not be comparable because they were developed with different objectives in mind. However, our view is that comparison is reasonable because the health risk as estimated by the AQHI and the quality of the air as indicated by the AQI are not independent phenomena.

Methods

One focus of this study is on reviewing the formulations of the two indices, their relationship to known health outcomes, and their generalizability across Ontario. Of particular interest are rural areas in Ontario where elevated ambient ozone concentrations usually occur as a result of transboundary air pollution and in urban areas with many sources of fuel combustion leading to high local concentrations of NO_2. In addition, we assessed the extent to which the AQHI and the AQI may perform with respect to identifying high versus low air pollution days and with respect to the number of advisories that would be issued with current trigger levels. We also reviewed modifications to the two indices, if any, made in other provinces of Canada and the pilot implementation studies of the AQHI in Ontario and other provinces.

We searched the literature for peer-reviewed journal articles on the two indices. The search was performed using MEDLINE and GOOGLE SCHOLAR with the keywords *AQI*, *AQHI*, *Air Quality Index*, and *Air Quality Health Index*. We combined this search with the following terms: *air pollution*; *ambient*; *outdoor*; *gaseous*; *particulate; traffic* or *rural* and with the following health outcomes: *respiratory disease*; *cardiovascular disease*; *cancer*; *asthma*; *hospital admission*; *emergency department visit*; *lung function*; *COPD;* and *mortality*. We perused the bibliographies of these articles for additional pertinent papers. In addition, we searched for non-peer-reviewed technical reports through the websites of government and non-government organizations, including, but not limited to, Environment Canada, U.S. Environmental Protection Agency, World Health Organization, Canadian Council of Ministers of the Environment, the Ontario Ministry of the Environment, the British Columbia Ministry of Environment, and the Committee on The Medical Effects of Air Pollutants (UK). To further identify “grey” literature, we contacted domain experts in this field.

To assess quantitatively both indices with regard to identifying high versus low air pollution days, we made use of hourly concentrations of $PM_{2.5}$, NO_2, O_3, SO_2, CO, and total reduced sulphur compounds (TRS) measured from 2003 to 2010 at 47 fixed-site stations in Ontario, Canada, that were operated by the Ontario Ministry of the Environment.[37] For each of the 47 fixed-site stations, we calculated the AQI for every hour from 2003 to 2010 using the latest AQI equations.[30] If incomplete air pollution data occurred at a given hour, at least $PM_{2.5}$ and O_3 should be present in order to calculate the AQI, otherwise the AQI was set to missing (personal communication: Dr. David Yap, Ontario Ministry of the Environment). Similarly, we calculated the AQHI at the fixed-site stations for every hour during the 2003-2010 period. The AQHI was calculated based on the national index formula using the rolling three-hour average concentrations of $PM_{2.5}$, NO_2, and O_3 as described in Stieb and colleagues (2008). If data for more than one hour of the rolling three hour were missing, the AQHI was set to missing.[33] To calculate city-wide AQI and AQHI, we averaged air pollution data from all fixed-site stations in a city and then applied the above procedures to the city-average pollutant concentrations.

The inter-agreement between the AQI and AQHI was calculated two ways. (1) We estimated the correlations between co-located AQI and AQHI using Spearman’s correlation coefficients for each city and season. We also assessed the agreement between the categories of the two indices using Kappa Statistics. (2) We assessed the ability of one index to predict the other (in both directions) using coverage probability, computed as the proportion of times each category of one index contained the corresponding category of the other one. To assess the differences between the AQI and the AQHI, we followed the following four procedures: (1) we compared their correlations with the concentrations of individual air pollutants at all fixed-site stations in Ontario; (2) we compared the frequency distributions of individual air pollutants as primary contributors to each of the two indices; (3) we evaluated the frequency distributions of high AQHI hours (i.e., AQHI $\geq$ 7), high AQI hours (AQI > 50), high AQHI days (daily maximum AQHI $\geq$ 7), and high AQI days (daily maximum AQI $\geq$ 50) for each month, year and city; and (4) we assessed diurnal variations of the AQI and the AQHI in response to transient change in pollutant concentrations during high air pollution episodes for the 2003-2010 period.[38]

Because issuing smog advisories is an important use of air quality index, we compared the number of smog advisories derived from the two indices. The AQI is currently integrated with the smog advisory, but the AQHI is not. In consultation with the Ontario Ministry of the Environment, we chose a triggering criterion for AQHI-based smog advisory as AQHI $\geq$ 7 for six hours or more. We applied the same persistence criterion to AQI (i.e., an AQI-based advisory would be issued if AQI value > 49 for six hours or more). This would allow the AQI- and AQHI-based advisories to be more comparable. It is important to note that in practice, AQI-based smog advisories in Ontario are issued when air quality is forecasted to be in poor category based on expectation of elevated, widespread and persistent levels of O_3 and/or $PM_{2.5}$. What constitute widespread and persistent is inherently arbitrary. Although it is appropriate to consider six consecutive hours as the persistence criterion in this sensitivity analysis, our estimated numbers of smog advisories can only be interpretable in this context.

Other sensitivity analyses were conducted with the AQHI by lowering the breakpoint between the moderate health risk and the high health risk categories from 7 to 6 to assess its impact on the number of high AQHI days. We then assessed the frequency distributions of high AQHI days based on the new breakpoint. As well, sensitivity analyses were conducted to evaluate uncertainty inherent in the formulation of AQHI. One important source of uncertainty in the AQHI is the coefficient of the three-hour maximum concentration of $PM_{2.5}$ because it is extrapolated using the ratio of a coefficient based on three-hour maximum concentration for the 1998-2000 period to that based on 24-hour concentration for the same period.[33] To estimate the statistical uncertainty, we used Monte Carlo sampling (100,000 replications) to repeatedly sample from the prior for this ratio. For each coefficient used in the ratio, we specified normal distribution with mean value equal to the coefficient and standard deviation equal to its standard error. From the resulting distribution, we considered the median as a new coefficient of $PM_{2.5}$ in the AQHI formula. We then analyzed the frequency distribution of high AQHI days (daily maximum AQHI $\geq$ 7) for each month and year for each city. This analysis was repeated by using the 25th and 75th percentiles of the distribution as new coefficients of $PM_{2.5}$, respectively.

In addition, we contacted other Canadian provinces to gather information regarding their possible modification to the AQHI. We also reviewed pilot studies that implemented the AQHI in Canada.

Air Quality Data, 2003-2010

The Ontario Ministry of the Environment administers a network of fixed-site air quality monitors in Ontario (***Figure 1***). The number of fixed-site monitors varied from 38 to 41 each year during the period of 2003 to 2010. They were located in a total of 33 cities and towns. The fixed-site monitors made continuous measurements of common air pollutants near real-time. The concentrations of O_3 and $PM2_{.5}$ were measured in all 33 cities and towns. In addition, NO_2 was measured in 29 cities and towns, SO_2 in 25, CO in 20, and total reduced sulphur compounds in five cities and towns.

Air Pollutants For Inclusion

The pollutants included in the Ontario AQI (referred to as the AQI) are $PM_{2.5}$, O_3, NO_2, SO_2, CO, and total reduced sulphur compounds (TRS). (The Ontario AQI is somewhat different from those used in other countries such as the United States. A discussion of the U.S. version of AQI was provided in this report.). At any given time the AQI is based on only one pollutant. In contrast, the AQHI is always the weighted sum of $PM_{2.5}$, O_3 and NO_2.

There is a large body of evidence linking short-term and long-term exposures of particulate matter to increased cardiopulmonary morbidity and mortality.[22,24,39-42] A study performed in 112 U.S. cities revealed a 0.9% increase in cardiovascular-related mortality and a 1.68% increase in respiratory deaths for a 10 $\mu g/m^3$ increase in two-day average $PM_{2.5}$.[19] The coherence of effects observed across studies done in 29 European cities[14] and various cities in Canada,[2,6,11,12,41] China,[43,44] and Japan[16] further substantiated the evidence for a causal association of particulate matter and cardiopulmonary morbidity and mortality.

Ozone and NO_2 have been studied extensively in both animals and humans. Both gases are relatively water insoluble and reach lower into the respiratory tract[27], where they can cause airway hyperresponsiveness, airway inflammation, lung injury, and impaired host defence.[45] Epidemiological studies have demonstrated significant adverse respiratory effects associated with increased ozone level well below Ontario Ambient Air Quality Criteria (1-hour: 80ppb) and National Ambient Air Quality Objectives (Maximum acceptable level: 82ppb). For example, in a study with 59 healthy young adults aged 19-35 who were exposed to 60 ppb ozone for 6.6 hours, Kim and colleagues found that exposure to the concentration of ozone below the current ozone standard for 6.6 hours resulted in a statistically significant decrement of FEV1 and an increase in neutrophilic inflammation in the airways, a marker for airway inflammation.[46] As for NO_2, analyses of the European data suggest that exposure to NO_2 was associated with cardiovascular-related mortality.[14] Because NO2 is highly correlated with other primary and secondary combustion products, it is a challenge to disentangle specific NO_2-related health effects as distinct from those effects of the whole traffic-related combustion mix. As a result, it remains unclear to what extent the health effects observed are actually attributable to NO_2 itself.[47] In any case, current epidemiologic data show that exposure to ozone and NO_2 can cause bronchoconstriction in both normal and asthmatic people.[48,49]

For SO_2, the acute bronchoconstrictive effects from this pollutant have been well documented in the literature.[50] For instance, controlled human exposure studies show clear relationship between inhalation of high concentrations of SO_2 and increased airway resistance in asthmatics[51-53] and in healthy normal volunteers.[50,54] Studies that focused on asthmatics have shown that patients with asthma are especially sensitive to the bronchoconstrictive effects of SO_2 and react to much lower levels.[53,55,56] In addition to the acute bronchoconstrictive effects, there is epidemiological evidence for cardiovascular-related mortality due to exposure to elevated levels of SO_2.[57]
The adverse effects of carbon monoxide have been documented in clinical observations of

patients with CO intoxication and in experimental and epidemiologic studies of individuals exposed to ambient-level CO.[58] The association between short-term variations in ambient CO concentrations and exacerbation of heart disease has been consistently reported in epidemiological and human clinical studies.[59] There is also suggestive evidence of a causal relationship between short- and long-term exposure to ambient CO and central nervous system effects as well as birth outcomes and developmental effects.[59] With respect to TRS, there is little evidence to draw any conclusion on its possible health effects. TRS was considered in the AQI mainly as a marker for odour.

Overall, there is strong evidence associating $PM2_{.5}$, O_3, NO_2, SO_2, and CO to a variety of health outcomes. In addition, a finding from recent research is that the exposure-response relationship between common air pollutants and cardiopulmonary effects is relatively linear with no observable threshold for pollutants such as $PM_{2.5}$ and NO_2.[22,49] The apparent absence of threshold concentrations has an important implication for how a level of the air quality standard is set, which will in turn determine how the AQI can be calculated.

Air Quality Index

The AQI was developed by the Ontario Ministry of the Environment to reflect possible health and environmental impacts (e.g., vegetation, property and visibility) associated with ambient air pollution.30 It is based on a scale from 0 to 100, with cautionary statement made for specific AQI levels. Site-specific AQI values are published every hour on the Ministry's AirQuality website (*http://www.airqualityontario.com/*).

Formulation of Air Quality Index

The equations of the AQI are provided in *Table 1*. In each hour, a sub-index is calculated for each pollutant. A highest sub-index becomes the Air Quality Index.

Although different equations are given for each AQI category and for each pollutant (***Table 1***), the relationship between the AQI and the hourly concentrations of pollutants is approximately linear (***Figure 2***). As a result, the AQI formula can be simplified into a simple linear regression model as follows:

$$\text{AQI} = \max\{B_i * \text{pollutant}_i\} \qquad (1)$$

where AQI is the maximum value for the sub-index calculated using the hourly concentration of individual pollutant *i* (i=1,…, 6), and B_i refers to a slope that is constant for pollutant *i* but differs from that of other pollutants. ***Figure 2*** illustrates that the slopes of $PM_{2.5}$ and O_3 are much steeper than that of NO_2 and SO_2. B_i is determined entirely by the air quality standards/guidelines. Considering the AQI as a simple linear function of individual pollutants should make clear why and under what circumstance the AQI and the AQHI may behave similarly. As will be described in a later section, the AQHI can be thought as a simple linear combination of three air pollutants (for more details see Equation 3).

The numeric AQI index is classified into five descriptive categories: (1) very good (0-15); (2) good (16-31); (3) moderate (32-49); (4) poor (50-99); and (5) very poor (>100). Each category is accompanied by a color scale.

Setting Breakpoints between AQI Categories

The breakpoints between the AQI categories are derived from the Ontario's Ambient Quality Criteria (AAQC), Canada-Wide Standard (CWS), National Ambient Air Quality Objectives (NAAQOS) (i.e., maximum desirable, acceptable, or tolerable levels), or mathematical extrapolation. ***Table 2*** describes the rationale for setting breakpoints between AQI categories.[60]

For 1-hour CO, the breakpoint between "Moderate" and "Poor" AQI categories is based on Ontario's AAQC (1-hour CO: 30ppm) while the breakpoint between "Very good" and "Good" AQI categories corresponds to NAAQOS (Maximum desirable level: 13ppm) (***Table 2-A***). Averaging these two standards would then result in the breakpoint between the "Good" and "Moderate" categories (~22ppm).

For 1-hour NO_2, the cut-off point of the "Moderate" level is determined using the AAQC of 200 ppb and close to the NAAQOS Maximum

Acceptable Level of 213 ppb (400 μg/m^3). The maximum concentration of the "Poor" level range (524 ppb) is close to the NAAQOS Maximum Tolerable Level of 532 ppb. The remaining AQI level ranges are derived through extrapolation.

The AQI level for O_3 is considered "Good" at a level below the NAAQOS Maximum Desirable Level of 100 μg/m^3 or ~50 ppb (***Table 2-D***). The "Moderate" level is defined as levels below the AAQC of 165 μg/m^3 (82.5 ppb) and NAAQOS Maximum Acceptable Level of 160μg/m^3 (80 ppb), and the AQI level is considered "Poor" at levels below the NAAQOS Maximum Tolerable Level of 300μg/m^3 (150 ppb). The "Very Good" level is determined through extrapolation.

Similarly, the 3-hour breakpoint value (45μg/m^3) for $PM_{2.5}$ between the "Moderate" and "Poor" categories was derived from the 24-hour Canada-wide Standard of 30μg/m^3 (***Table 2-E***). The remaining AQI levels are determined through extrapolation from the CWS.

Scientific Basis for Air Quality Index

Because of close relationship between the AQI and existing air quality standards, the scientific basis for AQI is directly linked to that of the standards. The Canada-Wide Standards, National Ambient Air Quality Objectives, and Ontario's AAQC are established for the criteria air pollutants separately. Particulate matter is considered as a single pollutant based on total mass and size distribution without consideration of its chemical form. Given that the AQI is dominated by O_3, $PM_{2.5}$, and NO_2 in almost all occasions (as can be seen in ***Table 15***), we focused our review of existing air quality standards for these three pollutants.

Current Ontario and Canadian standards for NO_2. The NO_2 standards described have not been updated since 1987. Derivation of the NAAQOS levels is described in the 1988 report, *Review of National Ambient Air Quality Objectives for Nitrogen Dioxide: Desirable and Acceptable Levels*, by the Federal-Provincial Advisory Committee on Air Quality. In preparing this report, toxicological, clinical and epidemiological studies were reviewed. There were few data concerning the effects of short-term exposure at concentrations less than 940 μg/m^3 at the time of this report. Therefore, a safety factor of 2 was added to derive the one-hour average maximum acceptable objective of 400μg/m^3.

In comparison, the US Environmental Protection Agency (US EPA) updated their NO_2 standards in 2010 to 200μg/m^3 or 106 ppb, based on the 98% percentile averaged over the last three years. The rationale behind the change was an update in the available research of the short-term and long-term health effects of NO_2 on human health from the 2003 standard. The Integrated Scientific Assessment for Oxides of Nitrogen report (2008)[49] summarized research available from 1993 to determine the health threshold. A total of 165 epidemiological studies that focused on NO_2 exposure and respiratory related symptoms, morbidity and mortality demonstrated consistent positive associations. Mean 24-hour average concentrations of NO_2 were in the range of 3 to 70 ppb among those studies, and maximum 1-hour concentrations ranged from 100 to 300 ppb. The epidemiological evidence is further supported by published clinical and animal studies during this period.

Similarly, the 2005 updated WHO air quality guidelines set a guideline of 200μg/m^3 or 106 ppb for NO_2, which is based on pulmonary responses in human and animal studies. In the WHO report, the lowest level of NO_2 to affect pulmonary function was found to be 560µg/m^3, but other studies have shown bronchial responsiveness in asthmatics at levels as low as 200µg/m^3, which formed the basis for the WHO guideline.

However, as no threshold has been identified for the exposure-response relationship of NO_2 and mortality, adverse health effects due to exposure to traffic-related combustion gases as represented by NO_2 likely occur even at levels below the standards set by US EPA and WHO.

Current Canadian standards for $PM_{2.5}$. The derivation of the CWS built upon the Science Assessment Document results for the NAAQOS for PM (1998) (*http://www.hc-sc.gc.ca/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/air/naaqo-onqaa/particulate_matter_matieres_particulaires/summary-sommaire/98ehd220.pdf*). The reference levels determined by the document refer to "several key epidemiological studies" that focused on mortality and hospitalization endpoints to establish an exposure-response relationship, but the specific studies used to establish that exposure-response relationship were not identified explicitly. The Science Assessment Document does reference one particular study that found a 1.5% increase in the overall mortality in six U.S. cities per 10 µg/m^3 increase in $PM_{2.5}$. In this study, the average exposure rates of $PM_{2.5}$ ranged between 11-30 µg/m^3. Although the Science Assessment Document recognized the lack of a demonstrated threshold for $PM_{2.5}$, a reference level was set at 15µg/m^3.

Canadian Council of Ministers of the Environment (CCME) released a document in 2004 to update the CWS based on emerging studies since 1997 (*http://www.ccme.ca/assets/pdf/prrvw_pm_fine_rvsd_es_e.pdf*). The CCME report reviewed 40 acute mortality studies, as well as long-term epidemiological, clinical and toxicological studies. Despite the well-recognized issue with Generalized Additive Models (GAMs) used in previous studies (including those cited by the 1998 Science Assessment Document), the previously reported positive associations between short-term $PM_{2.5}$ and health effects were generally consistent with the newer research. CCME concluded that the CWS of 30µg/m^3 was appropriate, after taking into account important factors including protecting human health, as well as achievability, feasibility and the costs of reducing pollutant levels. The CWS achievement is based on the 3-year moving average of the 98th percentile.

In comparison, the U.S. EPA conducted a comprehensive review of the literature pertaining to PM exposure and health effects in 2009 (*http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=216546*). They found that the risk estimates for all-cause mortality ranged from 0.29% to 1.21% per 10 µg/m^3 increase $PM_{2.5}$. A causal relationship may exist between $PM_{2.5}$ exposure and mortality, considering all epidemiological, clinical and toxicological evidence. The rationale behind the 24-hour exposure standard of 35µg/m^3 was not further elaborated, but achievement is based on the 3-year moving average of the 98th percentile.

On the other hand, the WHO air quality guideline in 2005 for $PM_{2.5}$ is set at 25µg/m^3 (*http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf*). At the time of the report, the majority of studies examining short-term effects focused on PM_{10}. These published studies and related meta-analyses showed mortality effects for PM_{10} ranging from 0.46% to 0.62% per 10 μg/m^3 increase. This is approximately equivalent to a 5% increase in mortality at a PM_{10} concentration of 150μg/m^3. With that, the guideline for PM_{10} was set at 50 μg/m^3 for a 24-hour average concentration, and the WHO halved that value to derive the 24-hour guideline for $PM_{2.5}$ at 25 μg/m^3. However, the WHO recommends that authorities achieve PM levels below the air quality guidelines because no thresholds for PM have been identified.

Current Ontario and Canadian standards for O_3. No document that describes the scientific basis behind the Ontario AAQC standard as compared to the NAAQOS could be identified. The Science Assessment Document for the NAAQOS (1999) (*http://www.hc-sc.gc.ca/ewh-semt/pubs/air/naaqo-onqaa/ground_level_ozone_tropospherique/summary-sommaire/index-eng.php*) shows the derivation of health reference levels for O_3. The reference levels are an estimate of the lowest ambient ozone level at which statistically significant increases in health responses have been detected, and not a level below which there are no possible health impacts. The NAAQOS health reference levels (daily, 1-hour maximum concentration of O_3) were set for two health responses: 20ppb for non-accidental mortality and 25ppb for respiratory hospitalization. The reference levels were derived using mortality and respiratory hospitalization data from 13 Canadian cities over an 11-year period. Increase in mortality was found at mean 1-hour daily ozone concentrations between 20 and 75 ppb, which were consistent with those from other studies conducted in the U.S. and Europe. After taking into account of other factors such as environmental protection and cost of attainment, the Maximum Acceptable Level for NAAQOS standards were set at 82 ppb for 1-hour average concentration of O_3.

CCME made use of the NAAQOS risk assessment data and conducted an update of the research in 2004 (*http://www.ccme.ca/assets/pdf/prrvw_oz_hlth_es_rvsd_e.pdf)*. Similarl to the PM standard update, CCME referred to the issues identified with the GAM function and the interpretation of the older results. Meta-analyses conducted found a stronger relationship between mortality and ozone exposure in the summer than in the winter. No details on further exposure-response calculations could be identified. The 8-hour ambient CWS standard is set at a level of 65 ppb, based on a consideration of protecting human health, as well as achievability, feasibility and the costs of reducing pollutant levels.

The US EPA has an 8-hour ambient standard of 75 ppb. A review was conducted to assess the literature available to support the EPA standard in 2006 (*http://cfpub.epa.gov/ncea/cfm/recordisplay.cfm?deid=114523*). Both single-city and multi-city studies were included, and the EPA concluded that there was likely a causal relationship between short-term exposure to O_3 and mortality.

The World Health Organization does not have a 1-hour exposure guideline for ozone (*http://whqlibdoc.who.int/hq/2006/WHO_SDE_PHE_OEH_06.02_eng.pdf)*. It only has an 8-hour guideline set at 100μg/m^3 (50 ppb). This value was lower than the previous guideline of 120μg/m^3 to recognize the lack of an identified threshold. In addition, evidence from human chamber studies that indicate high variability in individual responses to ozone.

Relationship with Known Health Effects

Despite their ultimate goals, air quality standards are usually a compromise between different objectives such as environmental protection, costs of reducing the pollutant emissions, and human health. Indeed, one important objective of the existing air quality standards in Canada emphasized environmental regulatory requirements, such as the levels that triggered regulatory action to get industry to reduce pollution, rather than public health concerns. In many case, existing standards have not been reviewed recently and have therefore not been able to incorporate all currently available research findings (***Table 2***). There are obvious instances where the current standards are not completely protective of human health. For example, Barnett et al. (2006) showed significant increases in cardiovascular hospital admissions with short-term exposure to NO_2, especially in the elderly, at the daily maximum concentrations under 80 ppb, which is well below the AAQC level for Max Desirable level (1-hour: 200 ppb).[61]

From the above discussion, it should be clear that there is no consistent quantitative relationship between risk to human health and current ambient air quality objectives and standards.

We identified only two peer-reviewed articles describing studies that were conducted to assess the relationship between the AQI and known health effects. Balluz and colleagues (2007) reported an ecological study in which they investigated an association between the prevalence of self-reported ischemic heart disease (IHD) using data from the Behavioral Risk Factor Surveillance System (BRFSS), a national telephone-based interview survey, and annual average level of $PM_{2.5}$-based AQI index across 51 U.S. counties during 2001.[62] Relative to the counties with annual average AQI $\leq$ 60, the estimated prevalence odds ratio for IHD for the counties of AQI > 60 was 1.70 (95% CI: 1.11-2.66). Because of inherent limitations in this study (*i.e.*, ecological and cross-sectional study design, substantial misclassification in ascertaining IHD and exposure, and lack of adequate control for confounding), this study provides some limited evidence on the relationship between the US AQI with known health effects. In another study, Letz and Quinn (2004) described the association between the number of daily emergency-department (ED) visits for asthma and the same-day AQI index using Pearson correlation coefficients. The AQI was not statistically correlated with the occurrence of ED visits.[63] Overall, there is a lack of evidence to show a consistent quantitative relationship between the AQI and known health effects.

Assumptions Underlying Air Quality Index

To use the AQI as the basis for health messaging requires four assumptions: (1) all individuals in the vicinity of a fixed-site monitoring station from which the AQI was calculated are exposed to the same level of air pollution; (2) the index reading communicates the worst effect of all six air pollutants; (3) with the same index value, the effects of all air pollutants are assumed to have equal importance with respect to air quality and the health significance; and (4) if the AQI is in the good or very good categories (AQI<32), it is unlikely that anyone, including susceptible individuals, would develop any adverse health effects.

The first assumption is probably never true. Air pollutants vary on multiple temporal and spatial scales, with emission rates, meteorological conditions, and diurnal/seasonal cycles in solar radiation and temperature having the greatest impact on the ambient concentrations.[22] Some common air pollutants such as O_3 and $PM_{2.5}$ may have regional distributions, while others are more influenced by local sources. For example, traffic-related air pollutants such as NO_2 and CO are highly variable within a short distance. In addition, individual-level exposure largely depends on factors such as individual mobility and activity patterns. The spatial mis-alignment between the exposed populations and the monitoring sites would lead to considerable misclassification in population- and individual-level exposures. As a result, individual's susceptibility and chronic exposures associated with spatial variability in air pollutant concentrations and source proximity (*i.e.*, the importance of spatial locations on increasing possible health effects) are not reflected in the index.

As described earlier, the AQI index is determined entirely by the standards. Because there is no consistent quantitative relationship between the standards and health effects, it is unlikely that the AQI index accurately reflects the health impacts of individual pollutants. In addition, extensive scientific research has failed to identify thresholds below which air pollution would not pose a risk to health. One important implication is that it may be difficult to attach health interpretation to the index and a description such as "fair" or "poor" is arbitrary.

Health Messages from Air Quality Index

There are health messages accompanying the AQI readings (***Table 3***). These health messages, however, vary across pollutants. For example, when the AQI is in a moderate category and is determined by O_3, the health message is: "Respiratory irritation in sensitive people during vigorous exercise; people with heart/lung disorders at some risk; damage to very sensitive plants". When the moderate category is determined by $PM_{2.5}$, however, the health message is: "People with respiratory disease at some risk". Although pollutant-specific messages do recognize the fact that same index levels are not equal to all pollutants, providing different health messages for the same index level may cause confusion among the public. It may also lead to a misunderstanding that individuals are exposed to a single pollutant at a time. In addition, the health messages for $PM_{2.5}$-derived AQI reading do not include people with existing cardiovascular conditions which are major effects of $PM_{2.5}$.

Consistency of Air Quality Index across Ontario

Because the AQI is based on a single-pollutant model, it cannot account for the combined effect associated with the simultaneous exposure of multiple pollutants. It also means that the index may have different implications for health when it is used to characterize an urban pollution mix versus the mix of air pollutants in a rural area. For example, at 15:00 on June 17 2006, the AQI was 45 in Sarnia due to O_3. The concurrent AQI sub-indices for $PM_{2.5}$, SO_2, and NO_2 were 43, 23, and 10, respectively. At 17:00 on April 23 2003, an AQI of 45 due to O_3 was also reported in Belleville. However, the simultaneous AQI sub-indices for $PM_{2.5}$, SO_2, and NO_2 were only 8, 0, and 1, respectively. One would expect that despite the identical value, the AQI of 45 was likely to induce more health effects in Sarnia than in Belleville. In other words, the consistency of the AQI across areas (e.g. from rural (or semi-rural) areas to urban settings) can be problematic.

The Air Quality Health Index

The Air Quality Health Index (AQHI) is based on the relationship between changes in mortality associated with short-term elevations in ambient air pollution in 12 Canadian cities.[33] The AQHI is based on a scale from 1 to 10+, with health messages and displayed graphically for each AQHI level. Regional AQHI index values are published every hour on the Environment Canada's Air Quality Health Index website (http://www.ec.gc.ca/cas-aqhi/default.asp?Lang=En).

Computation of the Air Quality Health Index

Under an assumption of additive health effects of $PM_{2.5}$, NO_2, and O_3, the equation of AQHI is constructed as the sum of excess daily mortality risk associated with these three pollutants, adjusted to a 0-10 scale. The AQHI formula is as follows:[33]

$$AQHI = (10/10.4)*100*\{e^{(0.000871*NO2)}-1 + e^{(0.000537*O3)}-1 + e^{(0.000487*PM2.5)}-1\} \quad (2)$$

To provide insights into the structure of the formula and to facilitate comparison to the AQI, we further simplified the above AQHI formula using Taylor series approximation as follows:

$$AQHI \simeq 10/10.4*100*\{(1+0.000871*NO_2)-1 + (1+0.000537*O_3)-1 + (1+0.000487*PM_{2.5})-1\}$$
$$= 0.084 * NO_2 + 0.052 * O_3 + 0.047 * PM_{2.5} \quad (3)$$

This simplification is reasonable when the ambient concentrations of NO_2, O_3, and $PM_{2.5}$ are modest ($\leq$ 100ppb), which was true over 99.99% of the time in Ontario during the period of 2003 to 2010. Equation 3 is illustrated in ***Figure 3***. It demonstrates that the AQHI is essentially a simple linear combination of NO_2, O_3, and $PM_{2.5}$. The slopes in Equation 3 are the estimation of exposure-response coefficients of NO_2, O_3, and $PM_{2.5}$ from a time-series study in 12 Canadian cities, multiplied by a scaling factor.[33]

To communicate possible adverse effects of air pollution to the public, the numeric AQHI scale is subdivided into four categories: (1) low risk (0-3); (2) moderate risk (4-6); (3) high risk (7-10); and (4) very high risk ($\geq$10). Categories were defined according to the relative frequency of the numeric AQHI scale across the 12 Canadian cities in a time-series study.[33]

Interpretation of Air Quality Health Index

To assist in interpreting the AQHI, we calculated the excess daily mortality associated with each value of the AQHI. An AQHI of 3 is associated with a 2.6-3.6% (median: 3.1%) increase in mortality rate in the exposed population (***Table 4***). At a value of 10, the AQHI is associated with a 10.4% (range: 10-10.9%) increase in daily mortality. In other words, each unit increase in AQHI is equivalent to a roughly 1% increase in daily mortality. As shown in ***Table 4***, the AQHI is in the moderate risk category (AQHI: 3-6) for a majority of days in Ontario. In this category, excess daily mortality risk ranged from 2.6% to 6.8%. This suggests that excess deaths may still occur even with low AQHI values. These deaths likely occurred mainly in the susceptible subpopulation, even if seemingly healthy, such as the elderly and those with (unrecognized) cardiovascular conditions.[22]

Health Basis for Air Quality Health Index

As described above, the formulation of AQHI is derived from observed association between ambient air pollutants and short-term mortality. Although mortality is considered as a useful measure as a one indicator of public health impact, the morbidity (e.g. hospitalizations, physician visits) due to air pollution exposure may represent as great or an even greater public health burden.

Relationship with Effects other than Mortality

There were few studies examining the relationship between the AQHI and morbidity. To and colleagues (2012) examined the short-term impact of ambient air pollution using daily maximum AQHI and daily maximum concentrations of NO_2, O_3, and $PM_{2.5}$ on asthma-related hospitalizations, emergency-department visits, and outpatient visits in Ontario from 2003 to 2006.[65] There was a 5.6% (95% CI: 1.053-1.058) increase in asthma outpatient visits and a 2.1% (95% CI: 1.014-1.028) increase in hospitalization rate for every unit increase of AQHI on the same day of exposure, as well as a 1.3% (95% CI: 1.010-1.017) increase in the rate of emergency department visits on the previous day. In another unpublished study that included 5.5 million cardiac and respiratory hospital admissions from across 24 Canadian cities in 1985-2005, Stieb and coworkers (personal communication: Dave Stieb, Health Canada) showed a 0.6% increase in cardiac-related hospitalization associated with each unit increase in AQHI on the day of event. In addition, they reported a 0.5% increase in respiratory hospitalization for every unit increase of AQHI. This recent evidence suggests that daily variation in AQHI may be associated with morbidity.

Assumptions Underlying Air Quality Health Index

As is the case for the AQI, use of the AQHI for health messaging requires several assumptions. For the AQHI, these assumptions include: (1) the total health effect associated with ambient air pollution can be estimated based on $PM_{2.5}$, O_3, and NO_2; (2) the effects of multipollutant exposures can be estimated using the sum of individual effects that were derived from single pollutant models; (3) although the coefficients used in the AQHI were estimated from the time period of 1991 to 2000, they remain currently relevant and can be generalized beyond the 12 cities on which they are based; and (4) all individuals in the vicinity of a fixed-site monitoring station from which the AQHI is calculated are exposed to the same level of air pollution.

When choosing individual pollutants to form the basis of the AQHI formula, $PM_{2.5}$ and O_3 have the strongest scientific evidence for being either causal (in the case of $PM_{2.5}$) or to serve effectively as a useful surrogate for photochemical components of the ambient pollution mixture (in the case of O_3). There is little correlation between $PM_{2.5}$ and O_3. However, it is difficult to interpret the coefficient for NO_2 in the AQHI formula because this is complicated by its (and its source) contribution to PM and acting as a surrogate for other exposures affecting the population such as traffic-related particles.[47] NO_2 may affect health through these pathways. Indeed, in two recent independent peer reviews on the health science issues underlying the AQHI,[64,66] a key concern was the proportional weight given to NO2 in the index. As well, the AQHI offers no opportunity for the inclusion of other harmful air pollutants such as SO_2. ***Figure 3*** illustrates that the AQHI tended to be more singularly associated with NO_2 concentrations than reflective of the overall mixture of pollutants.

The AQHI is formulated assuming additive effects of multipollutant exposures. However, individual pollutants may interact in synergistic or antagonistic ways.[67] There is no universal agreement on specific approaches to incorporate a multi-pollutant mixture in an index. A challenge of current statistical methods is that they treat all predictors symmetrically and do not take advantage of the hierarchical nature of the air pollution mixture as a whole.[68] In addition, current statistical methods are inadequate for estimating high order interactions. Given the complex causal pathways linking air pollution to excess mortality and morbidity, we are still at a relatively early stage in estimating the total health effect associated with simultaneous exposure to multiple pollutants and their potential interactions. Assuming additive effects, the AQHI formula considers the total health effects as the sum of mortality effects associated with each of $PM_{2.5}$, NO_2, and O_3. The effect was derived for each of the three pollutants from a single pollutant model associating this pollutant and mortality outcome. The rationale for aggregating the apparent effects of these three pollutants from their single-pollutant model is not currently well substantiated by the literature.

There is no way to determine whether the coefficients in the AQHI formula are still relevant for recent years without empirical data. A recent study reported that public health risks related to NO_2 appeared to be increasing in 12 Canadian cities, despite decreasing ambient concentrations of NO_2 from 1981 to 2000.[69] Although this study provided some suggestive evidence on the relative stability of health risks of air pollutants over time, given the scanty evidence, further evidence using more recent data is needed to evaluate possible time trends of effect. Similar to the AQI, the AQHI fails to recognize possible health effects associated with chronic exposures to air pollution and because it assumes the same level of exposure occurs to all individuals in the vinicity of a fixed-site monitoring station, the importance of fine-scale variation in pollutant concentrations on an individual's risk is also not recognized.

Health Messages from Air Quality Health Index

Table 5 shows the accompanying health messages for the AQHI categories. As a communication tool, the AQHI provides separate health advice for the "at-risk" and the general population, although the validity of this approach is unclear. On the other hand, one may be concerned that since the index does not differentiate between the same index value arising from different combinations of pollutants, the messages would lead to different results (in terms of reduced exposures and doses) in some scenarios relative to others.[64,66]

Generalizability of Air Quality Health Index across Ontario

The validity of generalizing the mortality relationships associated with the air pollution mix in 12 major Canadian cities to rural areas with a different set of sources and mix of pollutants is unclear. For example, one can imagine a scenario in which the AQHI of 6 was reported for both a large urban center and a rural area. An AQHI of 6 from the urban setting is likely the combination of a value of 2 due to $PM_{2.5}$, 2 due to O_3, and 2 due to NO_2. On the other hand, the AQHI from a rural setting was likely due to O_3 entirely. This is because in the rural town affected predominately by O_3, an extremely high level of O_3 is required in order for the AQHI to reach 6 (in this case, $O_3 \simeq 115$ ppb and O_3-related AQI $\simeq 75$).

Quantitative Comparison of the Two Indices

Distributions of Individual Pollutants with the Two Indices

Descriptive statistics pertaining to individual pollutants with each AQI category are presented in ***Table 6 (A).*** The good and very good AQI categories are associated with relatively low pollutant concentrations and low (but still present) levels of air pollution related mortality risk. From the moderate AQI category, the levels of O_3 and $PM_{2.5}$ increased considerably, with $PM_{2.5}$ exhibiting a sharp increase. The concentrations of NO_2, SO_2, CO, and TRS remained largely unchanged across five AQI categories. In contrast, ***Table 6 (B)*** shows that the concentrations of $PM_{2.5}$, O_3, NO_2, SO_2, and CO increased steadily across four AQHI categories. This suggests that the AQHI may be more broadly associated with the mixture of air pollutants as a whole than the AQI.

Correlation between AQI and AQHI

Figure 4 shows estimated Spearman correlation coefficients (*r*) between the AQI and the AQHI in 28 cities and towns, respectively. The correlation was strikingly higher in the warm season (April to September) than the cool season (October to March). For example, in Tiverton the correlation coefficient was 0.89 in the warm season while in the cool season it was 0.56. In addition, the correlation appeared much stronger in rural towns (Tiverton and Grand Bend) than large urban centers (Hamilton and Toronto). Similar patterns were observed when we assessed the degree of agreement between the AQI and the AQHI according to their categorical values using Kappa Statistics (***Table 7***).

The rural versus urban difference in correlation between the AQI and AQHI is likely due to the fact that rural towns in Ontario were affected mostly by O_3. When a city was affected predominantly by a single pollutant such as O_3, the AQHI approximated a simple linear function of O_3 (i.e., AQHI $\simeq$ 0.052*O_3, see **Equation 2**). Simultaneously, the AQI was likely a linear function of O_3 (i.e., AQI $\simeq$ 0.655*O_3, ***Figure 2***). As a result, the values of both indices should be highly collinear except that they are in a different scale because of different slopes in their functions. Under this circumstance, the index values of AQI and AQHI should characterize the quality of the air **equally** (either well or poorly). This indicates that any observed discrepancy in the different number of advisory days issued by using the AQI and AQHI for the rural area would be due to different triggering levels: for AQI, the trigger threshold is related to the standards, while for AQHI, it is related to the distribution of excess daily mortality risk across 12 large cities.[33]

Conversely, in large urban centers such as Toronto where the levels of multiple pollutants were concurrently high, the agreement between the two indices decreased. This is because while the AQI remains a function of a single pollutant, the AQHI is now an approximately linear combination of three pollutants (see Equation 2).

Coverage Probability of AQI and AQHI

We assessed the ability of the AQI to predict the AQHI (and vice versa) using coverage probability, computed as the proportion of times each category of the AQI contained the corresponding category of the AQHI. As shown in ***Table 8 (A, B),*** when the AQHI index indicated moderate health risk, it was contained by the moderate AQI category 40% of the time. Conversely, when the AQI suggested moderate air quality, it was contained by the moderate category of AQHI 81% of the time. This indicates that the AQHI may be a better predictor of AQI than the opposite. A sensitivity analysis revealed that in rural towns such as Grand Bend and Tiverton, however, the AQI category was more likely to predict AQHI than vice versa (***Table 9: A, B***).

Relationship between AQI and Excess Daily Mortality Risk

Excess daily mortality risk for each AQI category was estimated assuming the same relationship existed between $PM_{2.5}$, O_3, and NO_2 with mortality as in the AQHI formula (***Table 10***). Although excess daily mortality risk generally increased across the AQI categories, each AQI category exhibited a wide range of mortality risk. For example, for the good AQI category (AQI: 26-31), the daily excess mortality risk may reach up to 8.8% (equivalent to the AQHI of 9 or high health risk).

Relationship between the Indices and Individual Pollutants

To determine the extent to which both indices are reflective of individual components of the air pollution mix, we estimated correlations between the two indices and individual pollutants across Ontario from 2003 to 2010 (***Table 11***). The AQI was highly correlated with O_3, but poorly correlated with other pollutants. On the other hand, the AQHI was correlated moderately with all pollutants, with the exception of CO and O_3. The association between the AQHI and O_3 increased in the warm season (***Table 12: A***), but it vanished completely in the cool season (***Table 12: B***). The opposite was seen for its correlation with NO_2. For AQI, the association with $PM_{2.5}$ and NO_2 were driven to zero or negative in the cool season. ***Table 13 (A, B, C)*** shows that the AQI was nearly perfectly correlated with O_3 in two rural towns. Overall, the AQHI tended to be more strongly associated with the mixture of air pollutants than the AQI.

As a sensitivity analysis, we calculated pair wise correlations between AQHI and AQI with each pollutant after controlling for the effects of other pollutants. We observed similar patterns, except that the strength of the relationship between AQHI and $PM_{2.5}$ became the smallest (i.e., correlation(AQHI, $PM_{2.5}|NO_2, O_3$) = 0.5 < correlation(AQHI, $NO_2|PM_{2.5}, O_3$) = 0.7 < correlation(AQHI, $O_3|PM_{2.5}, NO_2$) = 0.8).

An important observation is that for each pollutant 1-hour average, they are almost perfectly correlated with the 3-hour rolling average. This indicates that a 3-hour rolling average is a reasonable averaging period given the need for an index to reflect current conditions. In addition, it averts being overly weighted by very short-term fluctuation in air pollution exposure. Additionally, we observed that there was moderate correlation among the individual pollutants.

Ranking of High-risk Days

Table 14 demonstrates the difference between the AQI and the AQHI pertaining to the rank orders of high air pollution days defined by each index. In Barrie the highest daily maximum AQHI was 11 (very high health risk) which occurred on February 28, 2003 when the daily maximum concentrations of NO_2 exceeded 110 ppb. On this day, the daily maximum AQI value was 48 due to $PM_{2.5}$. Because of small slope for the linear function of NO_2 with the AQI (***Figure 2***), the AQI sub-index from NO_2 was only 25. On the other hand, the highest-risk day for AQI in Barrie (AQI=68) occurred on June 28, 2005 because daily maximum $PM_{2.5}$ reached 68µg/m^3.

In general, there was more divergence than agreement between both indices with respect to the rank orders of high air pollution days (***Table 14***). The cities with the most common high-risk days between the both indices are Grand Bend (5 days), Parry Sound (4 days), and Kingston (3 days). While high air pollution days occurred mostly in warm season according to the AQI, high risk days may have also occurred in cold seasons, according to the AQHI. This is particular true for urban areas such as Barrie and Burlington.

Individual Pollutants as Primary Contributors to the Indices

For AQHI, ozone was most frequently reported as its primary contributor, followed by NO_2 (***Table 15: A***). This was especially true for rural towns (e.g., Grand Bend) and cities affected by transboundary air pollution (e.g., Kingston). In only a handful of cities such as Sarnia and Brantford was $PM_{2.5}$ a primary contributor to the AQHI. For AQI, it was $PM_{2.5}$ and O_3 that mainly determined the index. In the warm season, the number of days in which O_3 was a primary contributor increased for both indices (***Table 15: B***). The number of days with NO_2 as the primary contributor nearly doubled from the warm to the cool season (***Table 15: C***). This is expected in that NO_2 concentrations tended to be higher in the winter while O_3 levels peaked in the summer.

To further understand the difference between the two indices, we restricted the analysis to the hours when AQI was in the “poor” and “very poor” categories (AQI$\geq$50) but the AQHI was in the moderate or low category (AQHI<7) (***Table 16: A***). The first column lists main contributors to the AQI index for each of 13 cities. The second column provides the distribution of hours associated with each primary contributor. The third to fifth column show the proportion of the time when $PM_{2.5}$, O_3, and NO_2 were a primary contributor to the AQHI index. The last three columns describe the distribution of AQHI index during these hours (AQI$\geq$50 but AQHI<7). The AQI index was determined by $PM_{2.5}$ or O_3 in most cities. In a few occasions in Sarnia and Hamilton, however, SO_2 and TRS drove AQI to exceed 50. The two pollutants would have no effect on the AQHI index because they are not included in the formula. For Belleville and Windsor, the hours when the AQI $\geq$ 50 but the AQHI < 7 were almost entirely related to elevated levels of O_3 but for Sarnia these hours were associated with $PM_{2.5}$. Overall, whenever the AQI was determined by O_3, O_3 was also a primary contributor to the AQHI. Again, this confirms that AQHI index correlated well with the AQI in the hours affected by elevated levels of O_3.

Table 16 (B) shows the distribution of the AQI and AQHI during the hours when AQHI $\geq$ 7 but AQI < 50. Nitrogen dioxide was the most frequent primary contributor to AQHI in most cities. In these hours, the AQI index was determined largely by $PM_{2.5}$. The AQI index in the hours when O_3 was primary contributor to the AQHI was much closer to 50 than the AQI in the hours when NO_2 determined the AQHI.

Number of Advisory Days

Table 17 provides the number of advisory days according to the AQI (defined as AQI$\geq$50 for at least 6 hours) and the AQHI (defined as AQHI$\geq$7 for at least consecutive 6 hours) for each city and year (Personal communication: Dr. Yushan Su, Ontario Ministry of the Environment). From 2003 to 2010, the number of advisory days decreased considerably, mainly due to the continuous decrease in the ambient levels of $PM_{2.5}$ and NO_2 in Ontario (data not shown). In the earlier period (2003-2006), the AQHI tended to trigger more advisory days than the AQI. In the more recent period (2007-2010), absolute difference in the number of advisory days between the indices decreased.

Figure 5 depicts the number of high air pollution days by both indices in each month, year and city. In the cool season, there were more high air pollution days triggered by the AQHI than the AQI in most urban centres and rural communities. The opposite was seen in the warm season. This observation is consistent with the findings from Table 16. ***Figure 6*** enumerates high air pollution *hours* in each month by both indices. It also demonstrates temporal change in the index values. By and large, the findings are comparable with those from ***Figure 5***.

Diurnal Variability of the Indices and Individual Pollutants in Smog Episodes

Figure 7 illustrates the diurnal variation of index values in response to pollutant concentrations during high pollution episodes in 2003-2010. Ideally, a real-time index should be responsive to transient fluctuation in pollutant concentrations during an episode. The top panel shows the AQHI and the concentrations of $PM_{2.5}$, O_3, and NO_2 in each hour during the episode. The X-axis represents hours. The Y-axis on the left shows the AQHI while the Y-axis on the right denotes the pollutant concentrations. The bars represent the index values. Three solid lines show the hourly concentrations of O_3, NO_2, and $PM_{2.5}$, respectively. The horizontal dash line indicates the breakpoint between the moderate and high health risk category (AQHI=7). Similarly, the bottom panel shows the variability of AQI and $PM_{2.5}$, O_3, and NO_2 in each hour during the episode. In this panel, the horizontal dash line indicates the breakpoint between the moderate and poor AQI categories (AQI=50).

Figure 7 (A) shows an extreme air pollution episode reported by the Ontario Ministry of Environment that took place in Belleville on August 14-15, 2003. During this episode, the AQI tended to be more responsive to the short-term change in ozone concentrations. In contrast, an air pollution episode in Hamilton revealed a different pattern (***Figure 7 B***). In this episode, there was a six-hour lag for the AQI to the threshold level compared to AQHI. The AQI and AQHI are responsive to different chemical composition in ambient air pollution. While the AQI is sensitive to the short-term variability of $PM_{2.5}$ or O_3 that may have regional distribution, the AQHI is more sensitive to changes in the locally influenced NO_2. Thus, when an extreme air pollution episode was mostly driven by NO_2, the AQHI would likely declare a high risk threshold earlier than the AQI. This generally occurred in urban centres such as Toronto and Hamilton where NO_2 is a major air pollutant and it is a good marker for traffic-related pollution in these urban areas.

Sensitivity Analyses

We assessed the consequence of lowering the triggering level of AQHI from 7 to 6 on the number of high-risk days (***Figure 8***). For Grand Bend, Tiverton, and Kingston, this resulted in the distribution of high-risk days more alike between both indices. However, for urban centers such as Toronto and Windsor, this change of triggering level led to a large increase advisory days in the cool season.

We further evaluated the robustness of AQHI formulation on model specification. There was no appreciable difference regarding the number of high-risk days after replacing the regression coefficients of $PM_{2.5}$ in the AQHI formula by different values taken from a distribution (data not shown). This finding confirms the robustness of the AQHI formulation.

Modifications in AQI and AHHI by Canadian Provinces

We contacted all other provinces to obtain information on their possible modification on the AQHI and AQI. A summary of each province's response is presented in this section. More details are provided in Appendix A.

Province of Alberta

Alberta had its own AQI in place before the implementation of the AQHI. The province adopted the AQHI; however they want to retain the advantages of the AQI (e.g. hourly reporting and inclusion of more pollutants). The basis of the index would be the national Air Quality Health Index; however, if hourly air quality readings exceed Alberta's Ambient Air Quality Objective values for individual pollutants, then the index value would be trumped by Alberta's Air Quality Index value. This accounts for rapidly changing air quality events such as forest fire smoke and ozone levels that exceed 82 ppb. So, if air quality is 6 or less using the AQHI, and the ambient objectives for specific pollutants are exceeded, then the AQHI value is replaced by the appropriate calculated value (7 or higher) based on the individual pollutant concentration. Also, if levels of individual pollutants exceed odor or visibility thresholds, a special air quality message will be issued on Alberta Environment's web site for the specific location where the event is occurring. This messaging is used for H_2S, TRS, $PM_{2.5}$ and SO_2 (Personal communication: Bob Myrick, Alberta Environment). In addition, the Alberta AQHI is calculated every hour instead of every three hours.

Several analyses were conducted in Alberta to compare the AQI and the national AQHI (Alberta Environment, unpublished report, 2008). First, in a comparison of the hourly values of the AQHI and the AQI in large urban centers, the AQHI was found to report low risk 59-89% of the times, whereas the AQI reported good air quality about 95% of the time. The results from small urban centers were more varied. At Fort McMurray, for example, the AQHI was more likely to report low risk than the AQI to report good air quality. Overall, the AQI and AQHI reports were more consistent in rural areas; however, the AQHI was more likely to report low risk than the AQI to report good air quality.

Second, in a comparison of daily maximums, the AQHI reported more alert days than the AQI in large urban settings. In fact, Alberta would report an average of 1-24 more alert days in large urban settings, and an average of 1-2 less alert days in small urban settings and rural areas each year with the implementation of the national AQHI.

Third, an analysis of what pollutants dominate the levels of the AQI and AQHI shows that ozone was the main driver of the AQI at Fair to Good levels of air quality, whereas $PM_{2.5}$ was the driver of poor and very poor levels. On the other hand, the AQHI was mostly determined by ozone at low risk levels, but by NO_2 at moderate and high risk levels. Very high risk category of AQHI was mostly influenced by $PM_{2.5}$.

Lastly, while the AQHI appeared to lead the responses to an air quality event, a lag time investigation showed that the AQI usually preceded the AQHI. Even though the AQI showed better air quality more often than the AQHI, when both indices reached high values, the AQI was quicker in its response than the AQHI. For the events where the AQHI preceded the AQI, they were usually due to elevations in ambient level of NO_2, and a long lag existed between the AQHI and AQI (approximately 2-19 hours). On the other hand, when the AQI preceded the AQHI, the lag time until the AQHI followed was much closer at approximately one hour.

Province of British Columbia

The province decided to utilize the AQHI over the AQI because the AQHI was based more on a scientific assessment of the short-term impacts of air pollutants on human health. It also looks at the combined impact of three criteria pollutants, not just one. The old AQI was also based loosely on health, but was not based on rigorous science. It also was triggered by one pollutant and did not use the other pollutants in its formula. BC has worked closely with Environment Canada and Health Canada in implementing the AQHI in this province. They did not modify the AQHI in any way (Personal communication: Eric Taylor, Ministry of Environment).

Province of Manitoba

The province switched from the AQI to the AQHI in summer 2010 based on federal recommendation. The province had no concerns about switching and has no plans for future studies assessing the change (Personal communication: Burt Krawchuk, Manitoba Conservation).

Province of New Brunswick

The province is using the AQHI for three cities (Fredericton, Moncton, and Saint John). However, they do continue to report IQUA (equivalent to AQI) data as well. The use of IQUA preceded the AQHI, and is still reported along with the AQHI results due to the fact that there are some groups that continue to look for this data. Also, the IQUA considers SO_2, which is not a parameter used to calculate the AQHI values. The IQUA values are available for additional areas in the province where monitoring data is available to report IQUA but not AQHI. The province is currently considering options for a system that could somehow marry the IQUA and AQHI together (Personal communication: Darrell Welles, Environmental Evaluation and Reporting).

Province of Newfoundland and Labrador

The province uses the AQHI, and did not have any air quality index prior to use of the AQHI. There was no specific rationale to choose the AQHI – decision was made in consultation with Health Canada (Personal communication: Peter Haring, Department of Environment).

Province of Nova Scotia

The province used the AQI prior to the implementation of the AQHI. They started implementing the AQHI in 2006 on the advice of Health Canada. No modification was made. The main concern with the index is that the majority of the province is rural and the AQHI was formulated based on urban areas (Personal communication: Barb Bryden, Nova Scotia Environment).

Province of Prince Edward Island

The province didn't use the AQI, so the AQHI was the first index. No modification of the AQHI was made and no pilot studies have been undertaken (Personal communication: Todd Fraser, PEI Dept. of Environment, Energy and Forestry).

Province of Quebec

The province has three pilot projects implementing the AQHI in Quebec City, Montreal and Gatineau-Ottawa. However, the index has not yet been adopted by the province (Personal communication: Roger Lemire, Ministère du Développement durable de l'Environnement et des Parcs).

Province of Saskatchewan

The province is currently using both the AQI and the AQHI. The province plans to use an “AQHI-plus” model similar to Alberta. Their primary concern was that pollutants that affect rural areas, such as SO_2 and H_2S, are not reflected in the AQHI (Personal communication: Chris Gray, Saskatchewan Environment).

United States Version of AQI

The US version of Air Quality Index, or US AQI, is a nationally uniform index for reporting and forecasting daily air quality. It is used to report the five most common ambient air pollutants that are regulated under the Clean Air Act: ground-level ozone, fine particulate matter, carbon monoxide, sulfur dioxide, and nitrogen dioxide.

The US AQI uses a normalized scale from 0 to 500. Since levels rarely exceed a value of 200 in the United States, in most cases only the range from 0 to 300 is shown. The higher the AQI value, the greater the level of pollution and the greater the health concern. An AQI value of 100 generally corresponds to the level of the U.S. National Ambient Air Quality Standard for the pollutant. The AQI is divided into six categories that correspond to different levels of health concern. AQI values below 100 are generally considered to be satisfactory. When AQI values are above 100, air quality is considered to be unhealthy, at first for members of susceptible populations, then for everyone as AQI values get higher.

The U.S. EPA's approach to selecting index breakpoints had been to simply set the AQI value of 100 at the level of the short-term standard for a pollutant and the AQI value of 50 at the level of the annual standard, if there is one, or at one-half the level of the short-term standard if there is not. The short-term standard is taken to define a level of health protection provided against short-term risks and thus is considered as a benchmark against which to compare daily air quality concentrations (*http://www.epa.gov/ttn/caaa/gen/aqi_issue_paper_020707.pdf*). EPA is proposing updates to the Air Quality Index for $PM_{2.5}$ (*http://www.epa.gov/pm/2012/fsstandards.pdf*). The following descriptions of the proposed updates were excerpted from the cited report.

The AQI converts concentrations for fine particles to a number on a scale from 0 to 500. EPA is proposing to change the upper end of the range for the "Good" AQI category (an index value of 50) by setting it at the level of the annual $PM_{2.5}$ standard.

EPA also is proposing to set the 100 value of the index at the level of the current 24-hour $PM_{2.5}$ standard, which is 35µg/m^3. An AQI of 100 is the upper end of the "Moderate" range and the level above which EPA begins cautioning at-risk groups. The proposal would set the upper end of the "Unhealthy for Sensitive Groups" range (AQI of 150) at 55µg/m^3, based on scientific evidence on $PM_{2.5}$ exposures and health.

EPA is proposing to retain the existing level of 500 µg/m^3 for the upper end of the "Hazardous" category (AQI of 500). The agency also is proposing to retain the existing levels of 150µg/m^3 and 250µg/m^3 for the upper ends of the "Unhealthy" (AQI of 200) and "Very Unhealthy" (AQI of 300) categories.

Primary (Health) Standards for Fine Particles: EPA sets both an annual and a 24-hour standard for $PM_{2.5}$. These standards work together to protect public health from harmful health effects from both long- and short-term fine particle exposures.

Annual Standard

The annual fine particle standard is designed to protect against health effects associated with both long- and short-term exposure to $PM_{2.5}$. The current annual standard has been in place since 1997. EPA is proposing that the current fine particle standards are not adequate to protect public health as required by law. The agency is proposing to strengthen the annual fine particle standard by lowering the level--from the current level of 15μg/m^3 to a level within the range of 12μg/m^3 to 13μg/m^3. An area would meet the standard if the three-year average of its annual average $PM_{2.5}$ concentration is less than or equal to the level of the final standard.

Twenty-four-hour Standard

The 24-hour primary standard is designed to provide supplemental health protection against short-term fine particle exposures, particularly in areas with high peak $PM_{2.5}$ concentrations. The current 24-hour standard was issued in 2006.

EPA is proposing to retain the existing level of the 24-hour standard, at 35μg/m^3, along with the current form of the standard. An area would meet the 24-hour standard if the 98th percentile of 24-hour $PM_{2.5}$ concentrations in one year, averaged over three years, is less than or equal to 35μg/m^3.

The proposed U.S. AQI for sub-index of $PM_{2.5}$ breakpoints is outlined in the table below (*http://www.epa.gov/pm/2012/ fsstandards.pdf*).

AQI Category	Index Values	Existing Breakpoints (1999 AQI) (μg/m^3, 24-hour average)	Proposed Breakpoints (μg/m^3, 24-hour average) *Note: Parentheses indicate a range*
Good	0 - 50	0.0 - 15.0	0.0 – (12.0 - 13.0)
Moderate	51 - 100	>15.0 - 40	(12-1 - 13.1) – 35.4
Unhealthy for Sensitive Groups	101 – 150	>40 – 65	35.5 – 55.4
Unhealthy	151 – 200	> 65 – 150	55.5 – 150.4
Very Unhealthy	201 – 300	> 150 – 250	150.5 – 250.4
Hazardous	301 – 400	> 250 – 350	250.5 – 350.4
	401 – 500	> 350 – 500	350.5 – 500

Pilot Implementation Studies of the AQHI in Canada

We gathered information regarding pilot implementation studies of the AQHI by Internet search and through telephone calls. A brief summary of the findings are presented below. More details are provided in Appendix B.

Province of Alberta

The province did not run “pilot” programs since their intention was to adopt the AQHI, with modifications, without a pilot program.

Province of British Columbia

The province had the highest level of implementation as compared to the rest of the provinces in terms of number of outreach tools and programs. They’ve also created Health Care Partnerships and have had AQHI ambassadors. No evidence could be identified that describes the success of the outreach programs or the level of public knowledge of the AQHI in comparison with other provinces. The main complaints they’ve received regarding the AQHI program was a perceived lack of response to elevated $PM_{2.5}$ concentrations, because $PM_{2.5}$ is only about 10% of the AQHI value for AQHI values below 4. A study conducted by Hasselback & Taylor (2010) stated that the AQHI is not necessarily applicable to smaller communities because of the differing populations, air pollutant mix, exposure characteristics in urban areas.[71]

Province of Ontario

The province has conducted pilot programs in the Greater Toronto Area and Ottawa since the spring of 2008 and, more recently, in Hamilton. The focus of the pilot study was on supporting promotion of the AQHI. Another goal was to promote the AQHI as a reminder of the need to reduce energy use (personal communication: Louise Aubin, Peel Public Health). Data from the evaluation of the Greater Toronto Area AQHI pilot in 2008 indicated that engaging physicians is a challenge for increased dissemination of materials related to air quality and health.[64] Only 12 of 2,789 physicians in the Toronto area accepted an offer of an AQHI brochure during the 2008 pilot project. The view was also expressed that AQHI information should be more actively disseminated, rather than posting the information on a website that people have to go to. In addition, an Ontario-based non-randomized feasibility trial study to examine the applicability and effectiveness of the AQHI in patients with asthma is under way.[72] In this study, one-third of 22 asthmatic patients who received AQHI high-risk notification at their smartphones engaged in risk-reduction behaviour multiple times throughout the study period of 81 days. The patients also reported improvements in asthma control during the study such as an improved asthma-related quality of life, symptom profile and reduced urgent health care utilization. Because a lack of comparison group and a relatively short study period, there is a need for more studies to demonstrate the effectiveness of integrating the AQHI information to improve asthma outcomes.

Province of New Brunswick

The province feels that the AQHI fails to account for SO_2 levels. For this reason, New Brunswick has occasionally issued air quality advisories based on parameters found in the provincial IQUA when the AQHI was low. However, in an air quality monitoring report produced in 2009, it was suggested that the IQUA will be terminated once people become accustomed to the AQHI since the AQHI is based on health risk. The report found that 98% of the times the AQHI was low, and the remaining 2% were moderate. In the Environment Canada report (2010), interviewees from New Brunswick mentioned that one of main barriers to full implementation was the lack of monitoring stations outside of Saint John. (Note: Since the release of this report, it appears two more communities now have access to AQHI data as seen on the Environment Canada AQHI website.) The report also mentioned that New Brunswick had engaged with educators and have tried to increase the capacity to answer the public and media's inquiries.

Province of Newfoundland and Labrador

The province did not have an air quality index before the implementation of the AQHI and adopted the index relatively easily with consultation with Health Canada. The 2010 Ambient Air Monitoring Report from Newfoundland does not discuss challenges associated with the index but does outline the results of the AQHI in addition to individual air pollutant levels. St. John's appeared to have the highest AQHI levels in comparison to other areas but remained low.[73] The highest AQHI reading (for one hour) was 10 during April, 2010. However, the average monthly AQHIs were highest at 2.8 in December, 2010. Grand Falls Windsor seemed to have the lowest AQHI values but was also missing a lot of data and only reported AQHI values for six months in 2010.

Province of Nova Scotia

The province felt air pollutants of high significance in Nova Scotia are not captured in the AQHI. In a report produced in 2011 entitled "Final Report: AQHI Implementation 2010 to 2011," the successes and challenges of the pilot studies are explained. Though the pilot was conducted alongside workshops targeting at-risk populations and media outreach, challenges were experienced in developing other provincial department partnerships and promoting the AQHI to First Nation communities. Furthermore, the report reveals some slow progress in getting real-time valid AQHI readings due to a case of malfunctioning equipment and lack of skilled staff to address technical issues. The province implemented many public outreach programs in a variety of media vessels. A public survey was conducted to assess the public's knowledge that revealed some positive results. The survey showed that the majority of the respondents would find an index useful, and approximately half of the respondents had heard of the AQHI. An Environment Canada report (2010) discussed Nova Scotia's outreach to rural communities to identify air quality issues of concern to rural communities and methods to promote the AQHI at a large-scale in rural areas.[64]

Province of Quebec

The Institut national de santé publique du Québec (INSPQ) conducted an analysis on the implementation of the AQHI in three pilot projects in Quebec City, Montreal Island and Gatineau-Ottawa (Personal communication, Huppe V and Sanfacon G, INSPQ, unpublished report, 2012). The report describes in detail the four stages involved with the implementation of the pilot project: (1) develop and validate the technical and organizational aspects of the three urban areas of the pilot project (for example, the determination of the spatial grouping of the measuring stations); (2) develop adaptations of the national AQHI to make it more suitable for Quebec by establishing an alert threshold and communication strategies; (3) implement the pilot project; and (4) evaluate the AQHI and the communication strategies in place.

The report describes the challenges associated with implementing the AQHI in tandem with the locally preferred AQI: (1) Quebec's AQI focused on disseminating air quality information to target populations, while Health Canada's AQHI is directed toward the general population; (2) local broadcasters disseminated different air quality information from that of weather channels hosted by Health Canada due to different indices, causing confusion in the public; and (3) the lower weight of $PM_{2.5}$ in the AQHI was cited as another major issue since local health authorities noted the lack of the AQHI's ability to capture certain situations such as wood burning.

A comparison of AQI and AQHI over a four-day period in August, 2009, and January, 2010, in the three cities showed that although the temporal trends of AQI and AQHI were similar, AQHI levels were constantly lower than 6 even though AQI levels were consistently higher than 50 across all three cities.

In summary, the province did not feel the AQHI captured the PM level sufficiently and had low levels of risk when their AQI showed high levels of PM. Quebec also disclosed its lack of monitoring stations to be a major challenge for the implementation of the AQHI.[64] Moreover, they feel that more time is necessary to introduce the AQHI to the public and get them accustomed to the value so as not to confuse them with many indices. To further complicate the matter, Quebec interviewees mentioned political barriers to the AQHI since many provincial jurisdictions selected the AQI and Info-Smog over the AQHI.

Province of Manitoba

No reports could be identified that discussed Manitoba's pilot programs or challenges, and a person correspondence indicated that Manitoba accepted the AQHI upon federal recommendation relatively easily and were not planning on studying the effect of implementing the AQHI. Environment Canada's report (2010) discussed Manitoba lacking capacity to conduct outreach programs.[64]

Province of Prince Edward Island

No reports could be found that discussed Prince Edward Island's experience with the AQHI, and a person correspondence indicated that Prince Edward Island accepted the AQHI upon federal recommendation relatively easily without a pilot program. Environment Canada's report (2010) stated that Prince Edward Island has developed capacity for outreach programs and to answer inquiries from the media and the public.[64]

Province of Saskatchewan

The most recent report that could be found from Saskatchewan regarding the AQHI was dated in 2005 and discussed the differences between using the PM_{10} versus $PM_{2.5}$ in AQHI calculations. Environment Canada's report (2010), however, discusses the political barrier Saskatchewan faces with Alberta's lack of participation in the AQHI project.[64] Furthermore, they indicated that they had little capacity to conduct outreach programs and could only present the data on their website and the Weather Network. Personal communication with Saskatchewan Environment revealed that they felt the primary pollutants that affect rural areas (SO_2 and H_2S) were not reflected in the AQHI.

Discussion

In this study, we observed that correlations between the Air Quality Index and the Air Quality Health Index varied in space and time. Stronger correlations were found in rural towns as compared to urban centres and in warm seasons as compared to cold seasons.

We also observed that the AQHI was more strongly associated with the mixture of air pollutants than the AQI. As well, the AQHI was found to be a better predictor of AQI than vice versa. While AQI-based smog advisory days occurred mostly in warm season, high-risk days may also occur in cold seasons, according to the AQHI. This is particularly true for urban areas, suggesting that the AQI may underestimate health risk associated mixes of air pollution particularly for urban centres.

For AQHI, O_3 was most frequently reported as its primary contributor for rural towns such as Grand Bend and for cities such as Kingston that were dominated by transboundary air pollution, followed by NO_2. In only a few cities, such as Sarnia and Brantford, was $PM_{2.5}$ a primary contributor to the AQHI. For AQI, it was $PM_{2.5}$ and O_3 that mainly determined the index.

The AQI can be considered as a series of simple linear functions, with slopes determined entirely by air quality standards and criteria. The basis of the AQI is air quality standards and criteria. Although protecting human health is an important goal of standards, other considerations such as feasibility and costs of reducing pollutant emissions were also taken into account. Attainment or non-attainment of standards has no consistent quantitative relationship to health risks. For example, the association between O_3 and mortality is usually described as log-linear within a range of concentrations and without an identifiable threshold. This is the same for NO_2 and $PM_{2.5}$. From a health-risk perspective, there is nothing unique or special about a standard of 80 ppb for O_3. Based on the above, it is difficult to argue that there is a direct relationship between the AQI and human health. This is supported by the lack of epidemiological evidence suggesting any consistent quantitative relationship between the AQI and morbidity or mortality, perhaps reflecting the fact that little effort has been given to research with the AQI (in comparison to the AQHI).

Because the AQI is based on a single-pollutant model, this approach does not account for the combined effect associated with the simultaneous exposure of multiple pollutants. This suggests that for any given AQI, the value would have different risk interpretations depending on the pollutant driving the AQI. The AQHI is a linear combination of NO_2, O_3, and $PM_{2.5}$, with the slopes determined from their exposure-response relationships with all-cause mortality in a study of 12 Canadian cities. Thus, it is inherently different than the traditional standards-based worst-pollutant index. On one hand, basing the AQHI on short-term mortality risks from the mix of ambient pollutants provides a stronger link to health than is the case for the AQI. On the other hand, there is inherent uncertainty concerning which individual pollutants should be incorporated into the index and how to model the combined effect associated with the simultaneous exposure of multiple pollutants. The rationale for aggregating the apparent effects of $PM_{2.5}$, NO_2, and O_3 from their single-pollutant models is not currently well supported by the research literature. In addition, it remains to be seen whether the AQHI has a consistent quantitative relationship to morbidity. Compared to the AQI, the AQHI takes on far fewer discrete numeric values. This may be viewed as an advantage or a disadvantage. Indeed, there is some preliminary evidence associating the AQHI with morbidity. However, further research is needed to confirm the links between the AQHI and health effects. This is the same for the AQI.

As the AQHI is based on the relationship between the air pollution mix and mortality risk in 12 Canadian cities, it is not clear that this relationship can be generalized to rural areas where the sources and mix of air pollutants may be quite different. The validity of breakpoints used to group AQHI values for messaging purposes is also open to question and implies a threshold for effects when none has been demonstrated. The AQHI may produce fewer alert days in rural communities than the AQI. To some extent, this is a reflection of using an AQHI of 7 to trigger an advisory. Because the triggering level was derived using the frequency distribution of mortality risk in 12 Canadian cities, an AQHI cut-point of 7 may not be applicable for a rural area.

The AQI is currently integrated with the smog advisory. In practice, there is nothing that would prevent the AQHI from being integrated with smog advisory. However, we recognize that NO_2 data may not be widely available in rural areas. This may prevent the calculation of the AQHI for these areas.

The difference between the AQI- and AQHI-based advisory or alert days decreased substantially between 2003 and 2010. This is largely due to the reduction in ambient levels of NO_2 and $PM_{2.5}$ during this period.

There is very little research to support the effectiveness of air pollution-related health advisories in reducing exposure to, and health risks from, air pollution. It is unlikely that the same behavioural advice would apply to active asthmatics (at risk of asthma exacerbation) and the sedentary indoor elderly (at risk of mortality). This is an area that would be benefit from more research.

Although both indices are compatible with a wide range of measures that have the potential to reduce exposure to air pollutants, protectiveness is not a property of any index. There is no action inherent in either the AQI or AQHI. Protection against air pollution-related health effects only occurs when effective measures are taken to reduce exposure to air pollutants.

Other important limitation of both indices is their failure to account for health effects associated with chronic exposure to air pollution and the importance of local or neighbourhood variation in pollutant level in influencing an individual's exposure to air pollutants. Long-term exposure to air pollutants likely plays a role in the pathogenesis of chronic heart and lung disease and in that manner increases the pool of individuals more susceptible to the effects of air pollution .[74]

Strengths and limitations of the two indices are summarized in ***Table 18***.

In making a choice between the AQI and AQHI, it is important to consider their strengths, limitations, as well as the intended use of the index and the evidence supporting its effectiveness in this application.

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Tables

Table 1. *AQI equation for six common air pollutants*

AQI Category	Concentration of Individual Pollutant	AQI Equation
$PM_{2.5}$ (3-hour running average, µg/m³)		
Very Good	<12	$1.364 \times [PM_{2.5}] + 0$
Good	12 to 22	$1.500 \times [PM_{2.5}] - 2.000$
Moderate	23 to 45	$0.7727 \times [PM_{2.5}] + 14.228$
Poor	46 to 90	$1.113 \times [PM_{2.5}] - 1.298$
Very Poor	>90	$1.100 \times [PM_{2.5}] + 0$
O_3 (hourly, ppb)		
Very Good	0 to 23	$0.6520 \times [O3] + 0$
Good	24 to 50	$0.5800 \times [O3] + 2.154$
Moderate	51 to 80	$0.5900 \times [O3] + 2.1$
Poor	81 to 149	$0.7200 \times [O3] - 8.37$
Very Poor	>149	$0.7200 \times [O3] - 8.37$
SO_2 (hourly, ppb)		
Very Good	0 to 79	$0.1899 \times [SO_2] + 0$
Good	80 to 169	$0.1685 \times [SO_2] + 2.520$
Moderate	170 to 250	$0.2125 \times [SO_2] – 4.125$
Poor	251 to 1999	$0.0280 \times [SO_2] + 42.97$
Very Poor	>1999	$0.0500 \times [SO_2] + 0$
NO_2 (hourly, ppb)		
Very Good	0 to 50	$0.300 \times [NO_2] + 0$
Good	51 to 110	$0.2543 \times [NO_2] + 3.00$
Moderate	111 to 200	$0.191 \times [NO_2] + 10.79$
Poor	201 to 524	$0.1517 \times [NO_2] + 19.5$
Very Poor	>524	$0.1903 \times [NO_2] + 0$
CO (hourly, ppm)		
Very Good	0 to 12.49	$1.2500 \times [CO] + 0$
Good	12.50 to 22.49	$1.6700 \times [CO] - 5.67$
Moderate	22.50 to 30.49	$2.4300 \times [CO] - 23.86$
Poor	30.50 to 49.49	$2.7200 \times [CO] - 34.39$
Very Poor	>49.49	$2.0000 \times [CO] + 0$
TRS (hourly, ppb)		
Very Good	0 to 5.49	$3.0000 \times [TRS] + 0$
Good	5.50 to 10.49	$3.7500 \times [TRS] - 6.50$
Moderate	10.50 to 27.49	$1.0625 \times [TRS] + 20.31$
Poor	27.50 to 999.49	$0.05046 \times [TRS] + 48.59$
Very Poor	>999.49	$0.1000 \times [TRS] + 0$

Source: *http://www.airqualityontario.com/press/faq.php#aqi_calc*

Table 2 (A) *Rationale for setting breakpoints between AQI categories using CO concentrations*

CO (1-hour)	Pollutant level (ppm)	Rationale	Last review on CO Standards
Very good	0-12.49	NAAQOS (Max. desirable level: 13ppm)	NAAQOS and AAOC on CO: 1996
Good	12.50-22.49	Mathematical interpolation	
Moderate	22.50-30.49	Ontario AAQC (30ppm) and NAAQOS (Max. acceptable level: 31ppm)	
Poor	30.50-49.49	Derived from NAAQOS (8-hour Max. tolerable level: 18ppm)	
Very poor	$\geq$ 49.50	-	

Table 2 (B) *Rationale for setting breakpoints between AQI categories using SO_2 concentrations*

SO2 (1-hour)	Pollutant level (ppb)	Rationale	Last review on SO2 Standards
Very good	0-79	Mathematical extrapolation	NAAQOS and AAOC on SO_2: 1989
Good	80-169	NAAQOS (Max. desirable level: 170ppb)	
Moderate	170-250	Ontario AAQC (250ppb)	
Poor	251-1999	Prudent level set for safety	
Very poor	$\geq$ 2000	-	

Table 2 (C) *Rationale for setting breakpoints between AQI categories using NO2 concentrations*

NO_2 (1-hour)	Pollutant level (ppb)	Rationale	Last review on NO_2 Standards
Very good	0-50	Mathematical extrapolation	NAAQOS and AAOC on NO_2: 1989
Good	51-110	Mathematical extrapolation	
Moderate	111-200	Ontario AAQC (200ppb) and NAAQOS (Max. desirable level: 213ppb)	
Poor	201-524	NAAQOS (Max. tolerable level: 532ppb)	
Very poor	$\geq$ 525	-	

Table 2 (D) *Rationale for setting breakpoints between AQI categories using O3 concentrations*

O_3 (1-hour)	Pollutant level (ppb)	Rationale	Last review on O_3 Standards
Very good	0-23	Mathematical extrapolation	NAAQOS and AAOC on O_3: 1998
Good	24-50	NAAQOS (Max. desirable level: 51ppb)	
Moderate	51-80	Ontario AAQC (80ppb) and NAAQOS (Max. acceptable level: 82ppb)	
Poor	81-149	NAAQOS (Max. tolerable level: 153ppb)	
Very poor	$\geq$ 150	-	

Table 2 (E) *Rationale for setting breakpoints between AQI categories using $PM_{2.5}$ concentrations*

$PM_{2.5}$ (3-hour)	Pollutant level ($\mu g/m^3$)	Rationale	Last review on $PM_{2.5}$ Standards
Very good	0-12	Mathematical extrapolation	NAAQOS and AAOC on $PM_{2.5}$: 1998
Good	13-22	Mathematical extrapolation	
Moderate	23-45	Derived from CWS (24-hour: 30 $\mu g/m^3$)	
Poor	46-90	Mathematical extrapolation	
Very poor	$\geq$ 91	-	

Table 2 (F) *Rationale for setting breakpoints between AQI categories using TRS concentrations*

TRS (1-hour)	Pollutant level (ppb)	Rationale	Last review on TRS Standards
Very good	0-5.49	Mathematical extrapolation	AAOC on TRS: 2005
Good	5.50-10.49	Ontario AAQC (for Methy Mercaptan)	
Moderate	10.50-27.49	Ontario AAQC (emitted from pulp mills)	
Poor	27.50-999.49	Maximum tolerable level	
Very poor	$\geq$ 999.50	-	

Table 3. *Health messages for the AQI readings*

AQI Category	Health Message
NO_2	
Very good (AQI: 0 - 15)	No health effects are expected in healthy people.
Good (AQI: 16 – 31)	Slight odor.
Moderate (AQI: 32 - 49)	Odor.
Poor (AQI: 50 - 99)	Air smells and looks brown. Some increase in bronchial reactivity in asthmatics.
Very poor (AQI: 100+)	Increasing sensitivity for asthmatics and people with bronchitis.
O_3	
Very good (AQI: 0 - 15)	No health effects are expected in healthy people.
Good (AQI: 16 – 31)	No health effects are expected in healthy people.
Moderate (AQI: 32 - 49)	Respiratory irritation in sensitive people during vigorous exercise; people with heart/lung disorders at some risk; damage to very sensitive plants.
Poor (AQI: 50 - 99)	Sensitive people may experience irritation when breathing and possible lung damage when physically active; people with heart/lung disorders at greater risk; damage to some plants.
Very poor (AQI: 100+)	Serious respiratory effects, even during light physical activity; people with heart/lung disorders at high risk; more vegetation damage.
$PM_{2.5}$	
Very good (AQI: 0 - 15)	Sensitive populations may want to exercise caution.
Good (AQI: 16 – 31)	Sensitive populations may want to exercise caution.
Moderate (AQI: 32 - 49)	People with respiratory disease at some risk.
Poor (AQI: 50 - 99)	People with respiratory disease should limit prolonged exertion; general population at some risk.
Very poor (AQI: 100+)	Serious respiratory effects even during light physical activity; people with heart disease, the elderly and children at high risk; increased risk for general population.
SO_2	
Very good (AQI: 0 - 15)	No health effects are expected in healthy people.
Good (AQI: 16 – 31)	Damages some vegetation in combination with ozone.
Moderate (AQI: 32 - 49)	Damages some vegetation.
Poor (AQI: 50 - 99)	Odor; increasing vegetation damage.
Very poor (AQI: 100+)	Increasing sensitivity for asthmatics and people with bronchitis.
CO	
Very good (AQI: 0 - 15)	No health effects are expected in healthy people.
Good (AQI: 16 – 31)	No health effects are expected in healthy people.
Moderate (AQI: 32 - 49)	Blood chemistry changes but no noticeable impairment.
Poor (AQI: 50 - 99)	Increased symptoms in smokers with heart disease.
Very poor (AQI: 100+)	Increasing symptoms in non-smokers with heart disease; blurred vision; some clumsiness.
TRS	
Very good (AQI: 0 - 15)	No health effects are expected in healthy people.
Good (AQI: 16 – 31)	Slight odor.
Moderate (AQI: 32 - 49)	Odor.
Poor (AQI: 50 - 99)	Strong odor.
Very poor (AQI: 100+)	Severe odor; some people may experience nausea and headaches.

Source: http://www.airqualityontario.com/science/background.php

Table 4. Projected increased daily mortality risk for each AQHI index across Ontario in 2003-2010, based on the national formula of AQHI and assuming the "no-risk" background concentrations of $PM_{2.5}$, O_3, and NO_2 are zero

Daily Maximum AQHI	AQHI Classification	Number of Days	Projected increased daily mortality risk (%)						
			Minimum	25th%	Median	75th%	Maximum	Mean	Std Dev
0	Low health risk	1	0.5	0.5	0.5	0.5	0.5	0.5	-
1	Low health risk	726	0.7	1.3	1.4	1.5	1.6	1.4	0.2
2	Low health risk	14470	1.6	2.0	2.3	2.4	2.6	2.2	0.3
3	Moderate health risk	24368	2.6	2.8	3.1	3.3	3.6	3.1	0.3
4	Moderate health risk	13804	3.6	3.8	4.1	4.3	4.7	4.1	0.3
5	Moderate health risk	5883	4.7	4.9	5.1	5.4	5.7	5.1	0.3
6	Moderate health risk	2111	5.7	5.9	6.1	6.4	6.8	6.1	0.3
7	High health risk	750	6.8	6.9	7.2	7.4	7.8	7.2	0.3
8	High health risk	227	7.8	8.0	8.2	8.5	8.8	8.2	0.3
9	High health risk	57	8.9	9.0	9.2	9.5	9.8	9.2	0.3
10	Very High health risk	4	10.0	10.2	10.4	10.7	10.9	10.4	0.4
11	Very High health risk	1	11.9	11.9	11.9	11.9	11.9	11.9	-

Table 5. *Health messages for the AQHI readings*

Health Risk	AQHI	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	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.

* People with heart or breathing problems are at greater risk. Follow your doctor's usual advice about exercising and managing your condition
*** Source:* http://www.ec.gc.ca/cas-aqhi/default.asp?lang=En&n=79A8041B-1

Table 6 (A) Distributions of historical concentrations of air pollutants in Ontario, 2003-2010, by AQI[a]

Metrics of Air Pollutant, by AQI	Hourly Concentration of Air Pollutant					
	Min	25th%	Median	75th%	Max	Mean
AQI: 0 to 15 (Very Good Air Quality)						
NO_2 (ppb)	0	7	13	21	50	15
O_3 (ppb)	0	9	15	20	23	14
$PM_{2.5}$ (3-hour average; µg/m^3)	0	2	4	7	11	5
SO_2 (ppb)	0	0	1	2	79	2
CO (ppm)	0	0	0	0	6	0
TRS (ppb)	0	0	0	1	5	0
AQI: 16 to 31 (Good Air Quality)						
NO_2 (ppb)	0	3	6	12	91	9
O_3 (ppb)	0	27	32	38	50	31
$PM_{2.5}$ (3-hour average; µg/m^3)	0	2	4	9	22	6
SO_2 (ppb)	0	0	1	2	169	2
CO (ppm)	0	0	0	0	7	0
TRS (ppb)	0	0	0	1	10	0
AQI: 32 to 49 (Moderate Air Quality)						
NO_2 (ppb)	0	4	7	14	110	12
O_3 (ppb)	0	42	54	60	80	49
$PM_{2.5}$ (3-hour average; µg/m^3)	0	11	20	28	45	20
SO_2 (ppb)	0	1	2	5	243	5
CO (ppm)	0	0	0	0	6	0
TRS (ppb)	0	0	0	1	20	1
AQI: 50 to 99 (Poor Air Quality)						
NO_2 (ppb)	0	5	10	19	128	15
O_3 (ppb)	0	47	82	87	149	68
$PM_{2.5}$ (3-hour average; µg/m^3)	0	29	42	49	90	40
SO_2 (ppb)	0	3	5	8	808	9
CO (ppm)	0	0	0	1	4	0
TRS (ppb)	0	0	0	1	34	1
AQI: > 100 (Very Poor Air Quality)						
NO_2 (ppb)	5	7	9	40	55	21
O_3 (ppb)	0	3	36	40	49	28
$PM_{2.5}$ (3-hour average; µg/m^3)	67	86	101	117	127	101
SO_2 (ppb)	2	3	41	56	102	39
CO (ppm)	1	1	1	1	2	1
TRS (ppb)	0	0	1	1	12	3

Table 6 (B) Distrubutions of historical concentrations of air pollutants in Ontario, 2003-2010, by AQHI[a]

Metrics of Air Pollutant, by AQHI	Hourly Concentration of Air Pollutant					
	Min	25th%	Median	75th%	Max	Mean
AQHI < 3 (Low Health Risk)						
NO_2: 3-hour running average (ppb)	0	4	8	14	46	10
NO_2 (ppb)	0	4	7	14	54	10
O_3: 3-hour running average (ppb)	0	16	25	33	62	24
O_3 (ppb)	0	16	25	33	74	25
$PM_{2.5}$: 3-hour running average (µg/m^3)	0	2	4	7	52	5
$PM_{2.5}$ (µg/m^3)	0	2	4	7	79	5
SO_2 (ppb)	0	0	1	2	239	2
CO (ppm)	0	0	0	0	4	0
AQHI: 4 to 6 (Moderate Health Risk)						
NO_2: 3-hour running average (ppb)	0	9	18	32	68	21
NO_2 (ppb)	0	8	18	32	81	21
O_3: 3-hour running average (ppb)	0	14	35	51	99	34
O_3 (ppb)	0	14	35	52	124	34
$PM_{2.5}$: 3-hour running average (µg/m^3)	0	10	15	21	86	16
$PM_{2.5}$ (µg/m^3)	0	9	15	21	177	16
SO_2 (ppb)	0	1	2	5	450	5
CO (ppm)	0	0	0	1	7	0
AQHI: 7 to 10 (High Health Risk)						
NO_2: 3-hour running average (ppb)	0	12	24	49	91	30
NO_2 (ppb)	0	11	23	48	110	30
O_3: 3-hour running average (ppb)	0	21	61	80	142	53
O_3 (ppb)	0	21	60	80	149	53
$PM_{2.5}$: 3-hour running average (µg/m^3)	5	31	38	45	125	38
$PM_{2.5}$ (µg/m^3)	0	31	38	46	135	38
SO_2 (ppb)	0	3	5	10	171	10
CO (ppm)	0	0	1	1	5	1
AQHI > 10 (Very High Health Risk)						
NO_2: 3-hour running average (ppb)	96	97	99	102	104	99
NO_2 (ppb)	88	90	92	101	110	96
O_3: 3-hour running average (ppb)	2	3	4	5	6	4
O_3 (ppb)	1	2	4	7	9	5
$PM_{2.5}$: 3-hour running average (µg/m^3)	37	40	44	47	50	44
$PM_{2.5}$ (µg/m^3)	38	41	46	48	49	45
SO_2 (ppb)	5	5	5	6	6	5
CO (ppm)	2	2	3	3	3	3

Table 7 *Estimated agreement between four categories of hourly AQHI and AQI in 2003-2010, Ontario*[a]

City	Kappa Statistics	
	Warm Season (April to September)	**Cool Season (October to March)**
Across Ontario	0.59 (moderate agreement)	0.25 (fair agreement)
Four Ontario cities [b]	0.49 (moderate agreement)	0.18 (slight agreement)
All other Ontario cities [c]	0.65 (substantial agreement)	0.31 (fair agreement)
Ontario rural towns	0.71 (substantial agreement)	0.64 (substantial agreement)

a For the AQI, the two categories of Very Good Air Quality and Good Air Quality were combined in order to allow comparison with AQHI

b Four urban cities that were included in a time series study of air pollution (Stieb et al. 2008)

c All other urban centers that were not included in a time series study of air pollution (Stieb et al. 2008)

Table 8 (A) *Observed coverage of AQI on AQHI across Ontario (2003-2010), computed as the proportion of times each category of AQI contained the corresponding category of AQHI.*

AQI	AQHI			
	Low Health Risk	Moderate Health Risk	High Health Risk	Very High Health Risk
Very Good to Good Air Quality	98%	-	-	-
Moderate Air Quality	-	40%	-	-
Poor Air Quality	-	-	44%	-
Very Poor Air Quality	-	-	-	0%

Table 8 (B) *Observed coverage of AQHI on AQI across Ontario (2003-2010), computed as the proportion of times each category of AQHI contained the corresponding category of AQI.*

AQHI	AQI			
	Very Good to Good Air Quality	Moderate Air Quality	Poor Air Quality	Very Poor Air Quality
Low Health Risk	89%	-	-	-
Moderate Health Risk	-	81%	-	-
High Health Risk	-	-	49%	-
Very High Health Risk	-	-	-	0%

Table 9 (A) *Observed coverage of AQI on AQHI in two rural towns (Grand Bend and Tiverton) of Ontario (2003-2010), computed as the proportion of times each category of AQI contained the corresponding category of AQHI*

AQI	AQHI		
	Low Health Risk	Moderate Health Risk	High Health Risk
Very Good to Good Air Quality	97%	-	-
Moderate Air Quality	-	79%	-
Poor Air Quality	-	-	90%

Table 9 (B) *Observed coverage of AQHI on AQI in two rural towns (Grand Bend and Tiverton) of Ontario (2003-2010), computed as the proportion of times each category of AQHI contained the corresponding category of AQI*

AQHI	AQI		
	Very Good to Good Air Quality	Moderate Air Quality	Poor Air Quality
Low Health Risk	99%	-	-
Moderate Health Risk	-	67%	-
High Health Risk	-	-	28%

Table 10 *Projected increased daily mortality risk for each AQI index across Ontario in 2003-2010, assuming (1) excess mortality caused by PM2.5, O3, and NO2 only, (2) same unit increase in mortality for PM2.5, O3, and NO2 as used in the AQHI formula, (3) and the "no-risk" background concentrations for PM2.5, O3, and NO2 are zero*

Daily Maximum AQI	AQI Classification	Number of Days	Projected increased daily mortality risk (%)						
			Minimum	25th%	Median	75th%	Maximum	Mean	Std Dev
0-5	Very good	3	0.5	0.5	1.1	1.2	1.2	0.9	0.4
6-10	Very good	261	0.7	1.3	1.9	2.2	3.3	1.8	0.6
11-15	Very good	2763	1.0	1.8	2.3	2.9	4.9	2.4	0.7
16-20	Good	11648	1.3	2.1	2.6	3.1	6.2	2.7	0.7
21-25	Good	18149	1.7	2.5	2.8	3.4	7.7	3.0	0.7
26-31	Good	14217	1.8	3.0	3.3	3.9	8.8	3.5	0.7
32-35	Moderate	5835	1.9	3.6	4.0	4.5	8.9	4.1	0.7
36-40	Moderate	4810	1.7	4.1	4.5	5.0	8.8	4.6	0.7
41-49	Moderate	3429	3.0	5.0	5.4	6.0	11.9	5.5	0.8
50-59	Poor	987	3.5	6.0	6.6	7.2	9.8	6.6	0.9
60-79	Poor	290	4.5	7.1	7.7	8.4	10.9	7.7	1.0
80-99	Poor	7	7.6	8.3	8.7	9.1	10.4	8.8	0.9
>99	Very poor	3	8.2	8.2	8.4	9.4	9.4	8.7	0.6

Table 11. *Estimated Spearman correlation coefficients between the AQHI and AQI and hourly concentrations of five air pollutants across Ontario, 2003-2010*

Air Pollution Index	Hourly Concentration of Individual Air Pollutant							
	$PM_{2.5}$ (3-hour running average) ($\mu g/m^3$)	**NO_2** (3-hour running average) (ppb)	**O_3** (3-hour running average) (ppb)	**$PM_{2.5}$** ($\mu g/m^3$)	**NO_2** (ppb)	**O_3** (ppb)	**SO_2** (ppb)	**CO** (ppm)
AQHI	0.6	0.5	0.3	0.6	0.5	0.3	0.4	0.3
AQI	0.3	-0.3	0.8	0.2	-0.3	0.9	0.1	0
$PM_{2.5}$_3hr	1	0.5	0	0.9	0.5	0	0.4	0.3
NO_2_3hr	0.5	1	-0.5	0.5	1	-0.5	0.4	0.4
O_3_3hr	0	-0.5	1	0	-0.5	1.0	-0.1	-0.2
$PM_{2.5}$	0.9	0.4	0	1	0.5	0	0.4	0.3
NO_2	0.5	1	-0.5	0.5	1	-0.5	0.4	0.4
O_3	0	-0.5	1	0	-0.5	1	0	-0.2
SO_2	0.4	0.4	-0.1	0.4	0.4	0	1	0.2
CO	0.3	0.4	-0.2	0.3	0.4	-0.2	0.2	1

Table 12 (A) *Estimated Spearman correlation coefficients between AQHI and AQI and hourly concentrations of five air pollutants across Ontario during the warm season (April to September), 2003-2010*

Air Pollution Index	Hourly Concentration of Individual Air Pollutant							
	$PM_{2.5}$ (3-hour running average) (µg/m³)	**NO_2** (3-hour running average) (ppb)	**O_3** (3-hour running average) (ppb)	**$PM_{2.5}$** (µg/m³)	**NO_2** (ppb)	**O_3** (ppb)	**SO_2** (ppb)	**CO** (ppm)
AQHI	0.7	0.4	0.6	0.7	0.4	0.6	0.5	0.2
AQI	0.5	-0.1	0.9	0.4	-0.1	0.9	0.3	0

Table 12 (B) *Estimated Spearman correlation coefficients between AQHI and AQI and hourly concentrations of five air pollutants across Ontario during the cool season (October to March), 2003-2010*

Air Pollution Index	Hourly Concentration of Individual Air Pollutant							
	$PM_{2.5}$ (3-hour running average) (µg/m³)	**NO_2** (3-hour running average) (ppb)	**O_3** (3-hour running average) (ppb)	**$PM_{2.5}$** (µg/m³)	**NO_2** (ppb)	**O_3** (ppb)	**SO_2** (ppb)	**CO** (ppm)
AQHI	0.6	0.6	0	0.5	0.6	0	0.4	0.4
AQI	0	-0.3	0.7	0	-0.3	0.7	0	0

Table 13 (A) *Estimated Spearman correlation coefficients between AQHI and AQI and hourly concentrations of five air pollutants in Toronto, Hamilton, Ottawa, and Windsor, 2003-2010*

Air Pollution Index	Hourly Concentration of Individual Air Pollutant							
	$PM_{2.5}$ (3-hour running average) (μg/m³)	NO_2 (3-hour running average) (ppb)	O_3 (3-hour running average) (ppb)	$PM_{2.5}$ (μg/m³)	NO_2 (ppb)	O_3 (ppb)	SO_2 (ppb)	CO (ppm)
AQHI	0.7	0.6	0.2	0.7	0.5	0.2	0.4	0.3
AQI	0.4	-0.2	0.7	0.3	-0.2	0.8	0.1	0

Table 13 (B) *Estimated Spearman correlation coefficients between AQHI and AQI and hourly concentrations of five air pollutants in urban centers of Ontario excluding Toronto, Hamilton, Ottawa, and Windsor, 2003-2010*

Air Pollution Index	Hourly Concentration of Individual Air Pollutant							
	$PM_{2.5}$ (3-hour running average) (μg/m³)	NO_2 (3-hour running average) (ppb)	O_3 (3-hour running average) (ppb)	$PM_{2.5}$ (μg/m³)	NO_2 (ppb)	O_3 (ppb)	SO_2 (ppb)	CO (ppm)
AQHI	0.6	0.4	0.4	0.6	0.4	0.4	0.4	0.3
AQI	0.3	-0.3	0.8	0.3	-0.3	0.8	0.1	0

Table 13 (C) *Estimated Spearman correlation coefficients between AQHI and AQI and hourly concentrations of five air pollutants in Tiverton and Grand Bend, Ontario, 2003-2010*

Air Pollution Index	Hourly Concentration of Individual Air Pollutant							
	$PM_{2.5}$ (3-hour running average) (μg/m³)	NO_2 (3-hour running average) (ppb)	O_3 (3-hour running average) (ppb)	$PM_{2.5}$ (μg/m³)	NO_2 (ppb)	O_3 (ppb)	SO_2 (ppb)	CO (ppm)
AQHI	0.6	0.4	0.8	0.5	0.4	0.7	0.4	-
AQI	0.2	0	1	0.2	0	1	0.3	-

Table 14 List of top 20 high risk days according to daily maximum AQHI and daily maximum AQI, by city, 2003-2010

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
Barrie								
1	11	2003	Feb	28	68	2005	Jun	28
2	9	2005	Jun	28	61	2005	Jun	27
3	8	2005	Feb	2	61	2007	Sep	21
4	8	2005	Feb	4	60	2003	Jun	26
5	8	2003	Mar	16	60	2003	Aug	21
6	8	2003	Feb	27	60	2005	Jun	29
7	8	2005	Feb	5	60	2005	Oct	4
8	8	2005	Feb	1	60	2007	Sep	22
9	8	2008	Mar	10	59	2003	Jun	24
10	8	2003	Mar	17	59	2004	Jul	22
11	8	2003	Apr	10	59	2005	Jun	10
12	8	2003	Jun	24	59	2008	Aug	23
13	8	2003	Jun	25	57	2005	Jun	30
14	7	2005	Oct	4	57	2005	Oct	5
15	7	2004	Sep	24	55	2003	Jun	25
16	7	2003	Apr	11	55	2005	Sep	14
17	7	2008	Aug	22	55	2008	Jul	6
18	7	2005	Jan	27	55	2008	Aug	22
19	7	2005	Jan	28	54	2005	Apr	19
20	7	2003	Mar	6	54	2007	May	31
					Number of days in common			**0**
Belleville								
1	10	2003	Jun	25	99	2003	Jun	25
2	9	2003	Jun	26	97	2003	Jun	24
3	9	2003	Jun	24	81	2007	Jun	26
4	8	2005	Jun	28	74	2003	Jun	26
5	8	2005	Jun	25	74	2003	Jul	4
6	8	2003	Jul	4	73	2003	Aug	15
7	8	2007	May	24	72	2005	Jun	25
8	8	2007	Jun	26	71	2003	Jun	23
9	8	2003	Aug	21	71	2007	May	24
10	8	2007	May	25	69	2007	Jun	25
11	8	2003	Aug	15	66	2005	Jun	28
12	8	2007	Sep	6	66	2006	Jun	17
13	8	2005	Sep	12	65	2007	Aug	29
14	7	2003	Jun	23	65	2007	Sep	6
15	7	2003	Jul	3	64	2006	Jul	31
16	7	2005	Aug	4	64	2007	May	25
17	7	2007	Jun	2	64	2007	Jul	10

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
Belleville *cont'd*								
18	7	2005	Sep	13	63	2003	Aug	21
19	7	2007	Jul	10	62	2003	Jul	3
20	7	2007	Sep	21	61	2005	Sep	12
					Number of days in common			**1**
Brampton								
1	9	2004	Mar	1	72	2003	Jul	3
2	9	2003	Oct	9	70	2007	Sep	21
3	9	2004	Sep	23	70	2007	Sep	22
4	9	2003	Oct	10	68	2007	May	24
5	9	2005	Jun	28	65	2003	Jun	24
6	9	2005	Oct	4	64	2003	Aug	21
7	9	2003	Apr	11	64	2005	Jun	28
8	9	2007	May	9	63	2003	Jun	25
9	8	2003	Apr	10	63	2005	Oct	5
10	8	2003	Jul	1	62	2004	Jul	22
11	8	2005	Feb	7	62	2005	Oct	4
12	8	2007	May	24	61	2004	May	14
13	8	2005	Jun	9	61	2005	Jul	12
14	8	2003	Jul	3	60	2003	Jul	2
15	8	2003	Jul	2	60	2005	Jun	13
16	8	2005	Jul	13	60	2005	Jun	27
17	8	2003	Jun	25	59	2004	Sep	24
18	8	2005	May	9	59	2007	Jun	2
19	8	2005	Feb	4	58	2003	Jul	1
20	8	2004	Sep	24	58	2005	Jun	10
					Number of days in common			**0**
Brantford								
1	8	2003	Oct	10	67	2004	Sep	4
2	8	2007	May	24	65	2007	May	24
3	7	2007	Sep	21	64	2004	Sep	3
4	7	2007	Sep	6	63	2003	Aug	21
5	7	2005	Oct	4	62	2007	Sep	21
6	7	2003	Aug	21	61	2005	Jun	24
7	7	2005	Jun	24	61	2007	Sep	6
8	7	2005	Aug	3	60	2003	Oct	10
9	7	2004	Sep	4	60	2005	Feb	5
10	7	2004	Sep	24	59	2003	Aug	20
11	7	2005	Jun	28	59	2006	Jun	17
12	7	2007	May	23	58	2004	Sep	24
13	6	2007	May	31	58	2005	Jun	28

Table 14 *continued…*

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
Brantford *cont'd*								
14	6	2007	Aug	2	57	2005	Jun	13
15	6	2008	Jul	18	57	2005	Aug	3
16	6	2003	Oct	11	57	2005	Sep	14
17	6	2005	Jun	25	57	2008	Jul	18
18	6	2005	May	9	57	2010	Jun	27
19	6	2005	Sep	13	56	2004	Jul	22
20	6	2005	Sep	12	56	2005	Oct	4
					Number of days in common			**1**
Burlington								
1	9	2007	Sep	21	78	2007	Sep	21
2	9	2006	May	31	68	2006	May	31
3	8	2007	May	24	67	2003	Jul	2
4	8	2003	Jun	25	64	2003	Jun	26
5	8	2004	Sep	23	63	2003	Jul	3
6	8	2003	Jul	3	63	2007	Sep	22
7	8	2007	Sep	6	61	2004	Sep	24
8	8	2003	Jun	24	61	2004	Sep	25
9	8	2005	Jan	30	60	2005	Jan	30
10	8	2005	May	7	59	2003	Jun	25
11	8	2004	Sep	24	59	2007	Jun	25
12	8	2007	May	25	59	2007	Jun	26
13	8	2004	Jun	7	58	2004	Jul	22
14	8	2005	Sep	13	58	2005	Aug	3
15	8	2005	Jun	9	58	2007	May	24
16	8	2003	Jun	26	57	2003	Jun	23
17	8	2004	Sep	4	57	2005	Jul	13
18	8	2007	Sep	22	56	2004	Sep	4
19	7	2005	Sep	14	56	2005	Aug	8
20	7	2005	Aug	3	56	2005	Sep	14
					Number of days in common			**3**
Chatham								
1	9	2005	Jun	27	72	2005	Jun	21
2	9	2005	Jun	28	71	2005	Jun	27
3	8	2007	Sep	21	71	2005	Jun	28
4	8	2005	Jun	25	70	2005	Jun	25
5	8	2005	Feb	4	68	2005	Jul	21
6	7	2005	Jun	24	64	2005	Jun	24
7	7	2007	May	24	64	2007	Sep	21
8	7	2005	Jun	21	63	2007	Jun	18
9	7	2005	Feb	3	62	2007	Jun	1

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Chatham** cont'd*								
10	7	2005	Jun	8	60	2005	Oct	4
11	7	2005	Jun	9	59	2005	Jun	8
12	7	2007	Jun	18	59	2005	Aug	26
13	7	2007	May	23	59	2007	Aug	2
14	7	2007	May	31	59	2008	Aug	22
15	7	2005	Sep	13	58	2008	Sep	3
16	7	2005	Aug	26	57	2005	Jun	7
17	7	2005	Oct	4	57	2005	Jun	9
18	7	2006	Aug	18	57	2007	May	23
19	7	2007	Aug	2	57	2007	May	31
20	7	2007	Aug	29	56	2008	Jul	18
					Number of days in common			**2**
Cornwall								
1	8	2010	May	31	138	2010	May	31
2	7	2008	Apr	18	70	2010	Jun	1
3	7	2007	May	24	61	2006	Jul	17
4	7	2007	May	25	60	2007	May	24
5	7	2007	Jan	23	56	2006	Jul	27
6	6	2007	Sep	6	54	2006	May	25
7	6	2006	Jun	18	54	2007	May	25
8	6	2006	Jul	17	54	2007	Jun	27
9	6	2007	Sep	7	54	2008	Apr	18
10	6	2009	Feb	3	53	2006	Jun	17
11	6	2008	Mar	18	53	2006	Jun	18
12	6	2007	Jun	26	53	2007	Jul	11
13	6	2007	Jan	31	53	2009	Aug	16
14	6	2007	Jun	19	52	2007	Sep	6
15	6	2008	Apr	19	51	2006	Mar	31
16	6	2008	Apr	22	51	2007	Jun	26
17	6	2008	Nov	6	51	2007	Sep	7
18	6	2006	Jun	17	51	2009	May	21
19	6	2009	Feb	2	50	2006	Jun	19
20	6	2007	Jun	27	49	2007	Apr	23
					Number of days in common			**1**
Grand Bend								
1	8	2010	Aug	29	73	2010	Aug	29
2	7	2010	Jul	6	72	2010	Jul	6
3	7	2010	Aug	31	69	2010	Jul	8
4	7	2010	Aug	3	66	2010	Aug	28
5	7	2010	Jul	8	66	2010	Aug	31

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Greand Bend** cont'd*								
6	7	2010	Aug	28	64	2010	Jul	4
7	7	2010	Jul	4	64	2010	Aug	30
8	6	2010	Aug	30	62	2010	Aug	3
9	6	2010	Jun	26	56	2010	Jun	26
10	6	2010	Sep	21	54	2010	Jun	19
11	6	2010	Jul	7	54	2010	Jul	3
12	6	2010	May	26	53	2010	Sep	21
13	6	2010	May	30	51	2010	May	26
14	6	2010	Jul	3	51	2010	May	30
15	5	2010	Jun	19	51	2010	Aug	15
16	5	2010	May	31	50	2010	Apr	15
17	5	2010	Apr	15	50	2010	May	31
18	5	2010	Aug	4	50	2010	Aug	4
19	5	2010	Aug	15	49	2010	Jul	7
20	5	2010	Sep	7	48	2010	Sep	7
					Number of days in common			**5**
Guelph								
1	7	2003	Feb	28	49	2010	Apr	3
2	7	2003	Mar	1	49	2010	May	28
3	6	2010	Jul	6	49	2010	May	31
4	6	2010	Mar	9	48	2010	Jul	6
5	6	2003	Feb	26	48	2010	Jul	8
6	6	2003	Jan	30	46	2010	Apr	15
7	5	2003	Feb	27	46	2010	Jul	4
8	5	2010	Apr	3	46	2010	Aug	29
9	5	2010	Jul	4	45	2010	Mar	9
10	5	2003	Jan	31	45	2010	Apr	1
11	5	2010	Aug	31	45	2010	Apr	30
12	5	2010	Apr	15	45	2010	Aug	31
13	5	2010	Jul	8	44	2010	May	5
14	5	2010	May	28	44	2010	Jun	27
15	5	2010	Jun	27	43	2010	Mar	8
16	5	2003	Mar	2	43	2010	Jun	26
17	5	2010	May	31	43	2010	Jul	3
18	5	2010	Jul	14	43	2010	Jul	14
19	5	2010	Apr	1	43	2010	Sep	7
20	5	2010	Aug	3	42	2003	Feb	4
					Number of days in common			**1**

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
Hamilton								
1	9	2004	May	13	79	2004	Oct	26
2	9	2004	Sep	23	72	2007	Sep	21
3	9	2007	May	9	69	2008	Sep	25
4	9	2006	May	31	68	2003	Jun	24
5	8	2005	May	7	68	2003	Jun	25
6	8	2004	May	12	65	2003	Jul	3
7	8	2005	Jun	9	65	2004	Jul	12
8	8	2003	Oct	9	64	2005	Jun	9
9	8	2004	May	14	64	2006	May	31
10	8	2005	Jul	12	63	2003	Aug	21
11	8	2005	Jan	29	62	2007	May	24
12	8	2005	Jul	13	60	2004	Sep	4
13	8	2005	Oct	3	60	2004	Sep	24
14	8	2003	Jun	25	60	2007	Oct	5
15	8	2005	Jun	28	59	2005	Oct	4
16	8	2007	May	24	58	2003	Aug	5
17	8	2003	Mar	17	58	2005	Oct	5
18	8	2005	Jun	8	57	2003	Oct	9
19	8	2004	Sep	24	57	2005	Jan	29
20	8	2003	Jul	3	57	2007	May	9
					Number of days in common			**0**
Kingston								
1	8	2007	Sep	6	63	2007	Sep	6
2	8	2007	May	25	62	2007	May	25
3	7	2007	Aug	29	61	2007	May	24
4	7	2007	Jun	1	61	2007	Jul	11
5	7	2007	Jul	10	60	2007	Jun	2
6	7	2007	May	24	60	2007	Aug	29
7	7	2007	Jun	25	57	2007	Sep	25
8	7	2007	Sep	7	57	2008	Nov	7
9	7	2007	Jun	2	56	2007	Jun	25
10	7	2007	Aug	3	56	2007	Jun	27
11	7	2007	Jun	27	56	2007	Jul	10
12	7	2007	Sep	25	56	2007	Sep	7
13	7	2010	Aug	31	56	2010	Aug	30
14	7	2007	May	31	55	2007	May	15
15	7	2010	Aug	30	55	2008	Apr	18
16	6	2008	Jul	18	55	2010	Aug	31
17	6	2010	Sep	1	55	2010	Sep	1
18	6	2007	Jun	26	54	2007	Jun	1

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Kingston** cont'd*								
19	6	2007	Jun	8	54	2007	Jun	26
20	6	2008	Apr	18	54	2007	Jul	31
					Number of days in common			**3**
Kitchener								
1	9	2003	Mar	17	78	2005	Jun	28
2	8	2003	Feb	26	66	2007	Sep	21
3	8	2005	Jun	28	65	2005	Sep	14
4	8	2005	Feb	4	64	2004	Sep	24
5	8	2003	Jan	30	64	2005	Jun	13
6	8	2003	Feb	27	61	2004	Jul	22
7	7	2007	Sep	6	61	2004	Sep	25
8	7	2003	Mar	1	61	2005	Jun	12
9	7	2007	Sep	21	61	2005	Jul	13
10	7	2007	May	24	61	2005	Aug	3
11	7	2005	Jun	24	60	2005	Oct	4
12	7	2005	Jul	13	60	2007	May	24
13	7	2005	Aug	3	59	2004	Sep	4
14	7	2005	Feb	5	59	2005	Jun	24
15	7	2003	Mar	16	59	2007	May	31
16	7	2004	Sep	24	57	2005	Feb	4
17	7	2008	Mar	10	57	2005	Oct	5
18	7	2005	Jan	29	56	2007	Sep	6
19	7	2010	Mar	9	55	2004	Jun	8
20	7	2005	Mar	5	55	2005	Feb	6
					Number of days in common			**0**
London								
1	9	2003	Jul	23	77	2005	Jun	28
2	9	2005	Jun	28	75	2005	Jun	27
3	8	2005	Feb	4	69	2004	Sep	5
4	8	2005	Jun	27	68	2005	Jun	13
5	8	2004	Sep	23	65	2003	Oct	11
6	7	2003	Aug	21	63	2003	Aug	21
7	7	2003	Aug	20	63	2005	Oct	4
8	7	2004	Sep	24	62	2005	Feb	4
9	7	2005	Feb	3	61	2003	Oct	10
10	7	2005	Aug	3	61	2005	Jun	12
11	7	2005	Jun	24	60	2004	Jul	22
12	7	2005	Oct	4	60	2004	Sep	4
13	7	2003	Jul	31	59	2003	Aug	20
14	7	2005	May	7	59	2005	Jun	24

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***London** cont'd*								
15	7	2007	May	24	58	2004	Sep	3
16	7	2004	Sep	5	57	2006	May	28
17	7	2007	Sep	6	56	2004	Jun	8
18	7	2006	Feb	23	56	2005	Aug	3
19	7	2003	Oct	9	56	2009	May	24
20	7	2008	Apr	18	55	2004	Sep	24
					Number of days in common			**1**
Mississauga								
1	8	2003	Jan	31	56	2009	Aug	15
2	7	2003	Jan	30	52	2008	Apr	19
3	7	2010	Jul	7	51	2008	Jul	18
4	7	2003	Dec	3	51	2009	May	21
5	6	2008	Jul	18	51	2010	May	27
6	6	2010	May	27	51	2010	Jul	7
7	6	2008	Apr	18	49	2008	Aug	22
8	6	2009	Aug	16	49	2008	Sep	3
9	6	2009	Jun	24	49	2010	May	26
10	6	2008	Jun	27	48	2008	Jul	19
11	6	2009	Aug	15	48	2010	Jul	8
12	6	2008	Aug	22	46	2008	Jul	16
13	6	2010	May	26	46	2010	Jul	4
14	6	2008	Apr	19	45	2008	Apr	18
15	6	2010	Jul	8	45	2008	Jul	7
16	6	2008	Sep	3	45	2009	Jun	24
17	6	2008	Jul	16	45	2009	Aug	14
18	6	2009	Feb	7	45	2009	Aug	16
19	6	2003	Jan	24	45	2010	Aug	29
20	6	2010	Jun	17	45	2010	Nov	12
					Number of days in common			**0**
Newmarket								
1	9	2005	Jun	28	74	2005	Jun	27
2	8	2007	May	24	69	2005	Jun	28
3	8	2003	Mar	16	68	2003	Jul	4
4	8	2003	Jul	4	67	2007	May	24
5	8	2004	Jul	21	63	2005	Jun	10
6	8	2005	Jun	27	62	2004	Jul	22
7	8	2005	Feb	1	61	2003	Jun	26
8	8	2007	Sep	21	61	2003	Aug	21
9	8	2005	Sep	13	61	2004	Jul	21
10	8	2003	Aug	21	61	2005	Jun	8

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Newmarket** cont'd*								
11	7	2007	Sep	6	61	2005	Jun	9
12	7	2004	Sep	24	61	2007	Jun	2
13	7	2005	Feb	3	60	2003	Jun	25
14	7	2005	Jun	9	60	2007	Sep	6
15	7	2004	May	13	59	2003	Jun	24
16	7	2005	Feb	5	59	2004	May	13
17	7	2003	Jun	26	59	2005	Jun	5
18	7	2007	Jun	2	59	2005	Jun	11
19	7	2003	Jun	25	59	2006	May	30
20	7	2007	Jun	26	59	2007	Aug	2
					Number of days in common			**0**
North Bay								
1	9	2005	Jun	28	72	2005	Jun	28
2	8	2003	Jun	26	57	2005	Jun	24
3	7	2005	Jun	27	56	2003	Jun	25
4	7	2003	Jun	25	56	2005	Jun	27
5	7	2003	Mar	1	56	2005	Oct	5
6	7	2005	Aug	3	55	2003	Jun	26
7	7	2005	Aug	4	55	2005	Jun	3
8	7	2005	Oct	5	55	2006	Jun	18
9	7	2004	Apr	29	54	2003	Jun	23
10	7	2007	Sep	6	54	2003	Jun	24
11	6	2004	Feb	29	54	2005	Aug	4
12	6	2003	Mar	16	54	2005	Sep	12
13	6	2007	May	24	53	2005	Jun	25
14	6	2007	May	23	52	2003	Jul	3
15	6	2003	Mar	17	52	2003	Jul	4
16	6	2006	Mar	31	52	2005	Aug	3
17	6	2003	Feb	28	52	2006	Jul	8
18	6	2003	Jun	24	52	2008	Oct	11
19	6	2005	Jun	24	51	2003	Aug	21
20	6	2005	Jun	25	51	2004	Sep	24
					Number of days in common			**1**
Oakville								
1	9	2006	May	31	74	2003	Jun	24
2	9	2003	Oct	9	72	2003	Jun	25
3	9	2004	Sep	15	71	2007	Sep	22
4	8	2003	Jun	24	70	2003	Aug	21
5	8	2007	May	24	70	2007	Sep	21
6	8	2004	May	14	68	2003	Jul	3

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Oakville** cont'd*								
7	8	2003	Jun	25	65	2004	May	14
8	8	2007	Sep	22	62	2003	Aug	5
9	8	2007	Sep	21	62	2005	Jun	28
10	8	2003	Oct	10	60	2003	Jul	4
11	8	2005	Jun	28	60	2004	Sep	24
12	8	2007	May	31	60	2007	May	24
13	8	2005	Jun	9	60	2007	Sep	6
14	8	2003	Jul	3	60	2010	Jul	7
15	8	2004	May	12	59	2004	May	13
16	8	2008	Apr	19	59	2005	Jul	13
17	8	2004	Sep	24	59	2006	May	31
18	8	2003	Jul	2	58	2003	Aug	20
19	7	2003	Aug	20	58	2004	Jul	22
20	7	2003	Jun	26	58	2007	Jun	26
					Number of days in common			**0**
Oshawa								
1	9	2003	Jun	25	70	2005	Jul	11
2	9	2003	Mar	17	69	2003	Jun	25
3	9	2005	Feb	4	66	2007	May	24
4	9	2003	Jun	26	66	2007	Jun	26
5	9	2003	Jun	24	64	2003	Jun	24
6	9	2003	Jul	4	64	2005	Jul	12
7	8	2003	Jul	3	63	2003	Jul	3
8	8	2003	Oct	9	63	2003	Jul	4
9	8	2004	Sep	23	62	2007	Jun	25
10	8	2007	May	24	61	2003	Jun	26
11	8	2003	Aug	21	61	2004	May	14
12	8	2004	May	13	61	2004	Sep	25
13	8	2005	Apr	20	61	2010	Jul	7
14	8	2005	Oct	4	60	2003	Aug	21
15	8	2005	Apr	19	60	2004	Sep	4
16	8	2003	Jul	1	59	2005	Oct	4
17	8	2005	Feb	5	59	2007	Jun	2
18	8	2005	Sep	13	57	2004	Sep	3
19	7	2003	Jul	15	57	2005	Jun	2
20	7	2005	Sep	12	57	2007	Aug	29
					Number of days in common			**2**
Ottawa								
1	10	2003	Feb	28	119	2010	May	31
2	9	2003	Mar	1	68	2005	Jan	30

Table 14 *continued…*

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Ottawa** cont'd*								
3	9	2003	Jun	26	67	2003	Jun	26
4	8	2003	Mar	17	63	2005	Jun	8
5	8	2003	Aug	21	62	2005	Feb	7
6	8	2010	May	31	61	2003	Aug	21
7	8	2003	Mar	16	61	2005	Feb	5
8	8	2003	Mar	25	60	2005	Jan	29
9	8	2005	Feb	5	58	2005	Feb	6
10	8	2004	Feb	18	57	2005	Jun	9
11	7	2005	Jan	30	56	2005	Jun	6
12	7	2005	Jan	29	55	2004	Jul	22
13	7	2005	Feb	6	55	2007	May	25
14	7	2006	Jun	18	54	2006	Jun	18
15	7	2005	Feb	7	54	2007	May	24
16	7	2005	Feb	4	53	2005	Sep	14
17	7	2007	May	25	52	2005	Sep	13
18	7	2003	Jul	4	52	2009	May	21
19	7	2003	Feb	27	51	2003	Jun	27
20	7	2008	Nov	6	50	2003	Mar	17
					Number of days in common			**2**
Parry Sound								
1	6	2010	Apr	3	53	2010	Apr	3
2	5	2010	Jul	4	49	2010	Jul	4
3	5	2010	Jul	5	48	2010	Apr	15
4	5	2010	Apr	1	48	2010	Jul	5
5	5	2010	Apr	15	45	2010	Apr	1
6	5	2010	Jul	6	44	2010	Apr	2
7	5	2010	Jul	28	44	2010	Jul	6
8	5	2010	Aug	31	43	2010	Apr	30
9	5	2010	May	31	43	2010	May	31
10	5	2010	Aug	3	43	2010	Jul	3
11	5	2010	Jul	7	43	2010	Jul	7
12	5	2010	Apr	2	43	2010	Sep	21
13	5	2010	Sep	21	42	2010	Aug	29
14	4	2010	Sep	1	40	2010	May	1
15	4	2010	Aug	30	40	2010	May	24
16	4	2010	Aug	29	40	2010	Jul	28
17	4	2010	Apr	30	40	2010	Aug	28
18	4	2010	May	24	39	2010	Apr	16
19	4	2010	Jul	3	39	2010	Aug	3
20	4	2010	Aug	28	39	2010	Aug	30
					Number of days in common			**4**

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
Peterborough								
1	9	2003	Jun	26	78	2003	Jun	24
2	8	2003	Aug	21	77	2003	Jun	26
3	8	2003	Jun	24	69	2003	Jul	3
4	8	2007	May	24	67	2003	Jul	4
5	8	2003	Jul	4	65	2003	Aug	21
6	8	2003	Jun	25	64	2007	May	24
7	7	2007	Jun	26	63	2007	Jun	26
8	7	2007	Sep	6	62	2003	Jun	25
9	7	2007	Jun	2	58	2003	Jul	2
10	7	2003	Mar	17	57	2010	Jul	6
11	7	2007	Sep	7	56	2007	Aug	2
12	7	2010	Aug	31	56	2008	Jul	17
13	7	2010	Jul	6	56	2010	Jul	8
14	7	2003	Mar	16	55	2007	Sep	7
15	7	2003	Jul	3	55	2009	May	21
16	7	2006	Jun	18	54	2006	Jun	18
17	7	2003	Jul	2	53	2007	May	25
18	6	2003	Aug	20	53	2007	Sep	6
19	6	2007	Aug	29	52	2003	Aug	20
20	6	2007	May	31	52	2008	Apr	19
					Number of days in common			**2**
Sarnia								
1	10	2005	6	24	122	2005	2	5
2	9	2007	5	23	98	2005	2	4
3	9	2007	Jun	18	96	2007	Feb	21
4	9	2005	May	5	82	2005	Feb	28
5	9	2003	Jun	18	81	2005	Feb	27
6	9	2005	Feb	3	78	2003	Jun	25
7	9	2005	Jun	28	78	2003	Jun	21
8	9	2003	Feb	25	74	2005	Jun	24
9	9	2005	Jun	10	73	2005	Aug	3
10	9	2003	Jun	20	72	2003	Jun	26
11	9	2007	Jun	30	72	2005	Feb	4
12	8	2003	Aug	21	72	2010	Jun	17
13	8	2007	May	19	71	2003	Oct	1
14	8	2006	Aug	17	71	2003	Jan	20
15	8	2005	Sep	27	68	2007	Aug	2
16	8	2008	Jun	23	67	2005	Aug	12
17	8	2007	Jun	29	67	2007	Aug	23
18	8	2005	Aug	4	67	2007	Sep	31

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Sarnia** cont'd*								
19	8	2003	Aug	3	67	2007	May	21
20	8	2005	Feb	3	66	2003	May	2
					Number of days in common			**0**
Sault Ste. Marie								
1	9	2003	Jun	23	74	2005	May	28
2	8	2003	Jun	25	74	2006	Jun	17
3	8	2006	Jun	17	71	2006	Jun	16
4	8	2006	Jun	16	63	2005	Sep	12
5	7	2005	Sep	12	60	2003	Jun	25
6	7	2003	Jun	26	56	2005	Sep	11
7	7	2005	Sep	11	54	2003	Jun	23
8	7	2003	Jun	24	53	2009	Aug	15
9	7	2003	Jun	22	52	2005	Jun	28
10	6	2003	Aug	20	51	2003	Jun	24
11	6	2003	Aug	19	50	2003	Jul	26
12	6	2005	Jun	28	50	2005	Aug	3
13	6	2003	Jul	31	49	2005	May	8
14	6	2007	May	24	49	2006	Jun	6
15	6	2003	Jul	26	49	2006	Jun	15
16	6	2007	May	30	49	2007	May	23
17	6	2003	Aug	1	49	2007	May	24
18	6	2005	Aug	3	49	2007	Jun	18
19	6	2003	Jul	3	48	2003	Jun	22
20	6	2005	Jul	11	48	2003	Jun	26
					Number of days in common			**0**
St. Catharines								
1	8	2007	Sep	6	71	2005	Oct	4
2	8	2007	May	24	64	2005	Aug	3
3	8	2007	Sep	21	64	2006	Aug	27
4	8	2005	Oct	4	64	2007	Sep	6
5	8	2005	May	7	63	2007	Sep	21
6	8	2007	May	25	62	2007	May	24
7	8	2005	Aug	3	61	2005	Jul	13
8	8	2007	Sep	7	57	2005	Jun	25
9	8	2008	Apr	18	57	2005	Sep	13
10	7	2005	Jun	25	56	2007	Sep	7
11	7	2005	Jul	13	56	2008	Apr	19
12	7	2007	May	9	55	2005	Jun	24
13	7	2007	May	31	55	2005	Sep	14
14	7	2008	Apr	19	55	2007	Jul	10

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
St. Catharines *cont'd*								
15	7	2006	May	31	54	2005	May	8
16	7	2005	May	8	54	2005	Jul	12
17	7	2005	Sep	14	54	2005	Oct	5
18	7	2007	Aug	29	54	2007	May	25
19	7	2005	Oct	3	54	2007	May	31
20	7	2005	Jun	30	54	2008	Apr	18
					Number of days in common			**0**
Thunder Bay								
1	7	2003	Dec	3	70	2008	Jun	2
2	7	2008	Apr	15	55	2003	Aug	18
3	6	2003	Mar	16	48	2003	Aug	20
4	6	2003	Apr	14	48	2003	Sep	12
5	6	2003	Sep	12	48	2007	Jun	1
6	6	2003	Mar	6	47	2006	Jun	17
7	6	2008	Jun	2	46	2003	Mar	6
8	6	2003	Feb	17	46	2003	Sep	11
9	6	2006	May	25	46	2006	May	25
10	6	2003	Sep	11	46	2008	Apr	15
11	6	2003	Aug	18	45	2007	May	31
12	6	2003	Apr	10	45	2007	Jun	13
13	5	2003	Oct	10	45	2008	Jul	26
14	5	2007	Jun	12	44	2003	Mar	16
15	5	2003	Sep	18	44	2006	Jun	29
16	5	2003	Jan	29	43	2003	Sep	17
17	5	2007	Jun	13	43	2003	Sep	18
18	5	2009	Mar	16	43	2006	May	23
19	5	2007	May	31	43	2006	Jul	7
20	5	2003	Oct	7	43	2007	Jun	14
					Number of days in common			**1**
Tiverton								
1	7	2007	Sep	19	67	2007	May	24
2	7	2007	Sep	21	67	2007	Sep	19
3	7	2007	May	31	64	2007	May	23
4	7	2007	May	23	62	2010	Aug	31
5	7	2007	May	24	61	2007	Jun	16
6	7	2007	May	30	57	2007	May	31
7	7	2010	Aug	31	57	2007	Sep	21
8	7	2006	Jul	31	56	2007	May	30
9	7	2007	May	25	56	2007	Jun	18
10	7	2007	Sep	6	56	2007	Jun	24

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Tiverton** cont'd*								
11	6	2007	Sep	22	56	2007	Sep	5
12	6	2008	Jul	7	56	2008	Aug	23
13	6	2007	Jun	18	55	2006	Jul	31
14	6	2007	Jun	16	55	2007	Jun	2
15	6	2007	Jun	2	54	2007	May	25
16	6	2007	Jun	19	54	2007	Jun	7
17	6	2008	Aug	23	54	2007	Sep	6
18	6	2007	Jun	24	54	2008	Jul	25
19	6	2007	Sep	7	52	2007	Aug	14
20	6	2008	Jul	25	52	2010	Sep	1
					Number of days in common			**0**
Toronto								
1	9	2003	Jul	3	71	2003	Jul	3
2	9	2003	Mar	17	70	2003	Aug	21
3	9	2003	Jun	25	65	2003	Jun	24
4	9	2003	Jun	24	64	2005	Oct	5
5	9	2005	Feb	4	63	2010	Jul	7
6	9	2007	May	24	61	2003	Jun	25
7	8	2003	Jul	1	61	2004	May	14
8	8	2003	Jun	26	61	2005	Jun	28
9	8	2005	Jun	28	60	2004	Jul	22
10	8	2003	Jul	2	60	2005	Aug	4
11	8	2003	Apr	10	59	2003	Jul	1
12	8	2005	Jun	9	59	2003	Jul	4
13	8	2003	Aug	21	59	2004	Sep	24
14	8	2003	Jul	4	59	2004	Sep	25
15	8	2003	Jan	30	59	2007	May	24
16	8	2007	Jun	26	58	2005	Jul	4
17	8	2005	Feb	3	58	2005	Oct	4
18	8	2007	May	31	57	2003	Jun	26
19	8	2003	Mar	7	57	2005	Jul	21
20	8	2006	May	30	57	2005	Aug	3
					Number of days in common			**1**
Windsor								
1	10	2003	Mar	17	79	2009	Jul	5
2	9	2004	Sep	22	77	2005	Jun	27
3	9	2005	Jun	27	77	2007	Aug	1
4	9	2005	Jun	28	72	2005	Jun	28
5	9	2003	Aug	20	70	2005	Jun	24
6	8	2007	Aug	1	68	2005	Jun	8

Table 14 continued…

Ranking	Daily Max. AQHI	Year	Month	Day	Daily Max. AQI	Year	Month	Day
***Windsor** cont'd*								
7	8	2005	Aug	3	66	2007	May	23
8	8	2006	Mar	29	65	2007	Aug	2
9	8	2005	Aug	26	64	2005	Aug	26
10	8	2003	Aug	1	64	2007	Jun	11
11	8	2008	Sep	3	63	2003	Aug	20
12	8	2010	Mar	17	63	2005	Jul	11
13	8	2003	Feb	28	63	2005	Aug	3
14	8	2005	Jun	24	63	2007	Aug	29
15	8	2007	May	30	62	2003	Mar	17
16	8	2003	Mar	16	62	2005	Jun	10
17	8	2007	Jun	18	62	2005	Jul	20
18	8	2003	Aug	21	62	2006	Jun	17
19	8	2003	Aug	25	62	2007	Jun	18
20	8	2007	Aug	29	61	2003	Jul	31
					Number of days in common			**2**

Table 15 (A) *Proportion of the time individual pollutants are primary contributor to the index, by cities, 2003-2010*

City	% of the time individual pollutant as primary contributor to AQHI			% of the time individual pollutant as primary contributor to AQI *				
	$PM_{2.5}$	O_3	NO_2	$PM_{2.5}$	O_3	NO_2	SO_2	TRS
BARRIE	0%	66%	34%	21%	74%	5%	0%	0%
BELLEVILLE	0%	82%	17%	13%	86%	2%	0%	0%
BRAMPTON	0%	61%	39%	22%	72%	6%	0%	0%
BRANTFORD	2%	75%	23%	24%	75%	1%	0%	0%
BURLINGTON	0%	53%	46%	26%	68%	6%	0%	0%
CHATHAM	0%	82%	18%	17%	82%	1%	0%	0%
CORNWALL	0%	82%	17%	16%	83%	1%	0%	0%
GRAND BEND	0%	96%	3%	10%	90%	0%	0%	0%
GUELPH	1%	79%	20%	15%	83%	2%	0%	0%
HAMILTON	0%	55%	45%	28%	69%	3%	0%	0%
KINGSTON	0%	92%	8%	10%	89%	0%	0%	0%
KITCHENER	1%	73%	27%	23%	76%	2%	0%	0%
LONDON	1%	66%	33%	27%	71%	2%	0%	0%
MISSISSAUGA	0%	61%	39%	22%	73%	5%	0%	0%
NEWMARKET	0%	79%	21%	15%	83%	2%	0%	0%
NORTH BAY	0%	78%	22%	12%	84%	4%	0%	0%
OAKVILLE	0%	66%	34%	21%	75%	4%	0%	0%
OSHAWA	1%	70%	29%	22%	77%	2%	0%	0%
OTTAWA	0%	71%	28%	20%	78%	2%	0%	0%
PARRY SOUND	0%	92%	8%	8%	91%	1%	0%	0%
PETERBOROUGH	1%	84%	15%	15%	84%	1%	0%	0%
SARNIA	2%	69%	29%	37%	62%	0%	0%	0%
SAULT STE. MARIE	0%	89%	11%	11%	89%	0%	0%	0%
ST. CATHARINES	0%	69%	31%	22%	75%	2%	0%	0%
THUNDER BAY	0%	73%	26%	17%	81%	2%	0%	0%
TIVERTON	0%	97%	3%	6%	94%	0%	0%	0%
TORONTO	0%	40%	59%	27%	66%	7%	0%	0%
WINDSOR	0%	49%	51%	31%	63%	5%	0%	1%

* Carbon Monoxide (CO) was never a primary contributor to the AQI index, 2003-2010

Table 15 (B) *Percentage of the time individual pollutants as primary contributor to the index during the warm season (April to September), by cities, 2003-2010*

City	% of the time individual pollutant as primary contributor to AQHI			% of the time individual pollutant as primary contributor to AQI *				
	$PM_{2.5}$	O_3	NO_2	$PM_{2.5}$	O_3	NO_2	SO_2	TRS
BARRIE	1%	76%	23%	21%	77%	3%	0%	0%
BELLEVILLE	0%	89%	11%	10%	89%	1%	0%	0%
BRAMPTON	0%	72%	28%	20%	77%	3%	0%	0%
BRANTFORD	4%	82%	15%	24%	76%	0%	0%	0%
BURLINGTON	0%	65%	35%	24%	71%	4%	0%	0%
CHATHAM	0%	94%	6%	13%	87%	0%	0%	0%
CORNWALL	0%	90%	10%	15%	85%	0%	0%	0%
GRAND BEND	0%	99%	1%	9%	91%	0%	0%	0%
GUELPH	1%	89%	9%	16%	84%	0%	0%	0%
HAMILTON	0%	66%	33%	27%	71%	2%	0%	0%
KINGSTON	0%	96%	4%	9%	91%	0%	0%	0%
KITCHENER	1%	84%	15%	20%	79%	1%	0%	0%
LONDON	1%	81%	18%	23%	76%	1%	0%	0%
MISSISSAUGA	1%	74%	26%	21%	77%	2%	0%	0%
NEWMARKET	0%	88%	12%	13%	87%	1%	0%	0%
NORTH BAY	0%	84%	15%	11%	87%	2%	0%	0%
OAKVILLE	0%	76%	24%	18%	80%	2%	0%	0%
OSHAWA	2%	80%	18%	20%	79%	1%	0%	0%
OTTAWA	1%	84%	15%	16%	83%	1%	0%	0%
PARRY SOUND	0%	93%	7%	9%	90%	1%	0%	0%
PETERBOROUGH	1%	93%	6%	13%	87%	0%	0%	0%
SARNIA	2%	80%	18%	33%	66%	0%	0%	0%
SAULT STE. MARIE	1%	93%	6%	10%	90%	0%	0%	0%
ST. CATHARINES	0%	77%	22%	22%	77%	1%	0%	0%
THUNDER BAY	1%	79%	20%	18%	82%	1%	0%	0%
TIVERTON	0%	100%	0%	4%	96%	0%	0%	0%
TORONTO	0%	56%	44%	25%	72%	3%	0%	0%
WINDSOR	1%	68%	31%	27%	71%	2%	0%	0%

* Carbon Monoxide (CO) was never a primary contributor to the AQI index, 2003-2010

Table 15 (C) *Percentage of the time individual pollutants as primary contributor to the index during the cool season (October to March), by cities, 2003-2010*

City	% of the time individual pollutant as primary contributor to AQHI			% of the time individual pollutant as primary contributor to AQI *				
	$PM_{2.5}$	O_3	NO_2	$PM_{2.5}$	O_3	NO_2	SO_2	TRS
BARRIE	0%	56%	44%	21%	72%	7%	0%	0%
BELLEVILLE	0%	76%	24%	15%	82%	2%	0%	0%
BRAMPTON	0%	50%	50%	24%	67%	9%	0%	0%
BRANTFORD	1%	67%	32%	23%	75%	2%	0%	0%
BURLINGTON	0%	42%	58%	28%	65%	7%	0%	0%
CHATHAM	0%	69%	30%	22%	77%	1%	0%	0%
CORNWALL	0%	75%	25%	17%	81%	1%	0%	0%
GRAND BEND	0%	92%	8%	12%	88%	0%	0%	0%
GUELPH	0%	73%	27%	14%	83%	2%	0%	0%
HAMILTON	0%	44%	56%	29%	66%	5%	0%	0%
KINGSTON	0%	88%	11%	12%	87%	1%	0%	0%
KITCHENER	0%	61%	39%	25%	72%	3%	0%	0%
LONDON	0%	51%	49%	32%	66%	3%	0%	0%
MISSISSAUGA	0%	50%	50%	23%	69%	8%	0%	0%
NEWMARKET	0%	70%	30%	18%	78%	4%	0%	0%
NORTH BAY	0%	71%	29%	12%	81%	7%	0%	0%
OAKVILLE	0%	55%	45%	24%	71%	6%	0%	0%
OSHAWA	0%	61%	39%	23%	74%	2%	0%	0%
OTTAWA	0%	58%	42%	24%	73%	3%	0%	0%
PARRY SOUND	0%	91%	9%	7%	92%	1%	0%	0%
PETERBOROUGH	0%	76%	24%	17%	82%	1%	0%	0%
SARNIA	1%	58%	41%	41%	58%	0%	0%	0%
SAULT STE. MARIE	0%	84%	15%	11%	88%	1%	0%	0%
ST. CATHARINES	0%	61%	39%	23%	74%	3%	0%	0%
THUNDER BAY	0%	66%	34%	17%	80%	4%	0%	0%
TIVERTON	0%	95%	5%	7%	93%	0%	0%	0%
TORONTO	0%	25%	75%	28%	60%	11%	0%	0%
WINDSOR	0%	31%	69%	35%	56%	7%	0%	1%

* Carbon Monoxide (CO) was never a primary contributor to the AQI index, 2003-2010

Table 16 (A) *Frequency distribution of individual pollutants as main contributor to the AQI and AQHI index in the hours when AQI > 50 but AQHI < 7 in 13 selected cities, 2003-2010*

Main contributor to AQI	Number of hours when AQI ≥ 50 but AQHI < 7	Percentage of the hours individual pollutants as main contributor to AQHI			AQHI index		
		$PM_{2.5}$	O_3	NO_2	Min	Median	Max
Barrie							
$PM_{2.5}$	63	49%	35%	16%	4	6	6
O_3	22	-	100%	-	5	6	6
Belleville							
$PM_{2.5}$	15	27%	73%	-	4	6	6
O_3	225	-	100%	-	4	6	6
Brampton							
$PM_{2.5}$	57	49%	26%	21%	5	6	6
O_3	80	-	100%	-	5	6	6
Brantford							
$PM_{2.5}$	114	65%	30%	5%	3	5	6
O_3	96	-	100%	-	5	6	6
Grand Bend							
O_3	43	-	100%	-	5	6	6
Hamilton							
$PM_{2.5}$	78	31%	46%	23%	4	6	6
O_3	20	-	100%	-	4	6	6
TRS	1	-	-	100%	4	4	4
Kingston							
$PM_{2.5}$	40	8%	88%	5%	4	6	6
O_3	72	-	100%	-	5	6	6
North Bay							
$PM_{2.5}$	25	56%	40%	4%	4	6	6
O_3	35	-	100%	-	5	6	6
Ottawa							
$PM_{2.5}$	83	54%	30%	16%	3	6	6
O_3	10	-	100%	-	5	6	6
Sarnia							
$PM_{2.5}$	333	76%	16%	8%	4	6	6
O_3	70	-	100%	-	5	6	6
SO_2	5	-	-	100%	4	4	4
Tiverton							
$PM_{2.5}$	3	-	100%	-	5	5	5
O_3	74	-	100%	-	5	6	6
Toronto							
$PM_{2.5}$	56	39%	14%	46%	4	6	6
O_3	27	-	100%	-	6	6	6

Table 16 (A) *continued…*

Main contributor to AQI	Number of hours when AQI ≥ 50 but AQHI < 7	Percentage of the hours individual pollutants as main contributor to AQHI			AQHI index		
		$PM_{2.5}$	O_3	NO_2	Min	Median	Max
***Windsor** cont'd*							
$PM_{2.5}$	62	63%	26%	11%	4	6	6
O_3	162	-	100%	-	5	6	6
TRS	3	33%	33%	33%	4	5	5

Table 16 (B) *Frequency distribution of individual pollutants as main contributor to the AQI and AQHI index in the hours when AQHI > 7 but AQI < 50 in 13 selected cities, 2003-2010*

Main contributor to AQHI	Number of hours when AQHI $\geq$ 7 but AQI < 50	Proportion of the hours when a pollutant is the main contributor to AQI			AQI index		
		$PM_{2.5}$	O_3	NO_2	Min	Median	Max
Barrie							
O_3	53	51%	49%	-	35	46	49
NO_2	109	98%	-	2%	21	38	48
Belleville							
O_3	22	18%	82%	-	39	48	49
NO_2	3	100%	-	-	39	40	46
Brampton							
O_3	128	46%	54%	-	32	45	49
NO_2	239	95%	4%	1%	20	39	49
Brantford							
O_3	9	33%	67%	-	44	48	49
NO_2	4	100%	-	-	40	46	47
Grand Bend							
O_3	1	-	100%	-	49	49	49
Hamilton							
O_3	124	55%	45%	-	33	44	49
NO_2	248	95%	4%	1%	20	40	49
Kingston							
O_3	11	64%	36%	-	45	48	49
North Bay							
O_3	4	50%	50%	-	45	48	48
NO_2	3	67%	33%	-	25	29	43
Ottawa							
O_3	17	76%	24%	-	33	46	49
NO_2	69	93%	3%	4%	19	37	49
Sarnia							
O_3	203	57%	43%	-	34	46	49
NO_2	28	96%	4%	-	35	45	49
Tiverton							
O_3	4	-	100%	-	48	49	49
Toronto							
O_3	209	57%	43%	-	32	45	49
NO_2	281	95%	2%	3%	18	39	49
Windsor							
O_3	85	36%	64%	-	32	46	49
NO_2	103	92%	7%	1%	20	41	49

Table 17 Number of advisory days according to the indices for each city and year, 2003-2010 *

City Name	Y2003		Y2004		Y2005		Y2006		Y2007		Y2008		Y2009		Y2010	
	AQI[a]	AQHI[b]	AQI	AQHI	AQI	AQHI	AQI	AQHI	AQI	AQHI	AQI	AQHI	AQI	AQHI	AQI	AQHI
Barrie	4	4	0	0	5	4	0	0	0	2	0	0	0	0	0	0
Belleville	5	5	2	1	8	4	2	1	7	5	1	0	0	0	0	0
Brampton	4	12	2	3	4	10	0	0	4	4	0	2	1	0	0	0
Brantford	1	0	1	0	4	1	0	0	3	1	1	0	0	0	0	0
Burlington	4	5	2	2	2	3	1	1	2	6	1	0	0	0	0	0
Chatham	-[c]	-	-	-	9	6	1	0	5	6	1	0	0	0	0	0
Cornwall	-	-	-	-	-	-	1	0	1	1	0	0	0	0	1	0
Grand Bend	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	1
Hamilton	5	9	3	6	3	13	1	0	3	3	1	2	0	0	0	0
Kingston	-	-	-	-	-	-	0	0	9	6	1	0	0	0	1	0
Kitchener	0	3	2	1	7	4	0	0	4	4	1	0	0	0	0	0
London	2	4	2	1	4	4	0	0	0	1	0	0	0	0	0	0
Newmarket	3	3	1	3	3	2	0	0	2	3	0	0	1	0	0	0
North Bay	1	1	0	0	4	1	0	0	0	0	0	0	0	0	0	0
Oakville	7	9	2	5	3	6	1	2	3	4	1	0	0	0	0	0
Oshawa	5	9	2	5	4	5	0	0	7	4	0	0	0	0	1	1
Ottawa	2	6	1	0	5	3	0	0	1	0	0	0	0	0	1	0
Peterborough	4	4	-	-	-	-	0	0	2	2	0	0	0	0	0	0
Sarnia	8	6	5	5	15	12	2	3	10	13	0	2	0	0	0	0
Sault Ste. Marie	0	1	-	-	1	0	0	0	0	0	0	0	0	0	0	0
St. Catharines	-	-	-	-	3	2	1	0	2	5	0	0	0	0	0	0
Tiverton	-	-	-	-	-	-	0	0	4	1	0	0	1	0	0	0
Toronto	5	16	4	5	6	13	1	1	4	8	0	1	0	0	0	0
Windsor	4	5	1	1	10	7	3	1	9	9	0	2	1	0	0	0

a AQI-based smog advisory day: AQI>50 for at least 6 consecutive hours
b AQHI-based smog advisory day: AQHI>7 for at least 6 consecutive hours
c Missing air pollution data, and thus the AQI and AQHI were unavailable

Table 18 *Major strengths and limitations of the AQI and the AQHI*

Air Quality Index		Air Quality Health Index	
Strengths	**Limitations**	**Strengths**	**Limitations**
- Includes five pollutants (O_3, $PM_{2.5}$, NO_2, SO_2, and TRS) with flexibility for easily adding more air pollutants	- The formula fails to capture effects from simultaneous exposure to the mix of air pollutants	- Includes three pollutants (O_3, $PM_{2.5}$, and NO_2) that have the best-established scientific grounds with respect to human health effects according to a daily time-series study conducted in Canada	- It remains uncertain whether the coefficient of NO_2 in the statistical relationship between air pollution and mortality reflects a direct causal effect, or more likely, is due to NO_2 acting as a proxy for other unmeasured air pollutants
- More responsive to transient change of O_3 and $PM_{2.5}$ (due to forest fire smoke)	- AQI is based on air quality standards/ guidelines; , existing air quality standards/guidelines are not linked to health effects in a consistent quantitative manner	- Reflects combined effects of air pollution as a mixture rather than a single pollutant and the index value has an interpretation that is directly related to the risk of mortality	- Knowledge regarding how multiple pollutants interact and impact on human health has not yet been fully established
- Pollutant-specific health messaging recognizes the fact that exposure reduction is not the same for all pollutants	- Pollutant-specific health messaging may lead to confusion and misunderstanding regarding the overall health impact of air pollution as a mixture	- Correlations with multiple air pollutants are stronger for the AQHI than the AQI	- Limited generalizability between urban and rural settings
	- A lack of evidence supporting any quantitative relationship between the AQI and known health effects	- More responsive to rapidly changing air quality due to NO_2, a marker for traffic-related air pollution	- Fails to recognize the public-health importance of chronic exposure to ambient air pollution
	- Fails to recognize the public-health importance of chronic exposure to ambient air pollution	- Based on a statistical relationship between air pollution and mortality. There is also preliminary evidence showing possible association between the AQHI and asthma- and cardiac-related hospitalizations	- Fails to recognize the importance of spatial locations on increasing individual's risk to ambient air pollution
	- Fails to recognize the importance of spatial locations on increasing individual's risk to ambient air pollution	- Includes a communication and education program developed through a national process that provides health messaging for individuals	- It is uncertain whether the coefficients currently used in the AQHI formula are still valid
	- Little evidence to support the effectiveness of advisories in reducing exposure to pollutants	- Consistent health messaging	-Little evidence to support effectiveness of advisories in reducing exposure to pollutants

Figure Legend

Figure 1. Locations of fixed-site air quality monitoring stations by Ontario Ministry of the Environment.

Figure 2. Relationship between hourly concentrations of $PM_{2.5}$, O_3, SO_2, and NO_2 and AQI index values

Figure 3. Relationship between hourly concentrations of $PM_{2.5}$, O_3, and NO_2 and AQHI index values, assume a simplified formula of AQHI (see Equation 2 in main text)

Figure 4. Spearman Correlation Coefficients between hourly AQHI and AQI at fixed-site monitors across 28 cities in Ontario, 2003-2010, by seasons (*Warm season*: April to September; *Cold season*: October to March).

Figure 5. Monthly distribution of high AQHI days (daily maximum AQHI $\geq$ 7) and high AQI days (daily maximum AQI $\geq$ 50) across Ontario from 2003 to 2010. AQI data were restricted to the months in which AQHI was also present in order to facilitate comparison. For any month where AQHI data were absent, the number of high AQHI and high AQI days were assigned blank space. Five cities (Dorset, Morrisburg, Parry Sound, Petawawa, and Port Stanley) with air quality monitoring stations are not shown here because data were missing from 2003 to 2010 for one or more air pollutant required for calculating AQHI.

Figure 6. Monthly distribution of high AQHI hours (AQHI $\geq$ 7) and high AQI hours (AQI $\geq$ 50) across Ontario from 2003 to 2010. AQI data were restricted to the months in which AQHI was also present in order to facilitate comparison. For any month where AQHI data were absent, the number of high AQHI and high AQI hours were assigned blank space. Five cities (Dorset, Morrisburg, Parry Sound, Petawawa, and Port Stanley) with air quality monitoring stations are not shown here because data were missing from 2003 to 2010 for one or more air pollutant required for calculating AQHI.

Figure 7. Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during high air pollution episodes occurred in Ontario, 2003-2010. For any hour in which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.

Figure 8. Sensitivity analysis on reclassifying high AQHI days according to AQHI $\geq$ 6: monthly distribution of high AQHI days (daily maximum AQHI $\geq$ 6) and high AQI days (daily maximum AQI $\geq$ 50) across Ontario from 2003 to 2010. AQI data were restricted to the months in which AQHI was also present in order to facilitate comparison. For any month where AQHI data were absent, the number of high AQHI and high AQI days were assigned blank space. Five cities (Dorset, Morrisburg, Parry Sound, Petawawa, and Port Stanley) with air quality monitoring stations are not shown here because data were missing from 2003 to 2010 for one or more air pollutant required for calculating AQHI.

Figure 1 Locations of fixed-site air quality monitoring stations by Ontario Ministry of the Environment

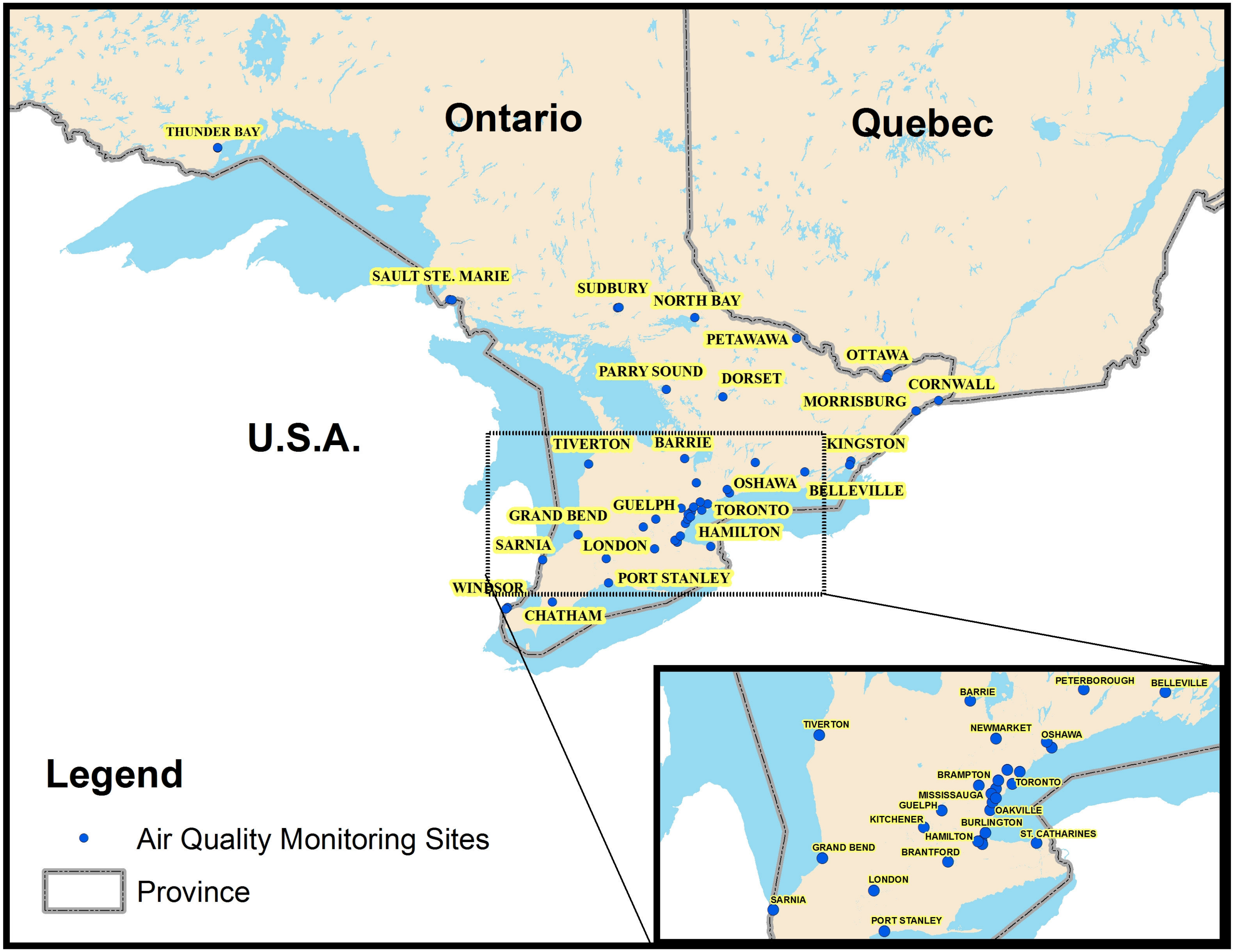


Figure 2. Relationship between hourly concentrations of $PM_{2.5}$, O_3, SO_2, and NO_2 and AQI index values

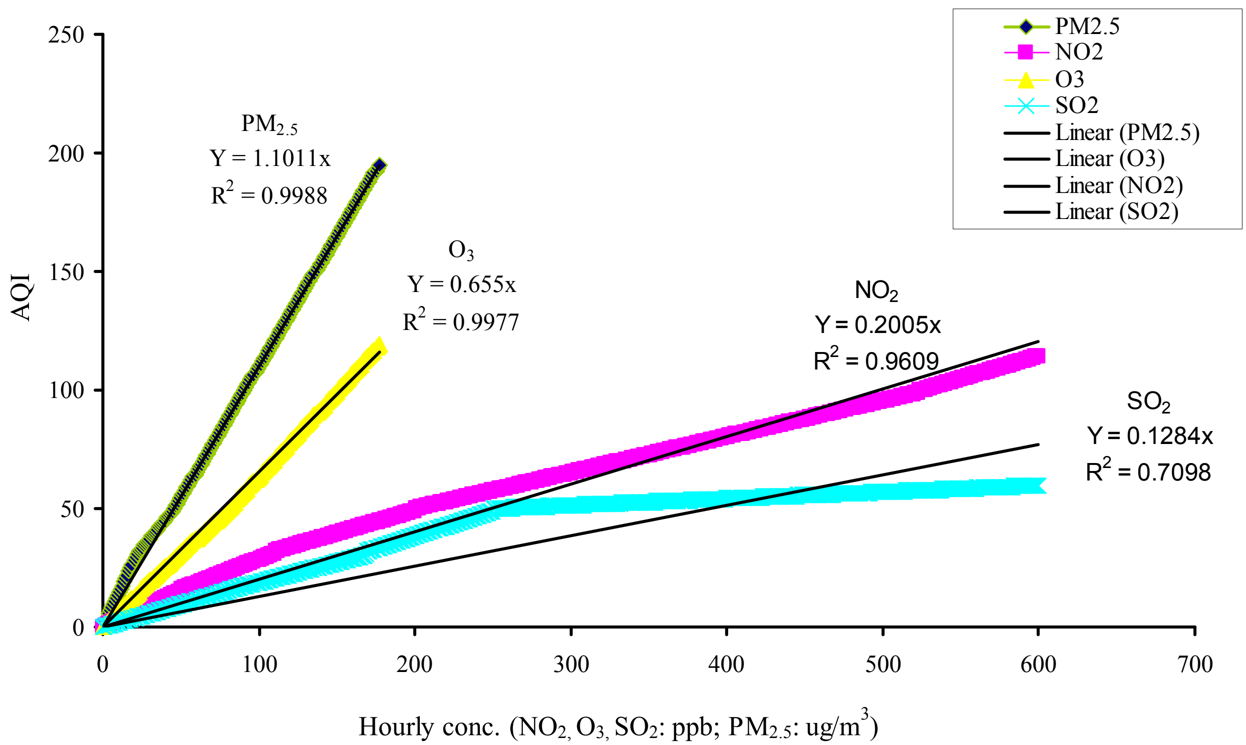


Figure 3. Relationship between hourly concentrations of $PM_{2.5}$, O_3, and NO_2 and AQHI index values, assume a simplified formula of AQHI (see Equation 2 in main text)

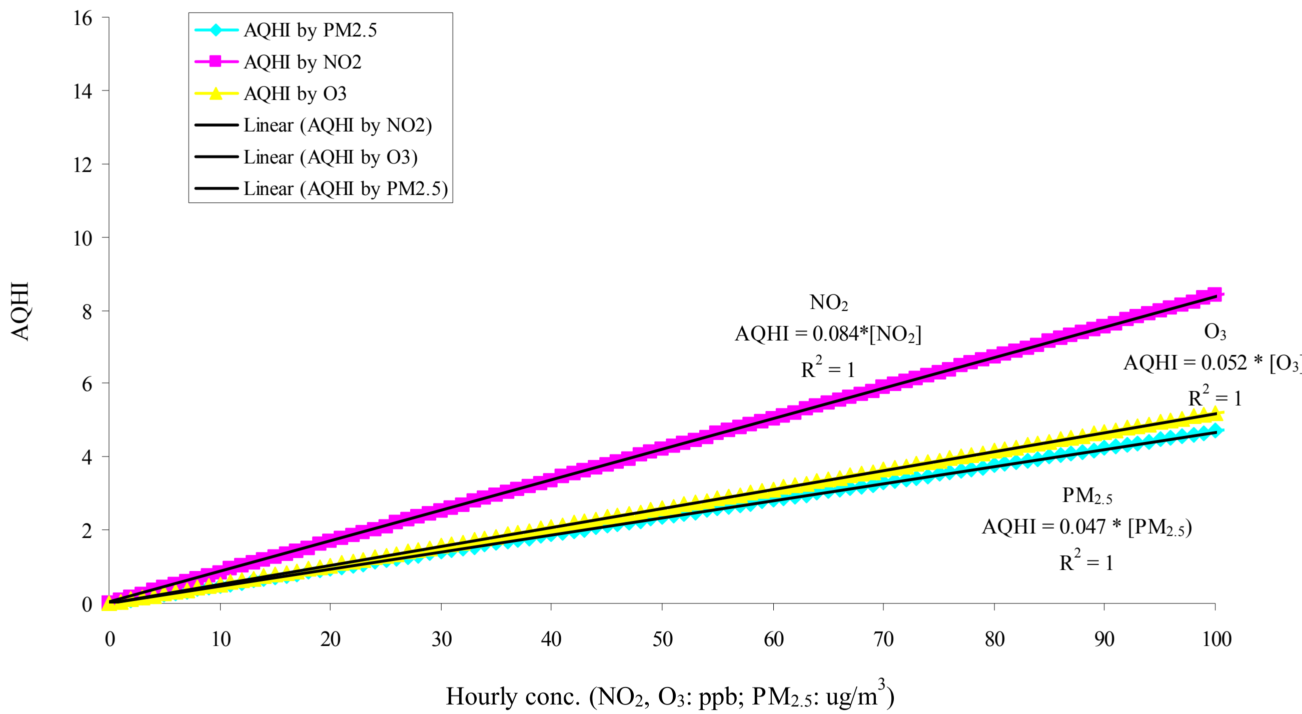


Figure 4. Spearman Correlation Coefficients between hourly AQHI and AQI at fixed-site monitors across 28 cities in Ontario, 2003-2010, by seasons (*Warm season*: April to September; *Cold season*: October to March)

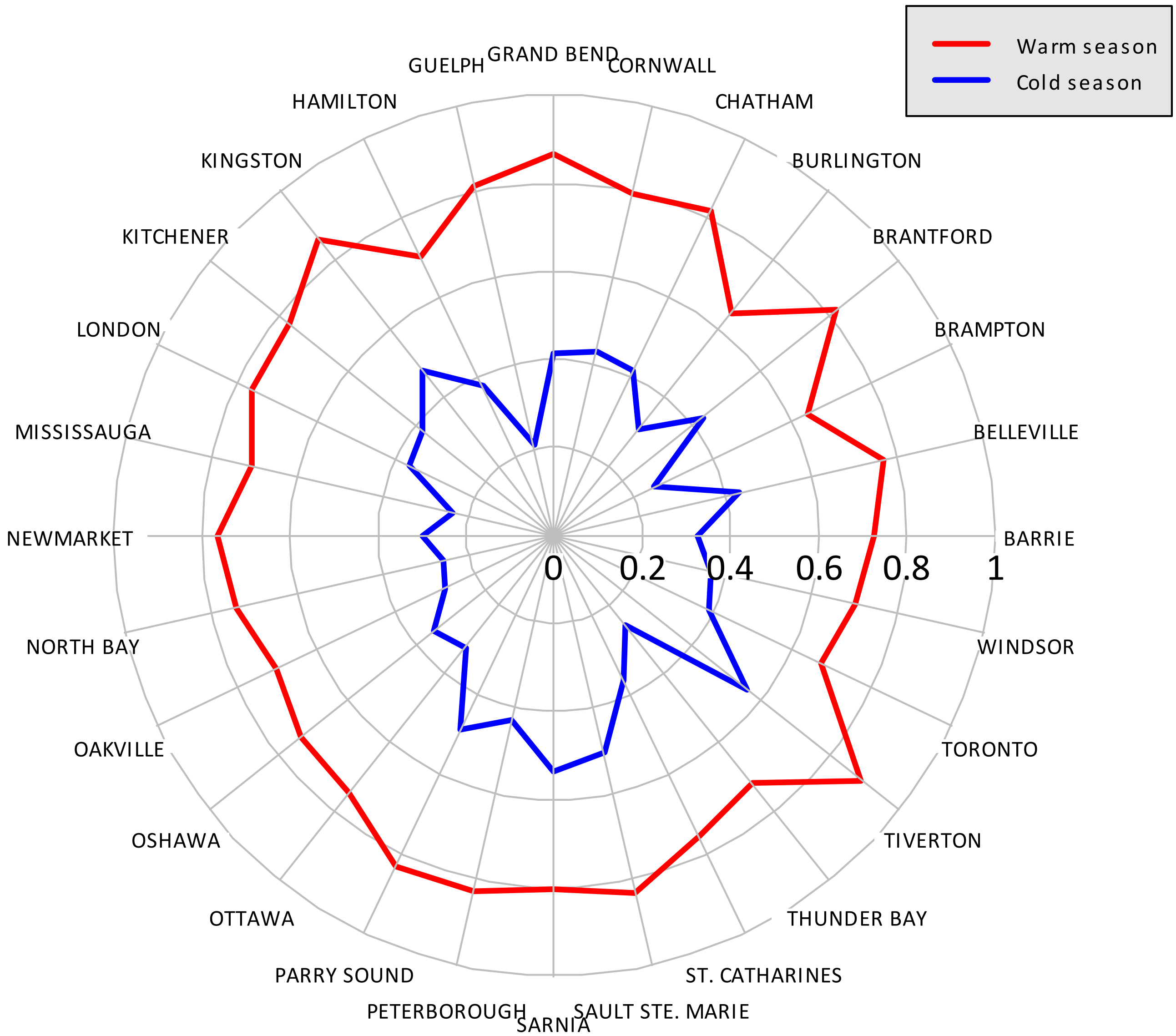
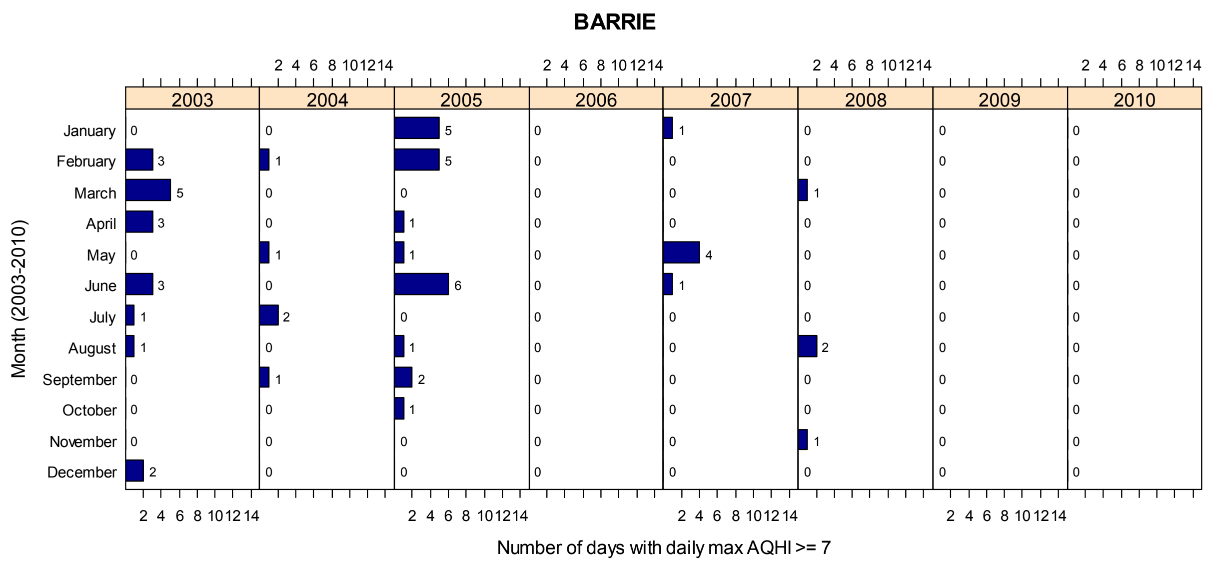


Figure 5. Monthly distribution of high AQHI days (daily maximum AQHI $\geq$ 7) and high AQI days (daily maximum AQI $\geq$ 50) across Ontario from 2003 to 2010. AQI data were restricted to the months in which AQHI was also present in order to facilitate comparison. For any month where AQHI data were absent, the number of high AQHI and high AQI days were assigned blank space. Five cities (Dorset, Morrisburg, Parry Sound, Petawawa, and Port Stanley) with air quality monitoring stations are not shown here because data were missing from 2003 to 2010 for one or more air pollutant required for calculating AQHI.



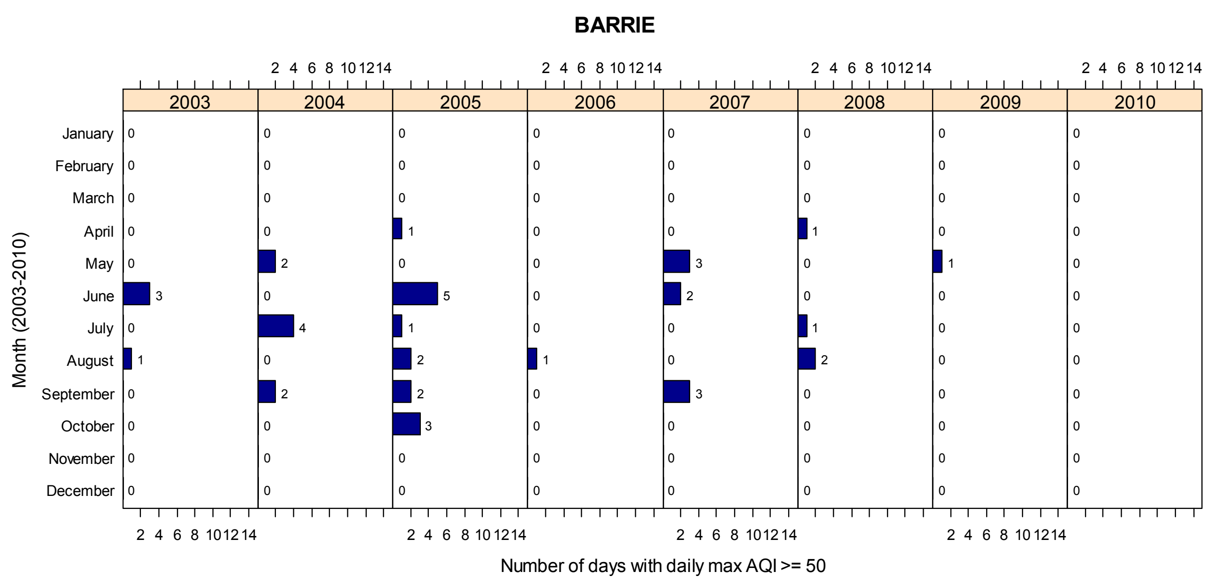
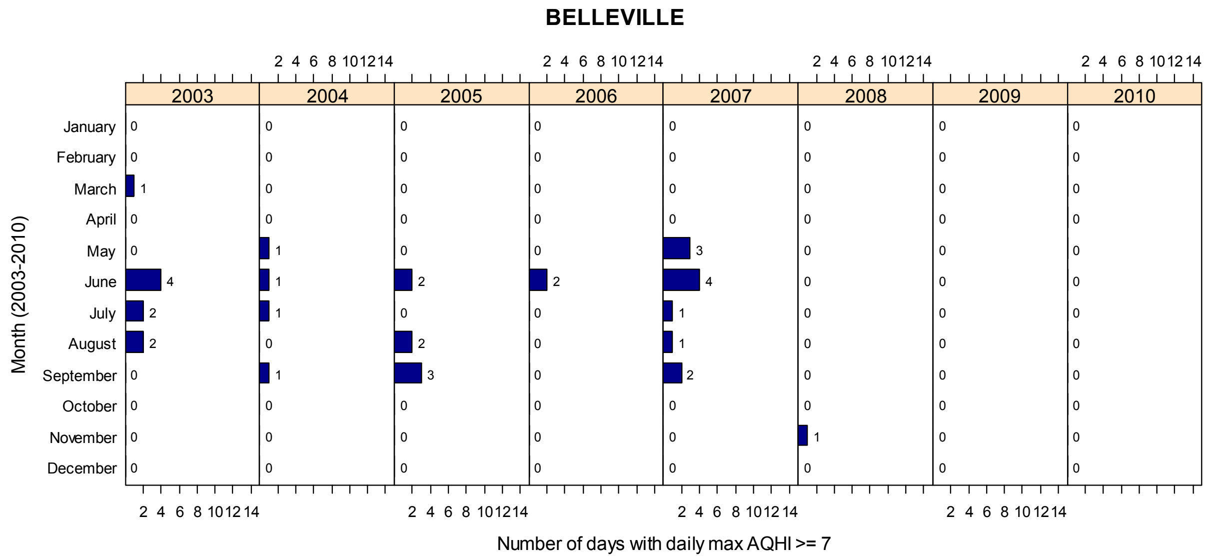


Figure 5. continued



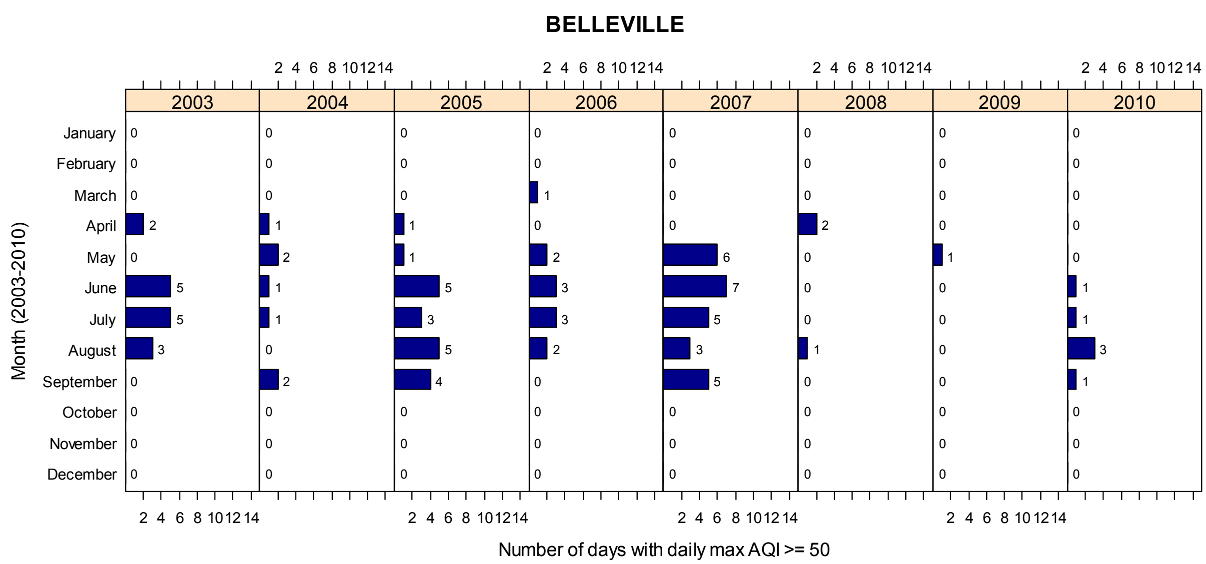
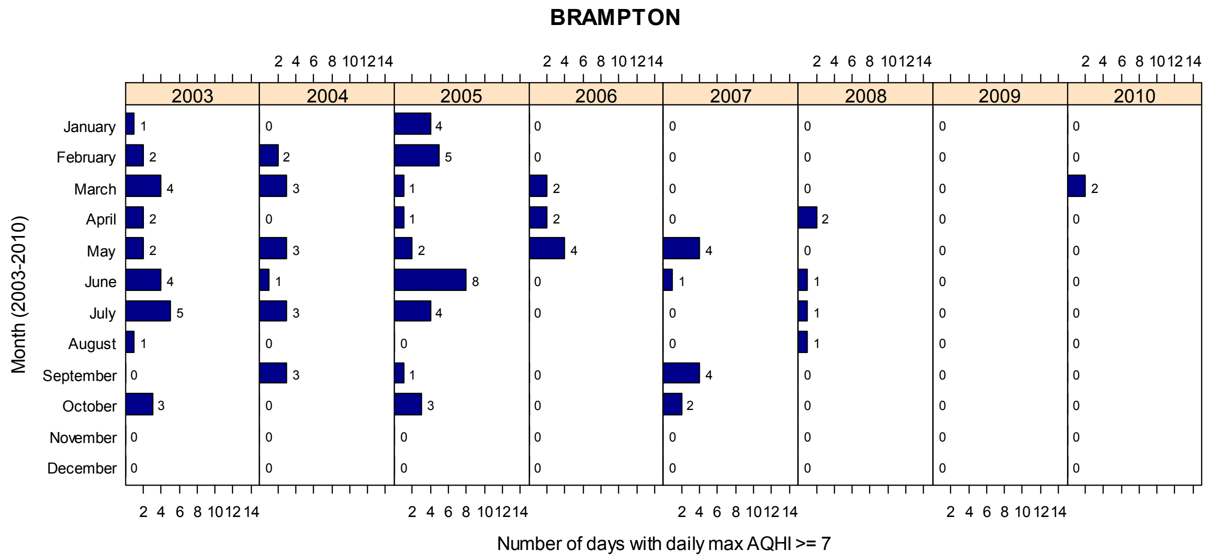
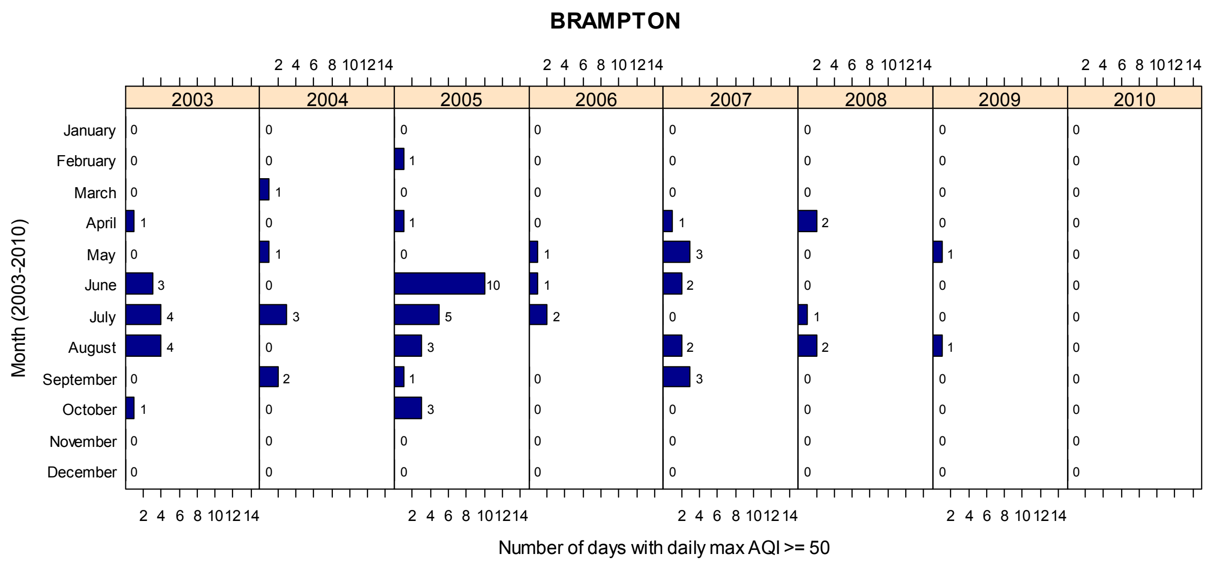


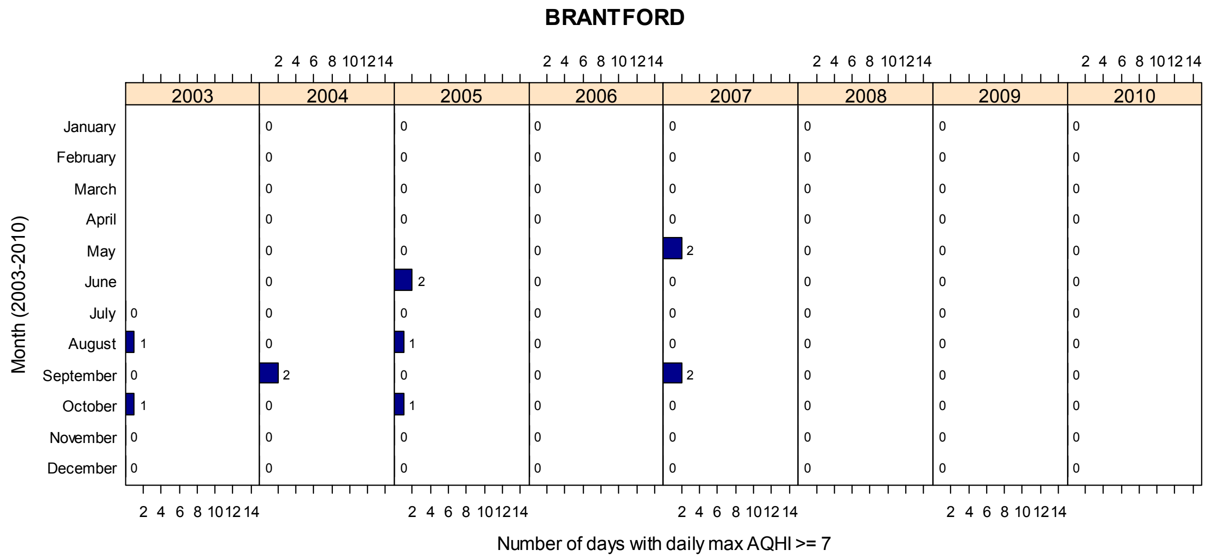
Figure 5. continued

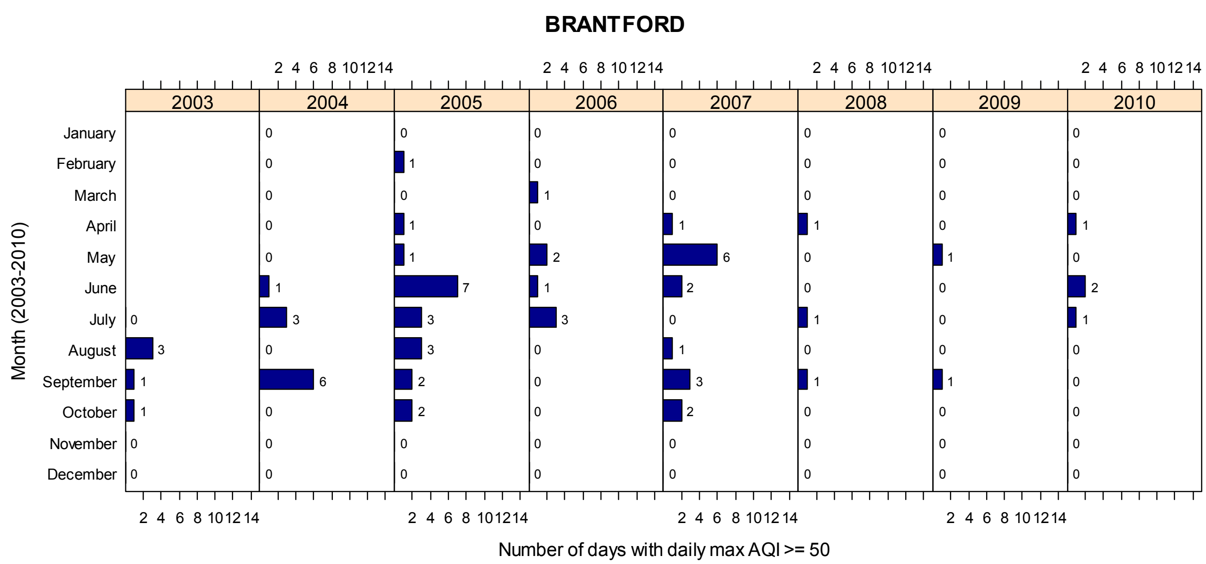




* AQHI was not available in August 2006 in Brampton, Ontario as indicated by blank space

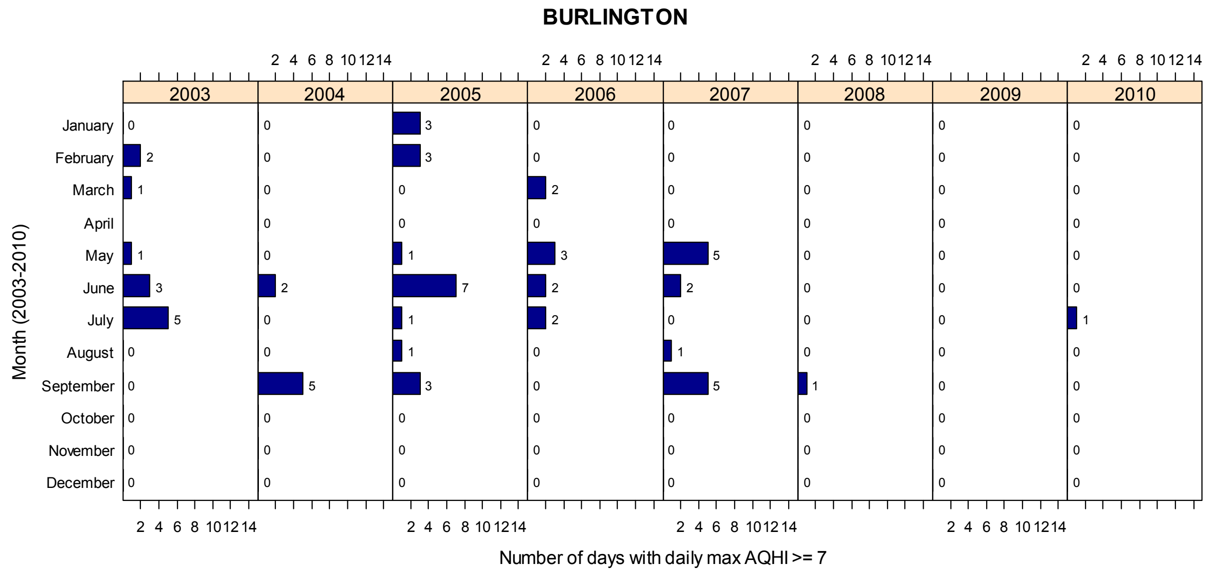
Figure 5. continued

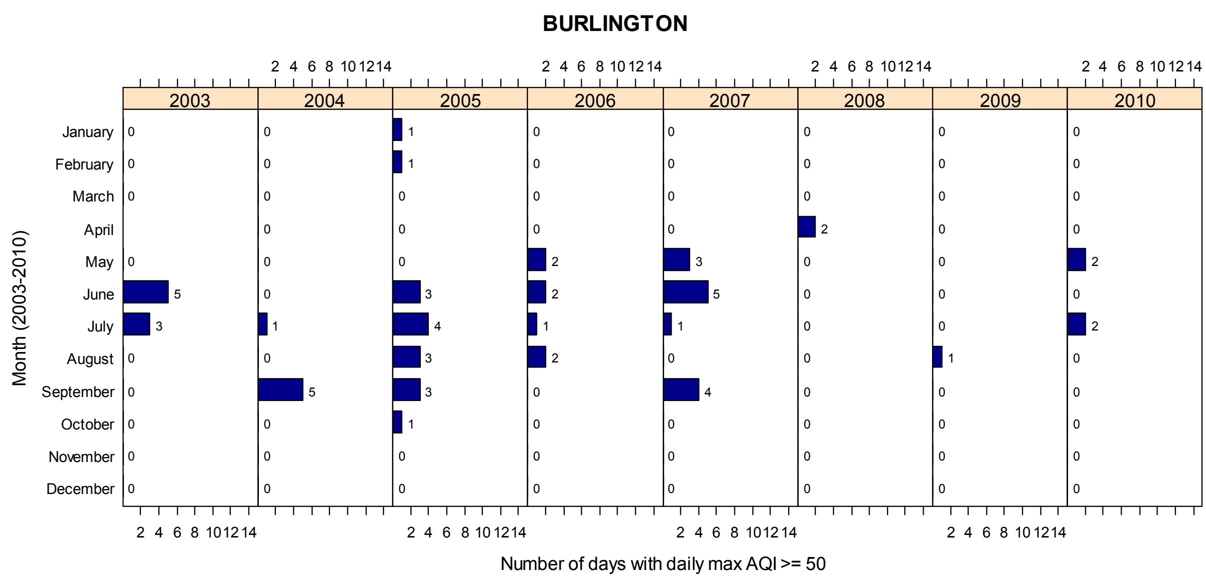




* AQHI was not available from January to June 2003 in Brantford, Ontario as indicated by blank space

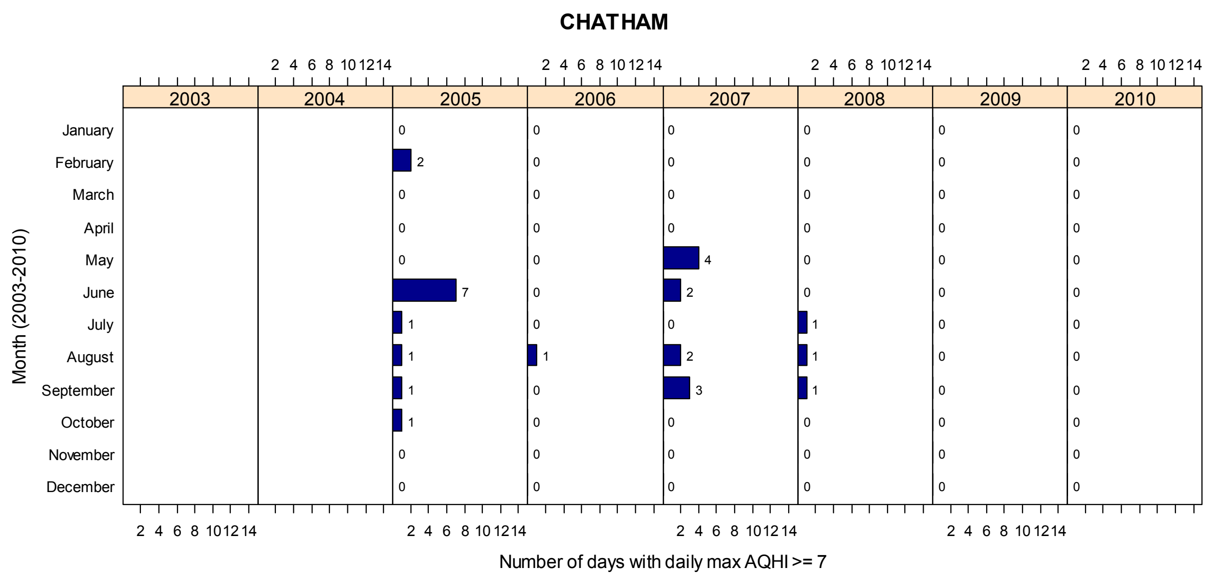
Figure 5. continued

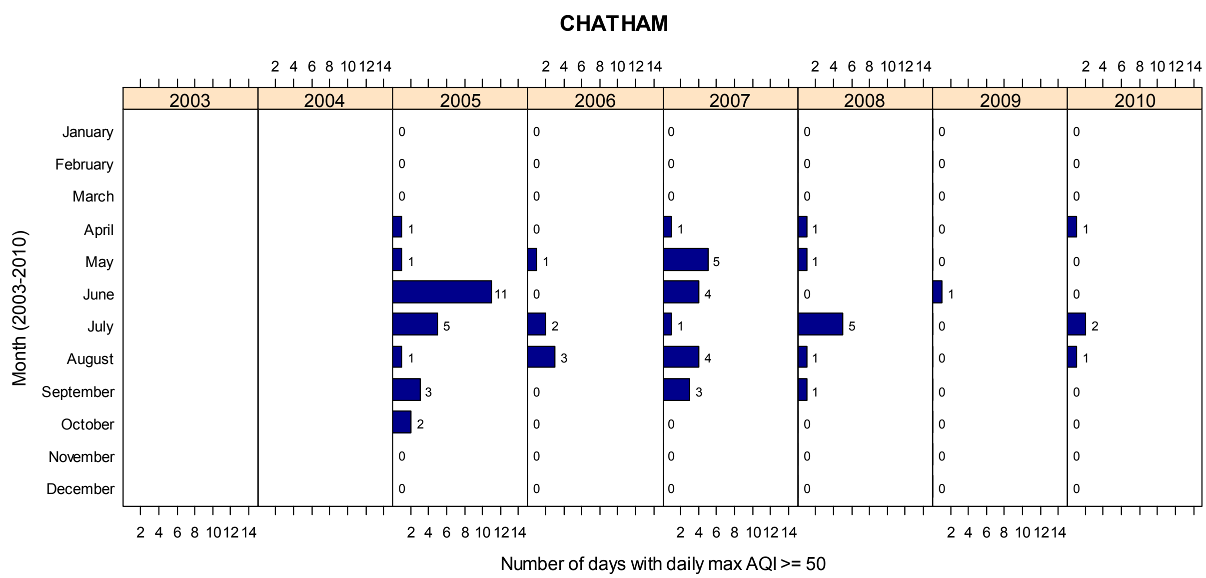




* AQHI was not available in April, 2003 in Burlington, Ontario as indicated by blank space

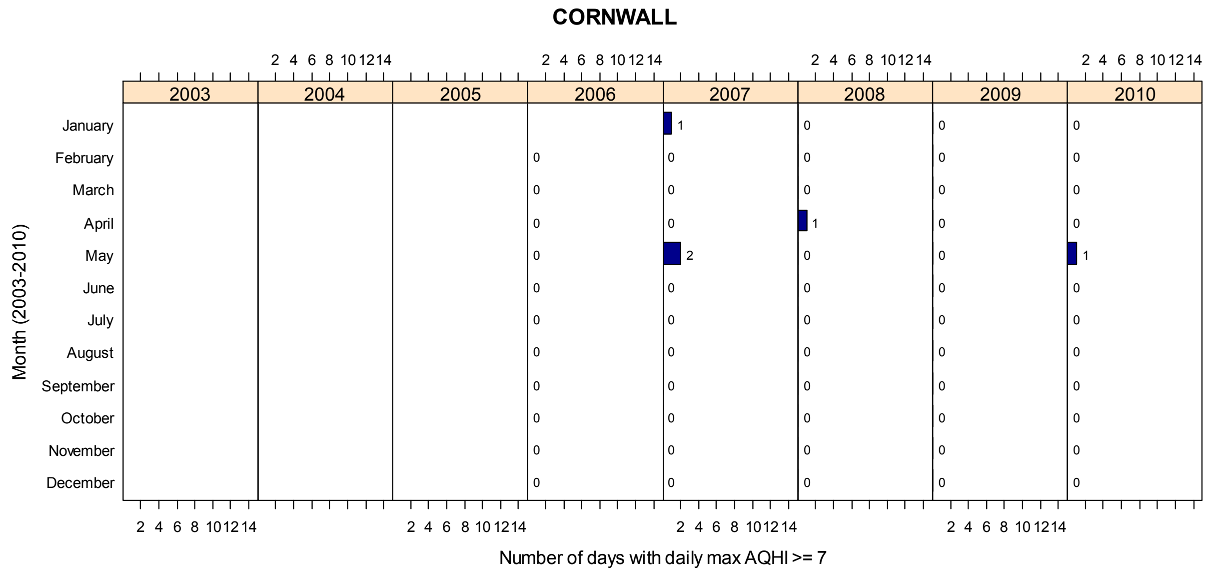
Figure 5. continued

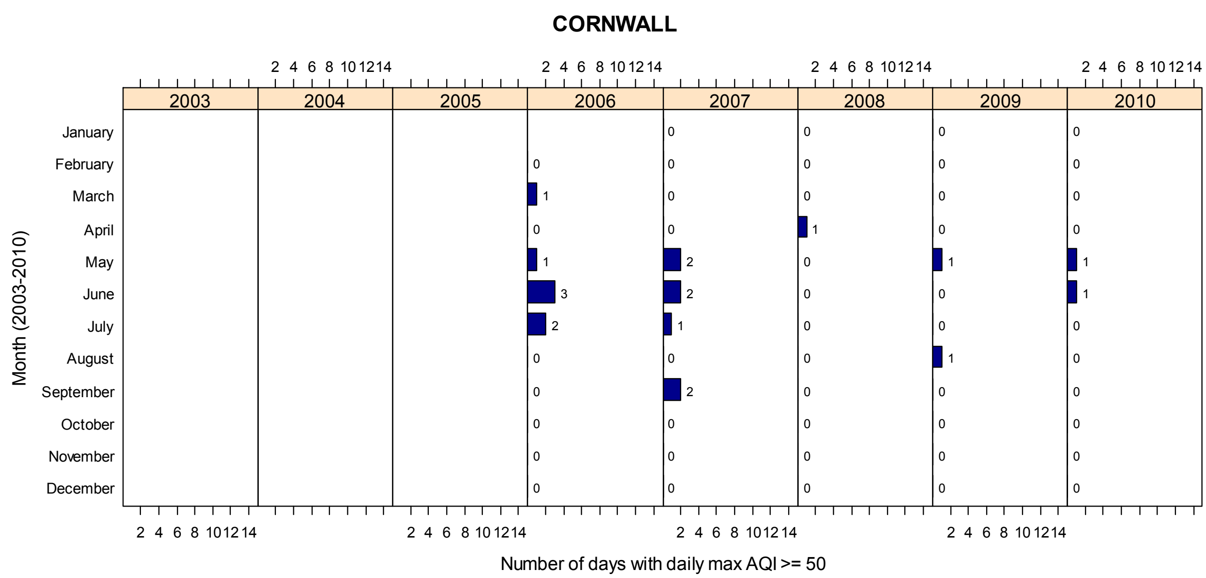




* AQHI was not available from 2003 to 2004 in Chatham, Ontario as indicated by blank space

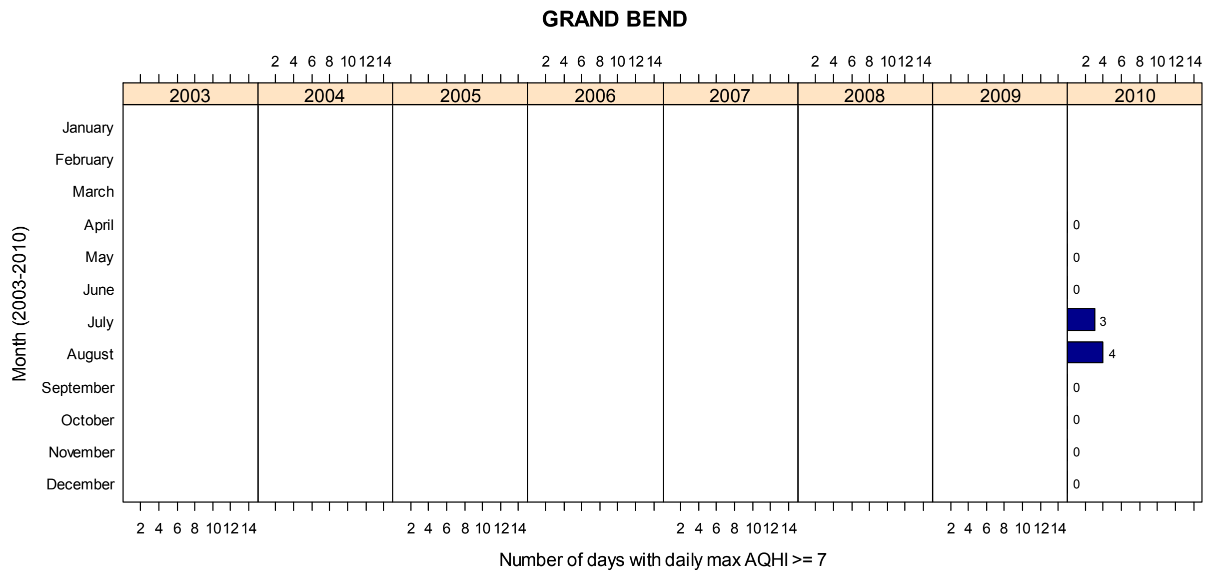
Figure 5. continued

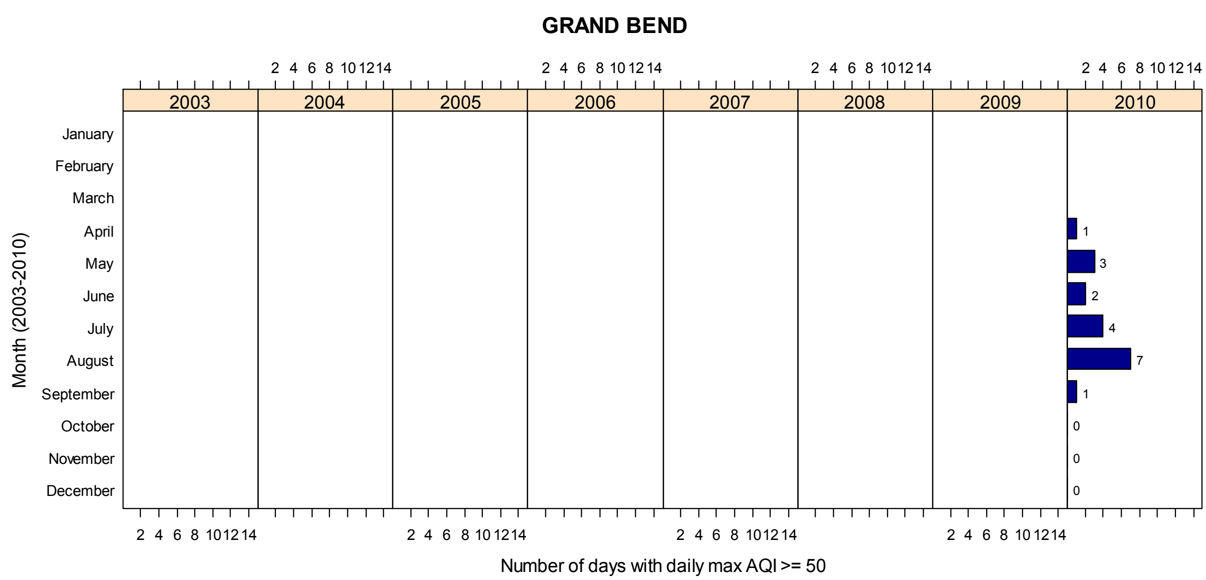




* AQHI was not available from 2003 to January, 2006 in Cornwall, Ontario as indicated by blank space

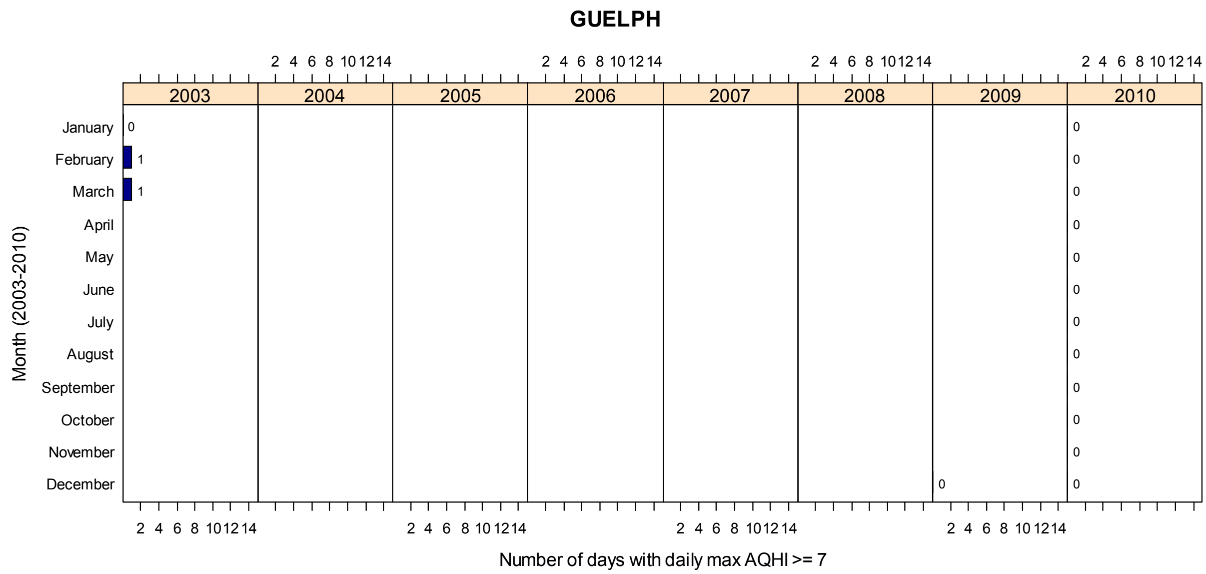
Figure 5. continued

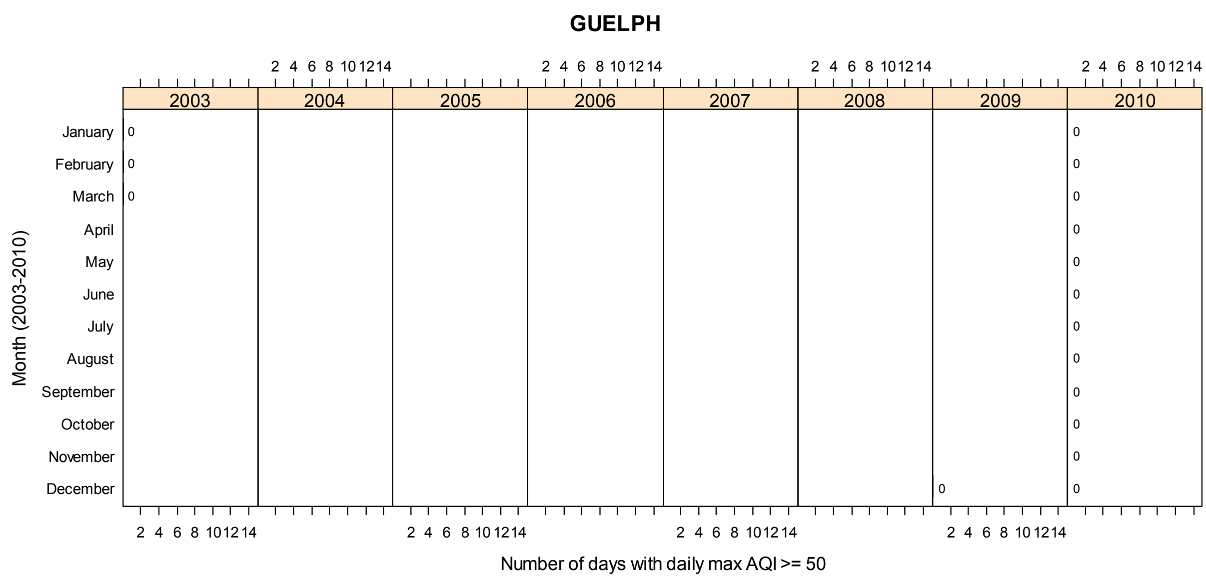




* AQHI was not available from January, 2003 to March, 2010 in Grand Bend, Ontario as indicated by blank space

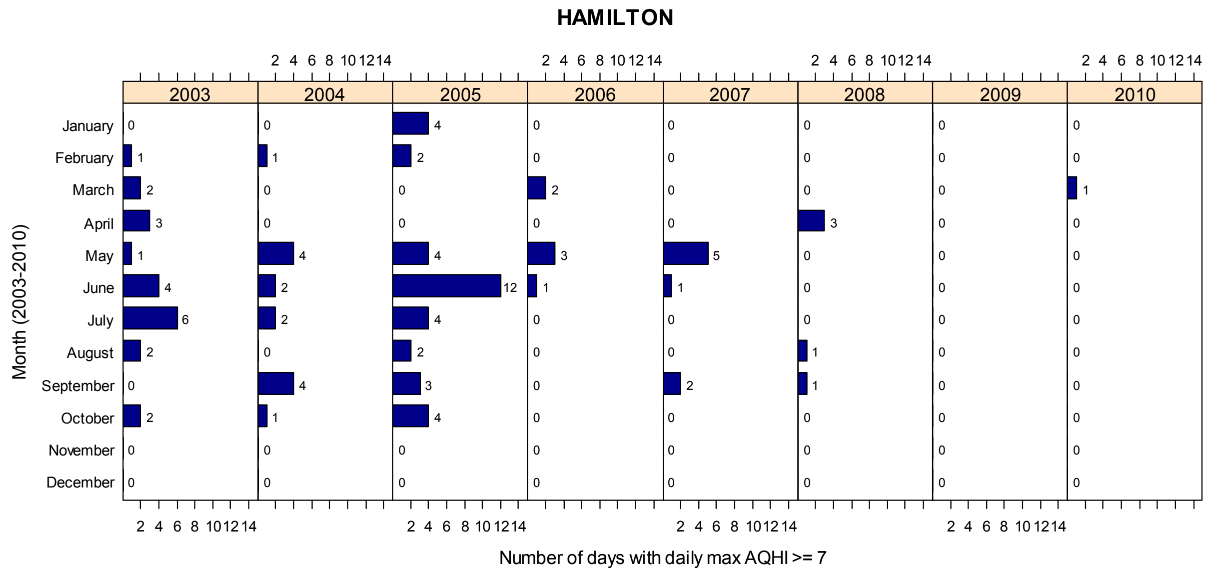
Figure 5. continued





* AQHI was not available from April, 2003 to November, 2009 in Guelph, Ontario as indicated by blank space

Figure 5. continued



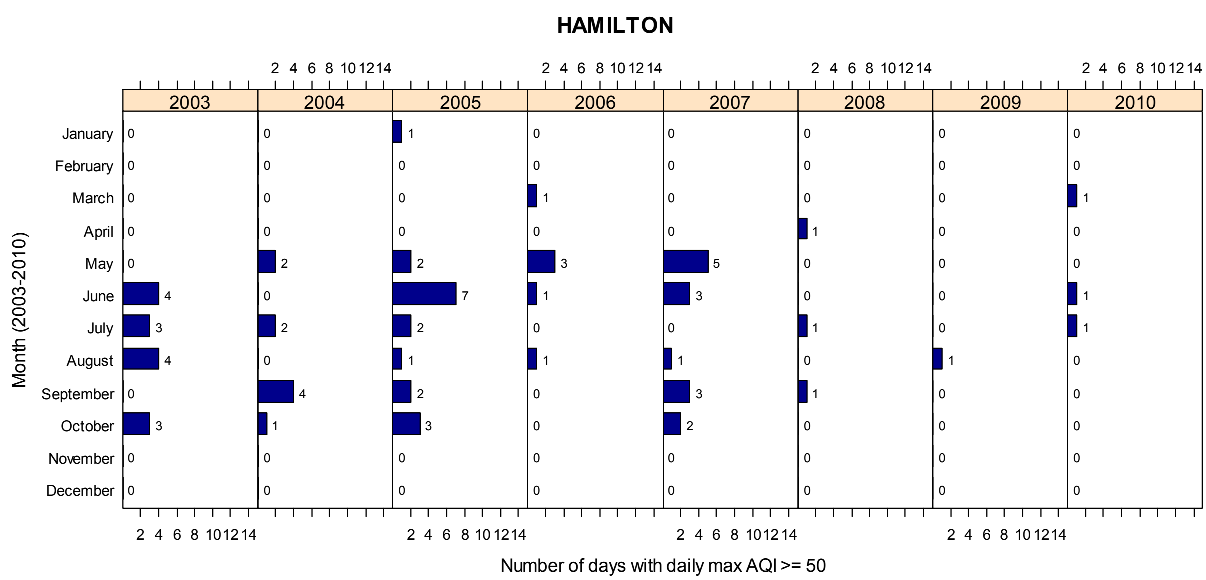
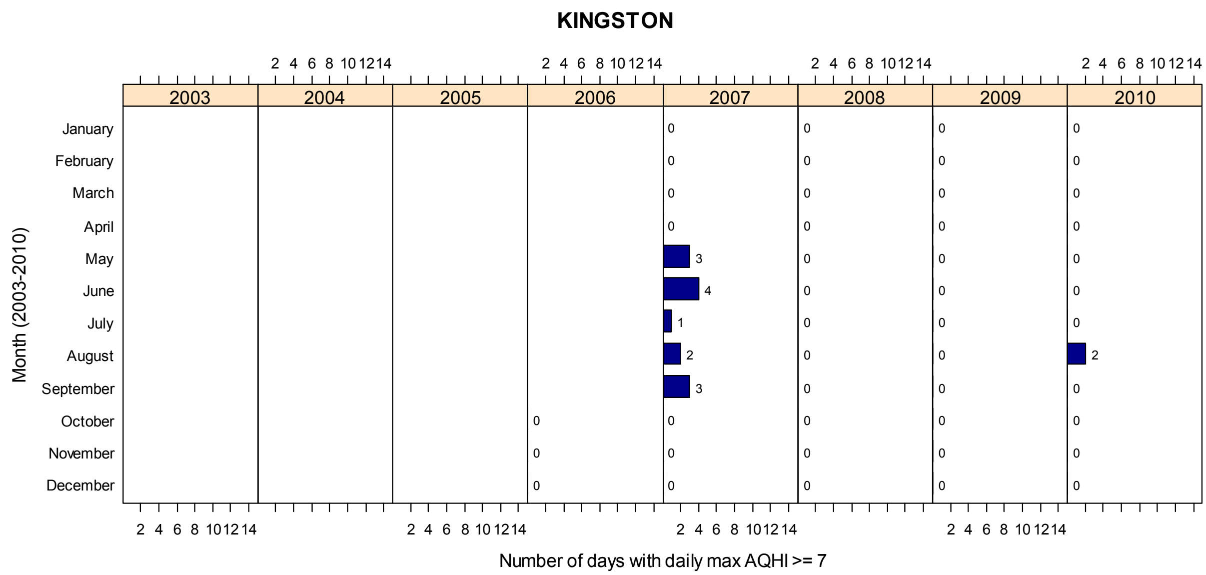
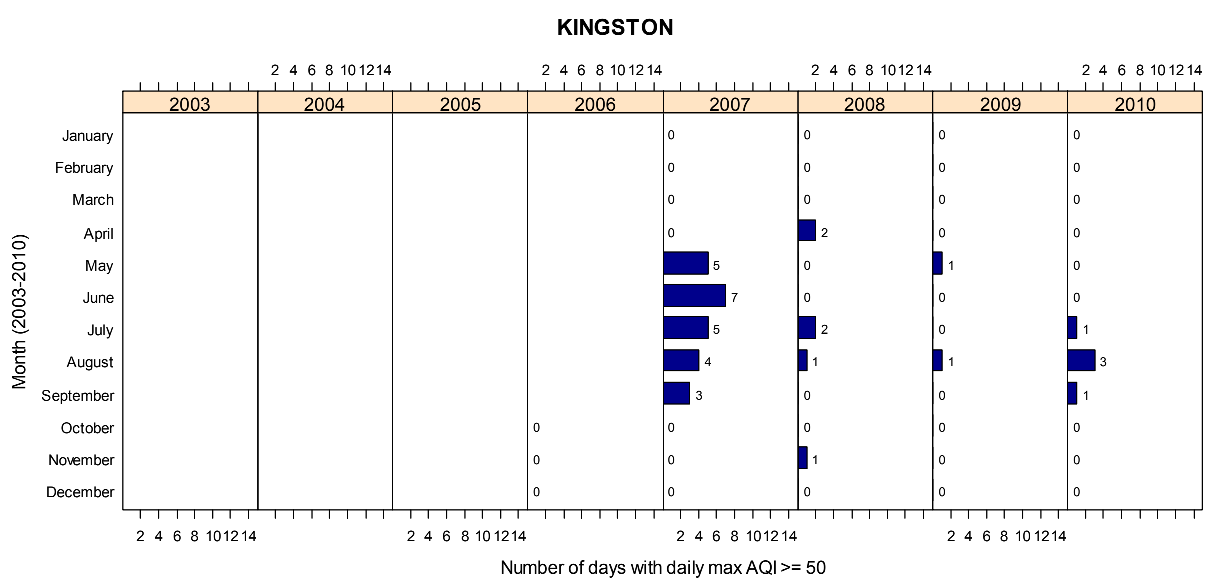


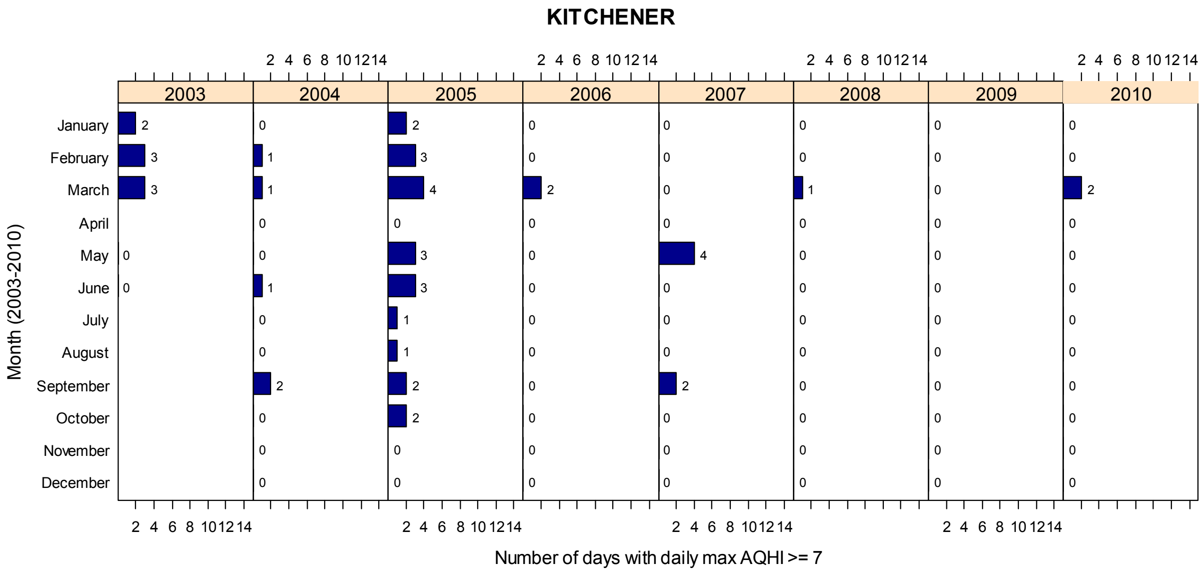
Figure 5. continued

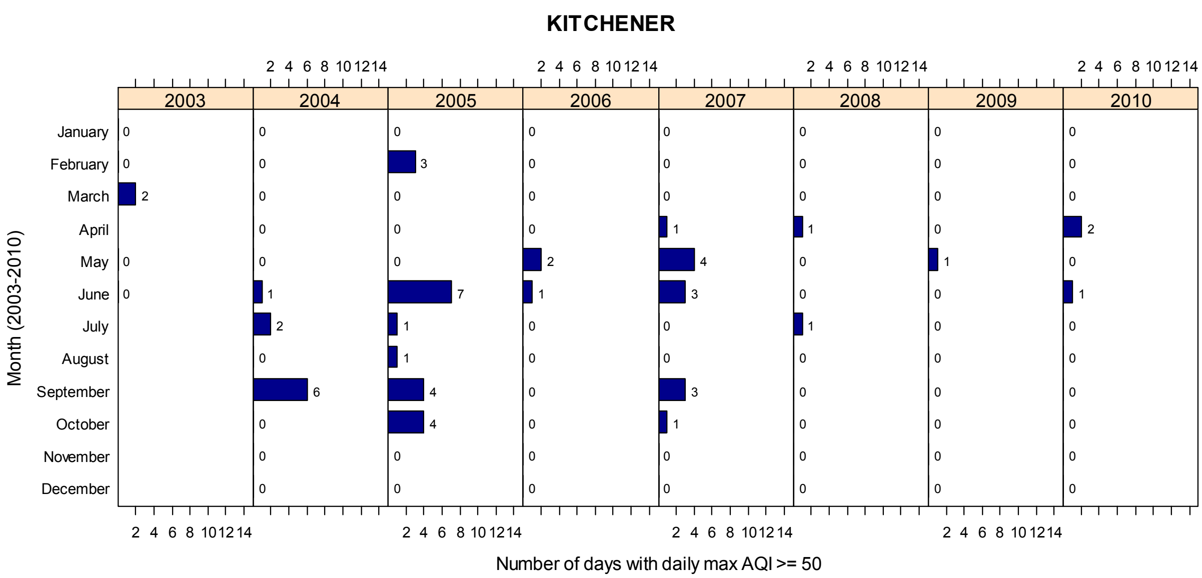




* AQHI was not available from January, 2003 to September, 2006 in Kingston, Ontario as indicated by blank space

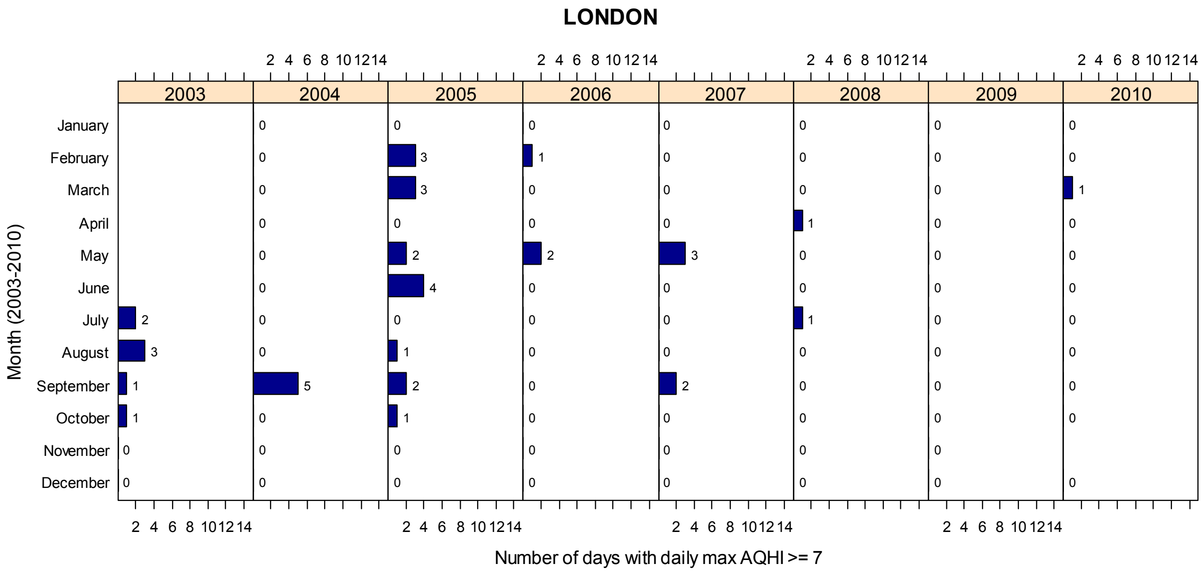
Figure 5. continued

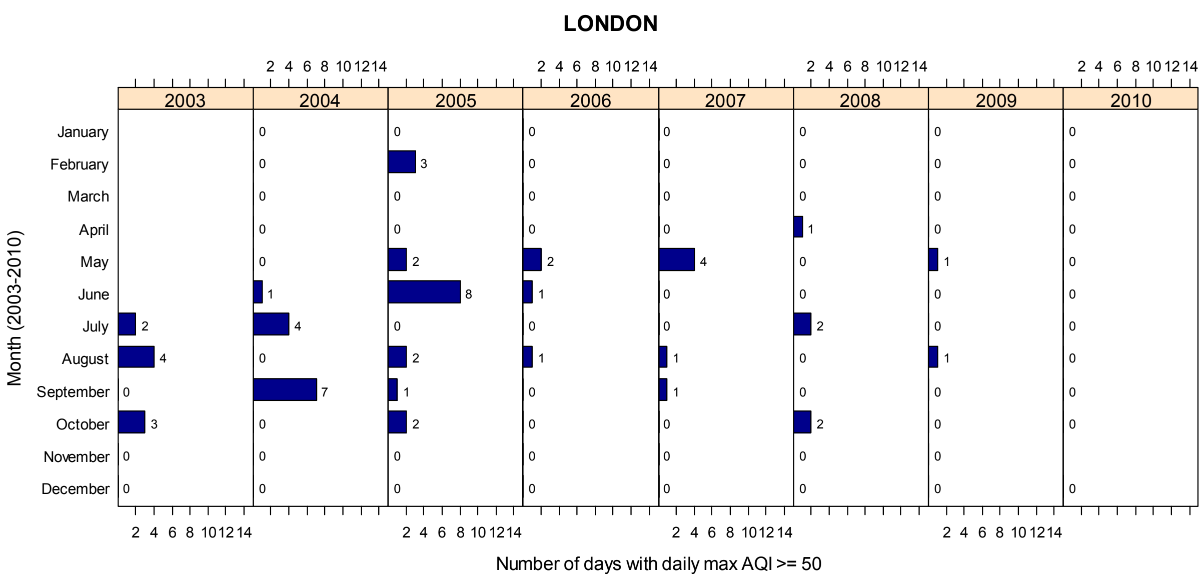




* AQHI was not available in April, 2003 and from July to December, 2003 in Kitchener, Ontario as indicated by blank space

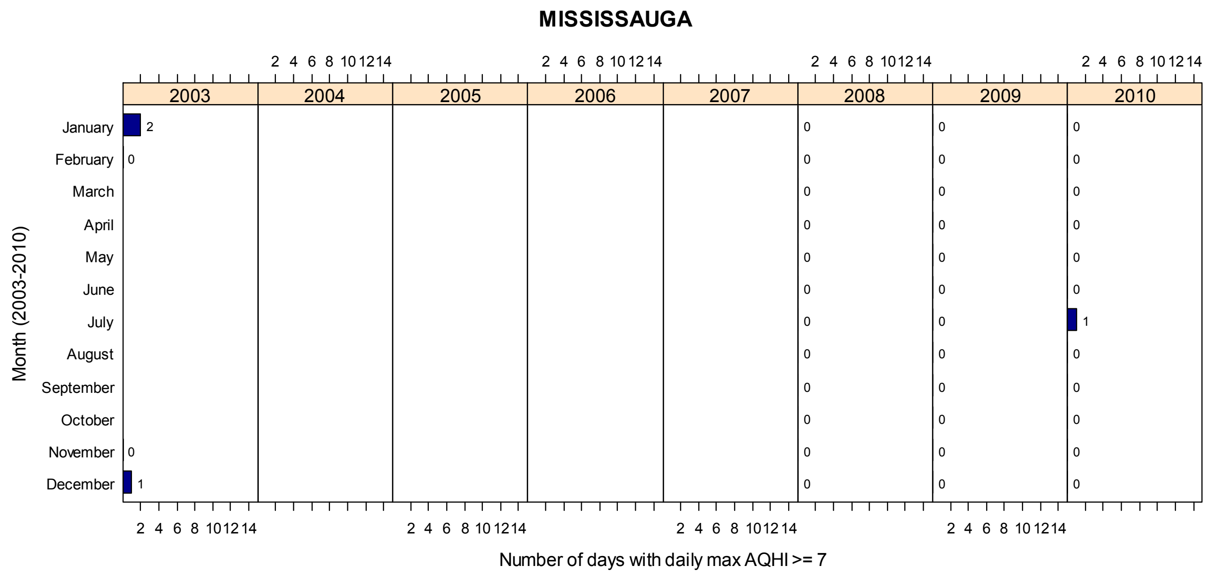
Figure 5. continued

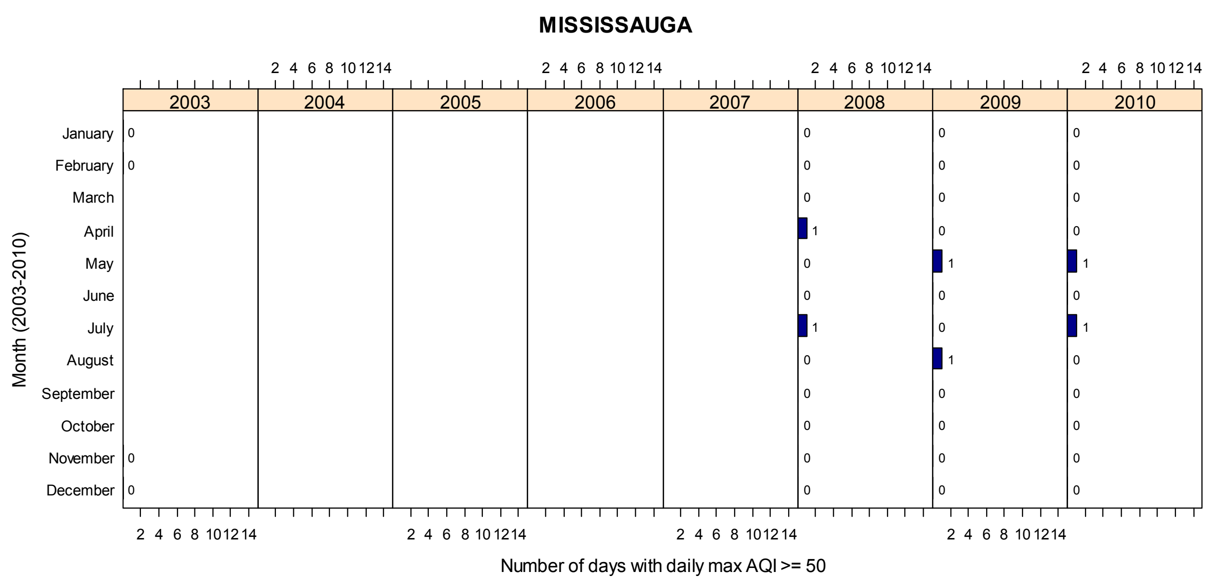




* AQHI was not available from January to June, 2003 and in November, 2010 in London, Ontario as indicated by blank space

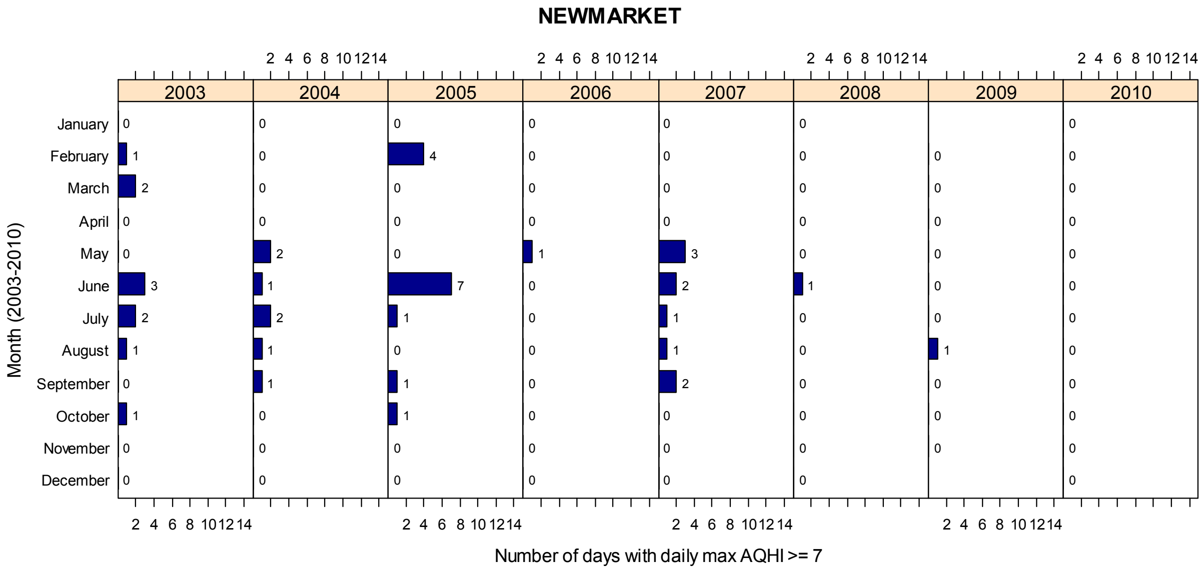
Figure 5. continued

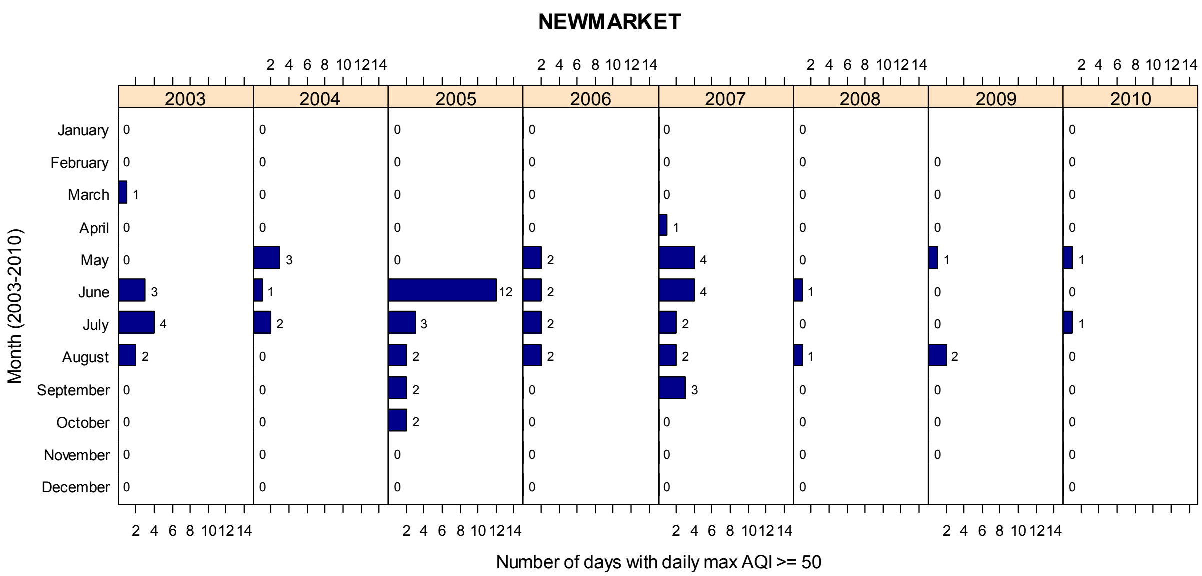




* AQHI was not available from March, 2003 to December, 2007 due to missing NO2 data in Mississauga, Ontario as indicated by blank space

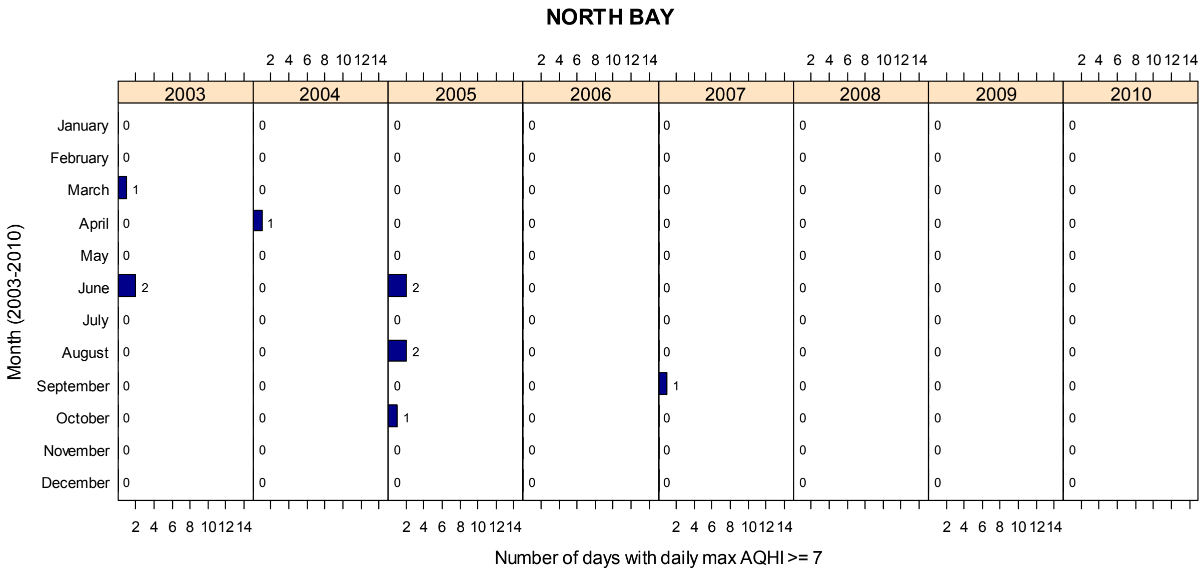
Figure 5. continued





* AQHI was not available in January and December, 2009 in NewMarket, Ontario as indicated by blank space

Figure 5. continued



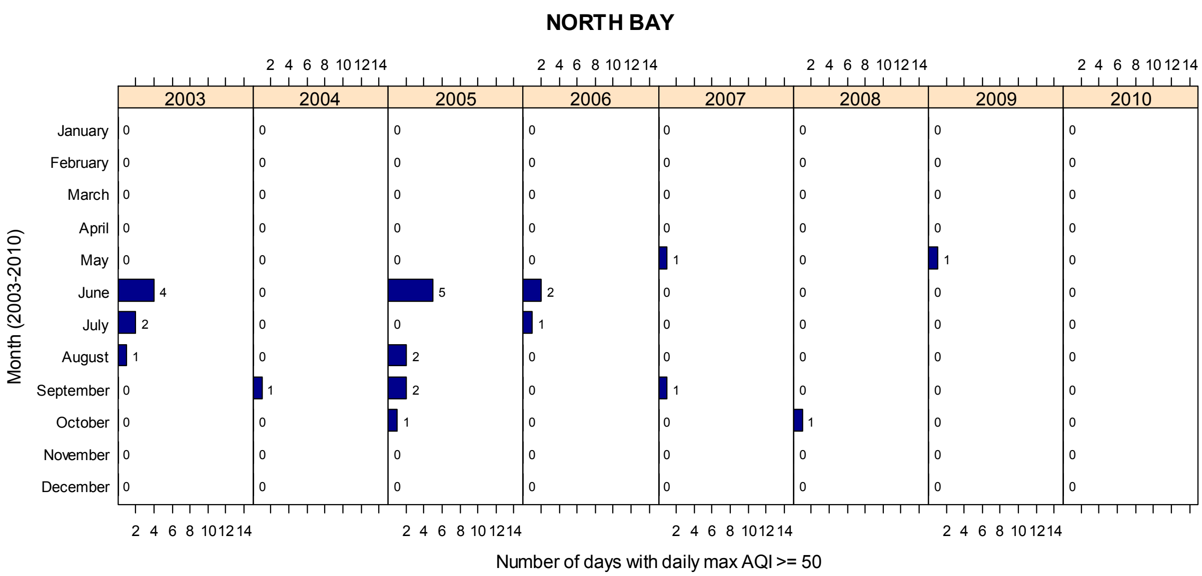
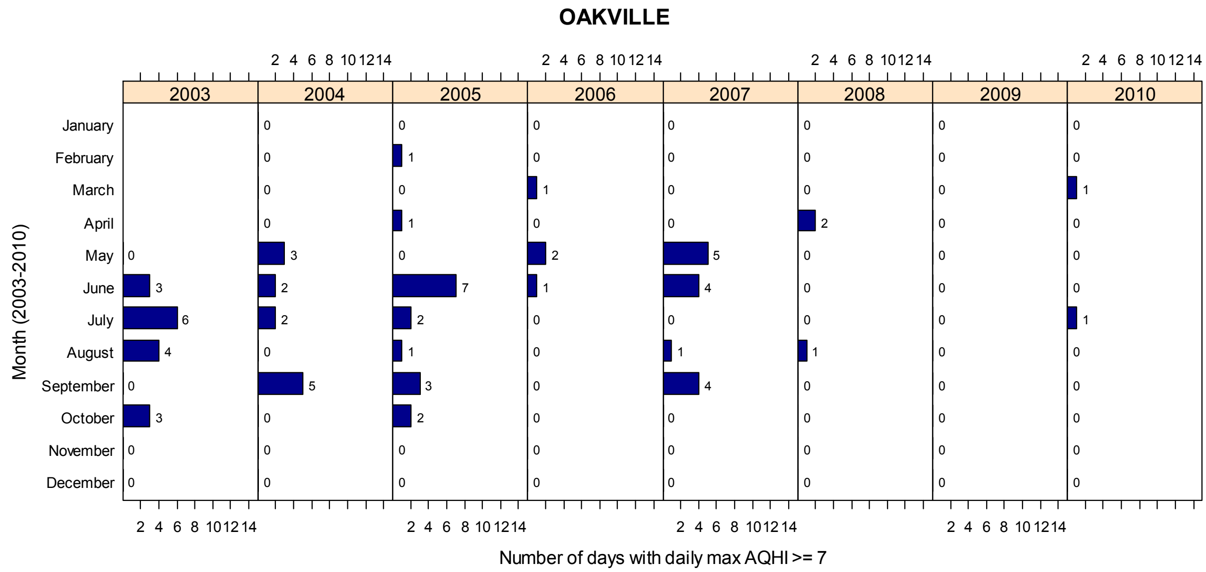
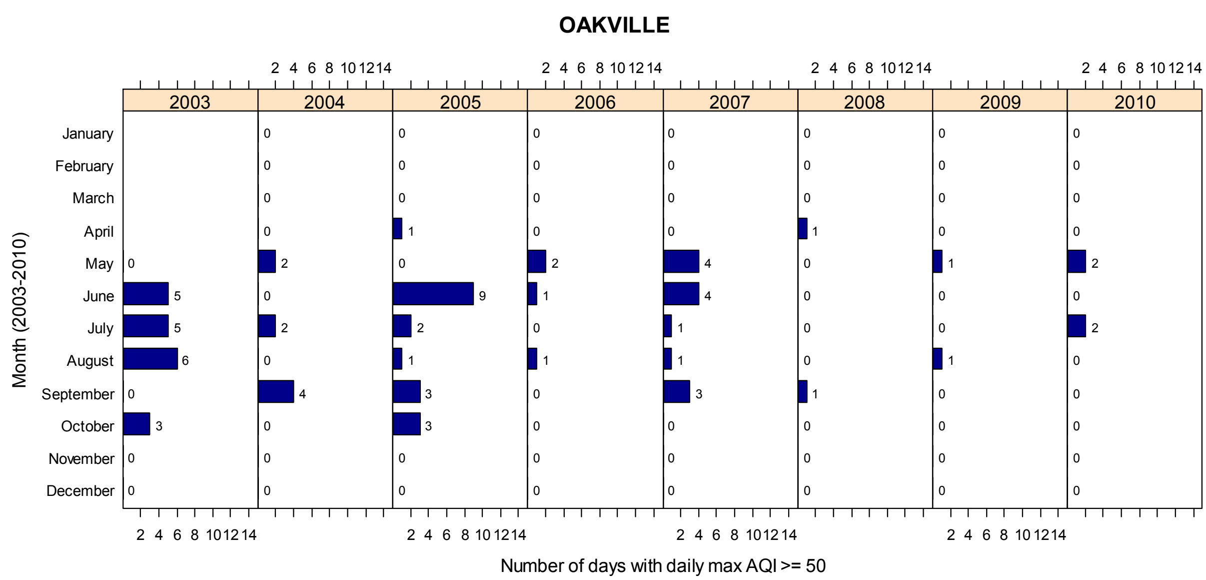


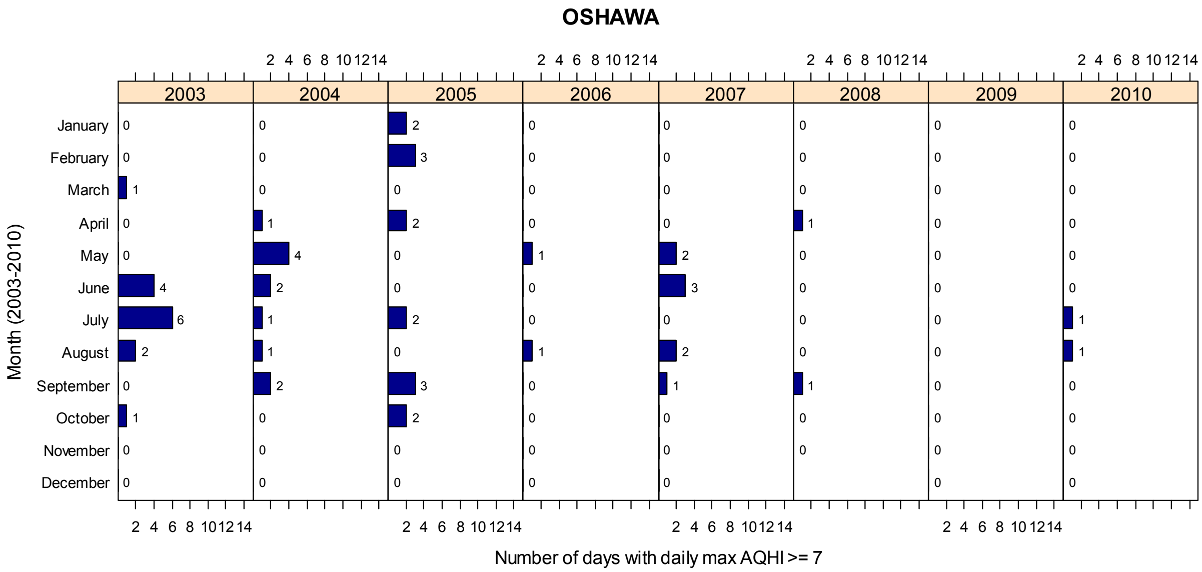
Figure 5. continued

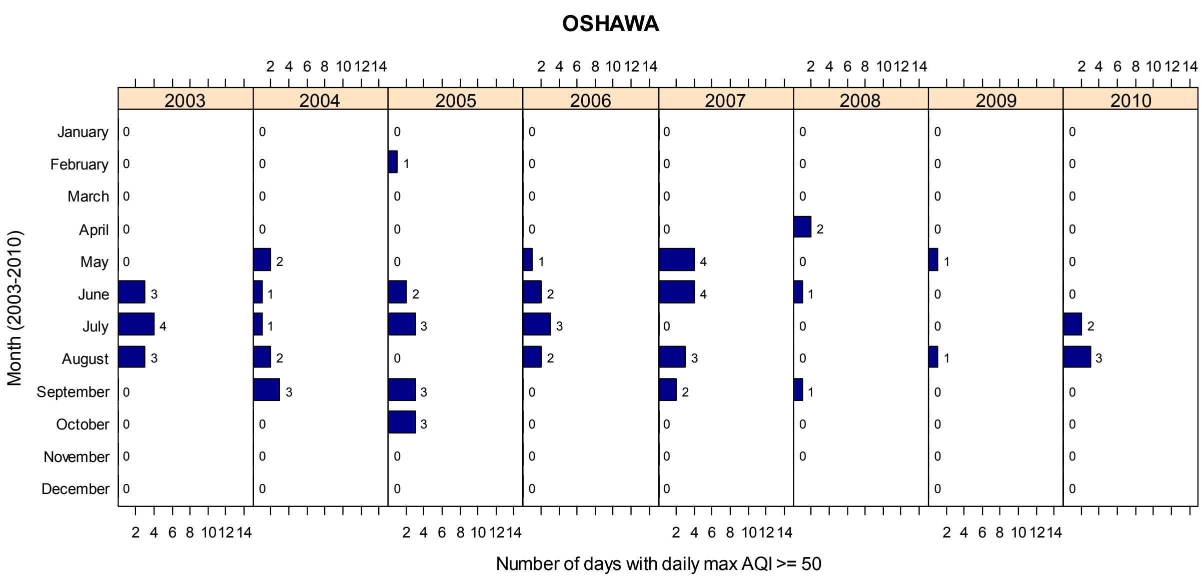




* AQHI was not available from January to April, 2003 in Oakville, Ontario as indicated by blank space

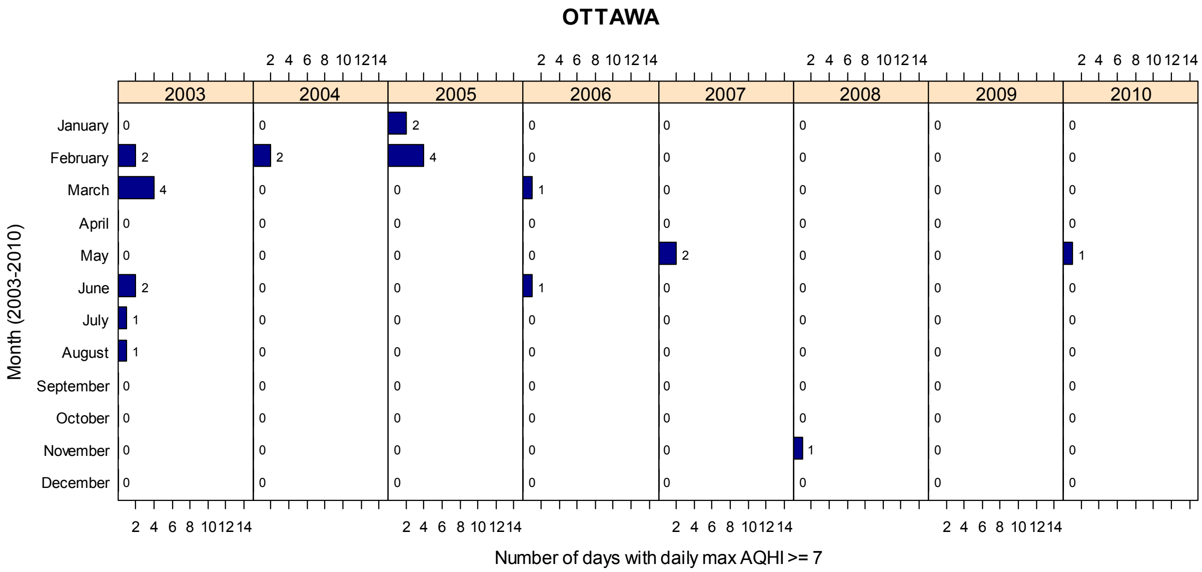
Figure 5. continued





* AQHI was not available in December, 2008 in Oshawa, Ontario as indicated by blank space

Figure 5. continued



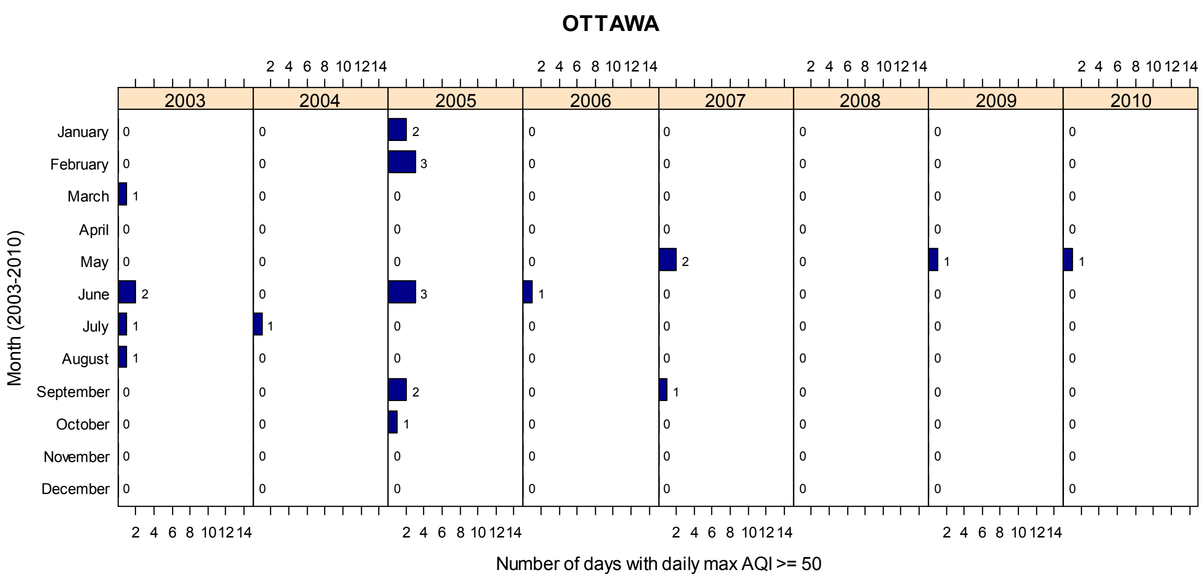
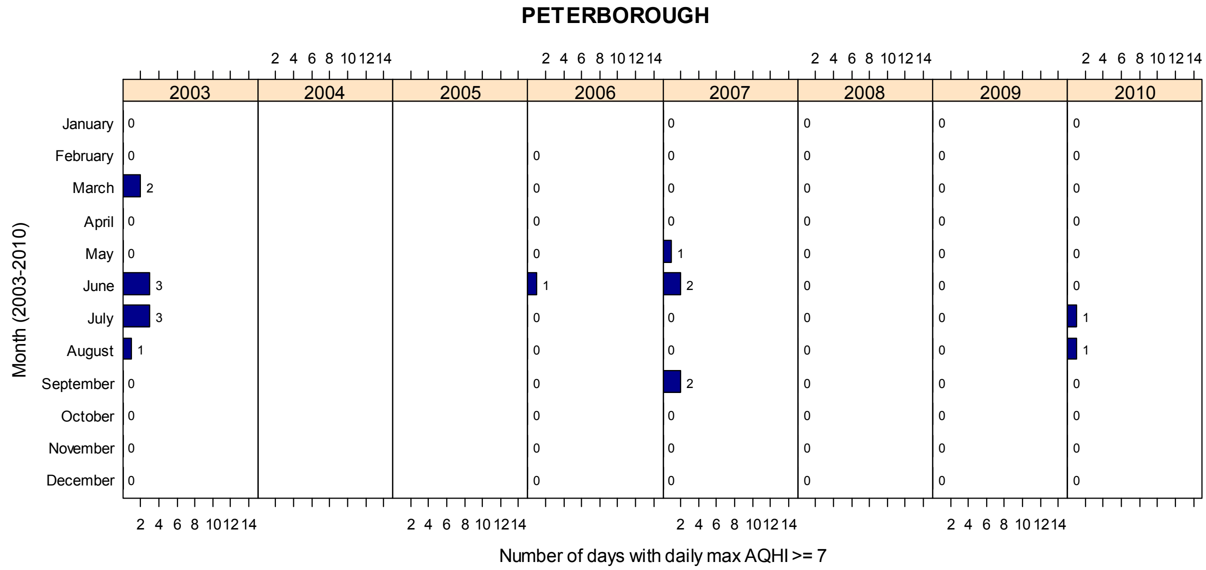
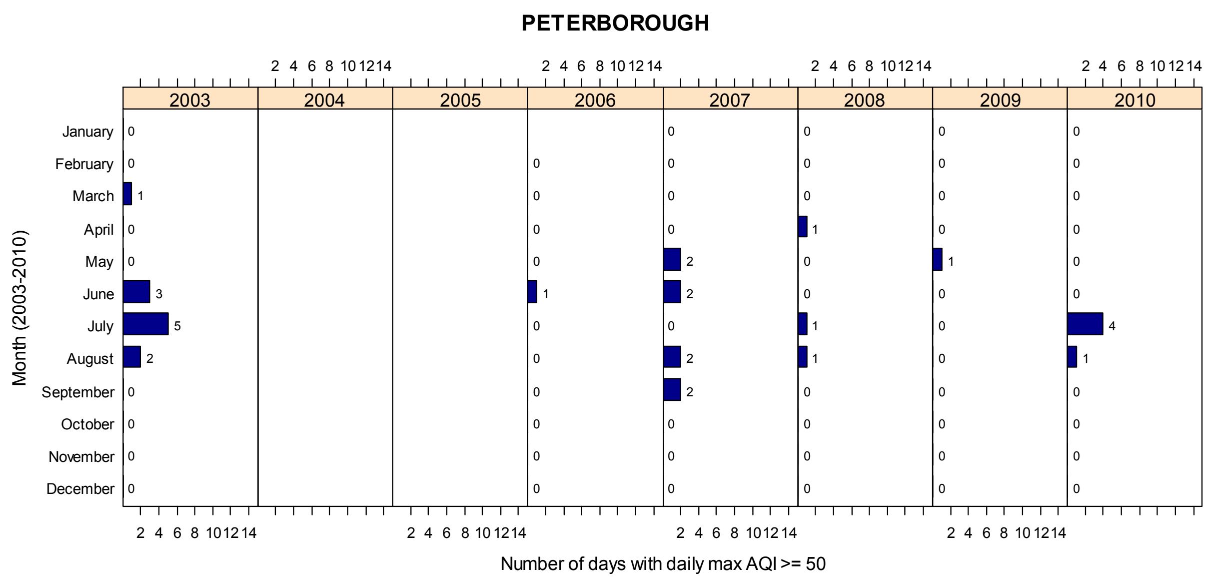


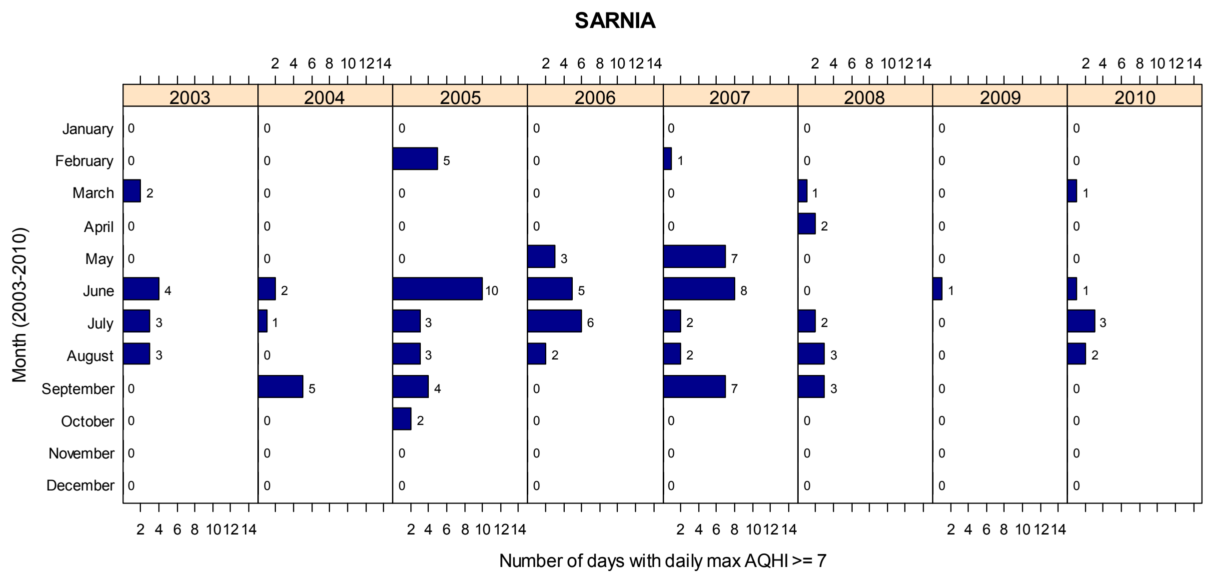
Figure 5. continued





* AQHI was not available from January, 2004 to January, 2006 in Peterborough, Ontario as indicated by blank space

Figure 5. continued



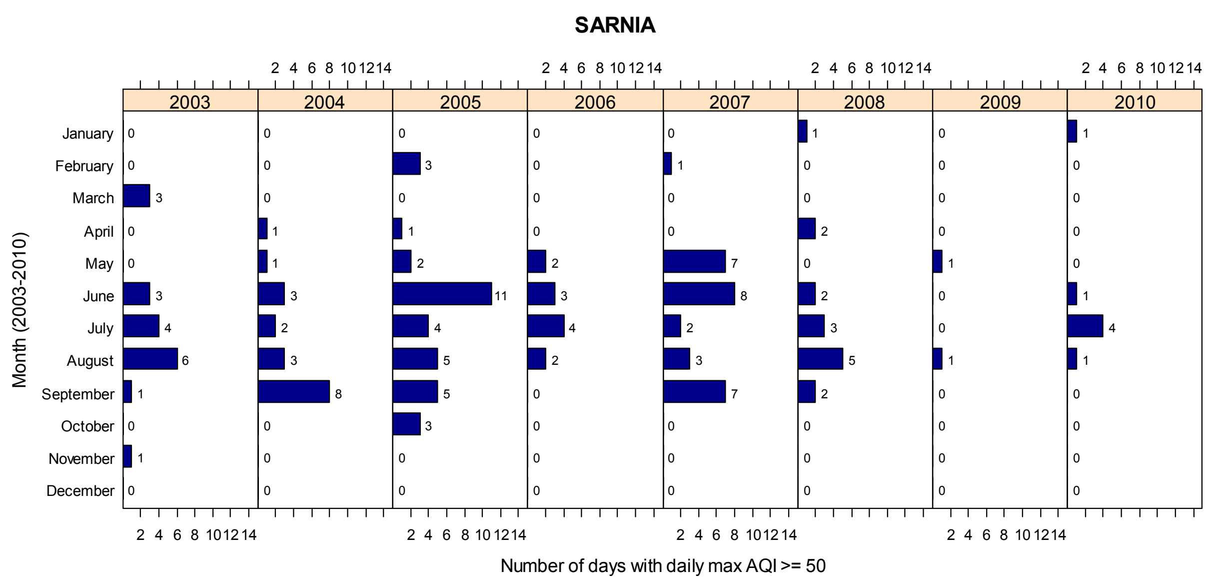
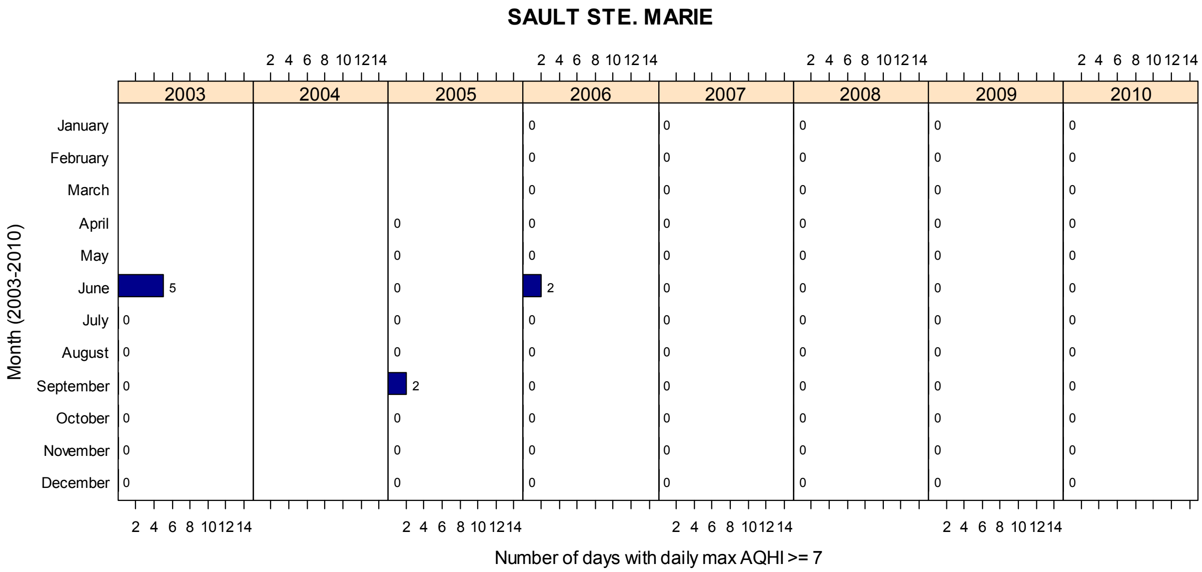
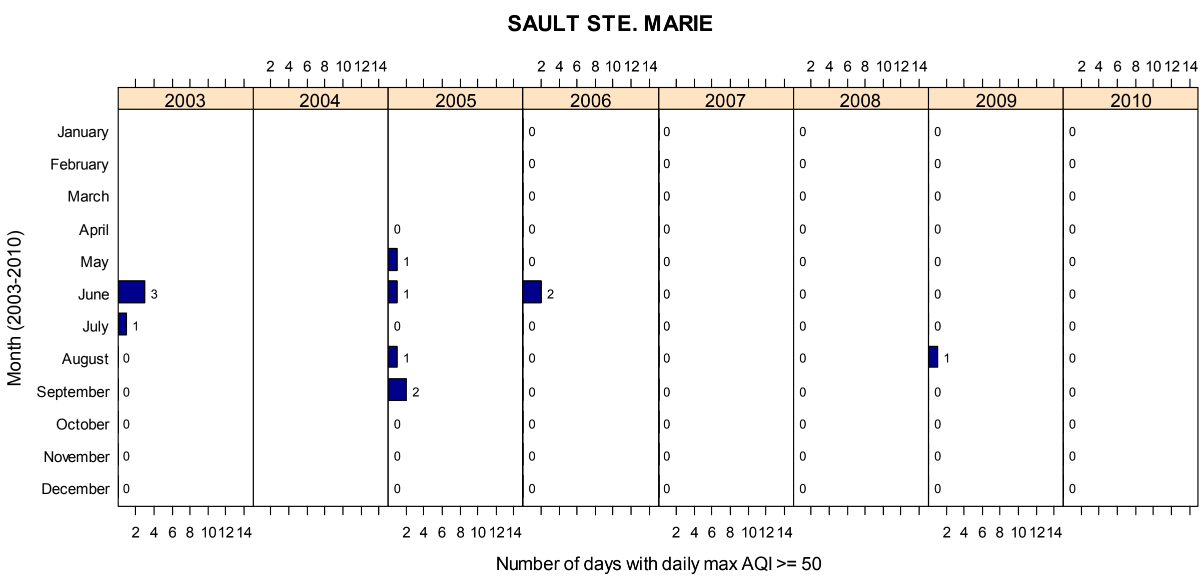


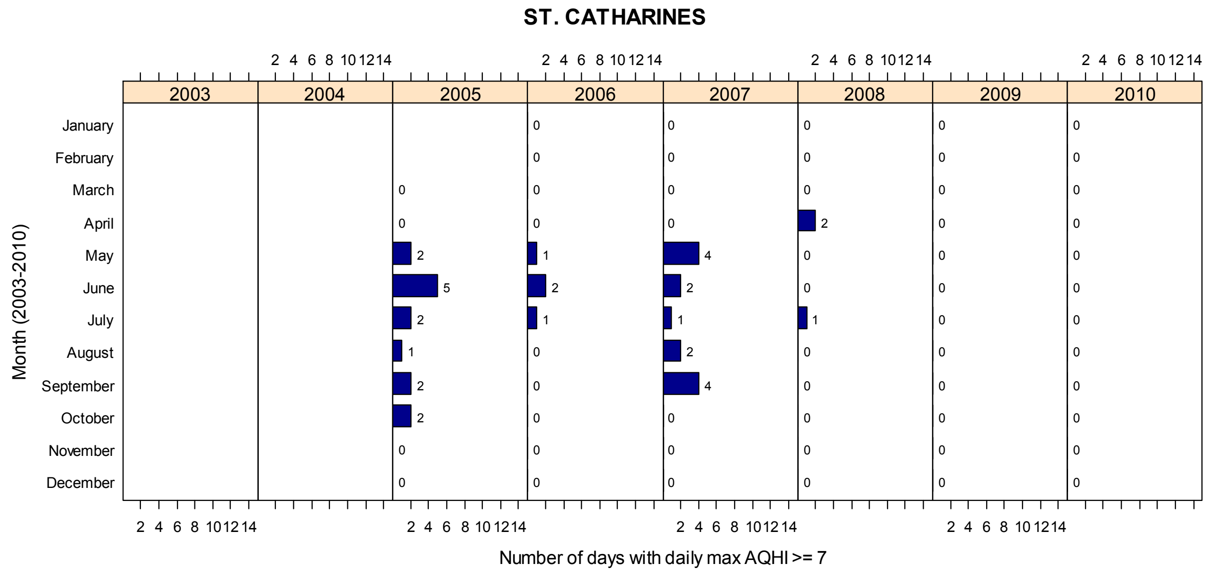
Figure 5. continued

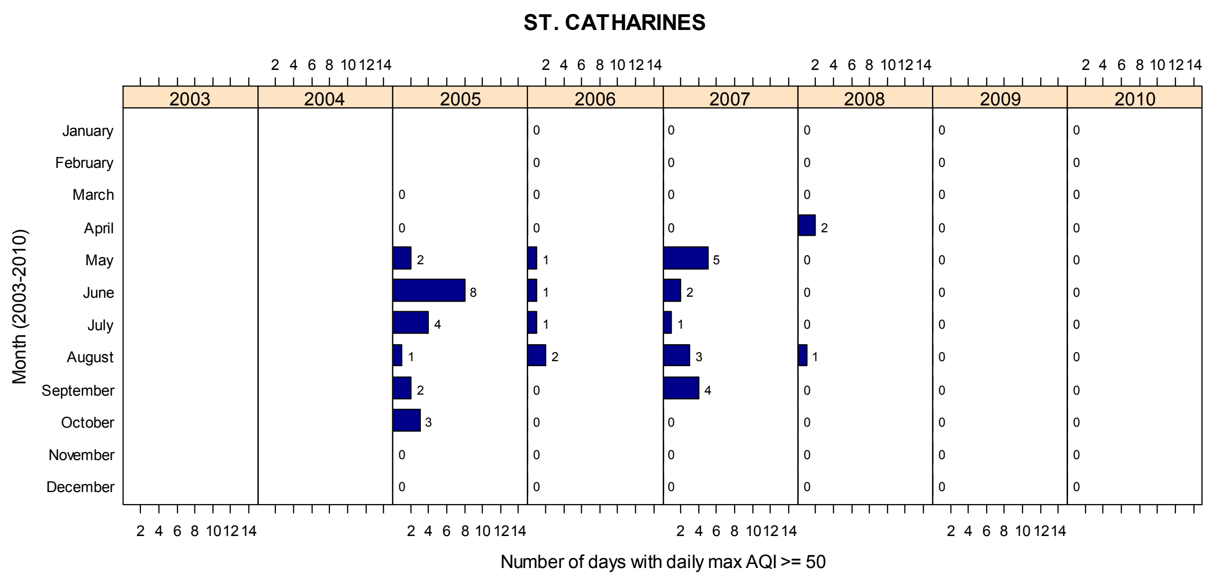




* AQHI was not available from January to May, 2003 and from January, 2004 to March, 2005 in Sault Ste. Marie, Ontario as indicated by blank space

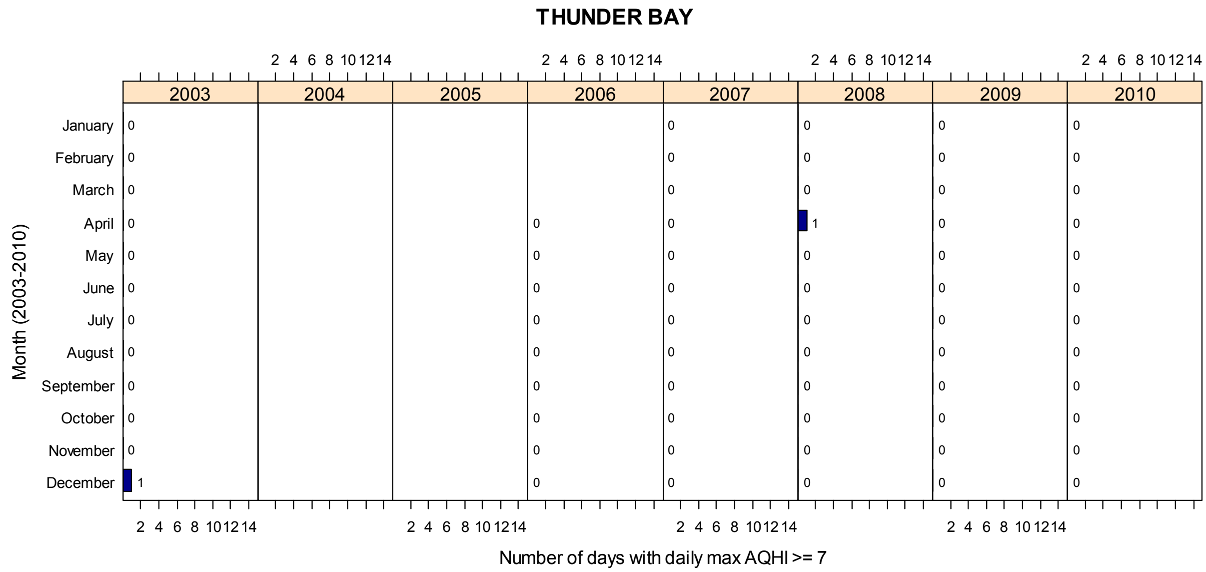
Figure 5. continued

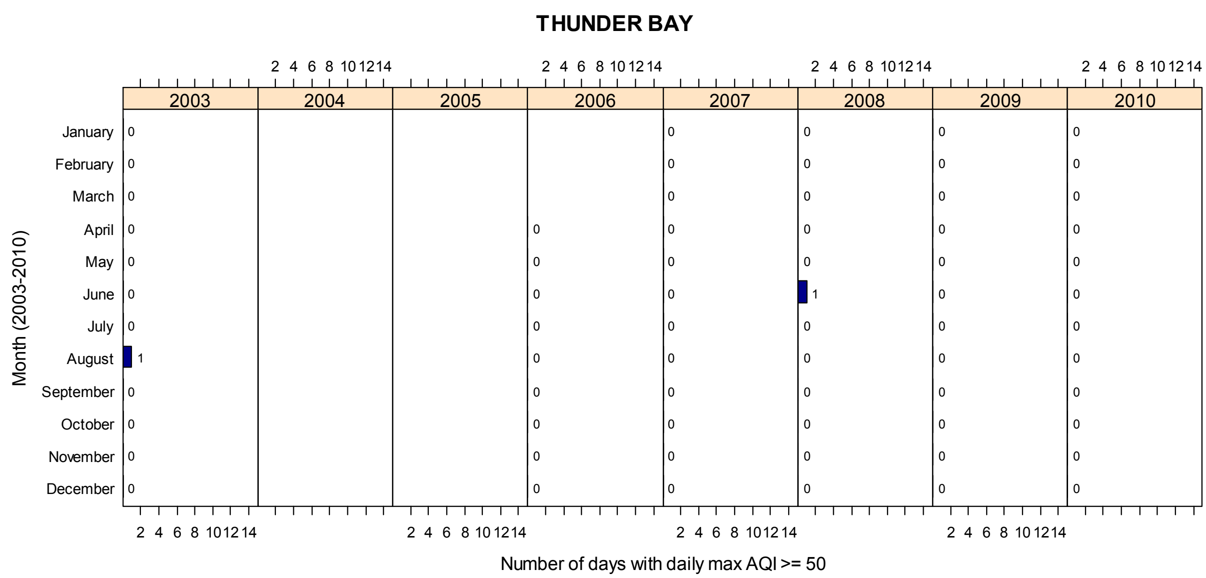




* AQHI was not available from 2003 to 2004 and from January to February, 2005 in St. Catherines, Ontario as indicated by blank space

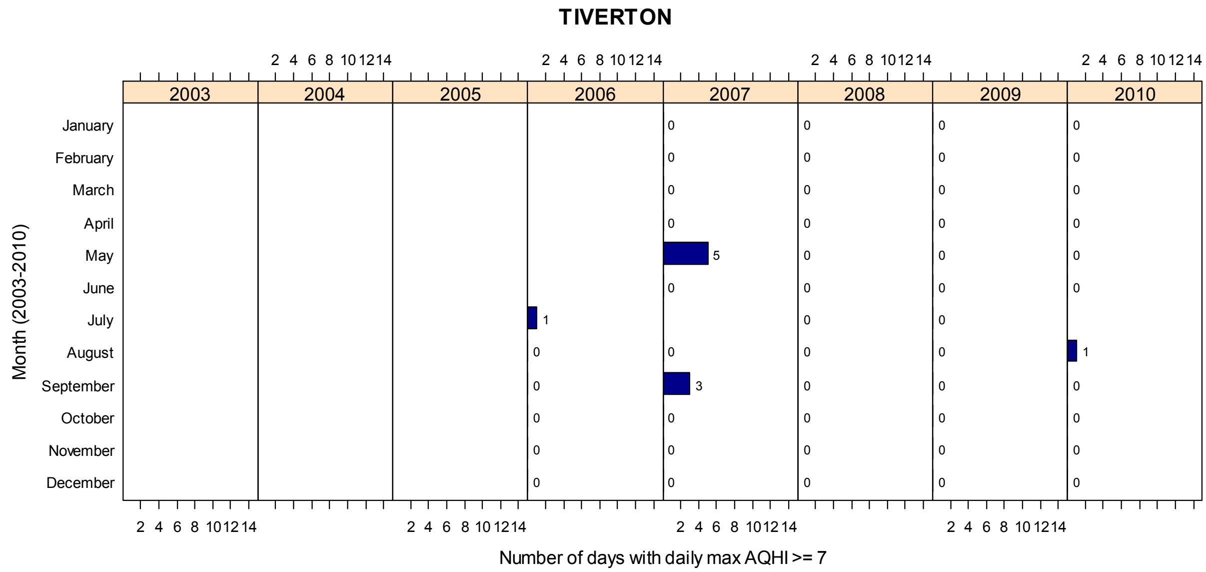
Figure 5. continued

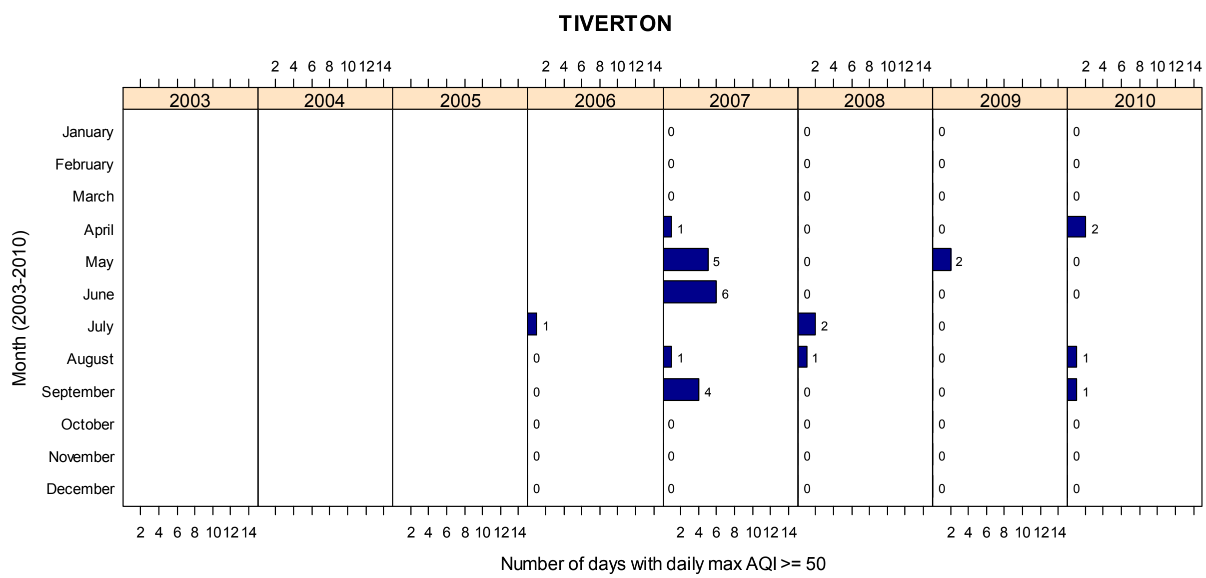




* AQHI was not available from January, 2004 to March, 2006 in Thunder Bay, Ontario as indicated by blank space

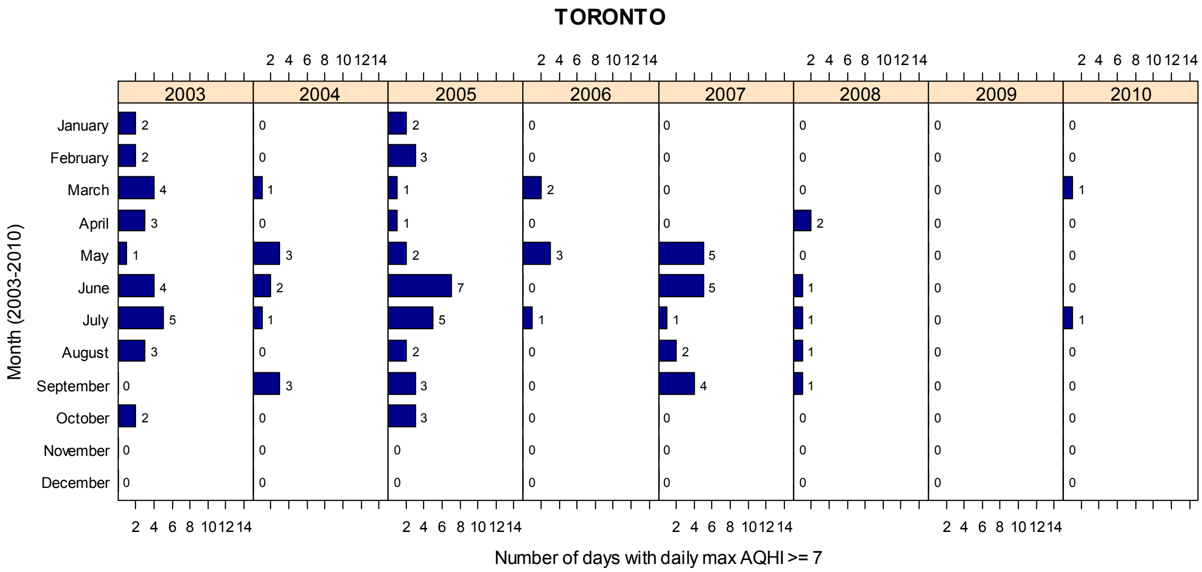
Figure 5. continued





* AQHI was not available from January, 2003 to June, 2006 in Tiverton, Ontario as indicated by blank space

Figure 5. continued



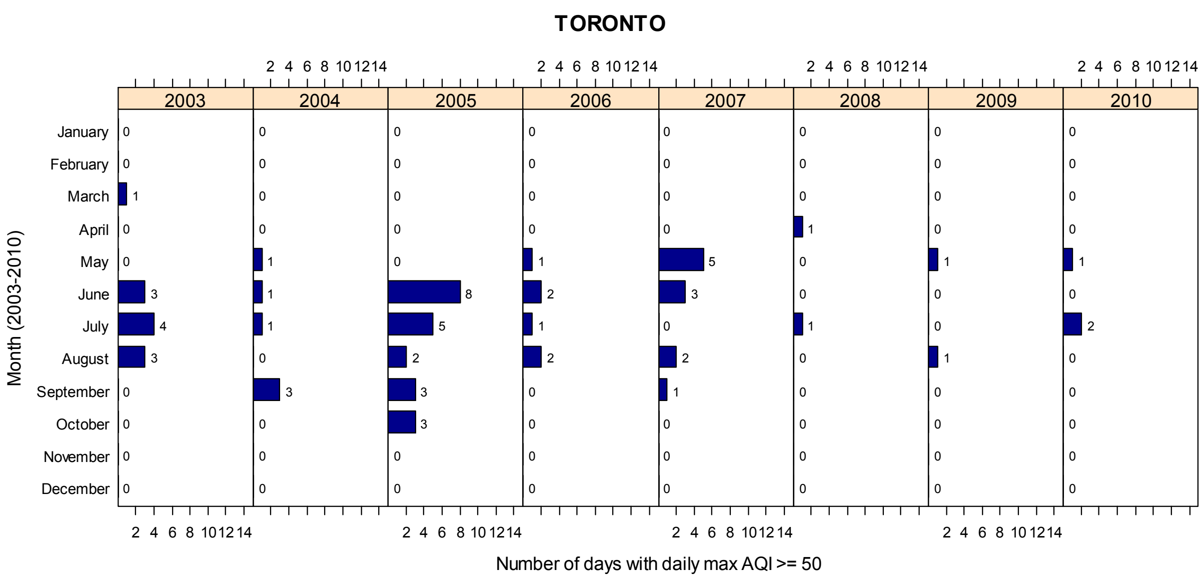
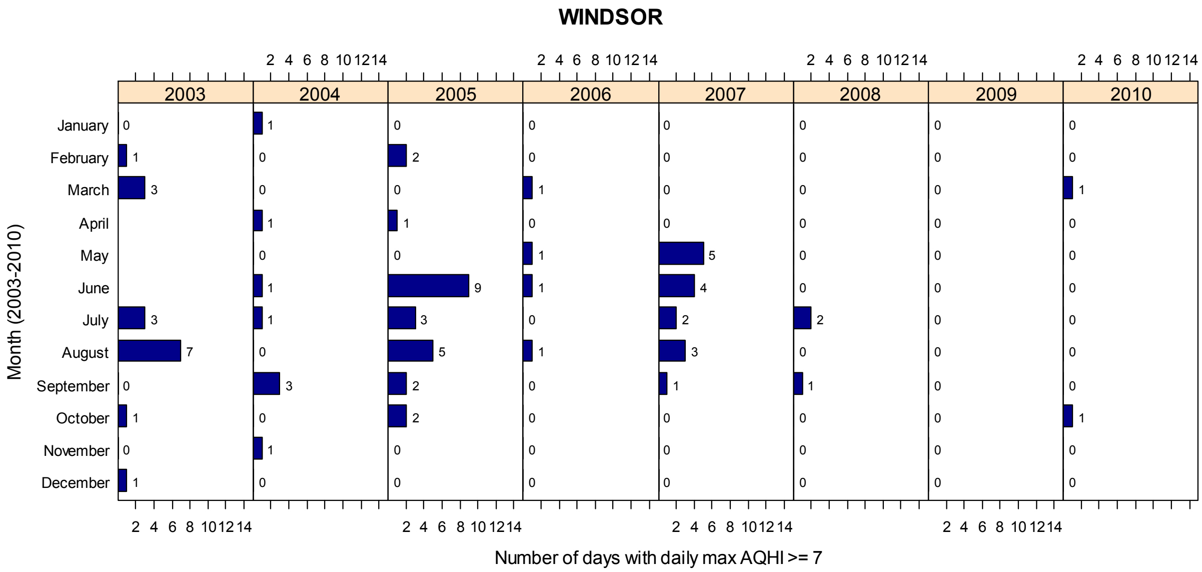
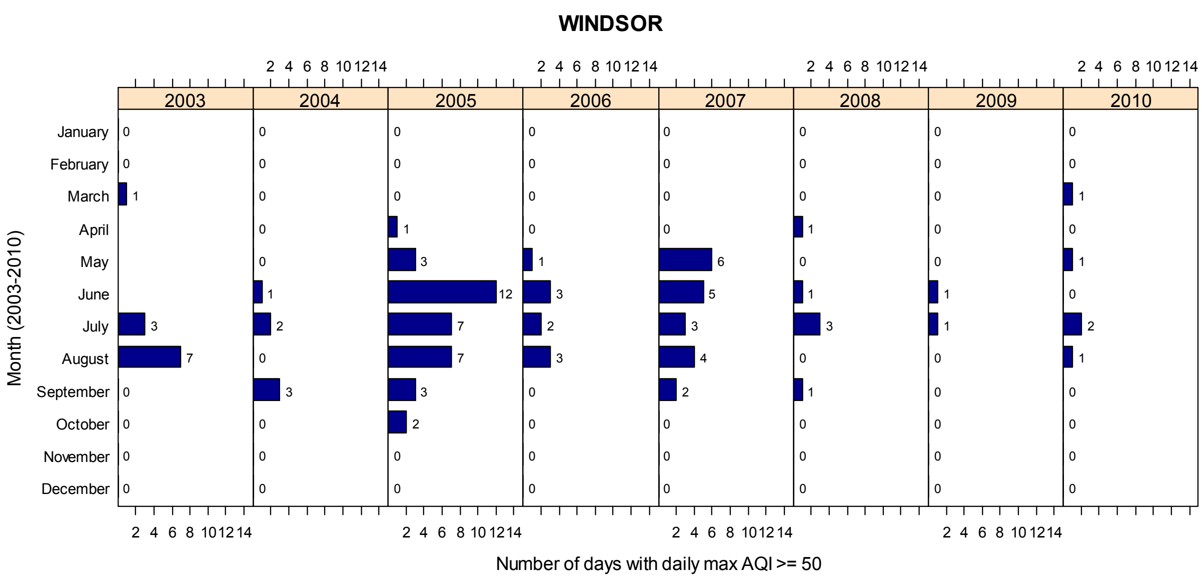


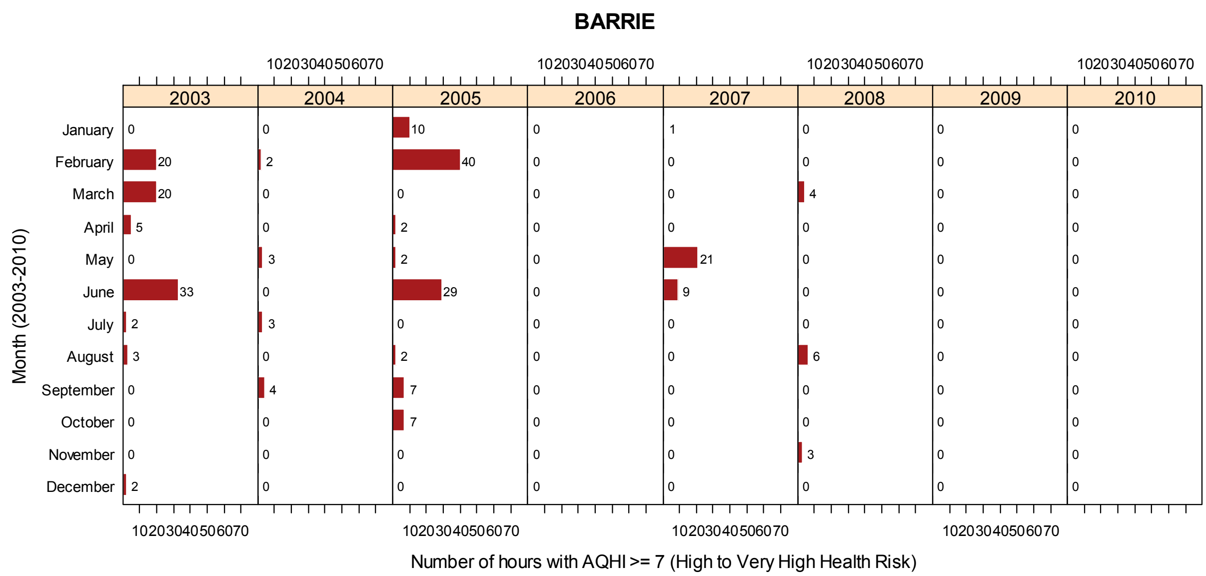
Figure 5. continued





* AQHI was not available from April to June, 2003 in Windsor, Ontario as indicated by blank space

Figure 6. Monthly distribution of high AQHI hours (AQHI > 7) and high AQI hours (AQI > 50) across Ontario from 2003 to 2010. AQI data were restricted to the months in which AQHI was also present in order to facilitate comparison. For any month where AQHI data were absent, the number of high AQHI and high AQI hours were assigned blank space. Five cities (Dorset, Morrisburg, Parry Sound, Petawawa, and Port Stanley) with air quality monitoring stations are not shown here because data were missing from 2003 to 2010 for one or more air pollutant required for calculating AQHI.



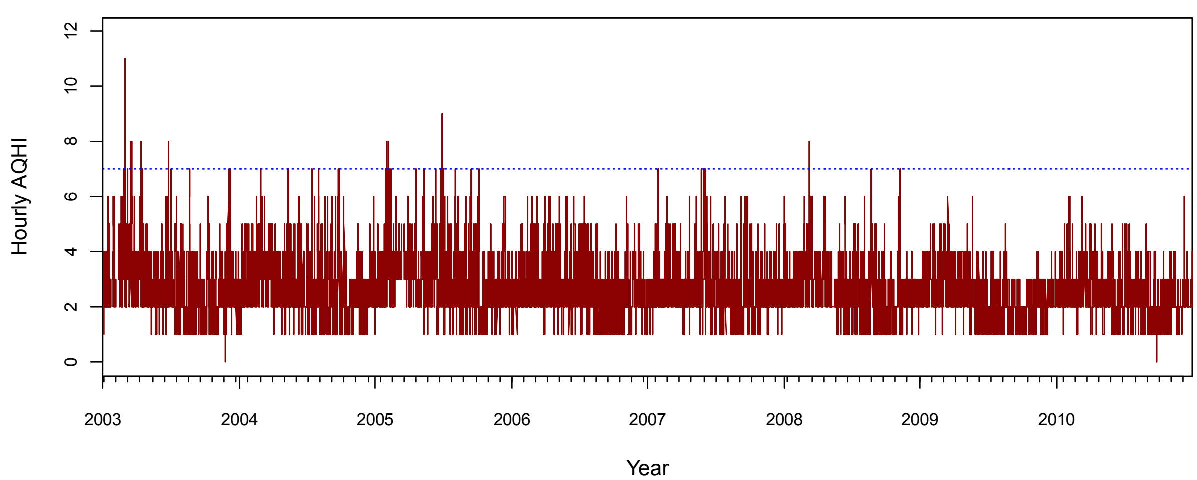
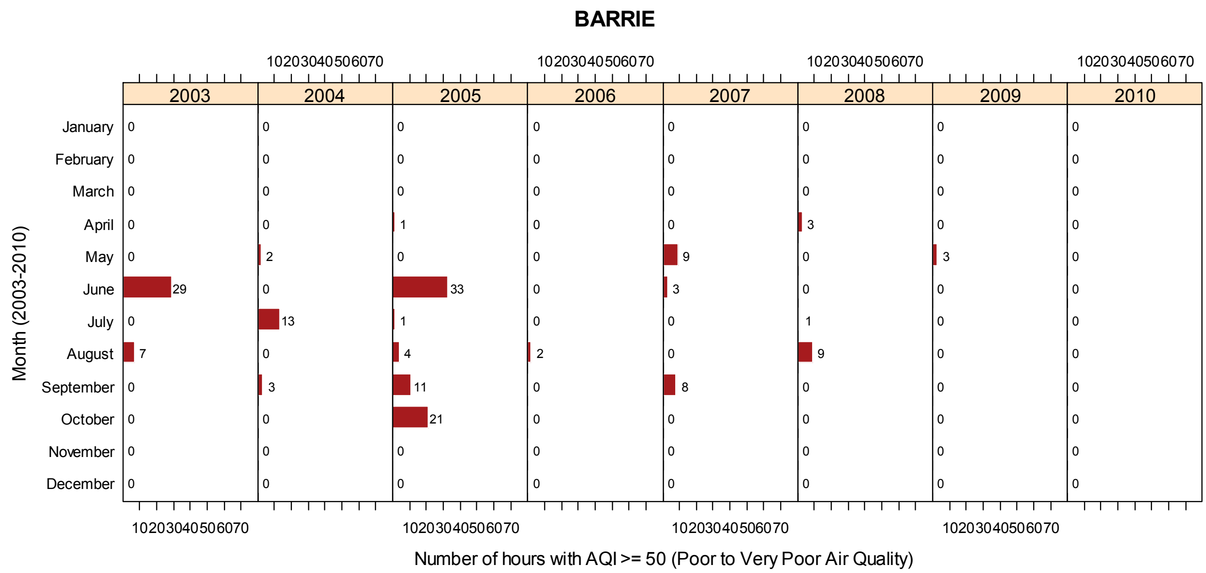


Figure 6. continued



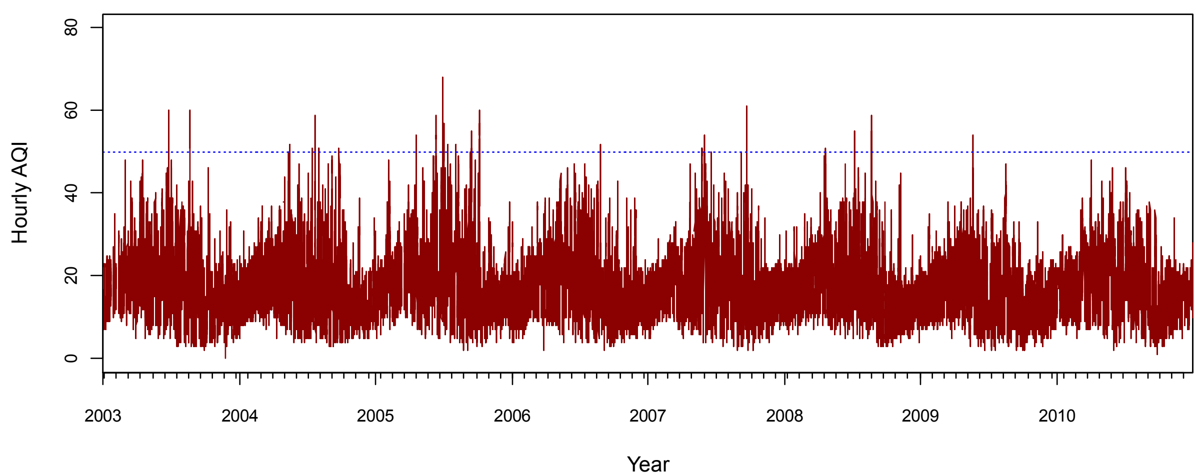
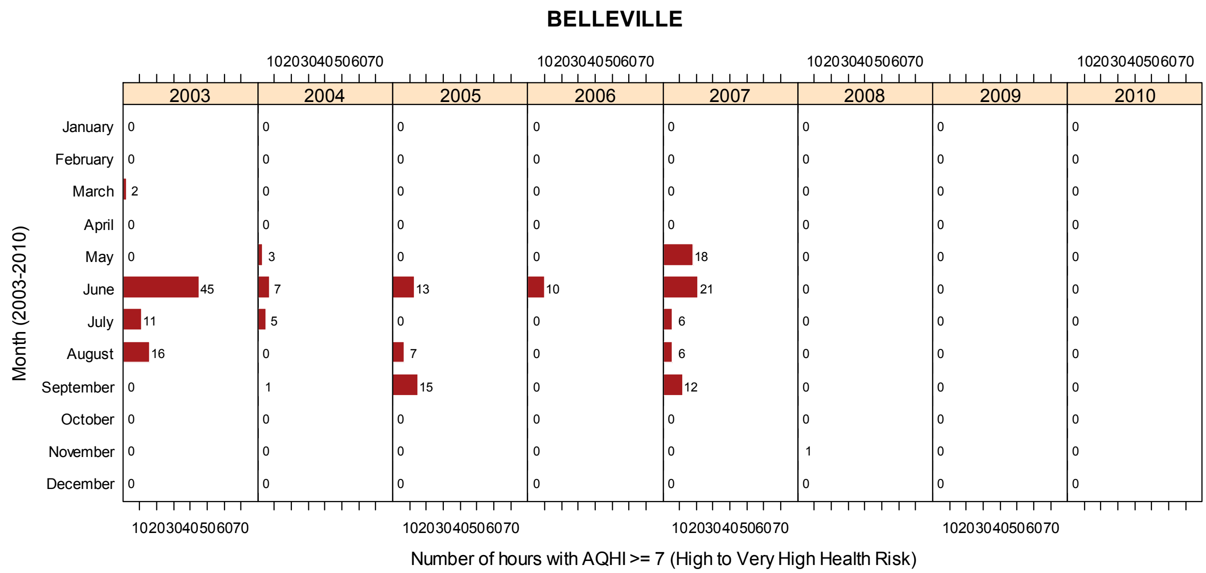


Figure 6. continued



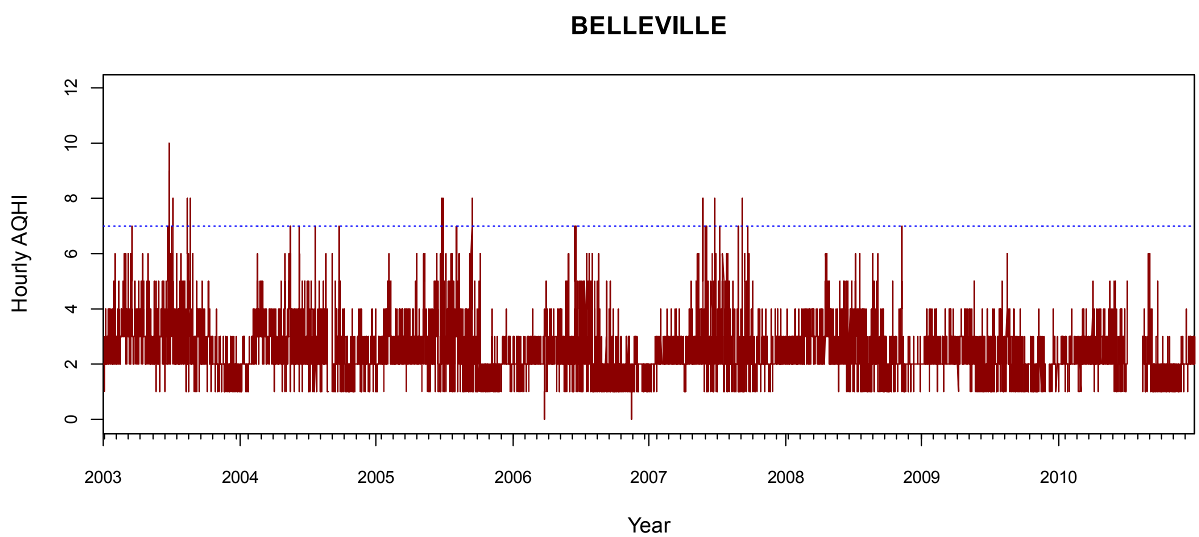
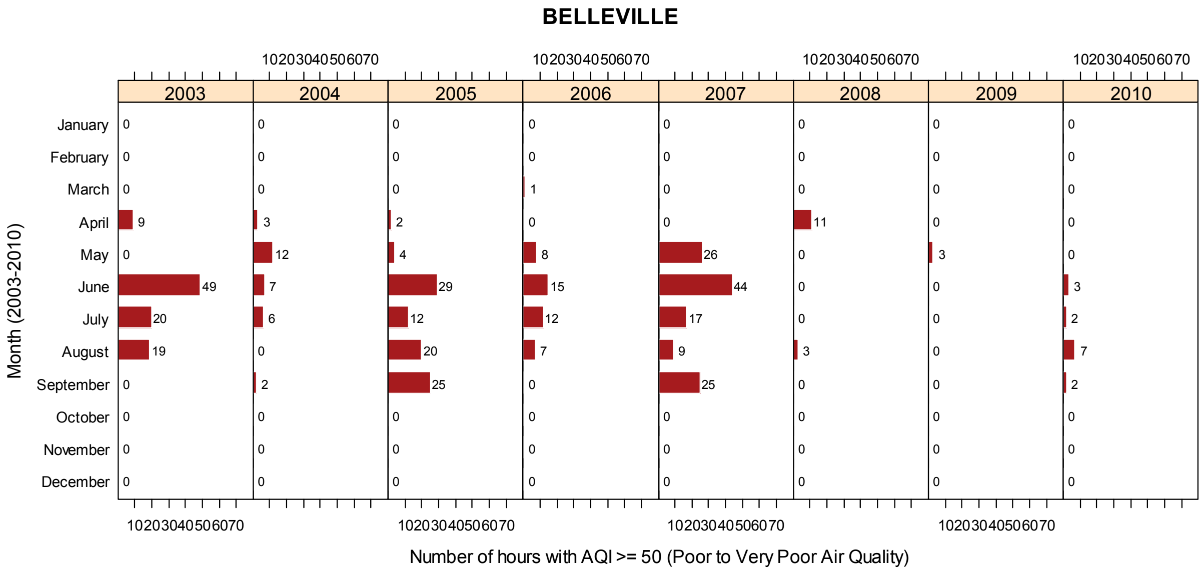


Figure 6. continued



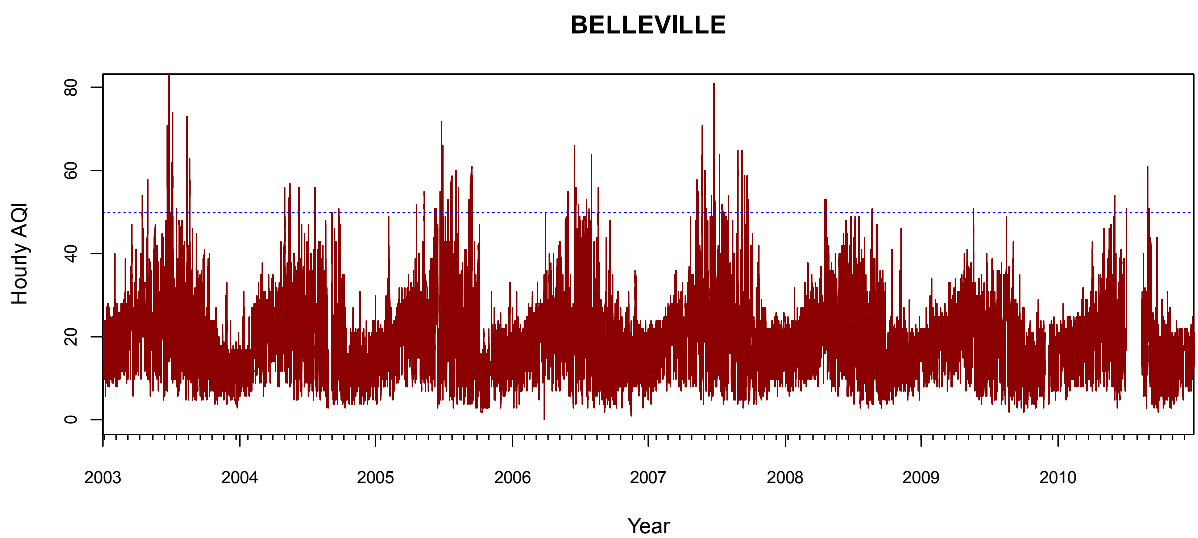
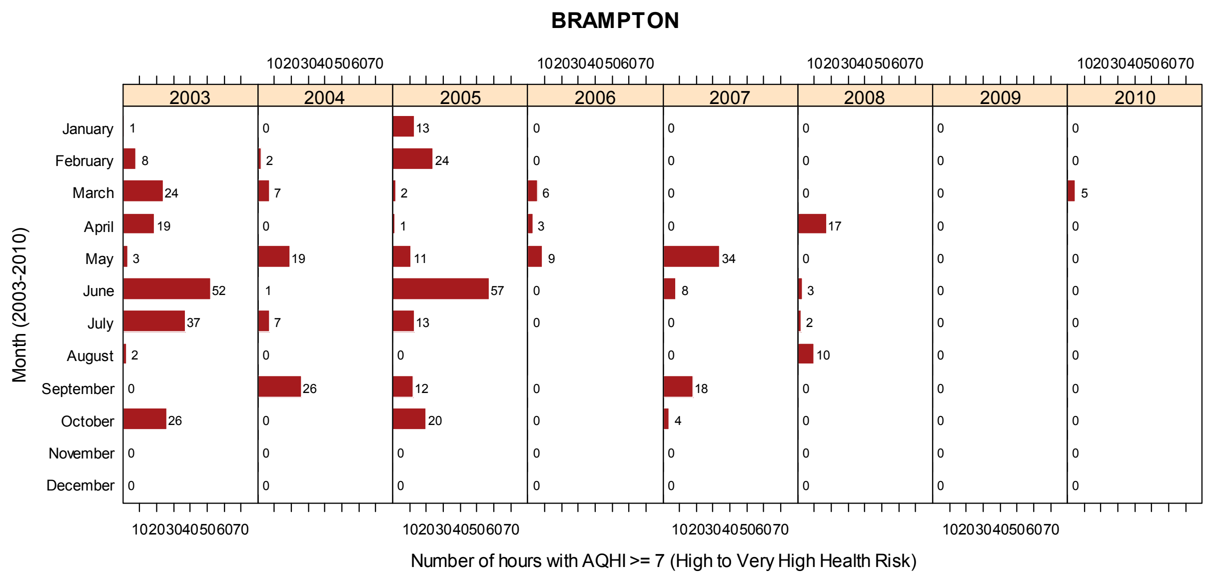


Figure 6. continued



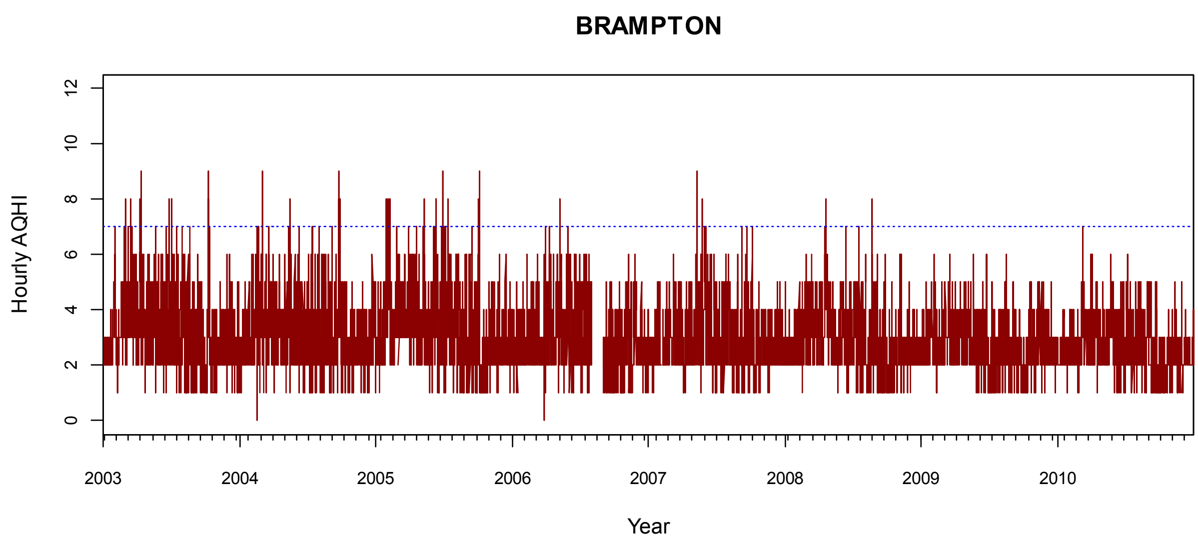
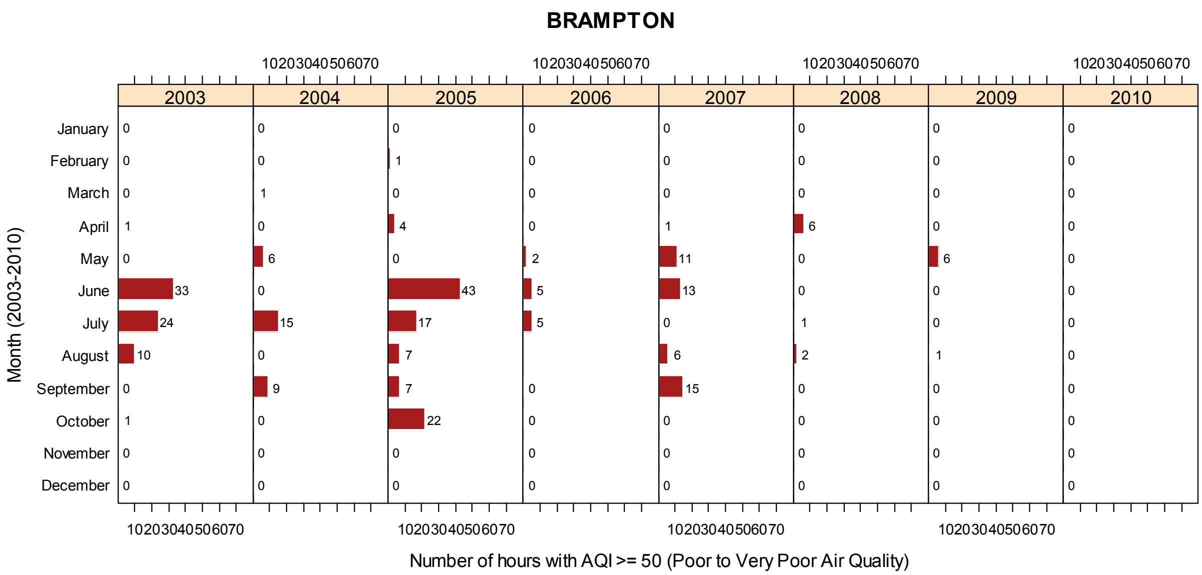
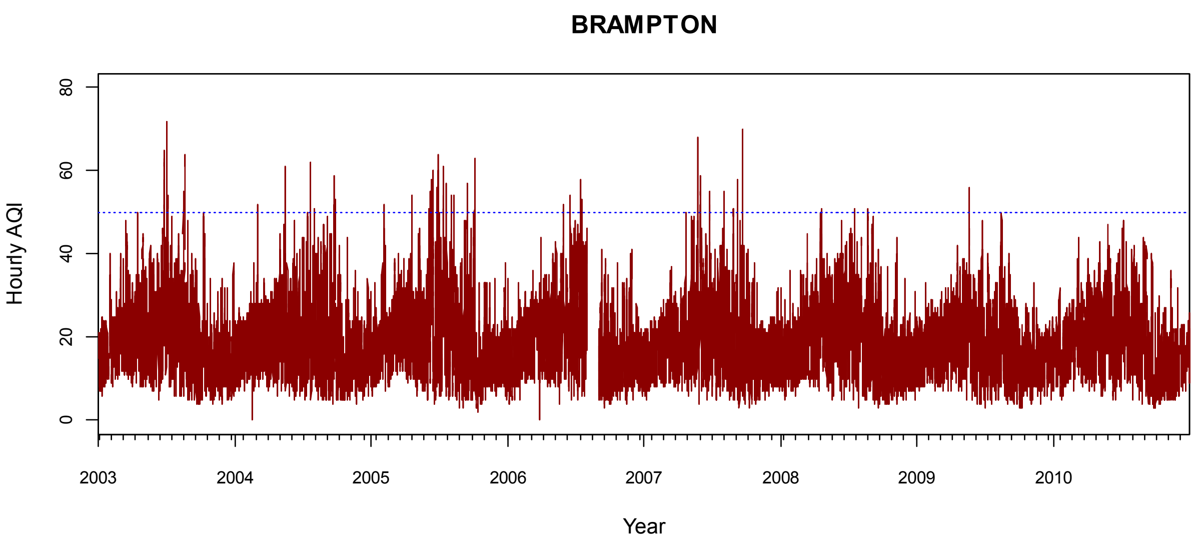


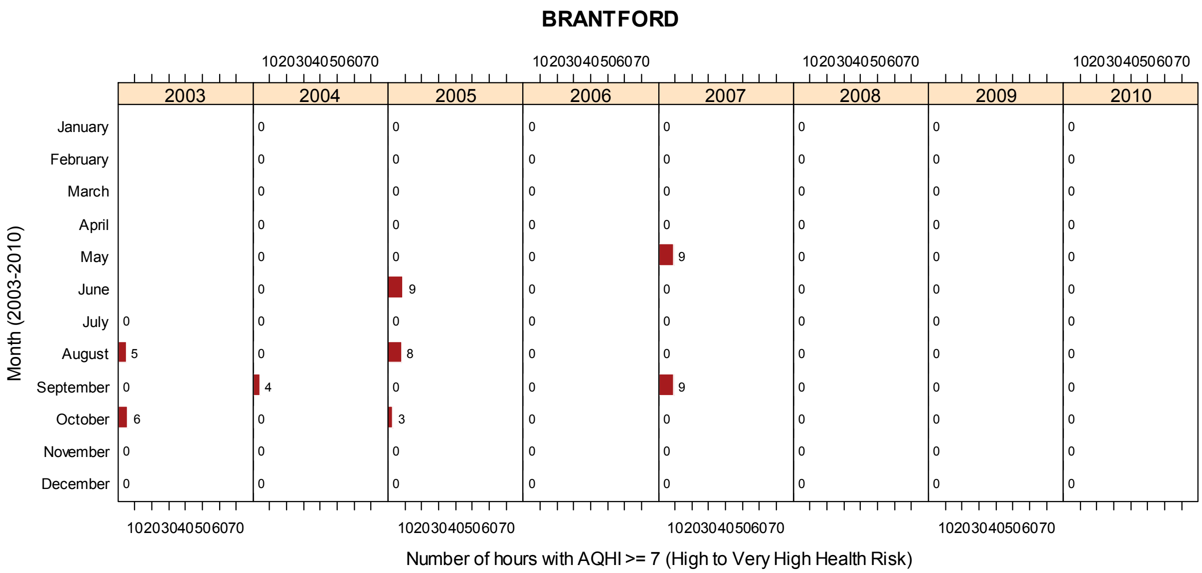
Figure 6. continued





* AQHI was not available in August 2006 in Brampton, Ontario as indicated by blank space

Figure 6. continued



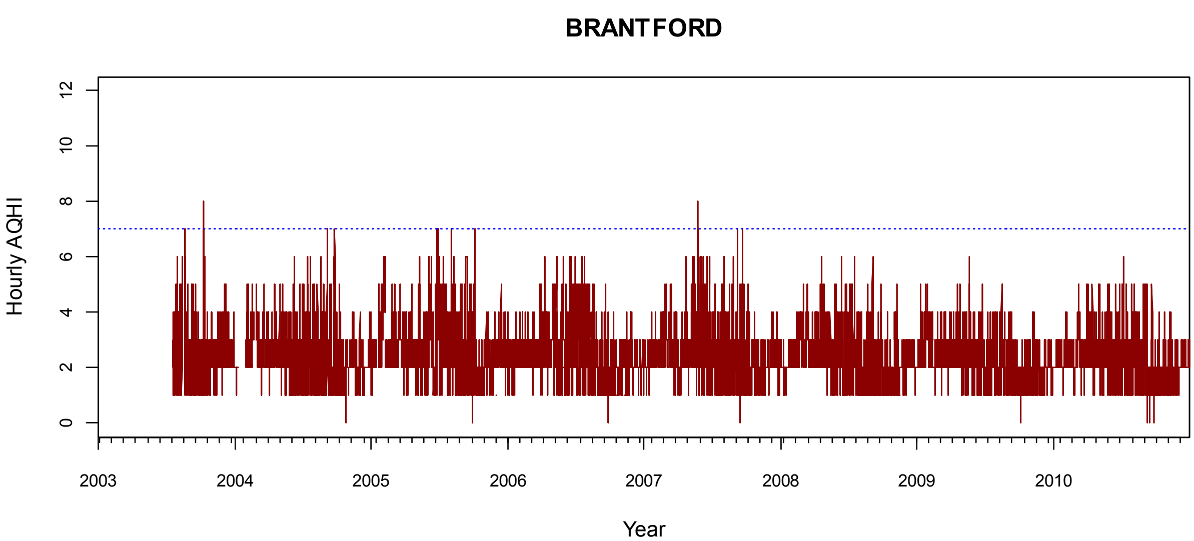
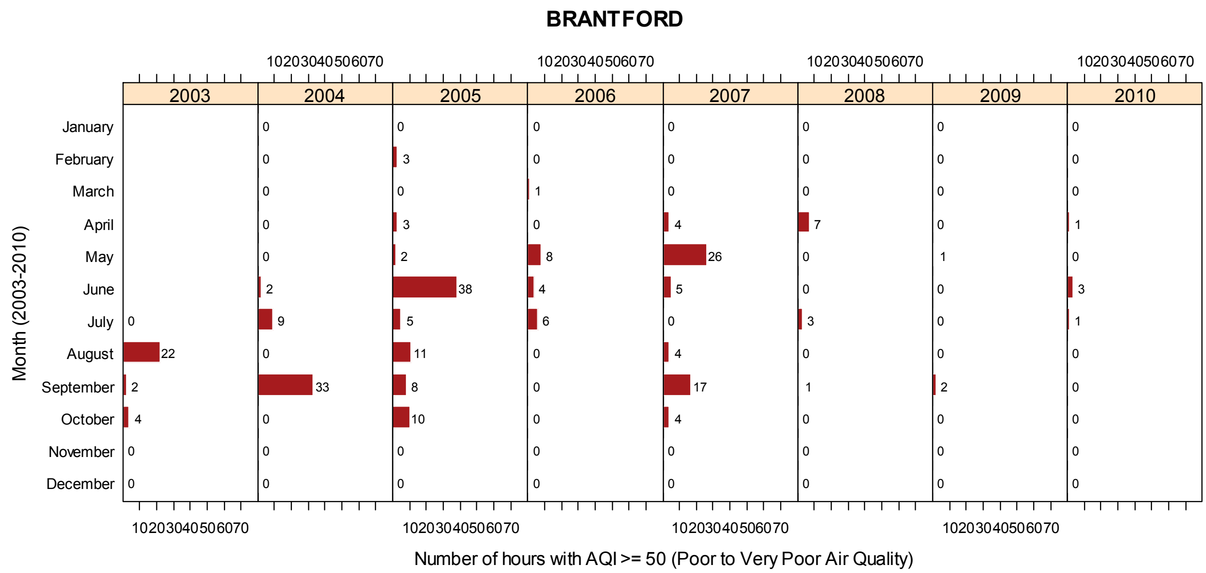
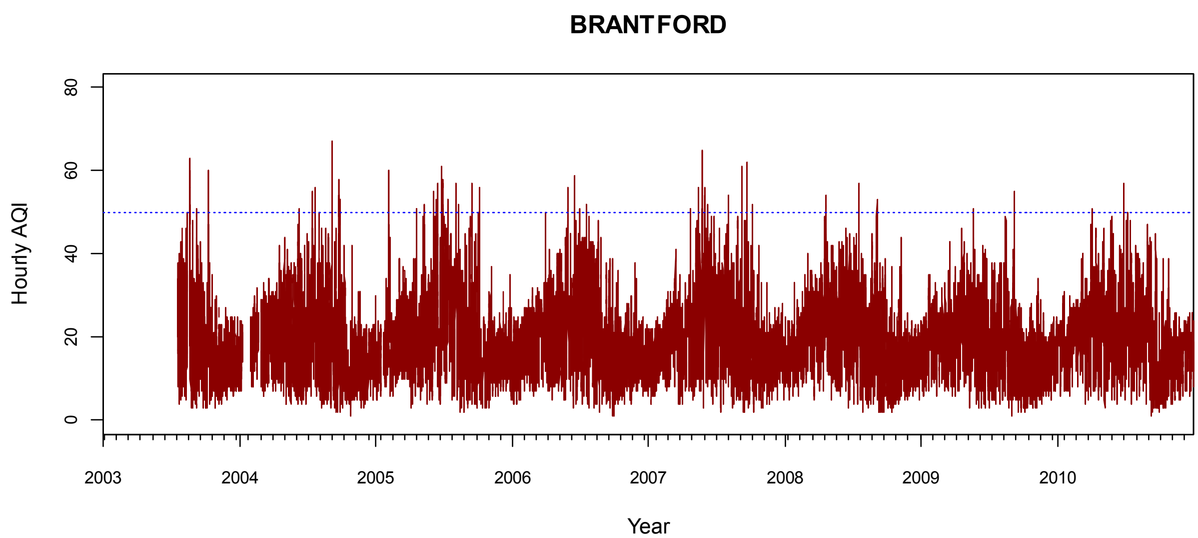


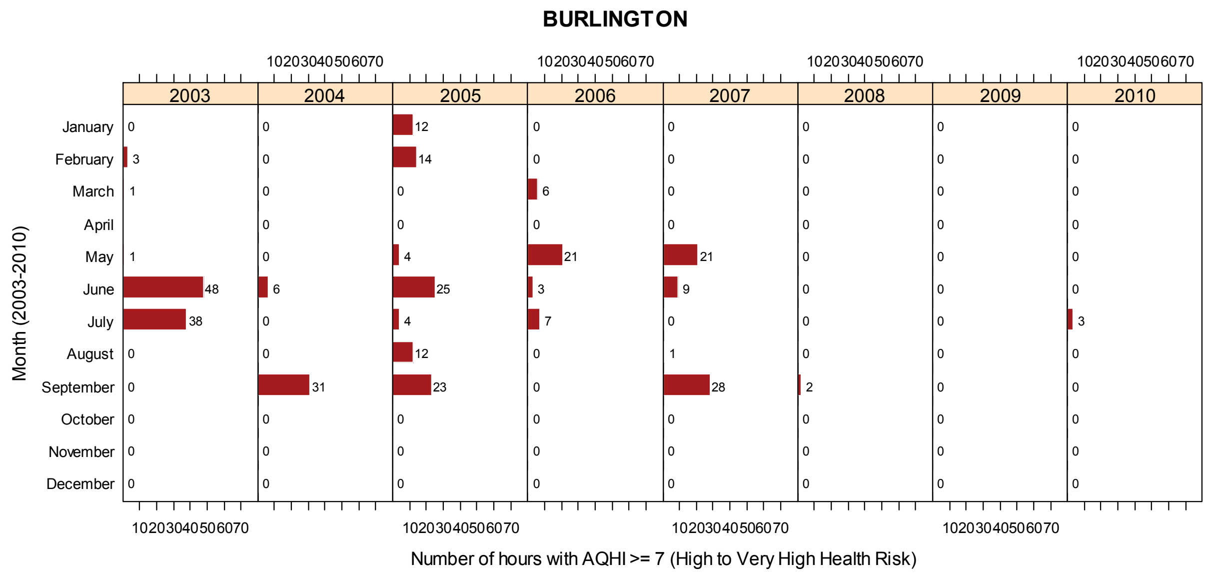
Figure 6. continued





* AQHI was not available from January to June 2003 in Brantford, Ontario as indicated by blank space

Figure 6. continued



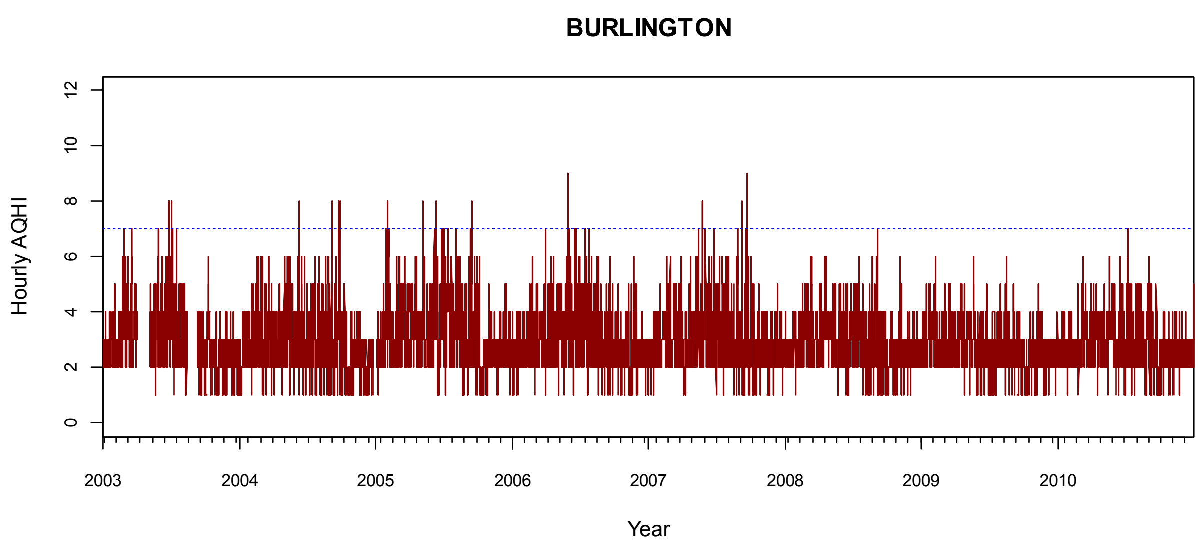
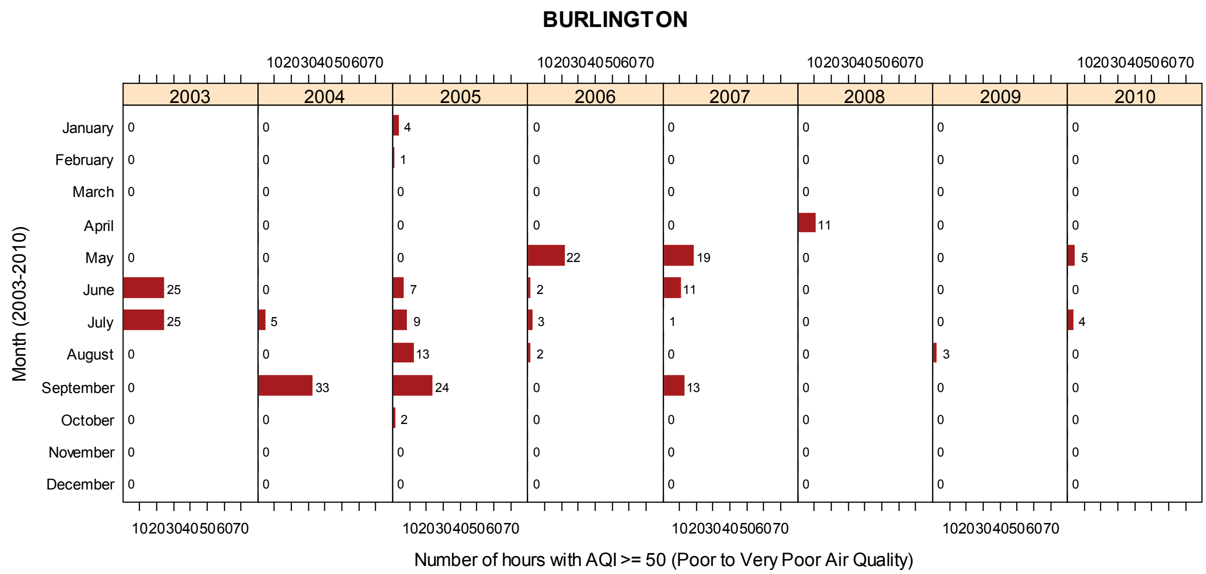
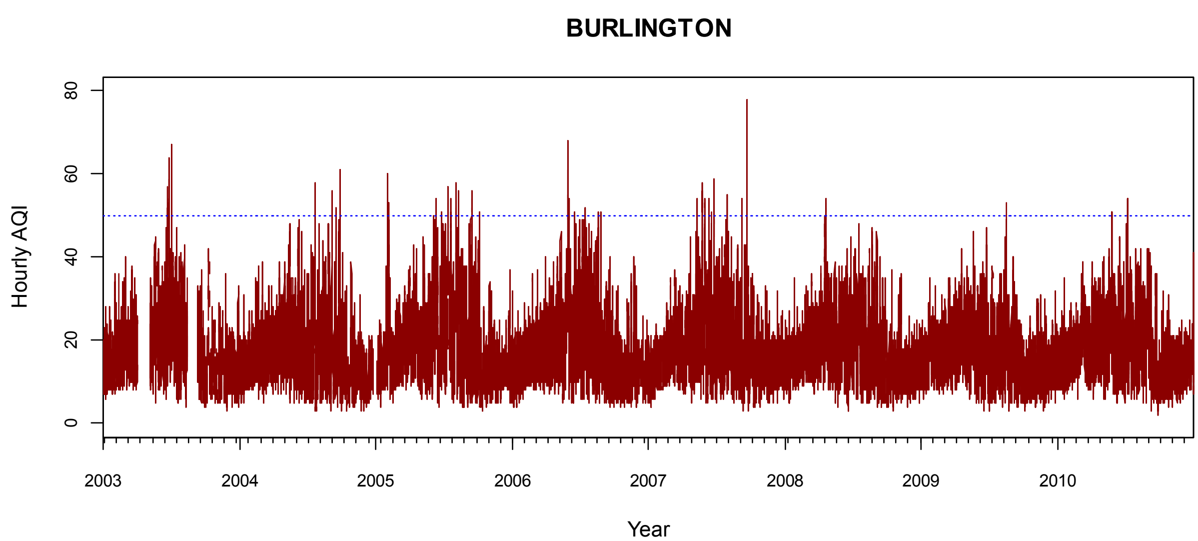


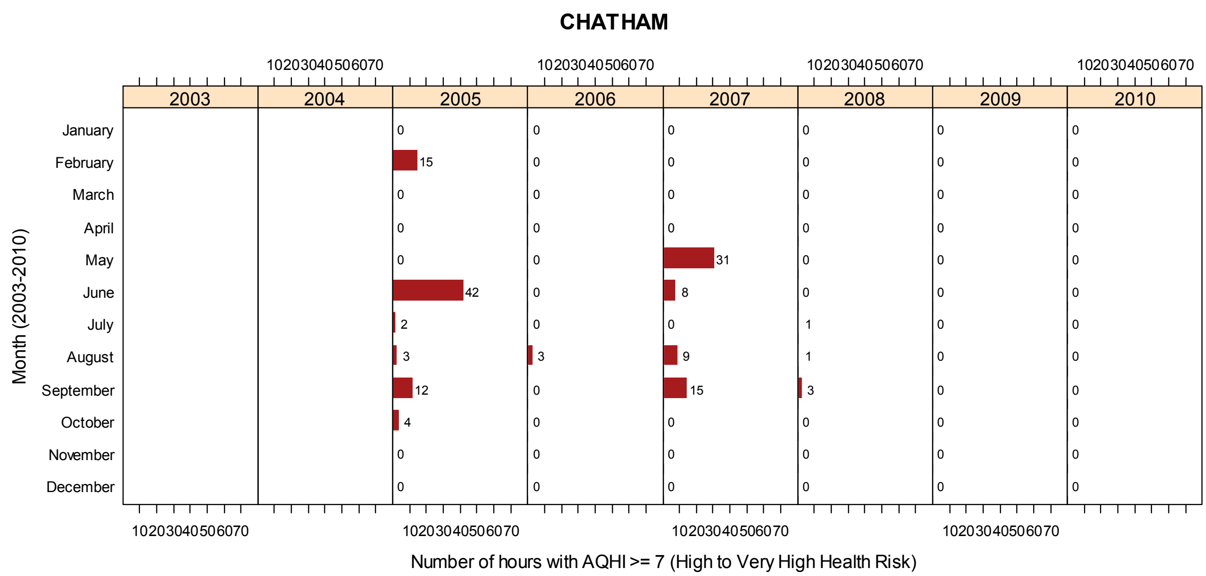
Figure 6. continued





* AQHI was not available in April, 2003 in Burlington, Ontario as indicated by blank space

Figure 6. continued



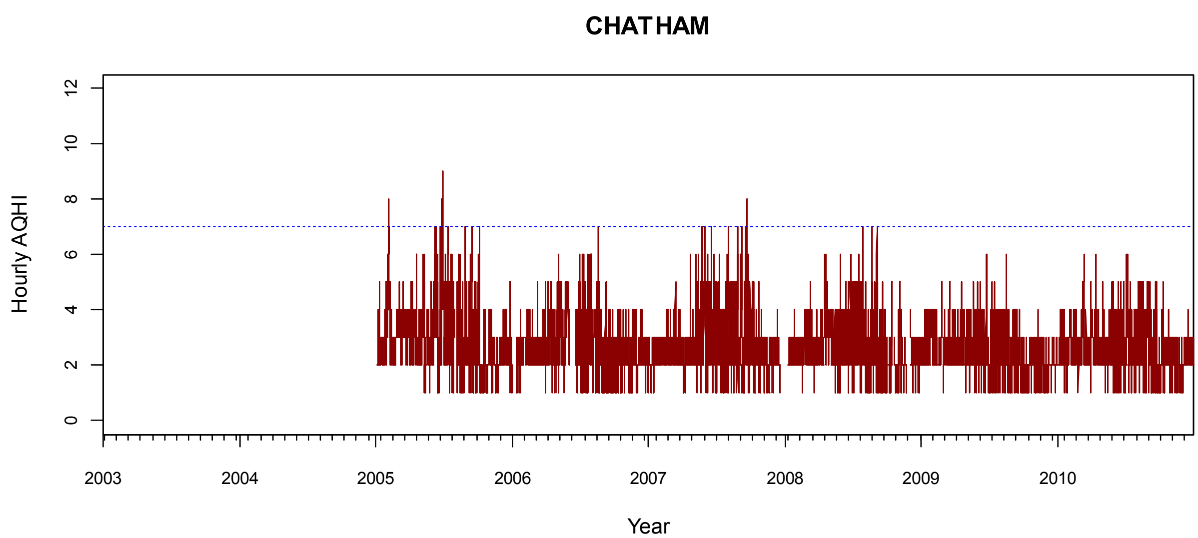
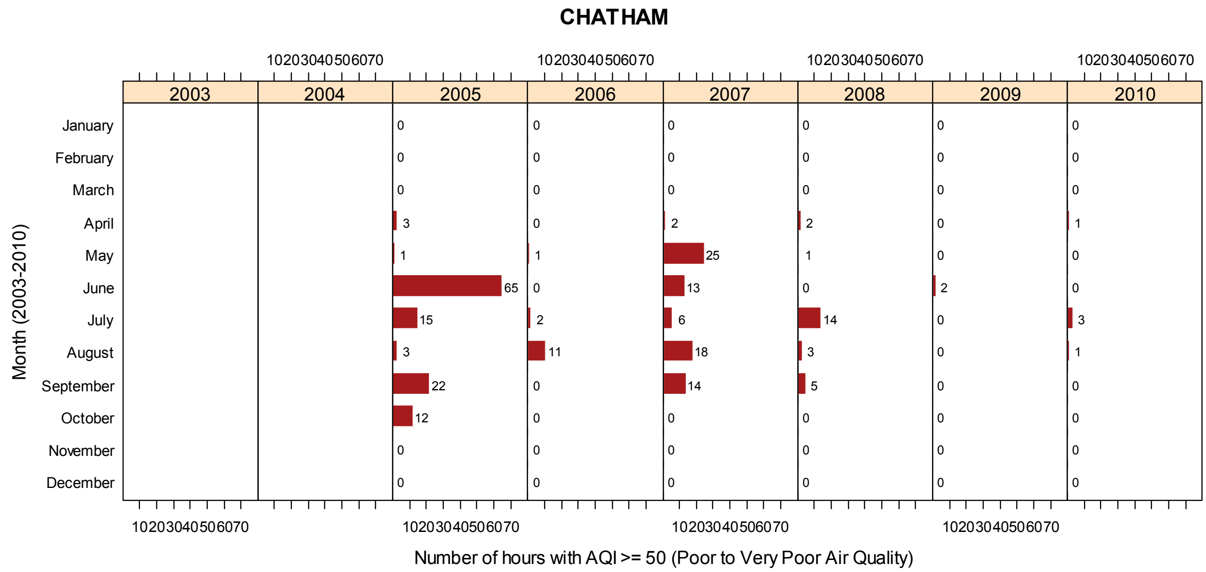
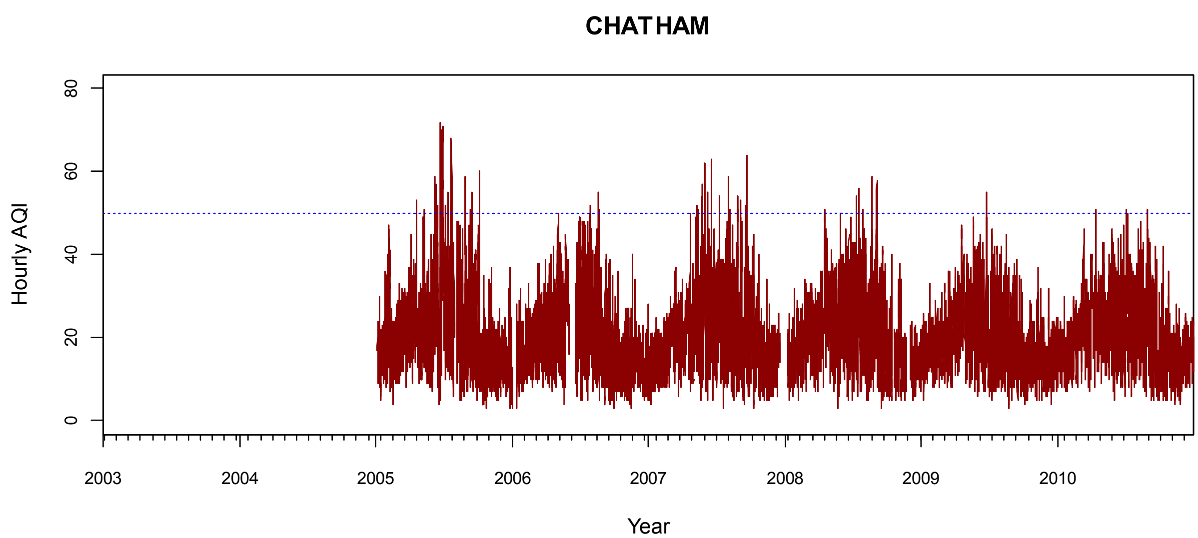


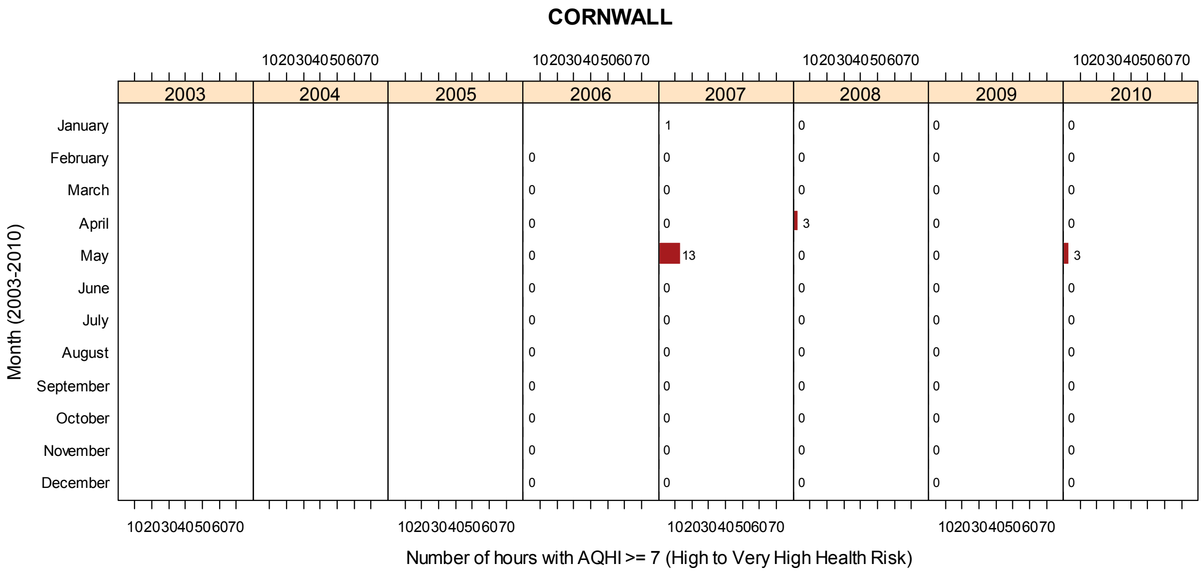
Figure 6. continued





* AQHI was not available from 2003 to 2004 in Chatham, Ontario as indicated by blank space

Figure 6. continued



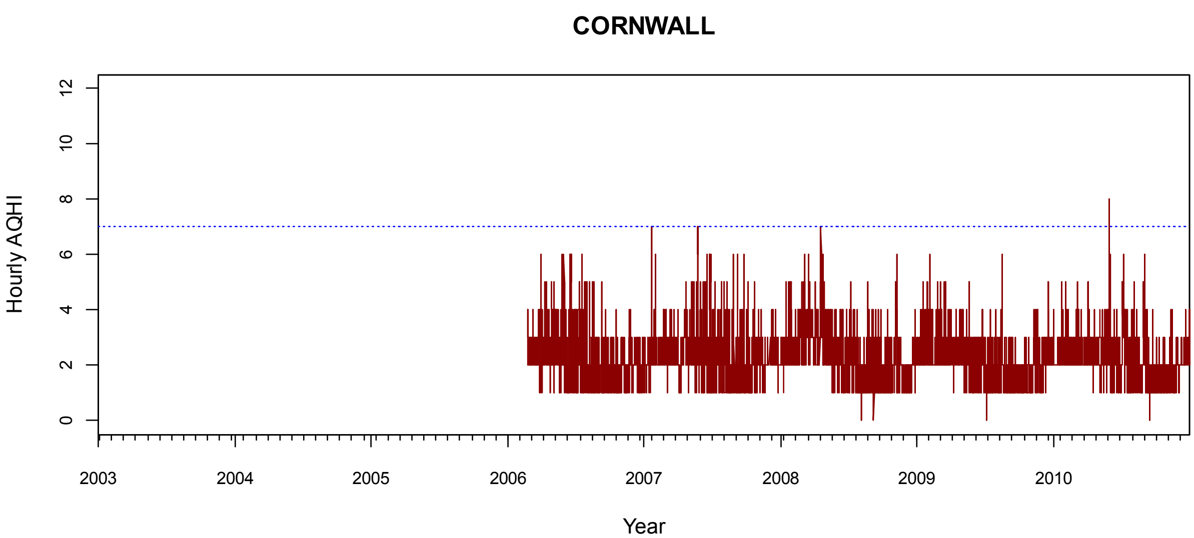
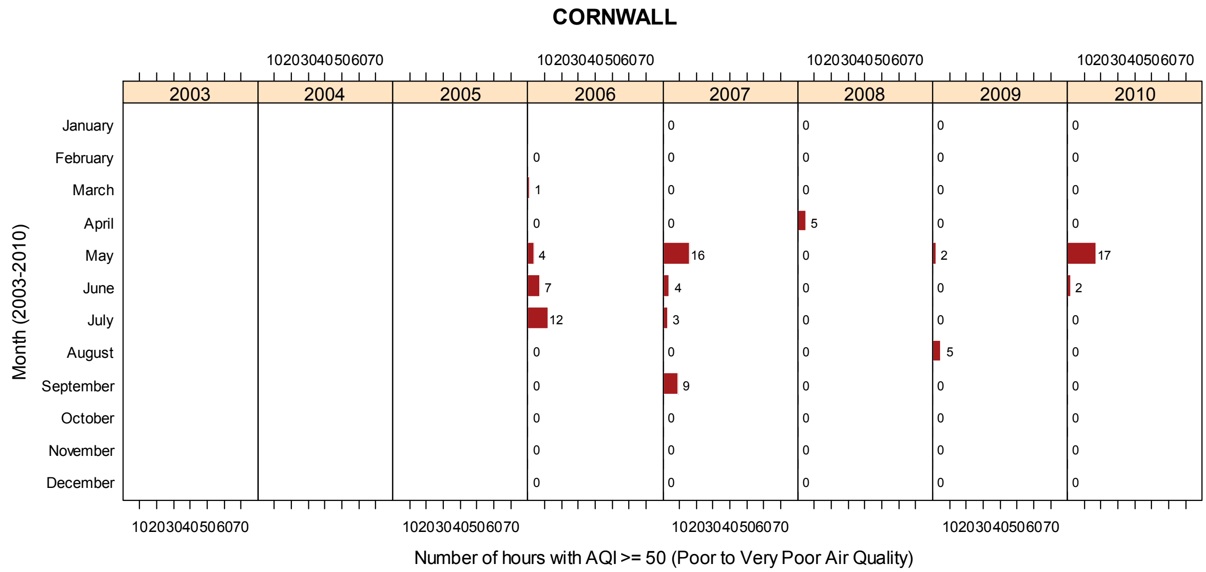
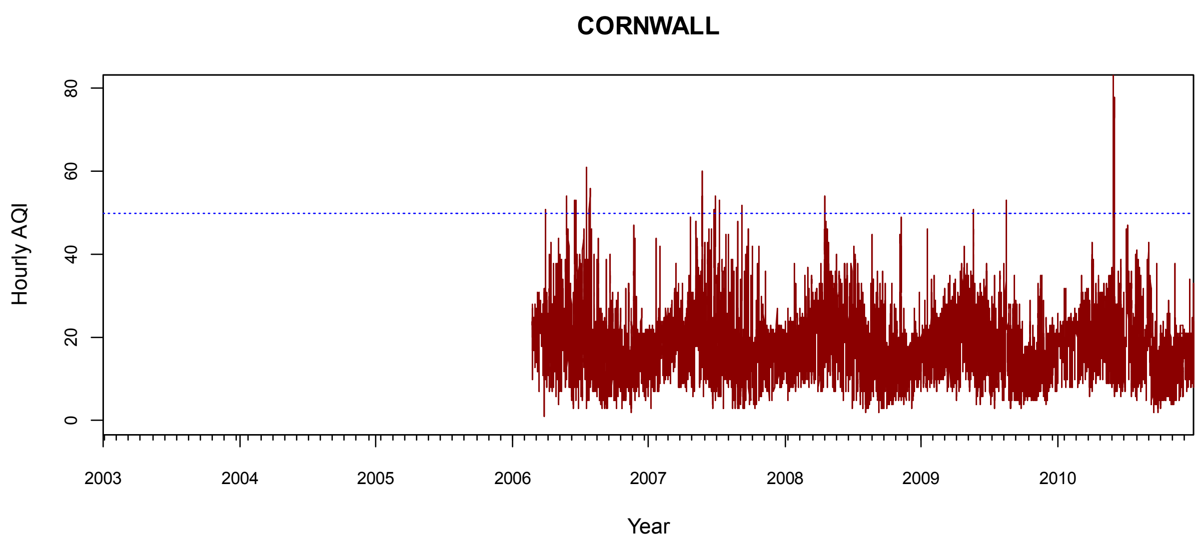


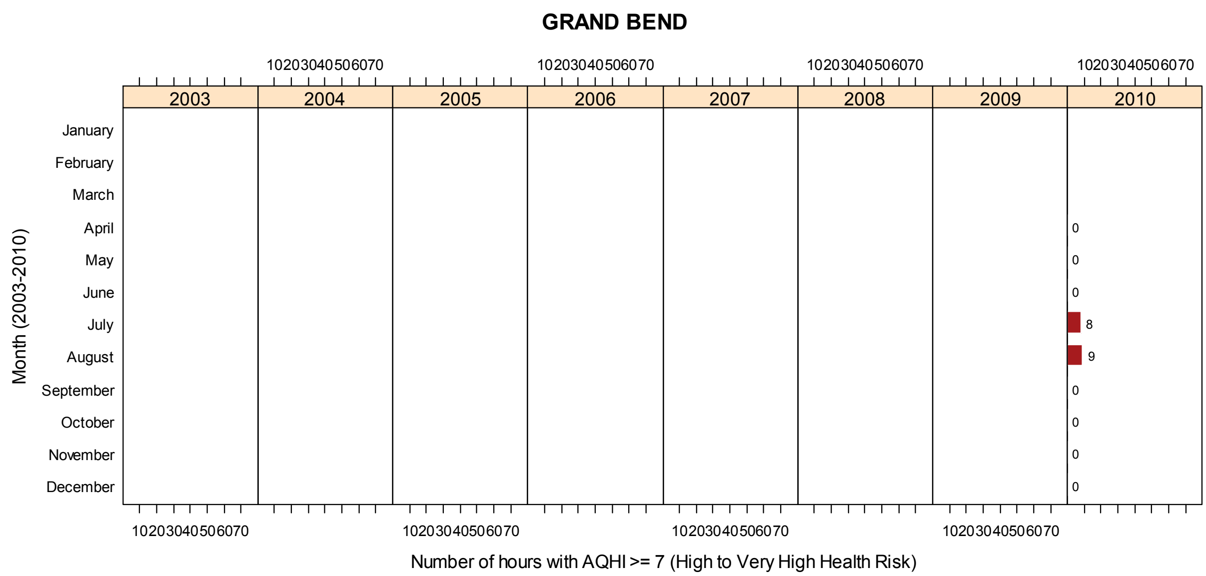
Figure 6. continued





* AQHI was not available from 2003 to January, 2006 in Cornwall, Ontario as indicated by blank space

Figure 6. continued



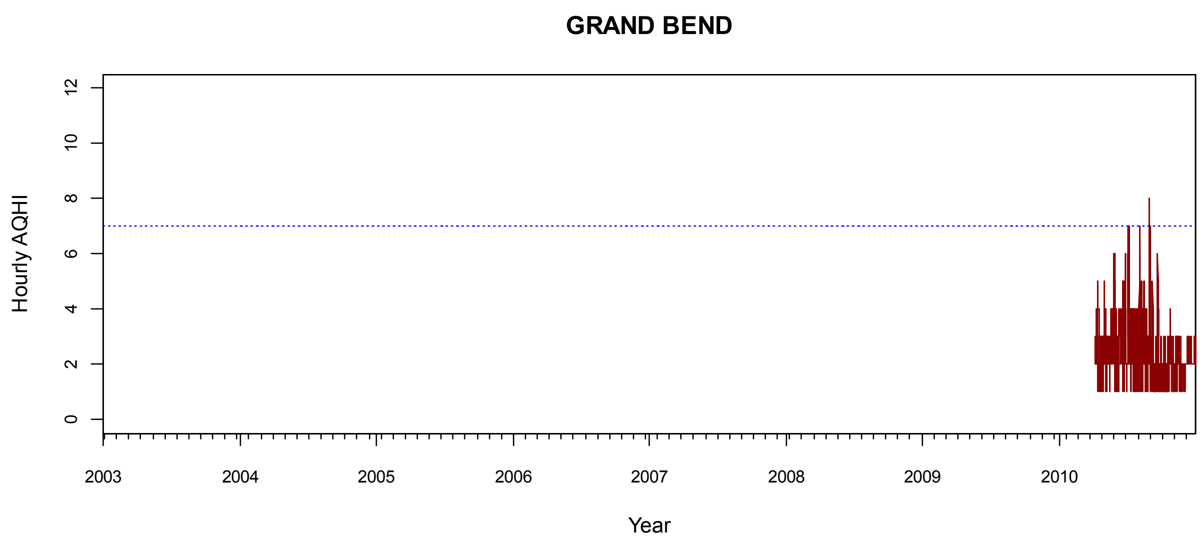
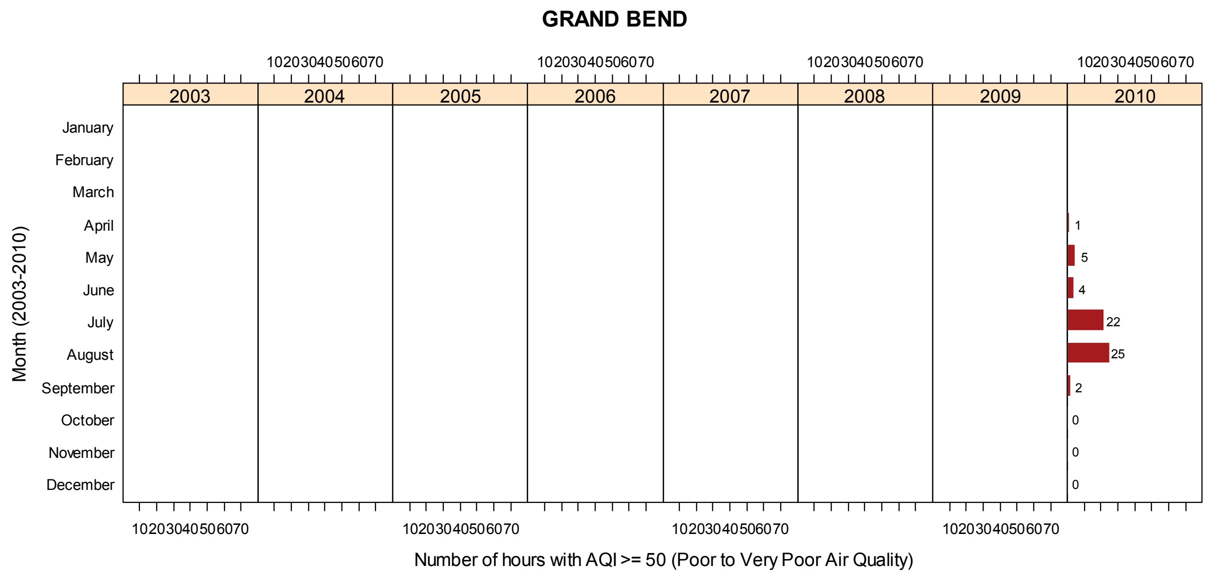
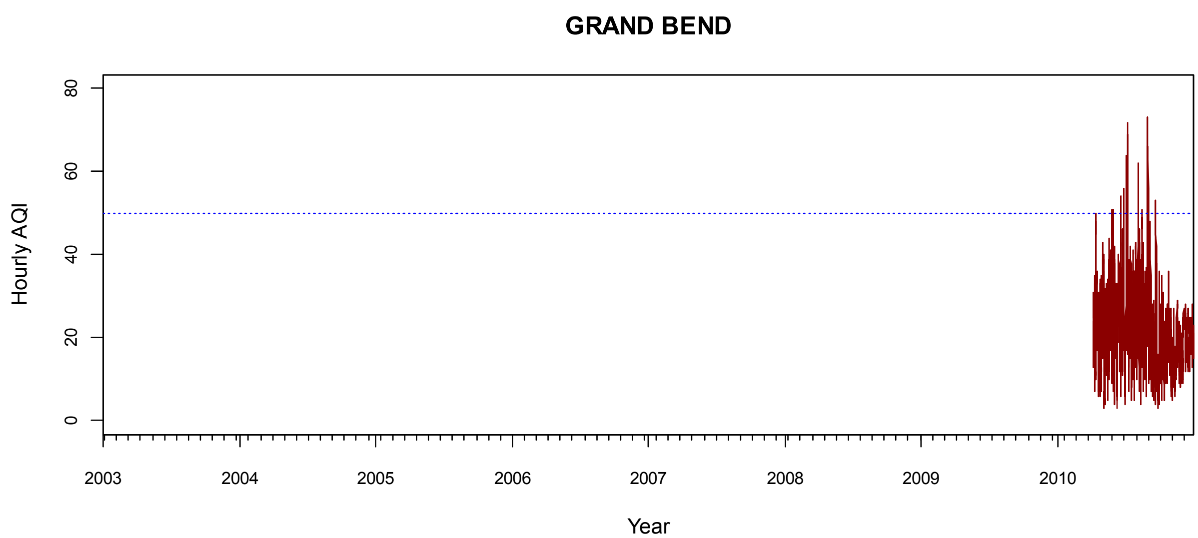


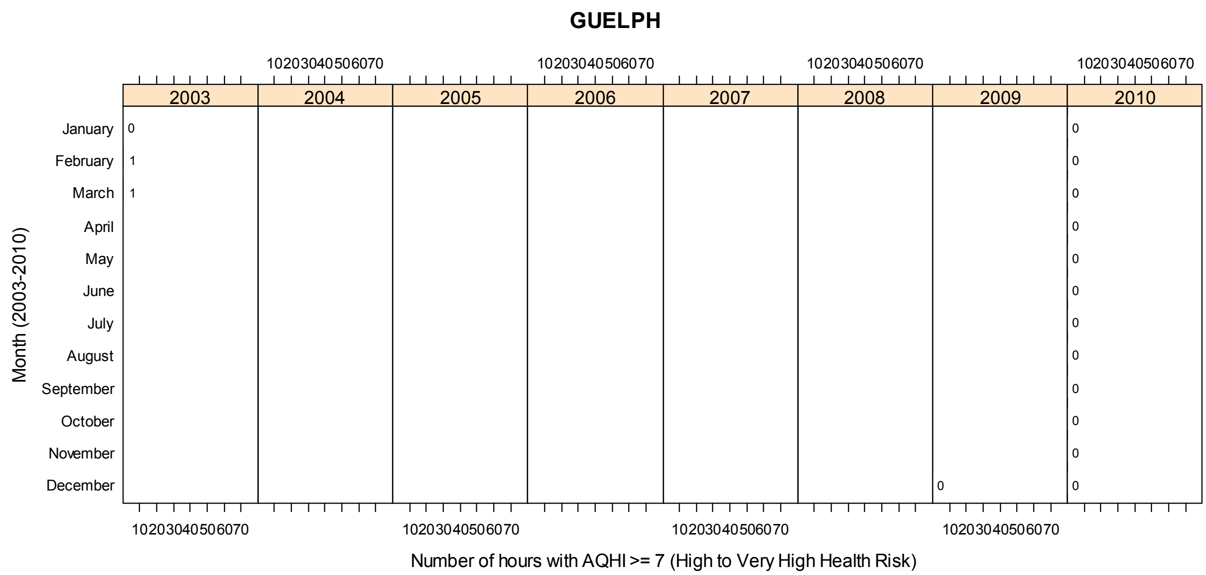
Figure 6. continued





* AQHI was not available from January, 2003 to March, 2010 in Grand Bend, Ontario as indicated by blank space

Figure 6. continued



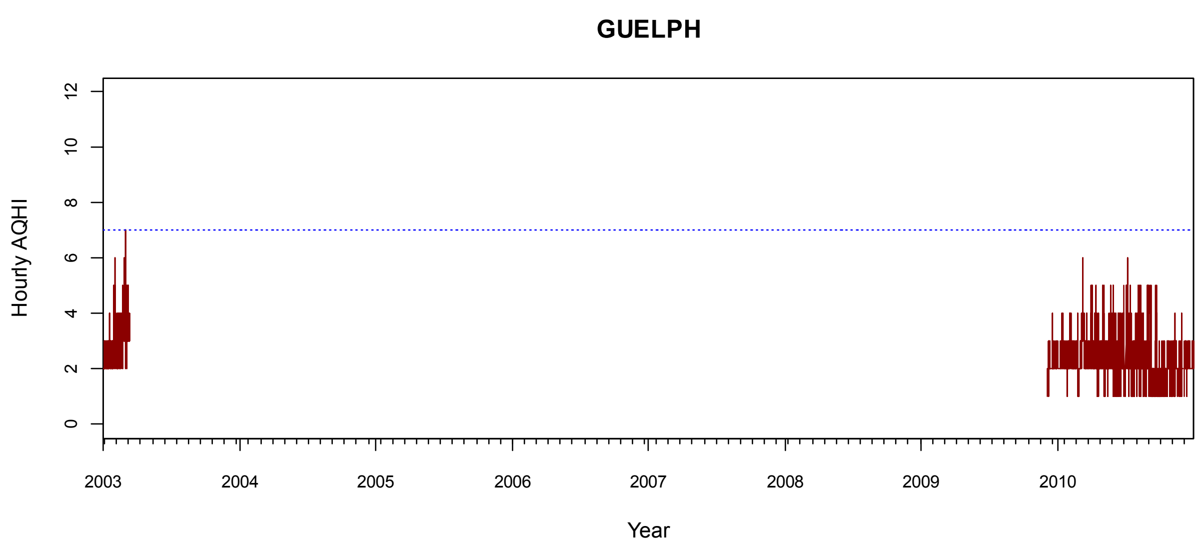
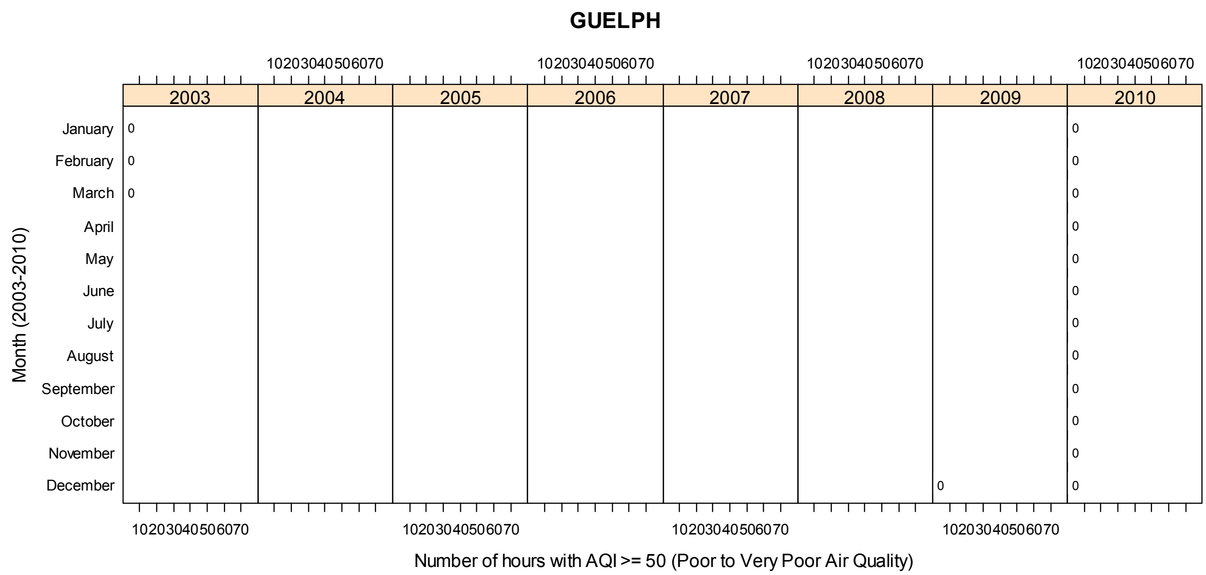
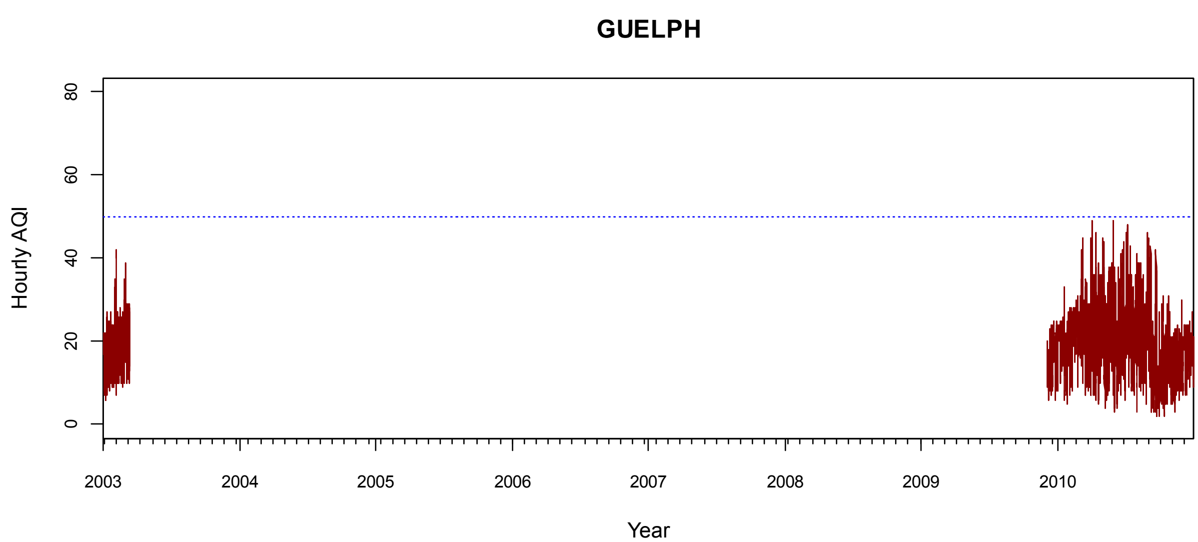


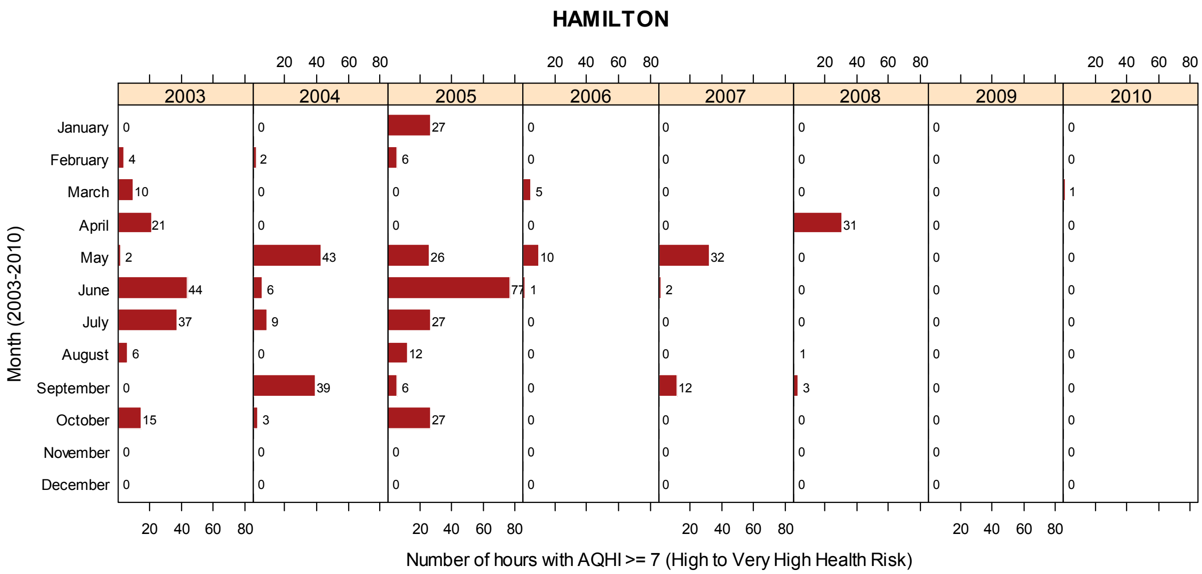
Figure 6. continued





* AQHI was not available from April, 2003 to November, 2009 in Guelph, Ontario as indicated by blank space

Figure 6. continued



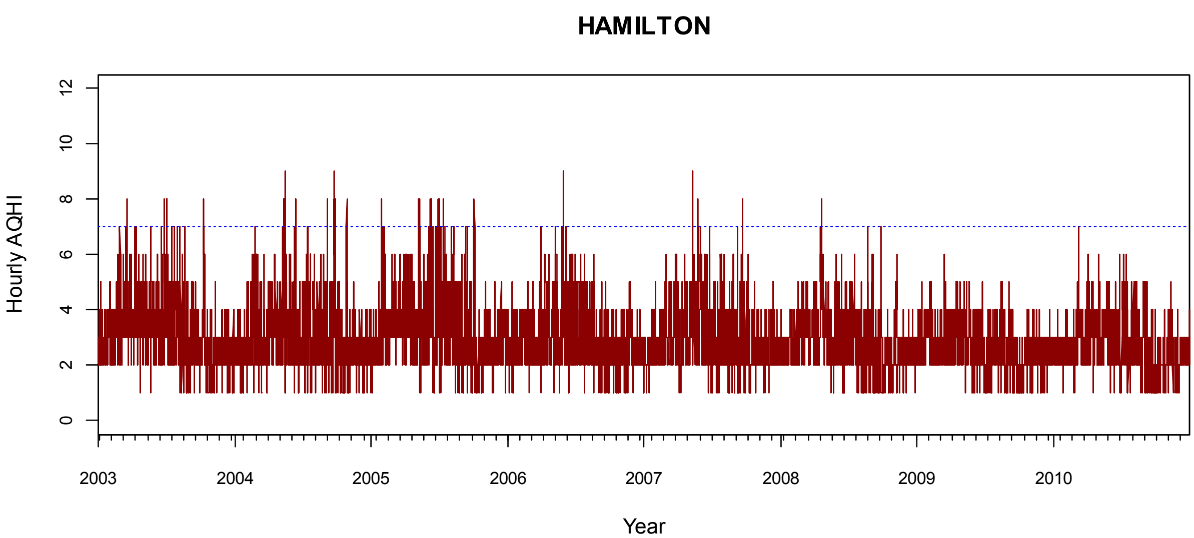
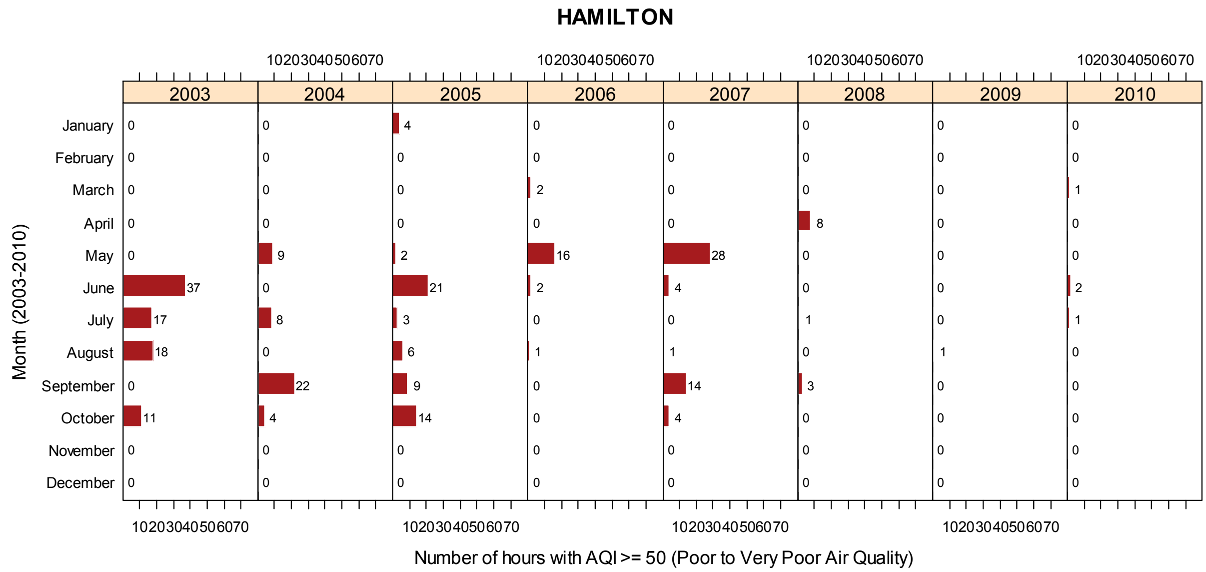


Figure 6. continued



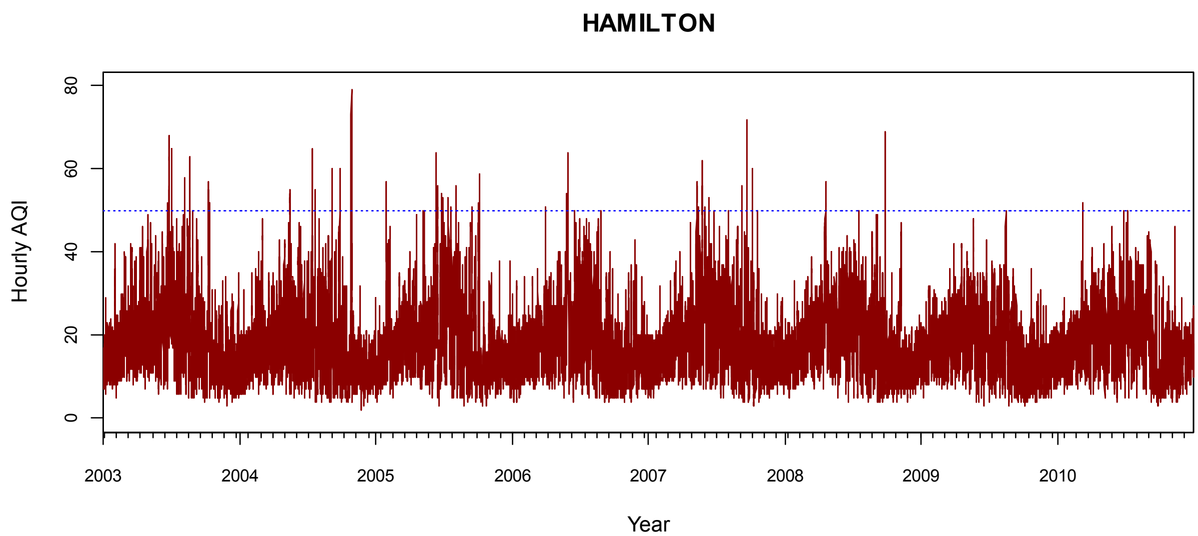
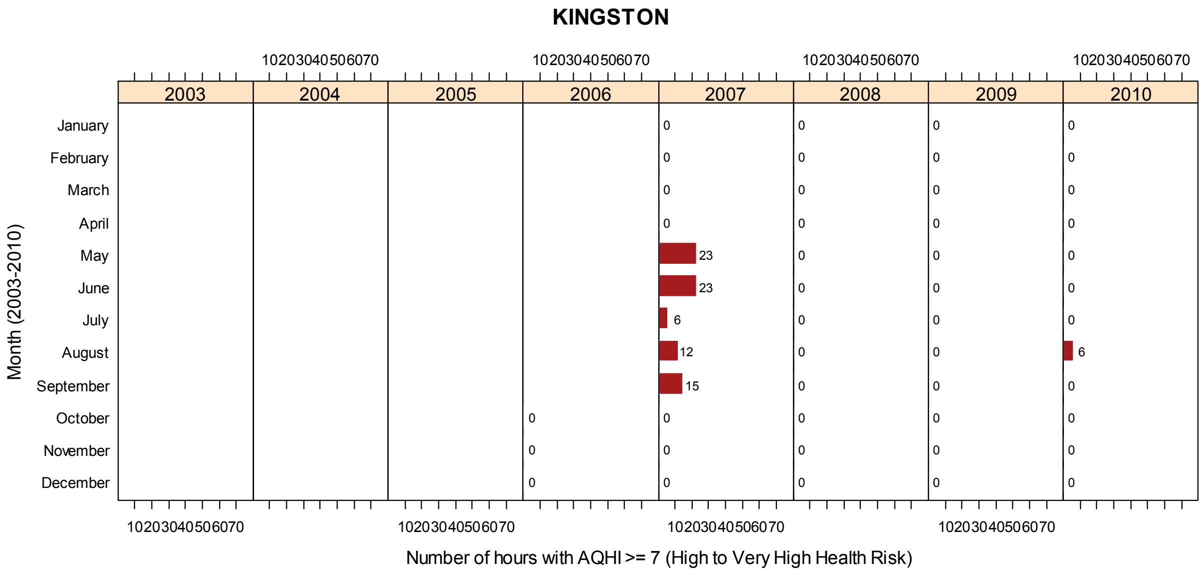


Figure 6. continued



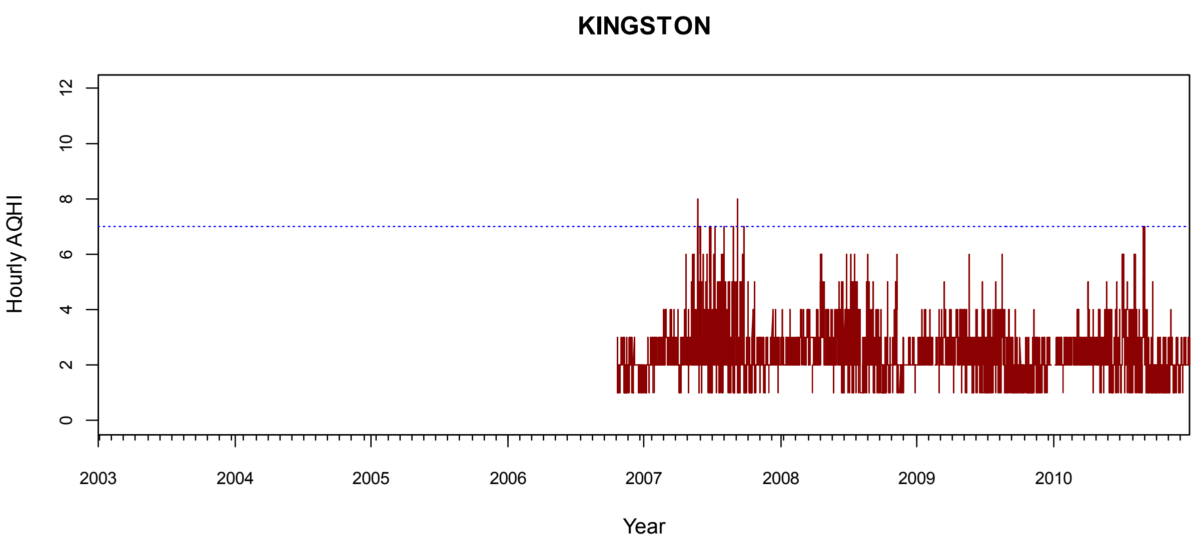
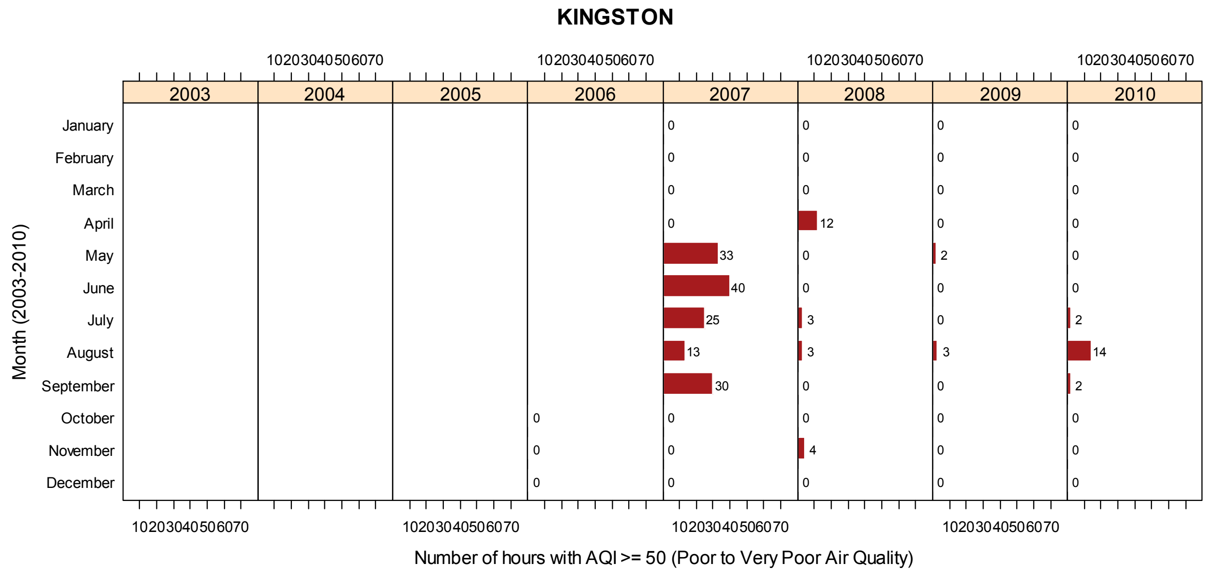
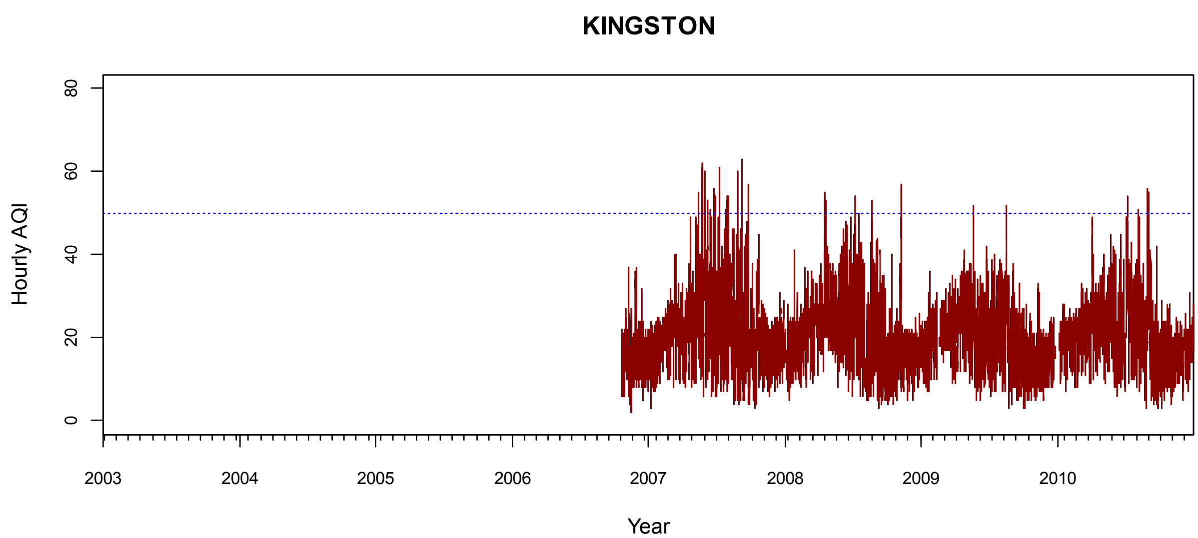


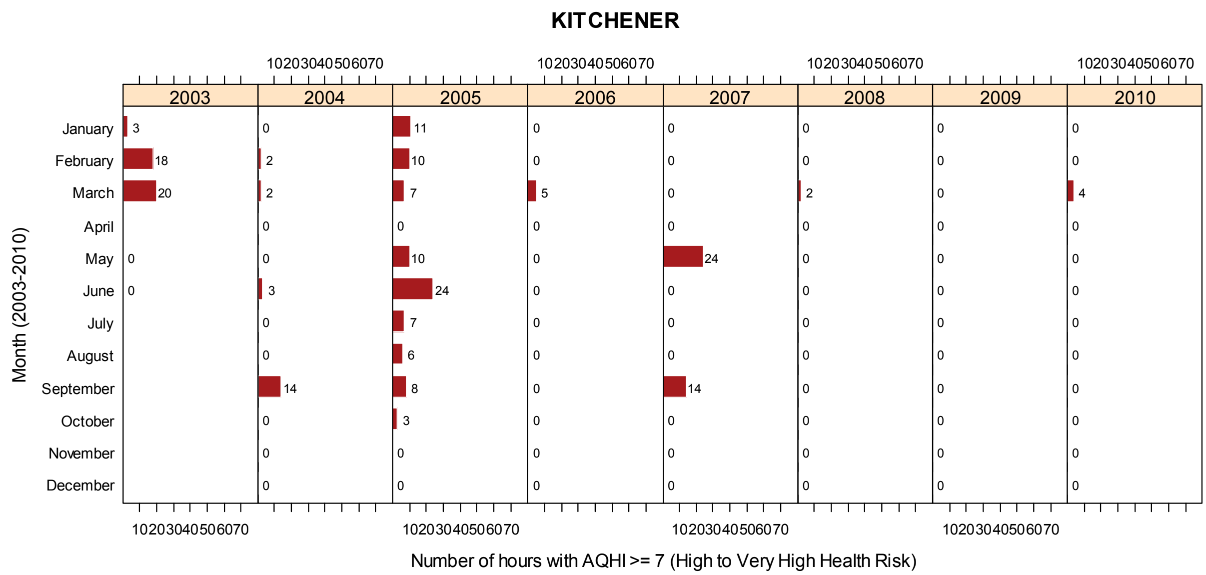
Figure 6. continued





* AQHI was not available from January, 2003 to September, 2006 in Kingston, Ontario as indicated by blank space

Figure 6. continued



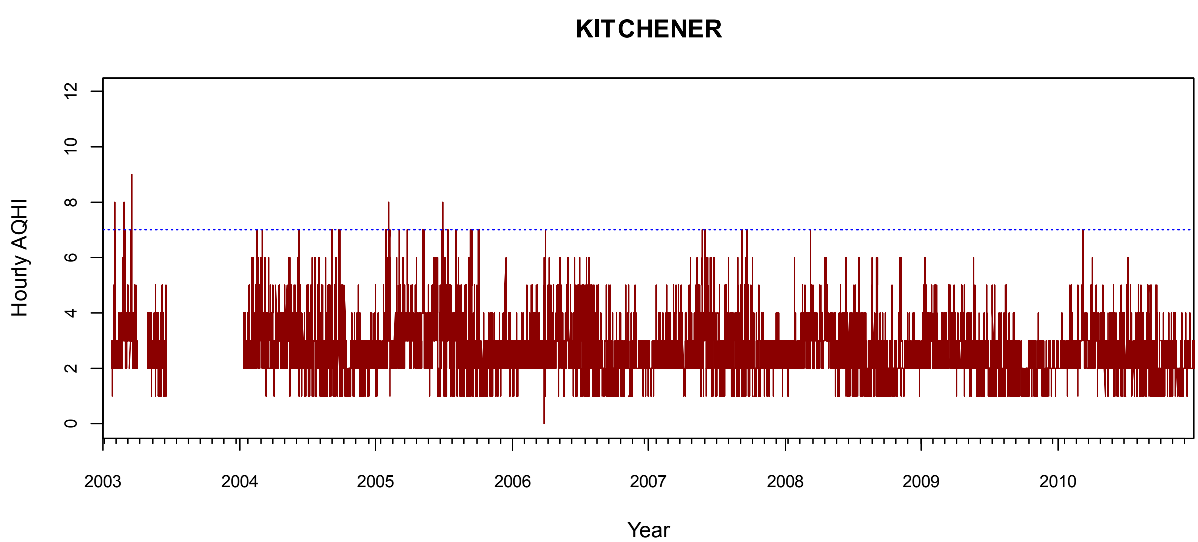
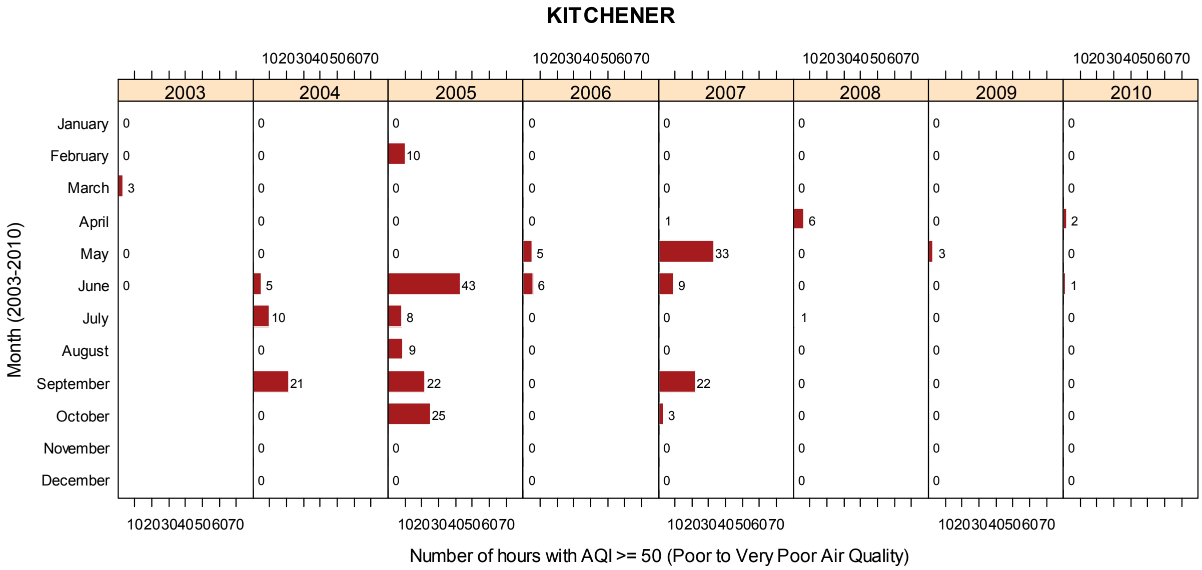
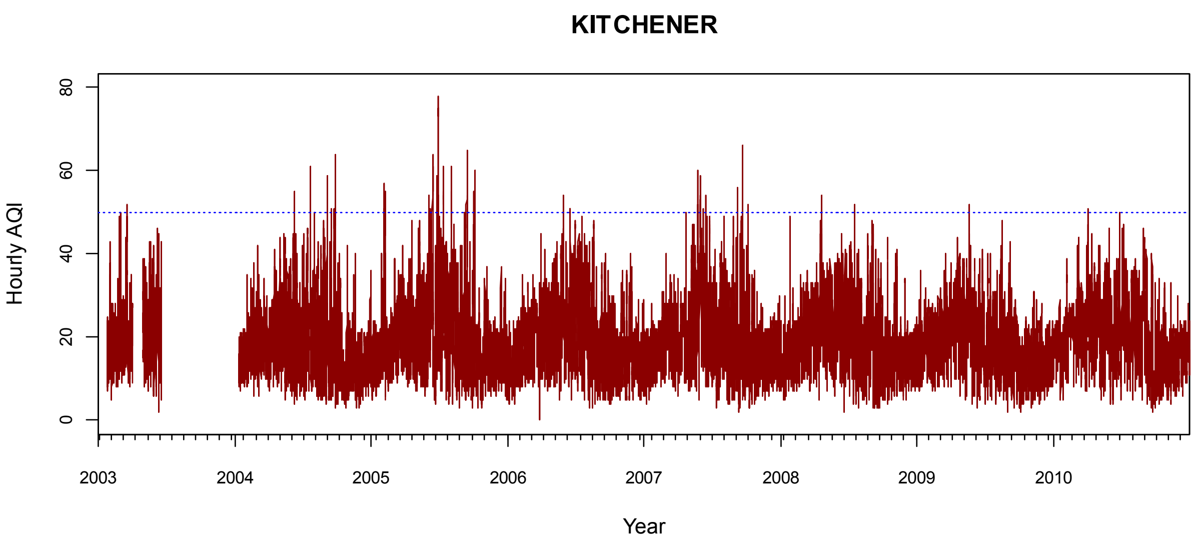


Figure 6. continued





* AQHI was not available in April, 2003 and from July to December, 2003 in Kitchener, Ontario as indicated by blank space

Figure 6. continued

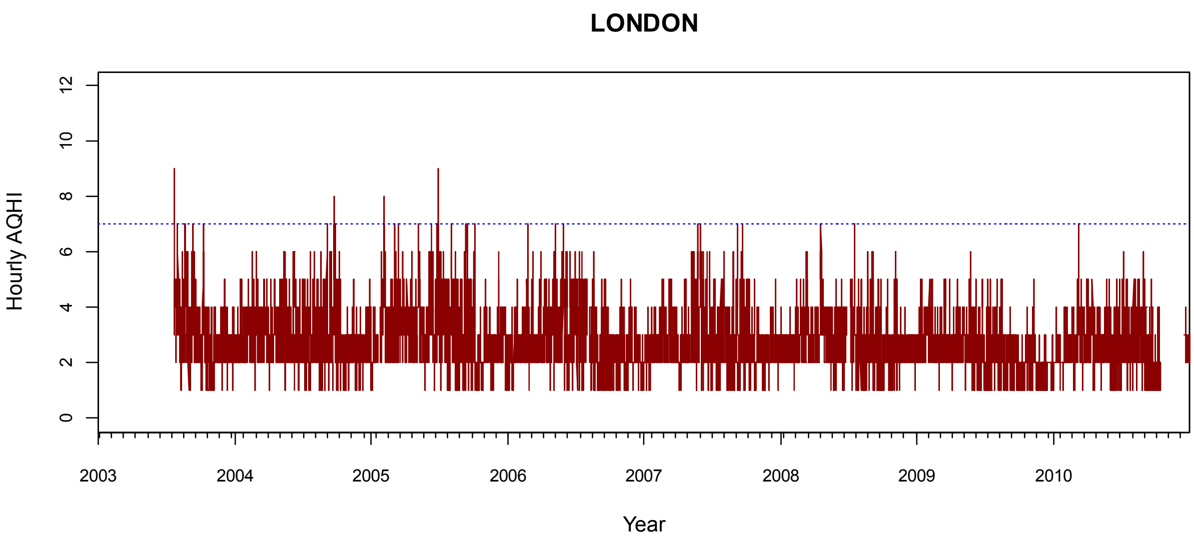
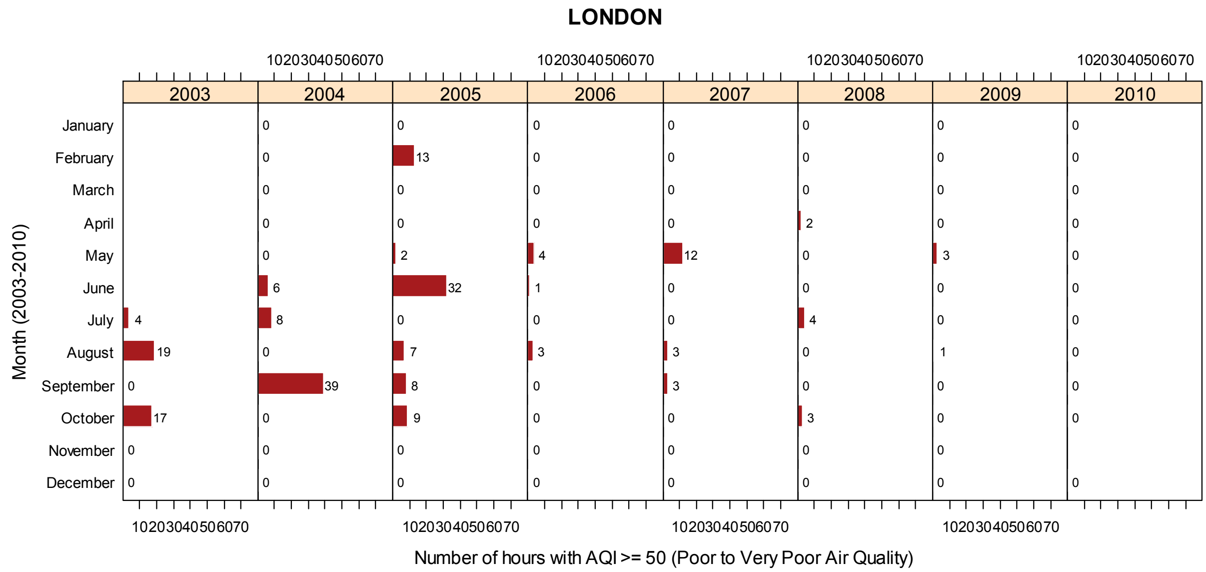
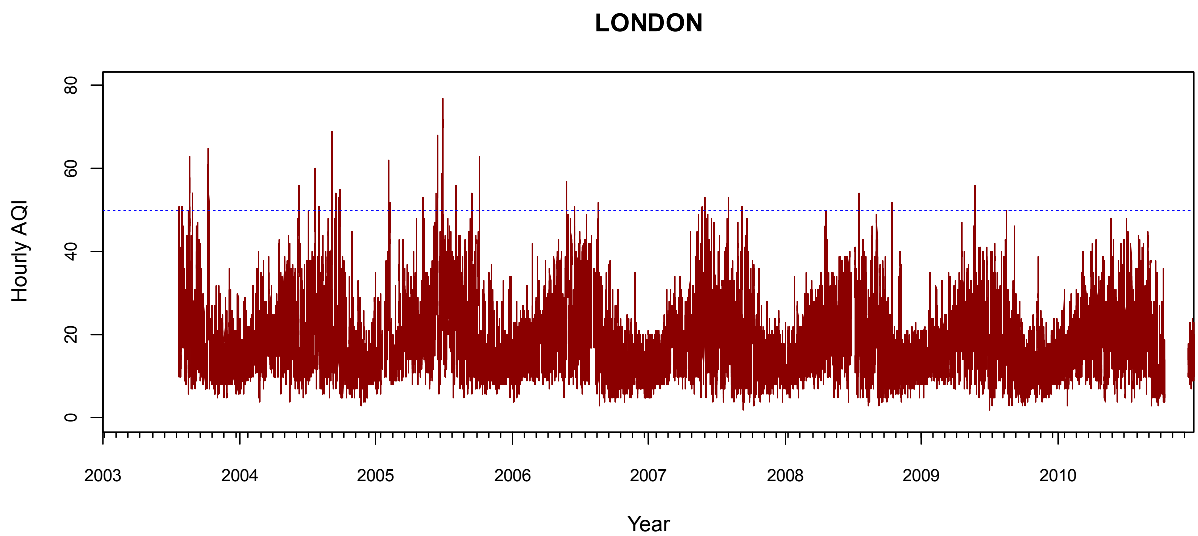


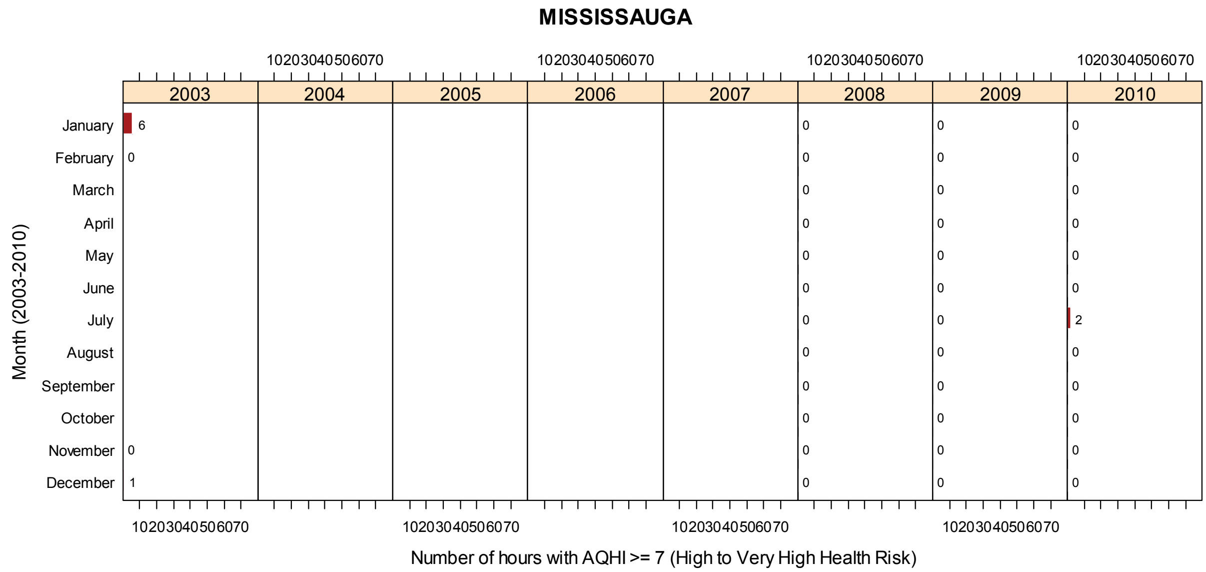
Figure 6. continued





* AQHI was not available from January to June, 2003 and in November, 2010 in London, Ontario as indicated by blank space

Figure 6. continued



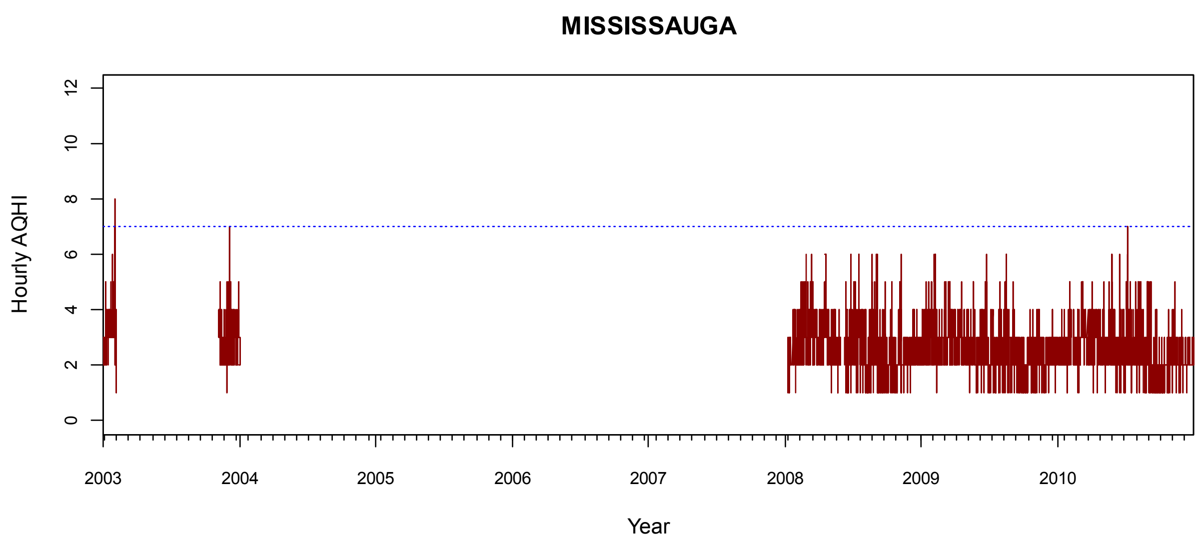
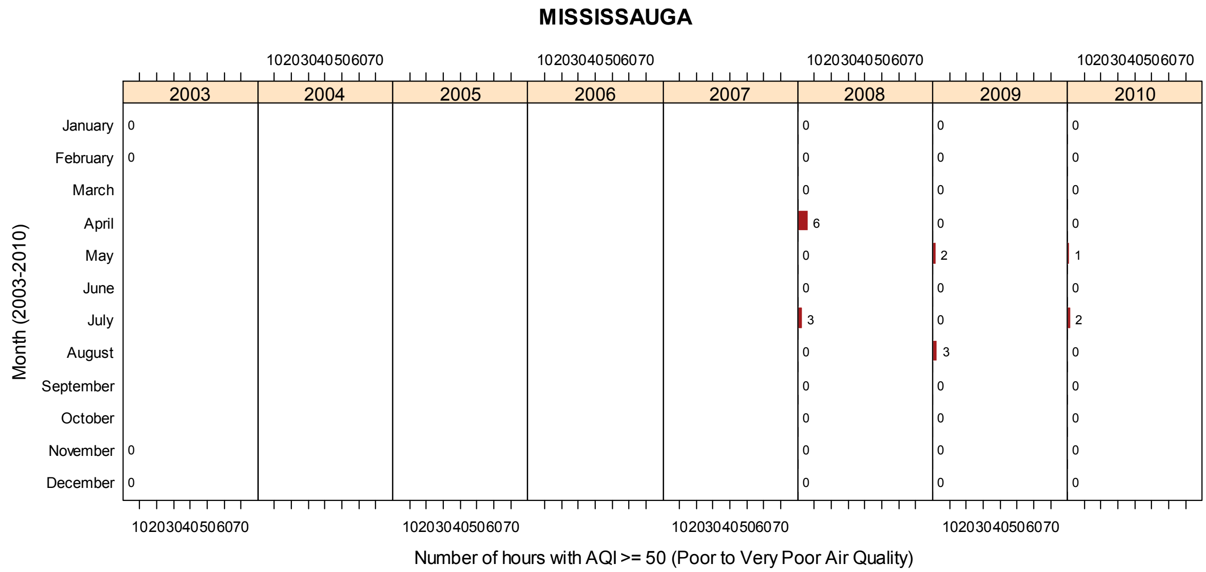
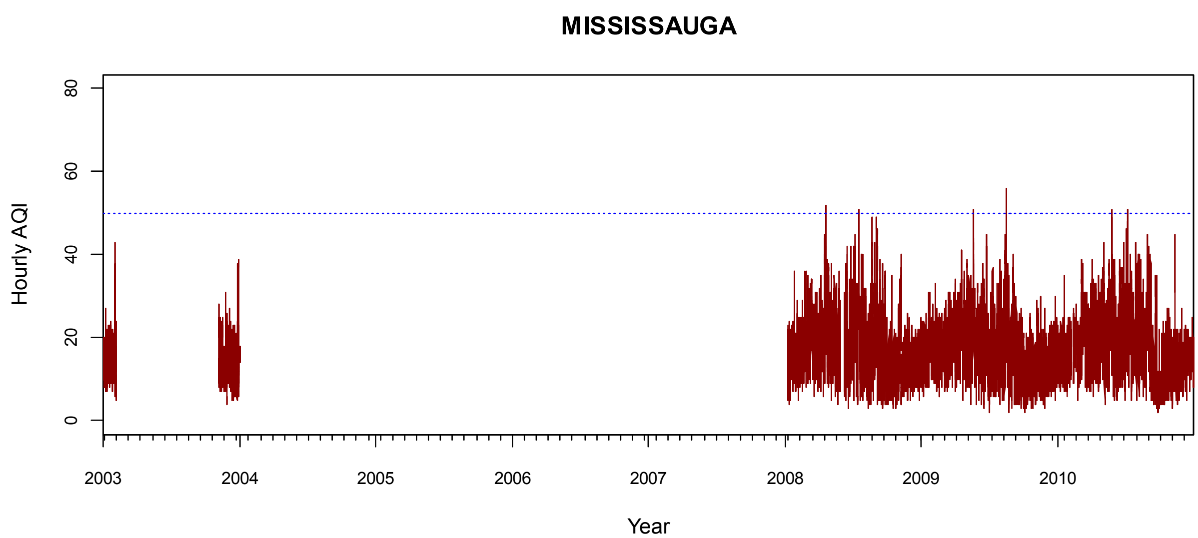


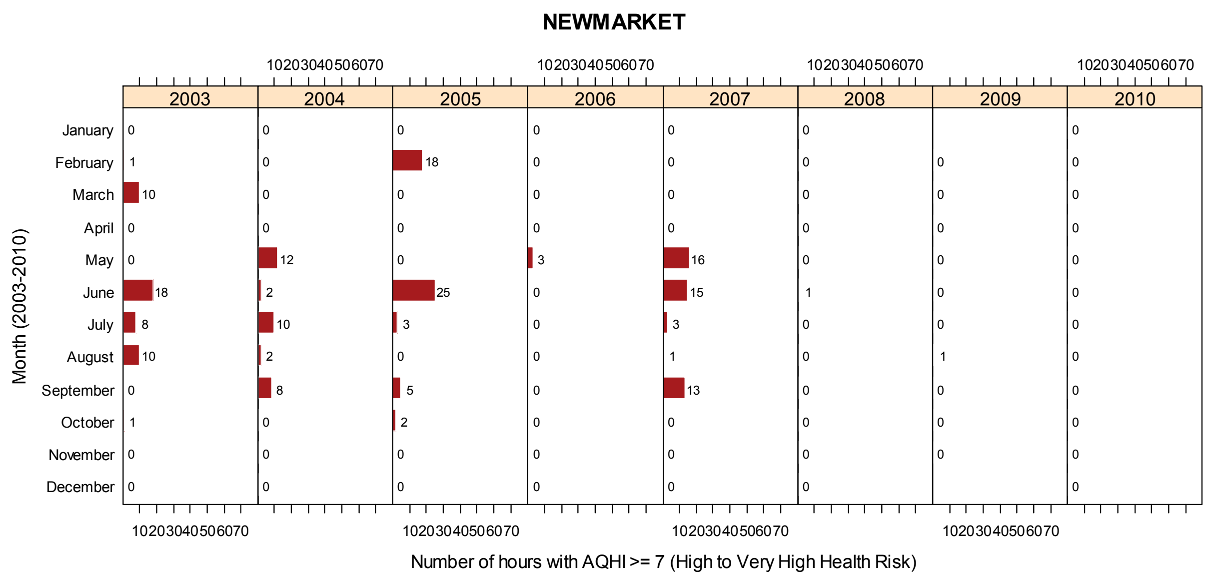
Figure 6. continued





* AQHI was not available from March, 2003 to December, 2007 due to missing NO_2 data in Mississauga, Ontario as indicated by blank space

Figure 6. continued



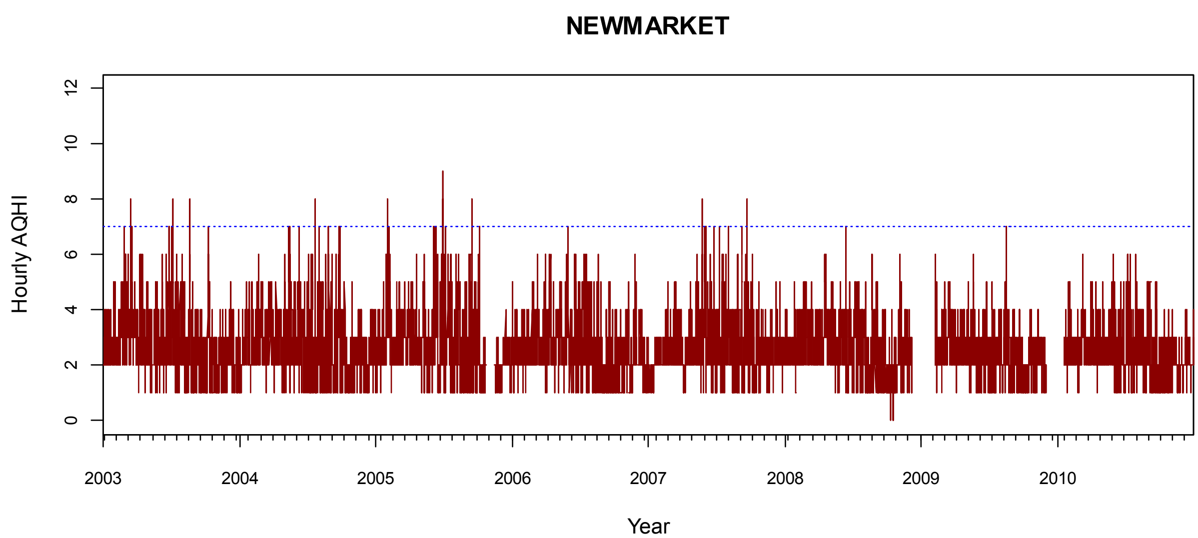
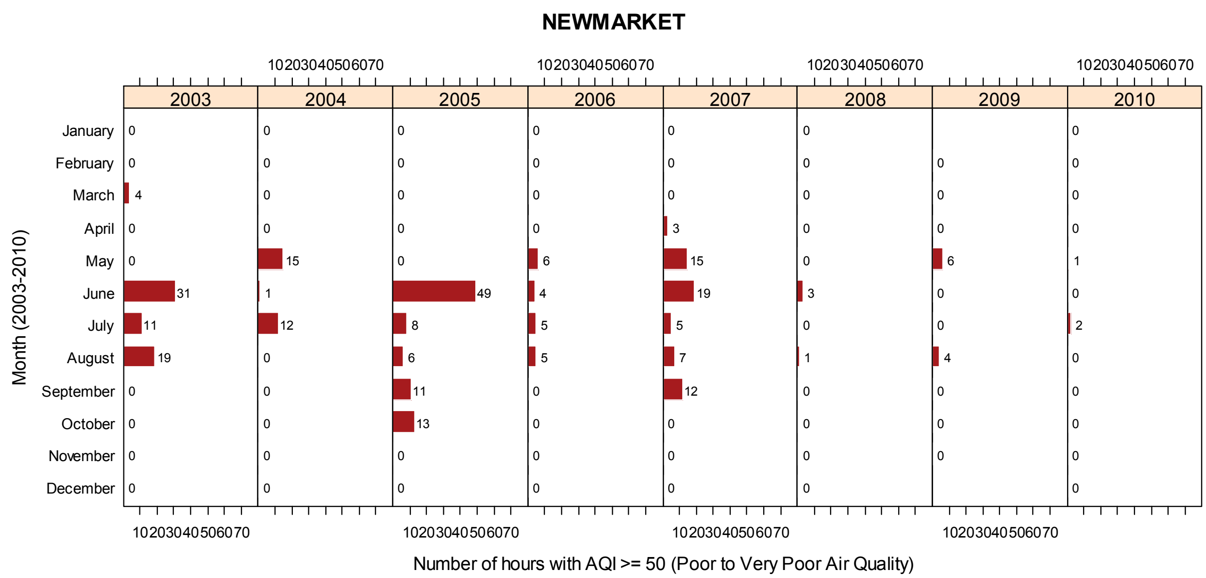
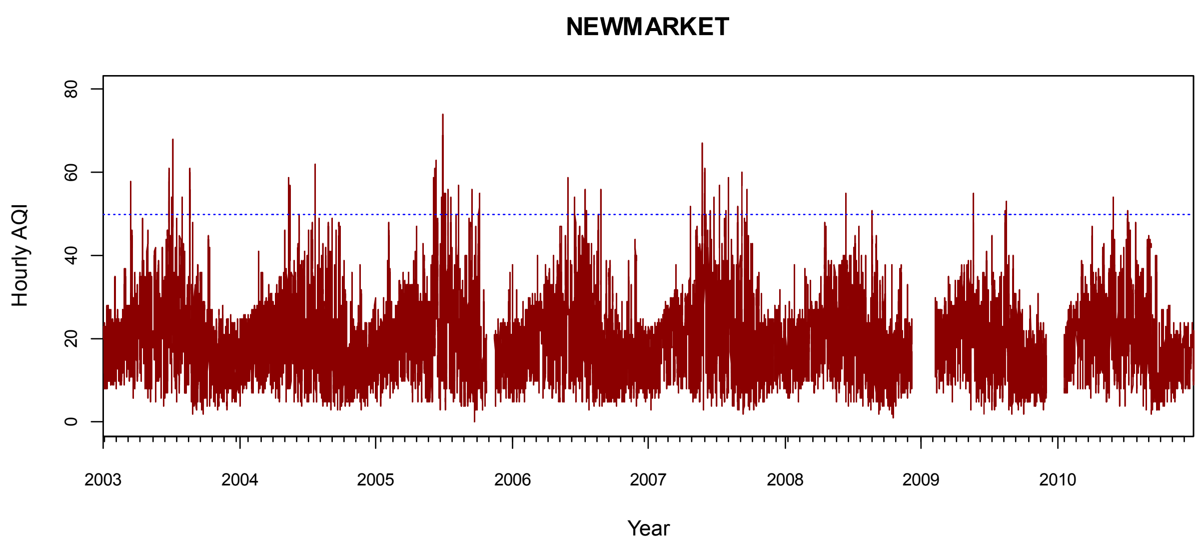


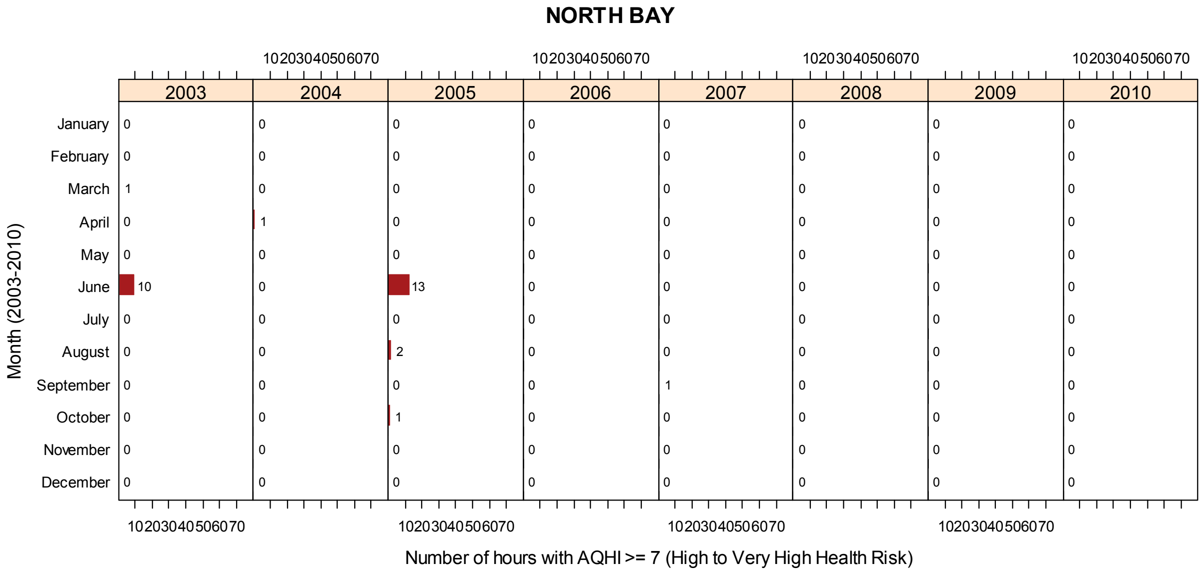
Figure 6. continued





* AQHI was not available in January and December, 2009 in NewMarket, Ontario as indicated by blank space

Figure 6. continued



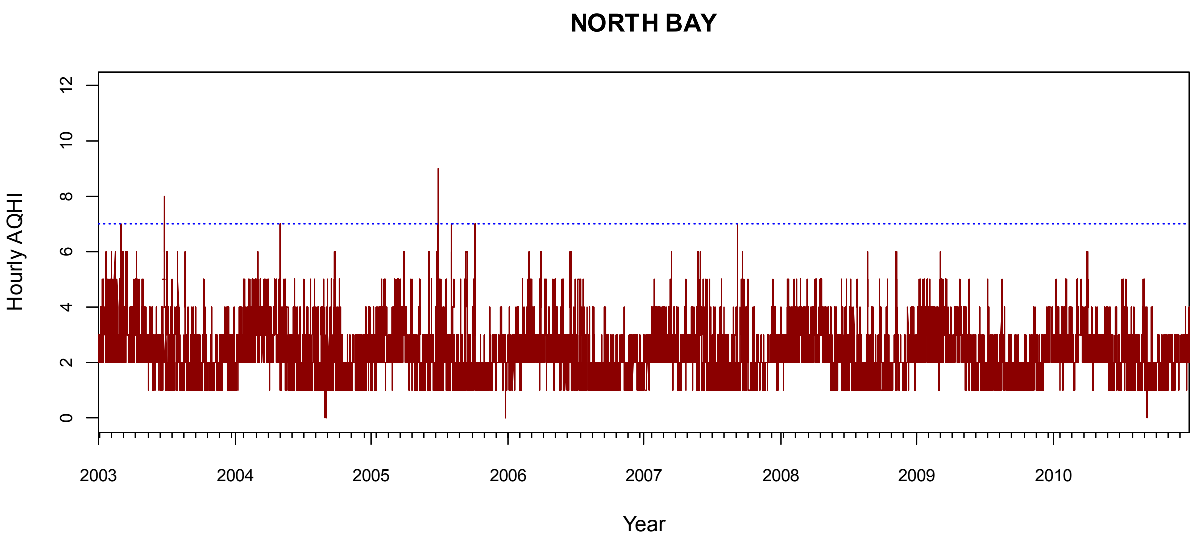
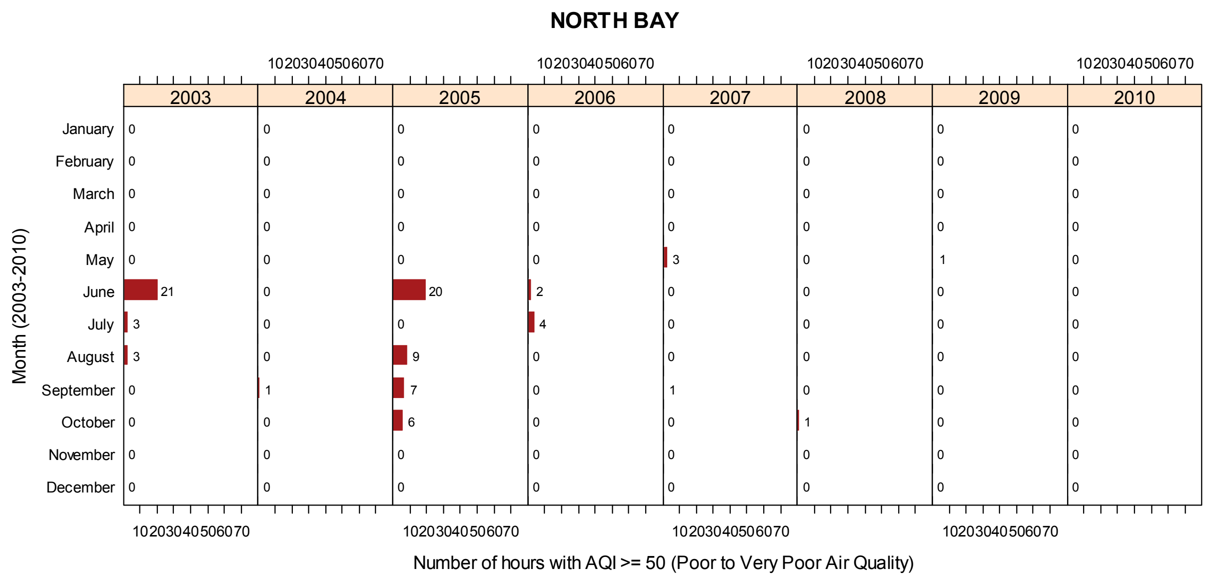
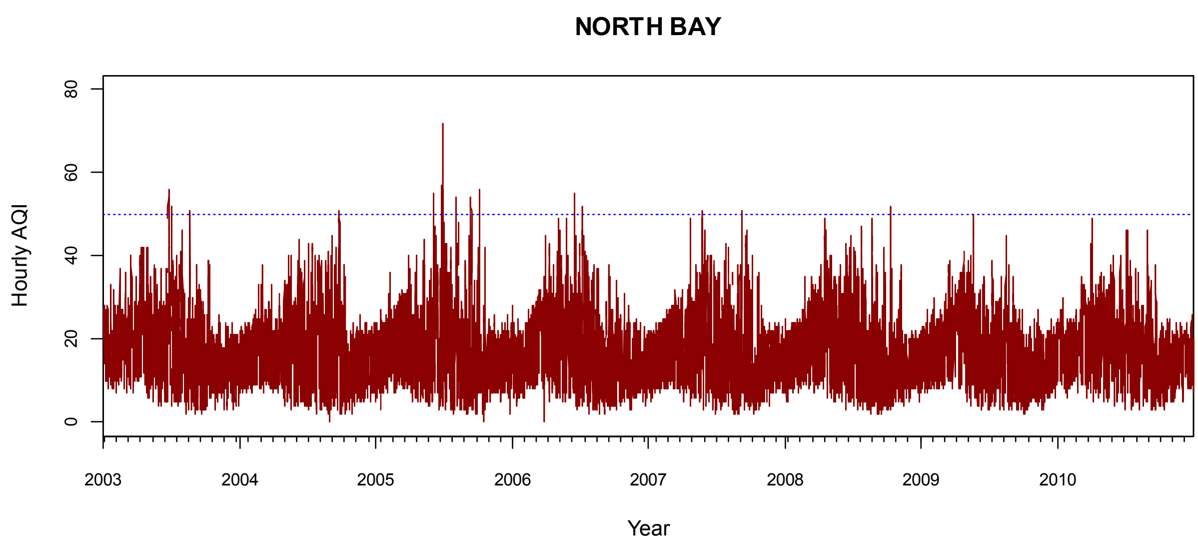


Figure 6. continued





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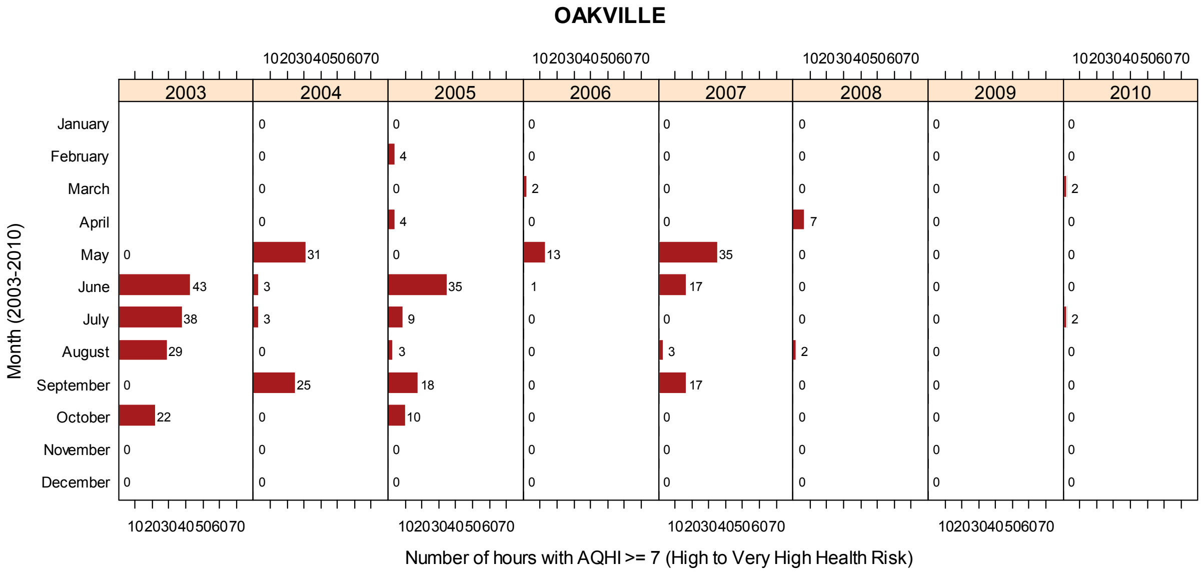

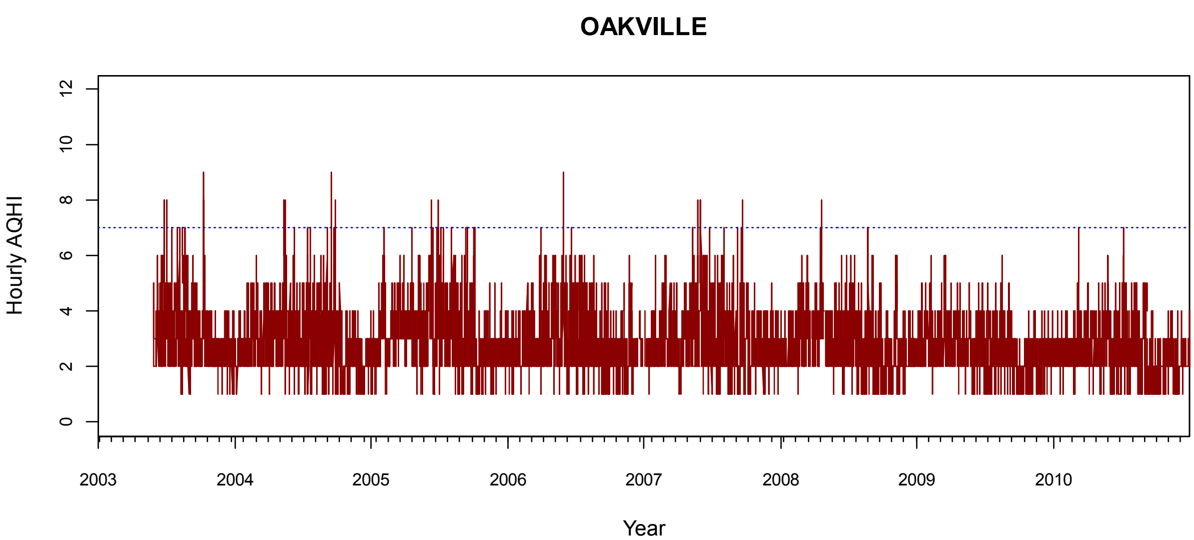

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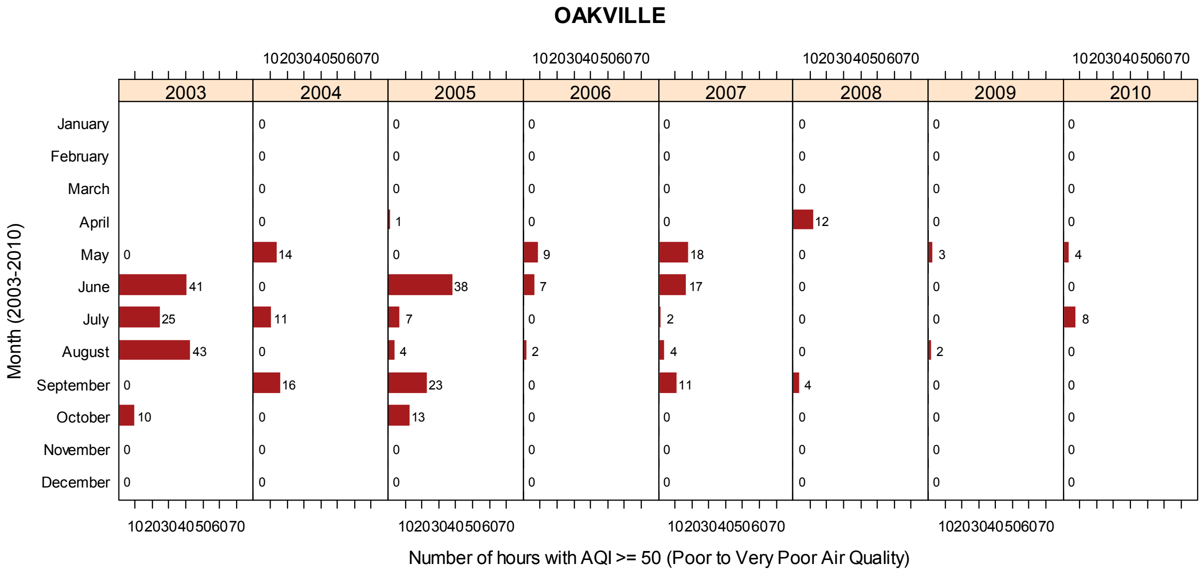
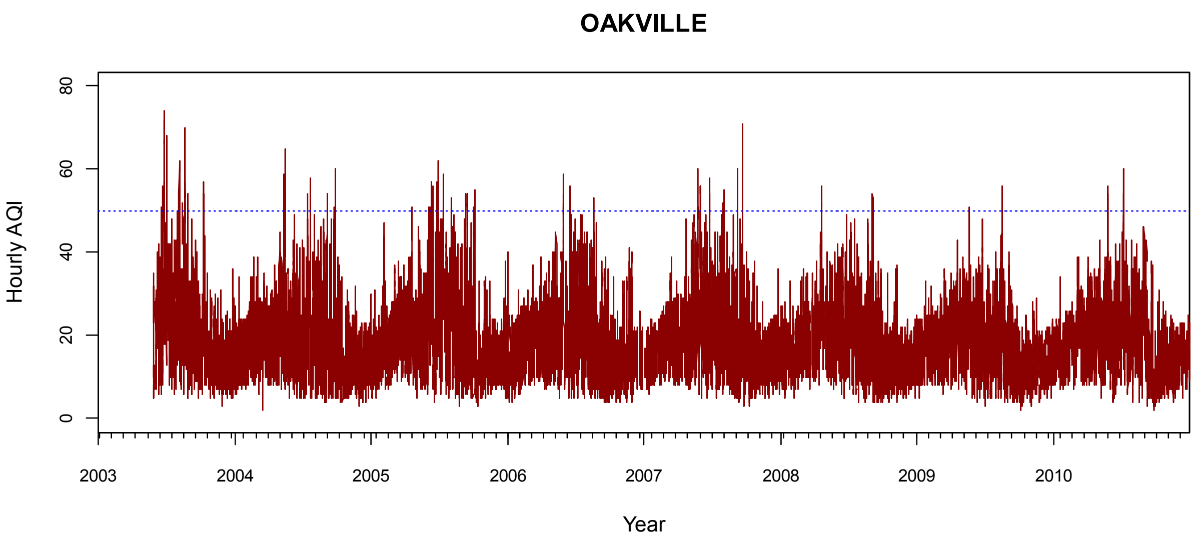
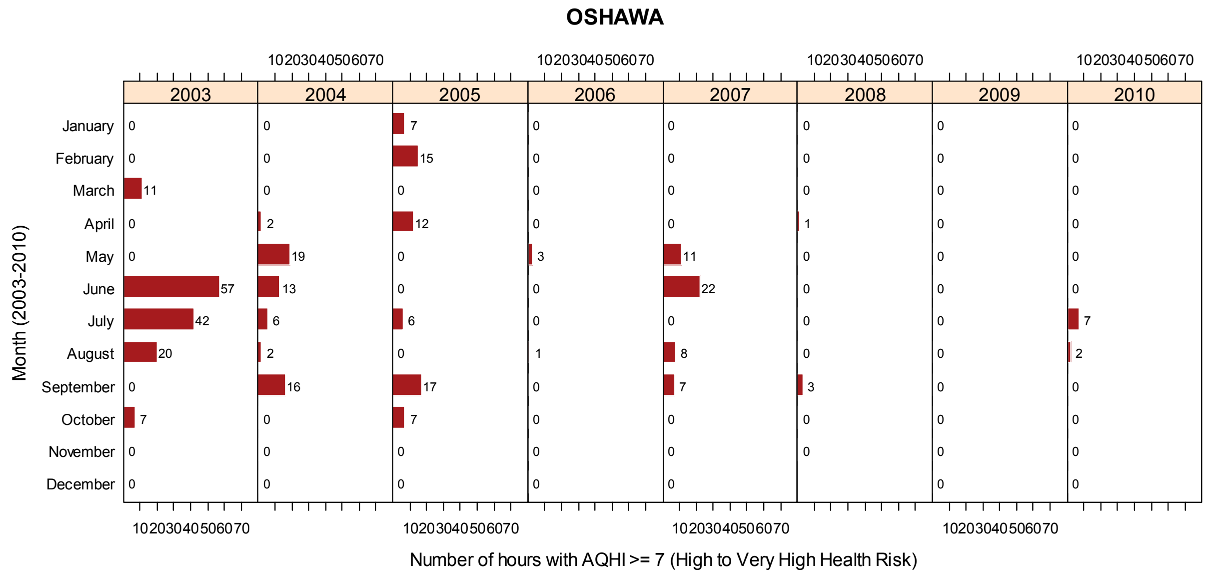
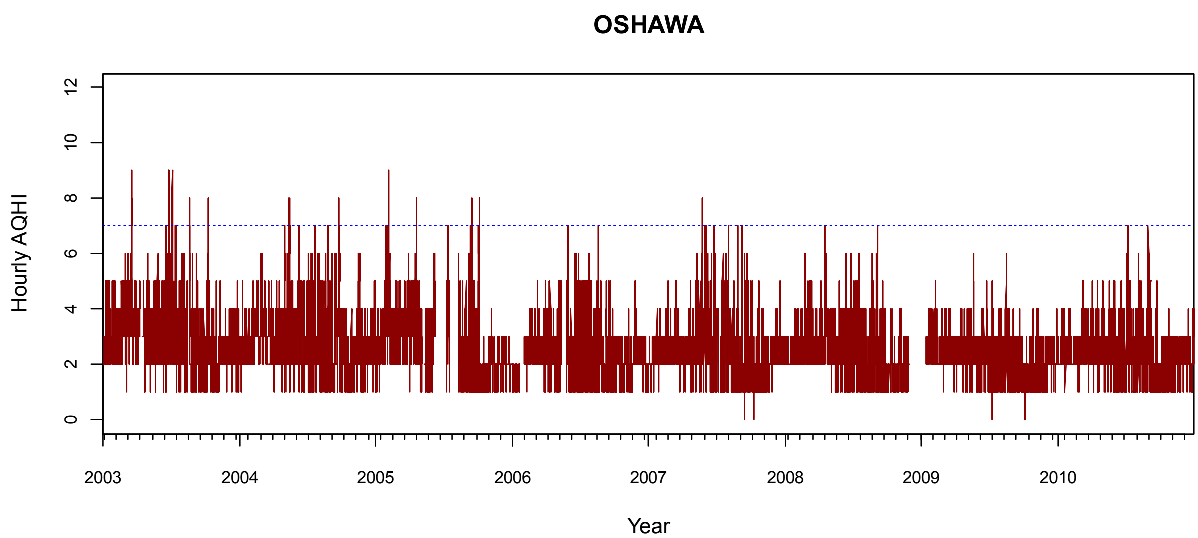




* AQHI was not available from January to April, 2003 in Oakville, Ontario as indicated by blank space

Figure 6. continued





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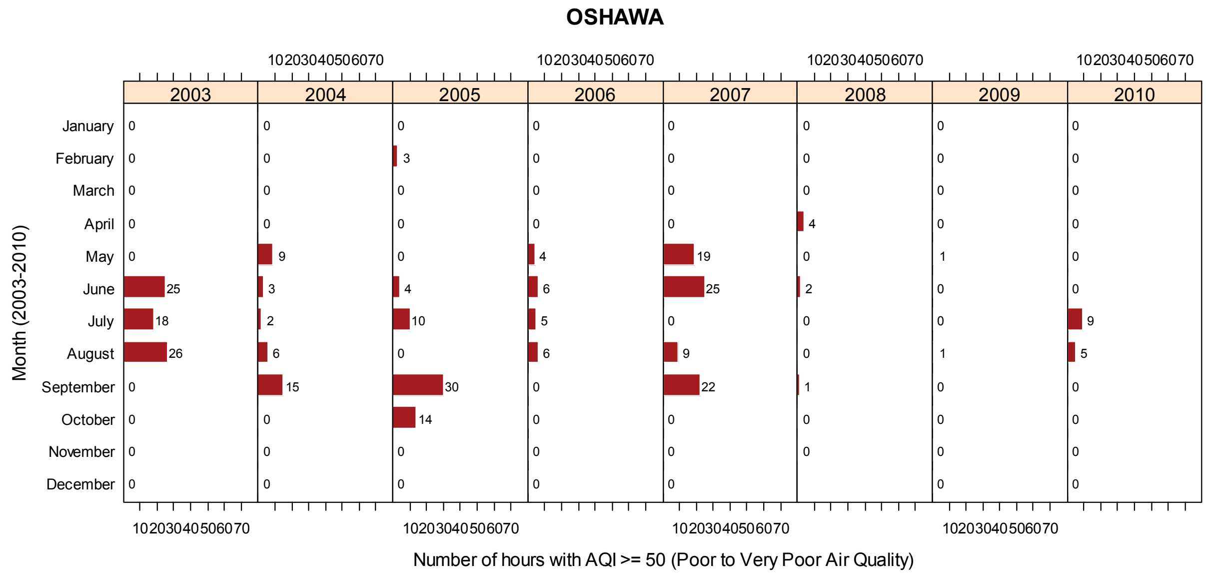
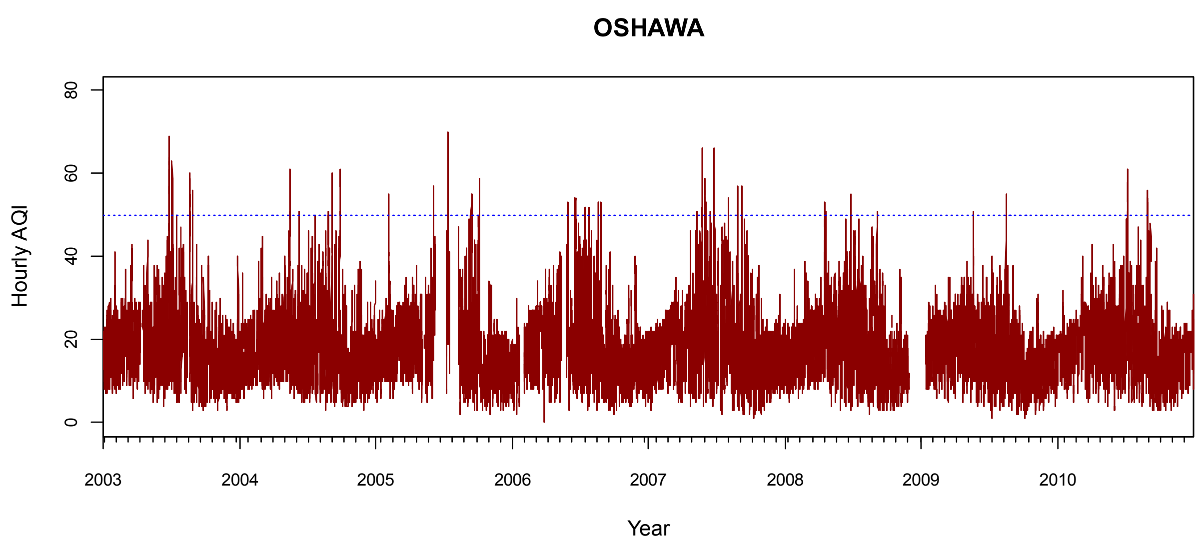
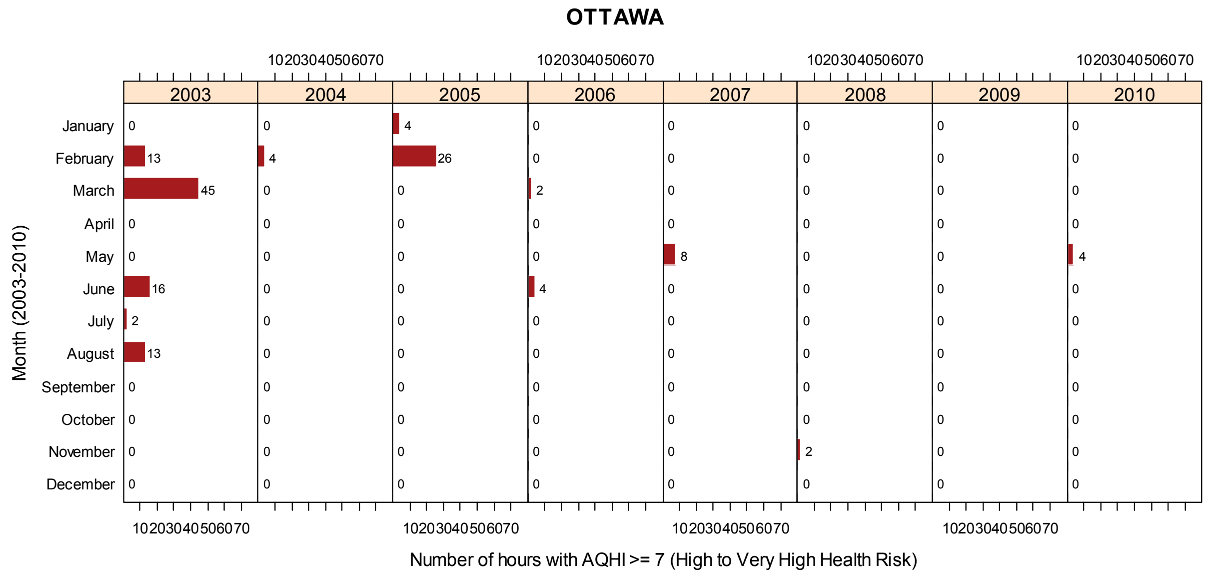
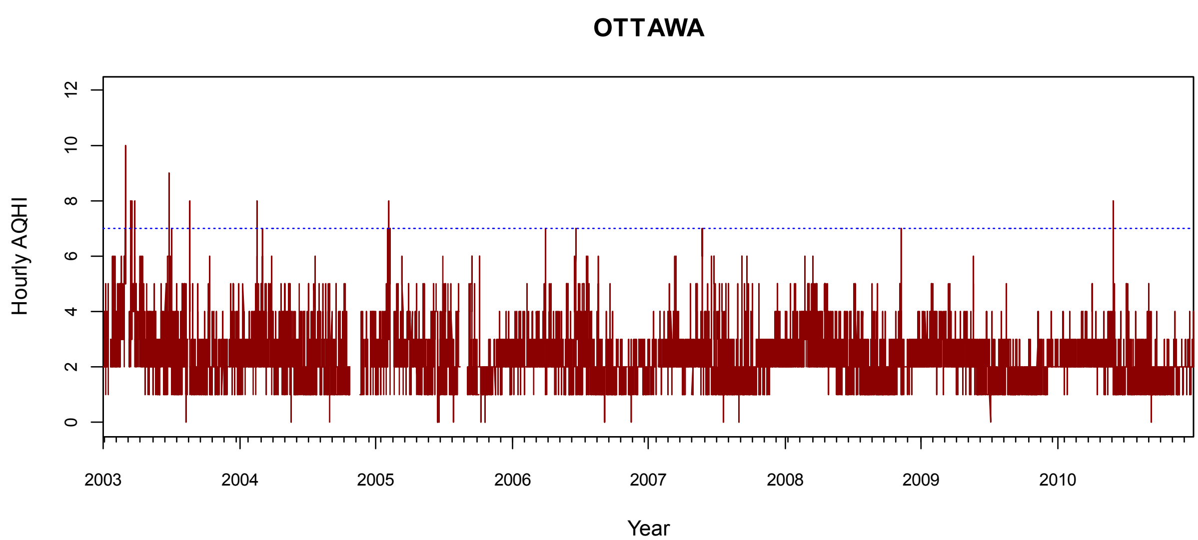




* AQHI was not available in December, 2008 in Oshawa, Ontario as indicated by blank space

Figure 6. continued





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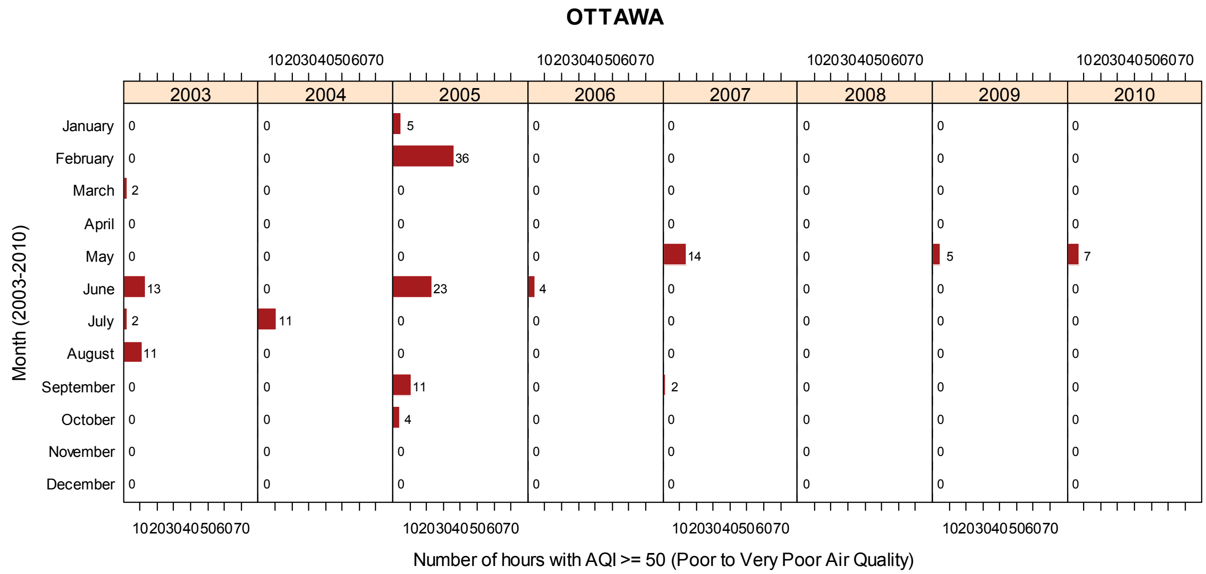

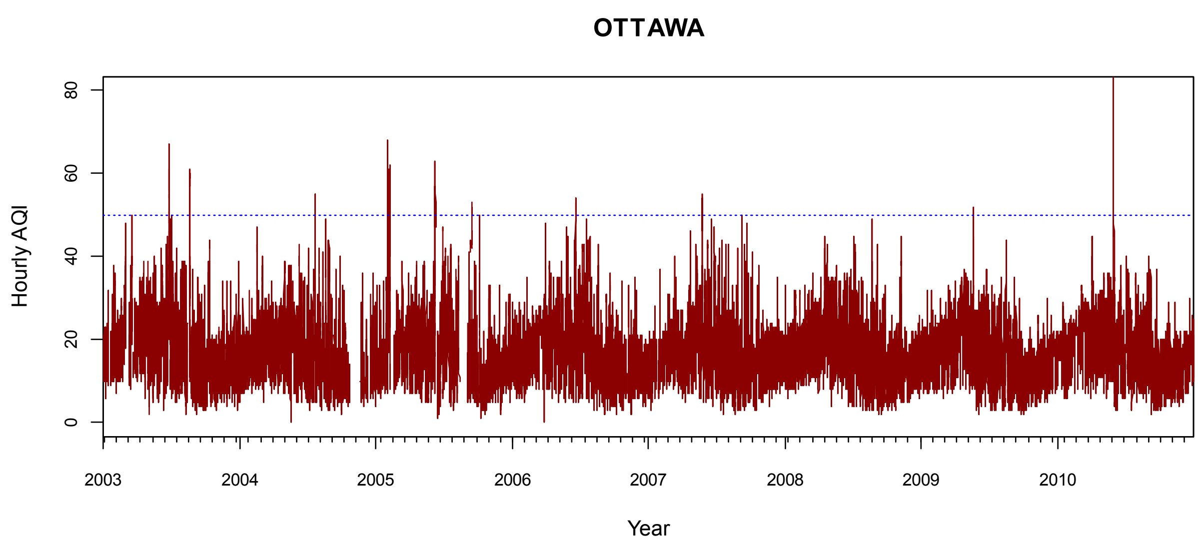

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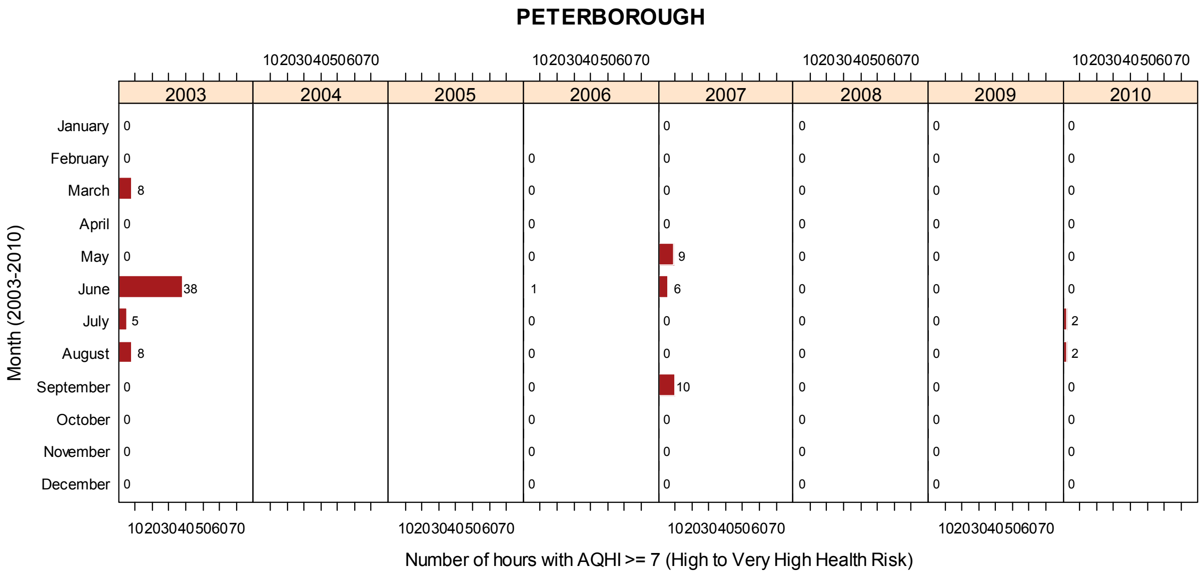

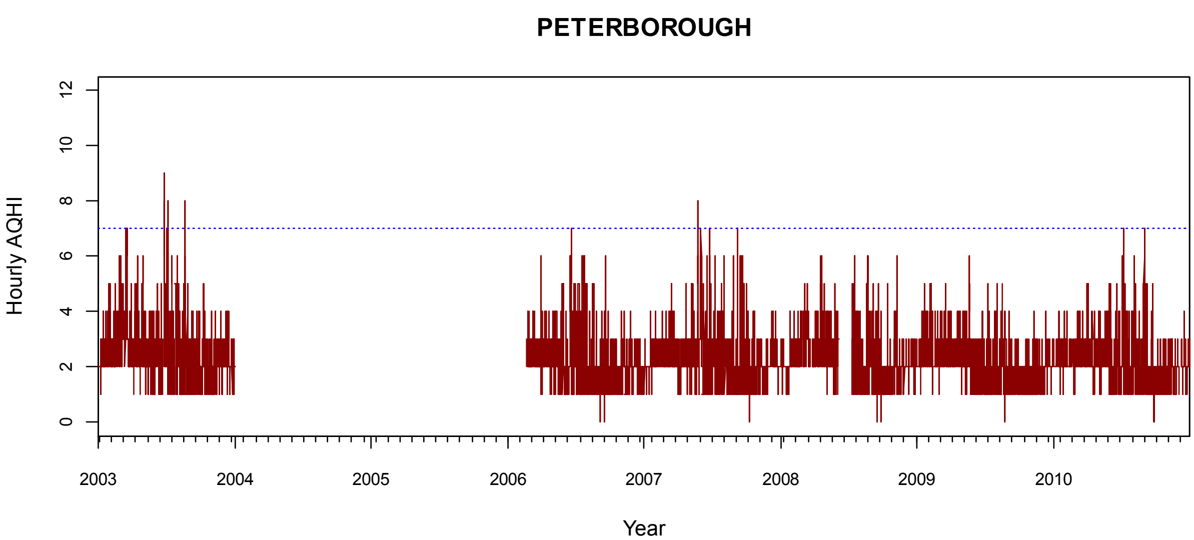

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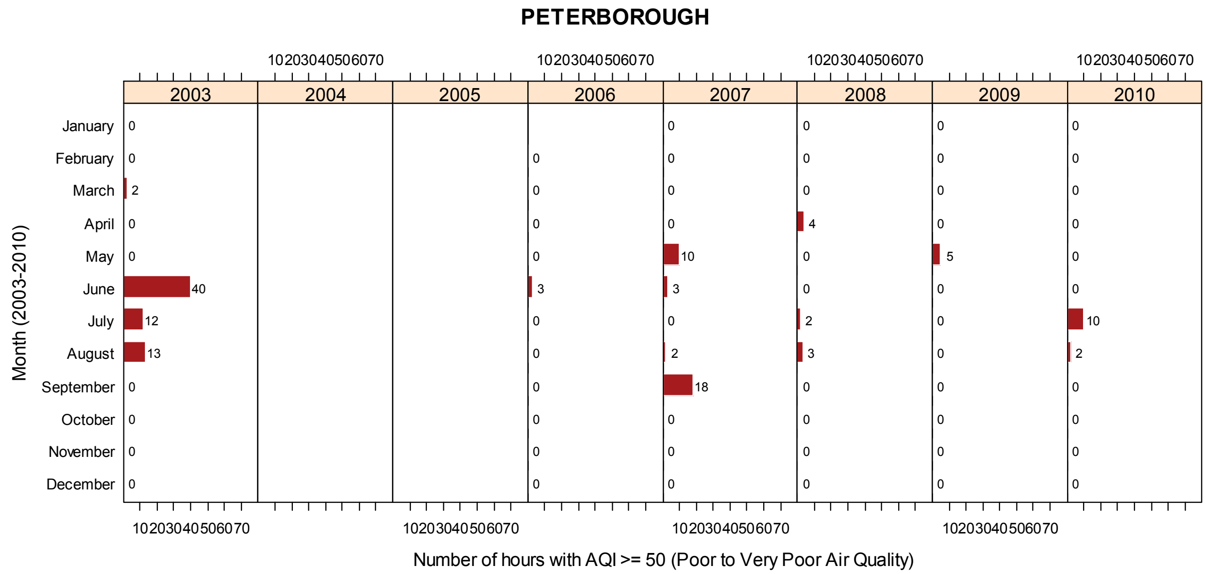
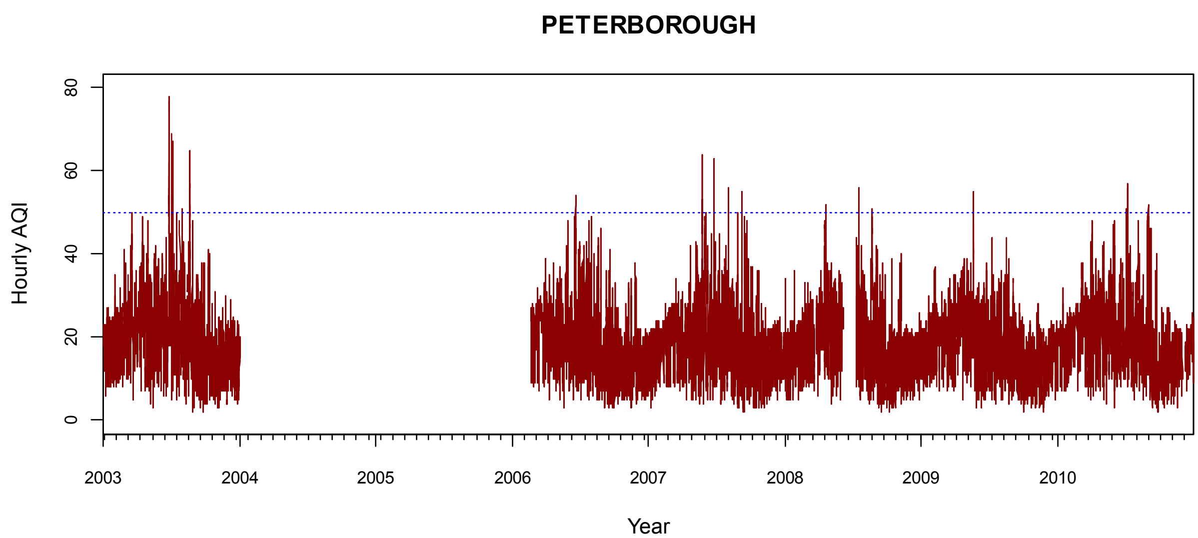
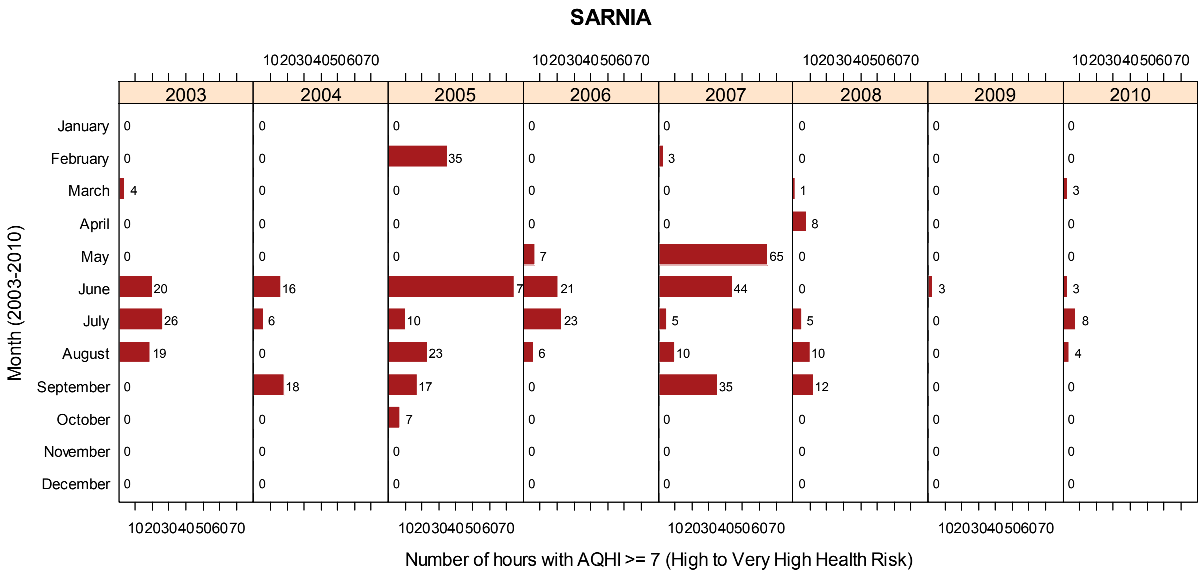
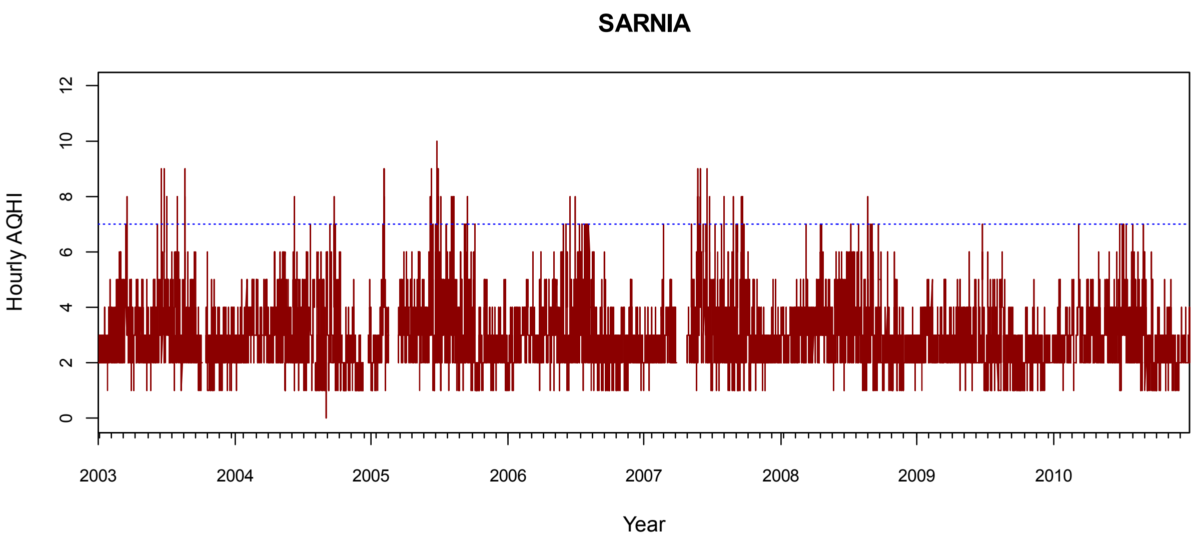




* AQHI was not available from January, 2004 to January, 2006 in Peterborough, Ontario as indicated by blank space

Figure 6. continued





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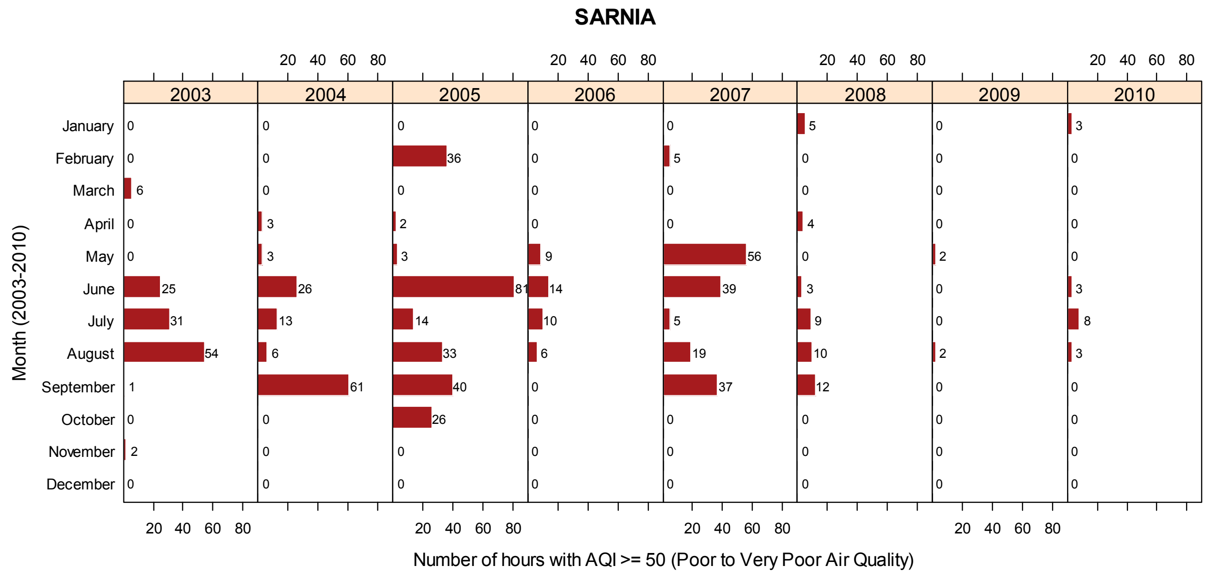

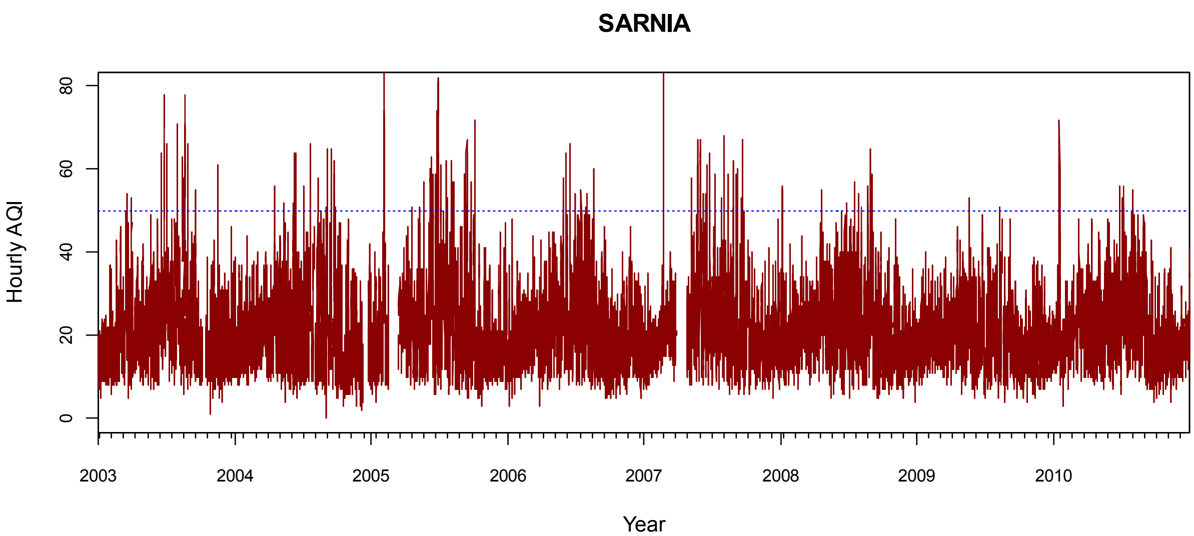

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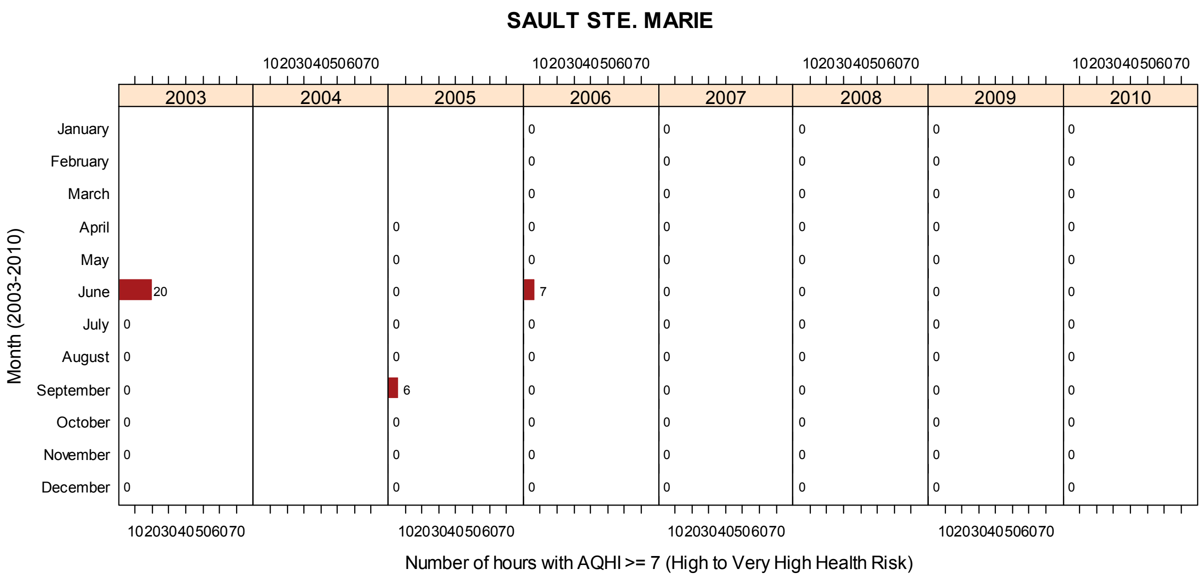

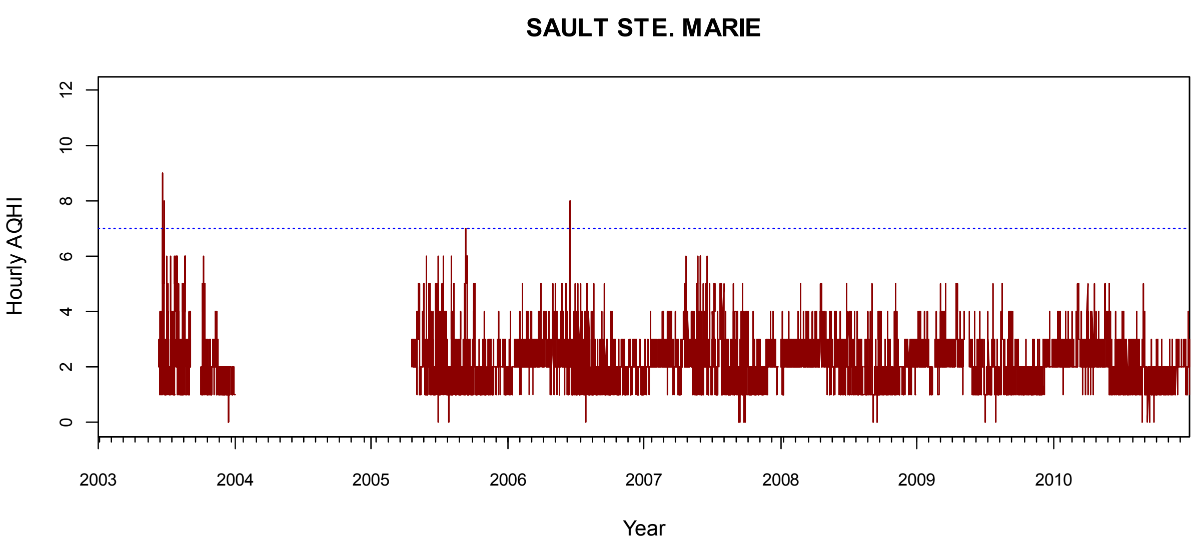

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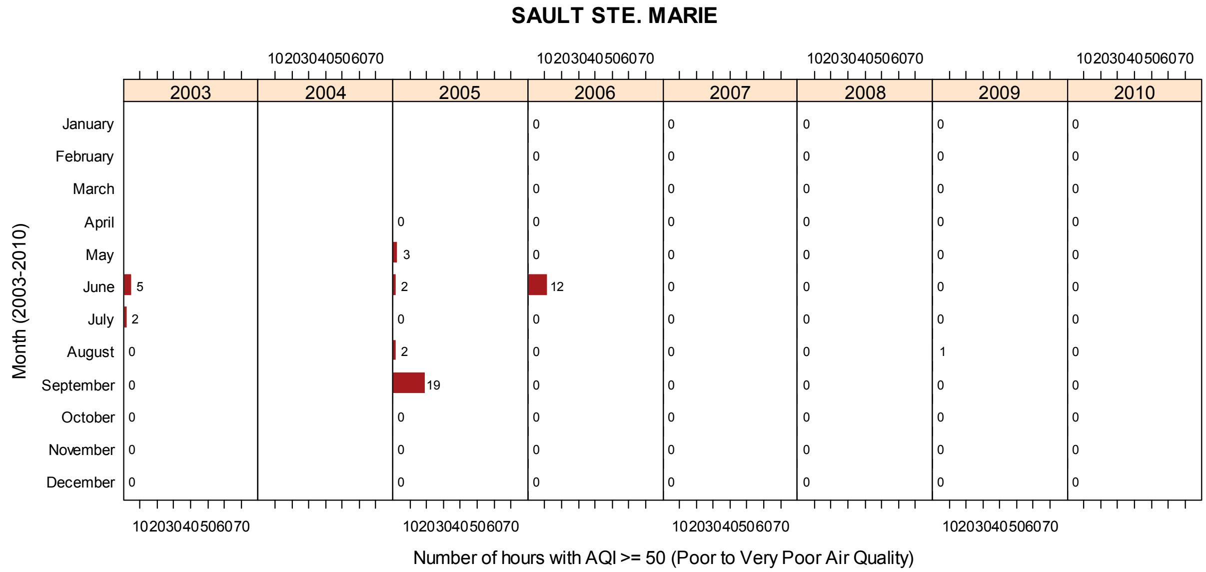
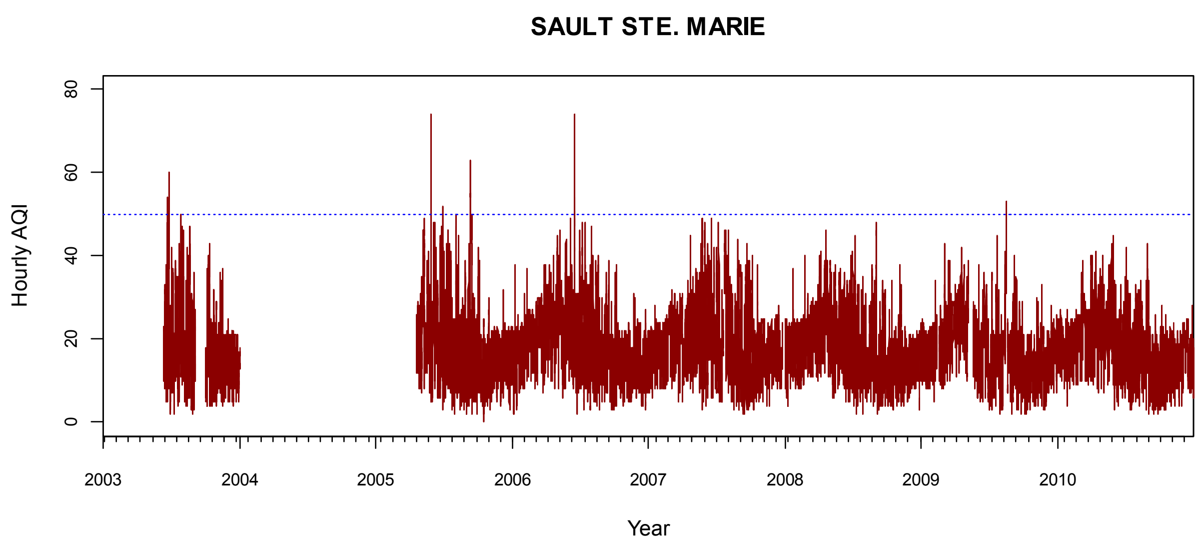
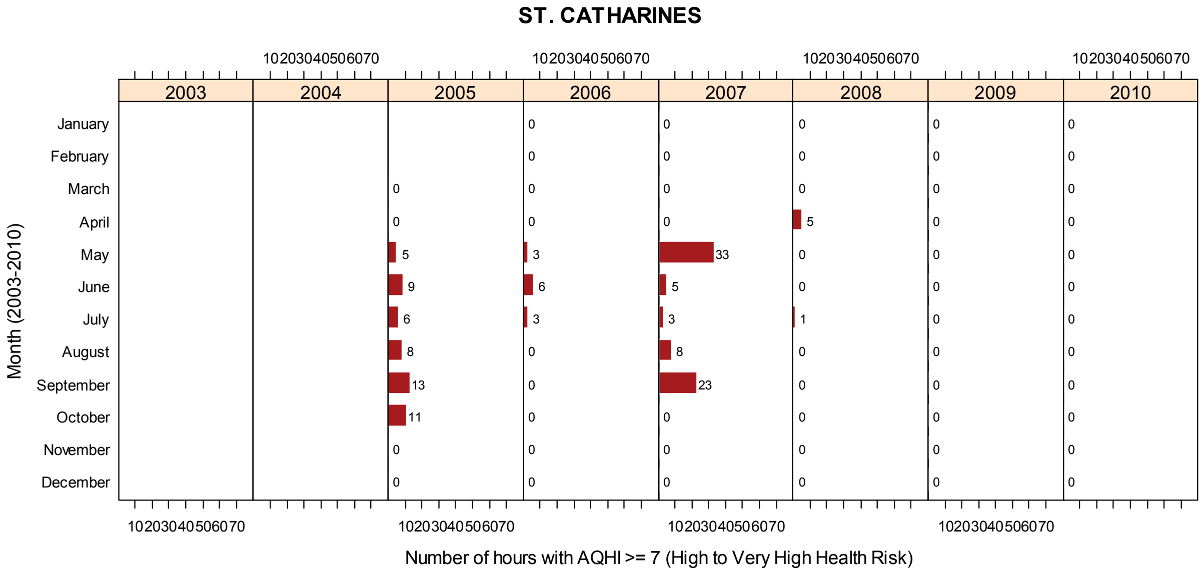




* AQHI was not available from January to May, 2003 and from January, 2004 to March, 2005 in Sault Ste. Marie, Ontario as indicated by blank space

Figure 6. continued



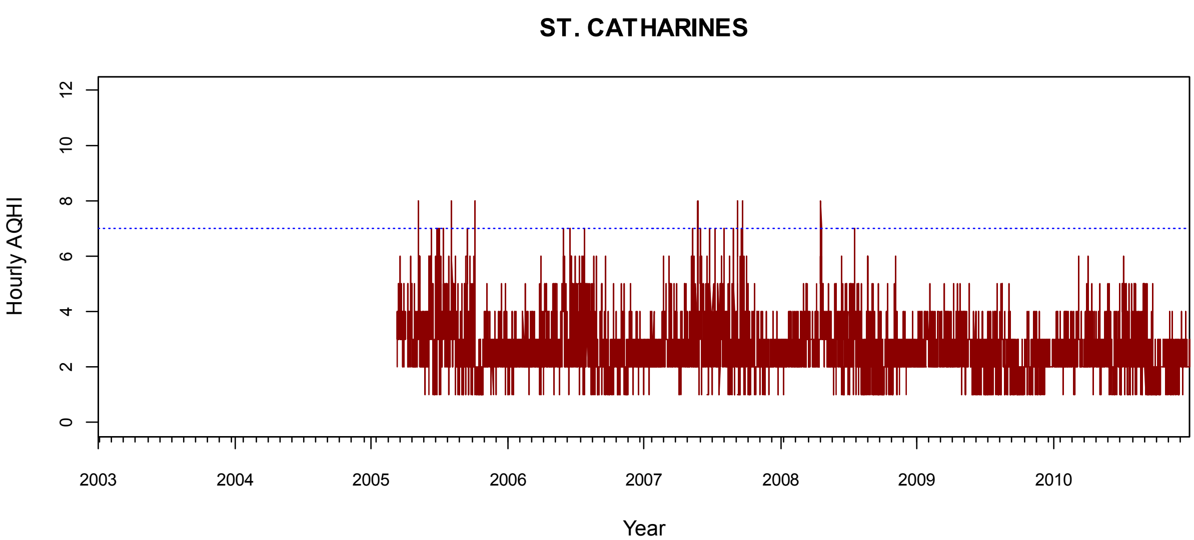
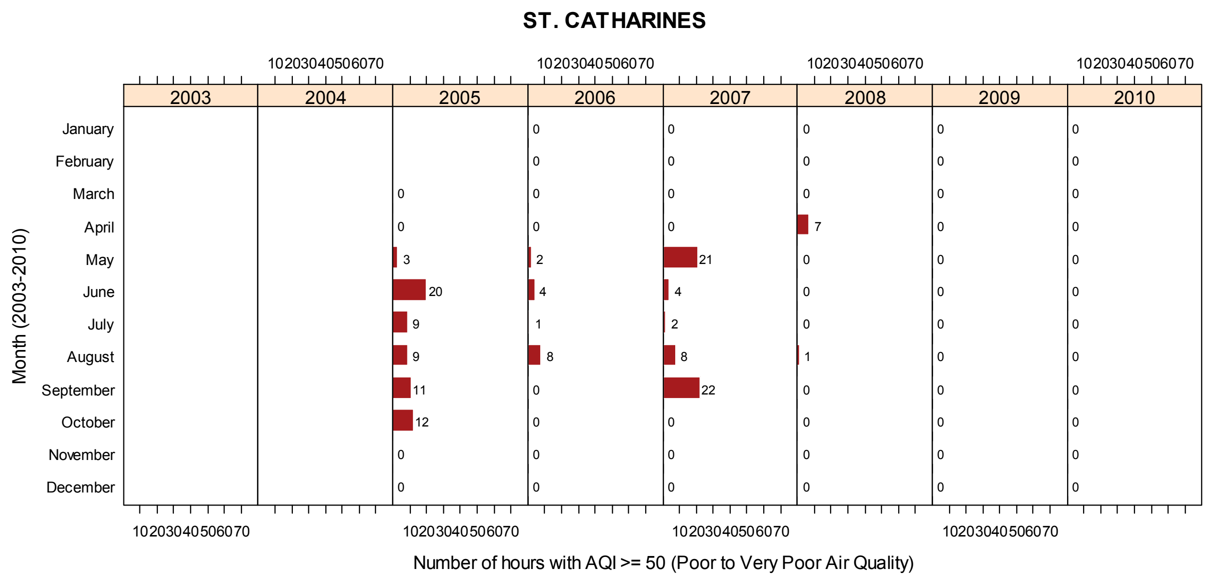
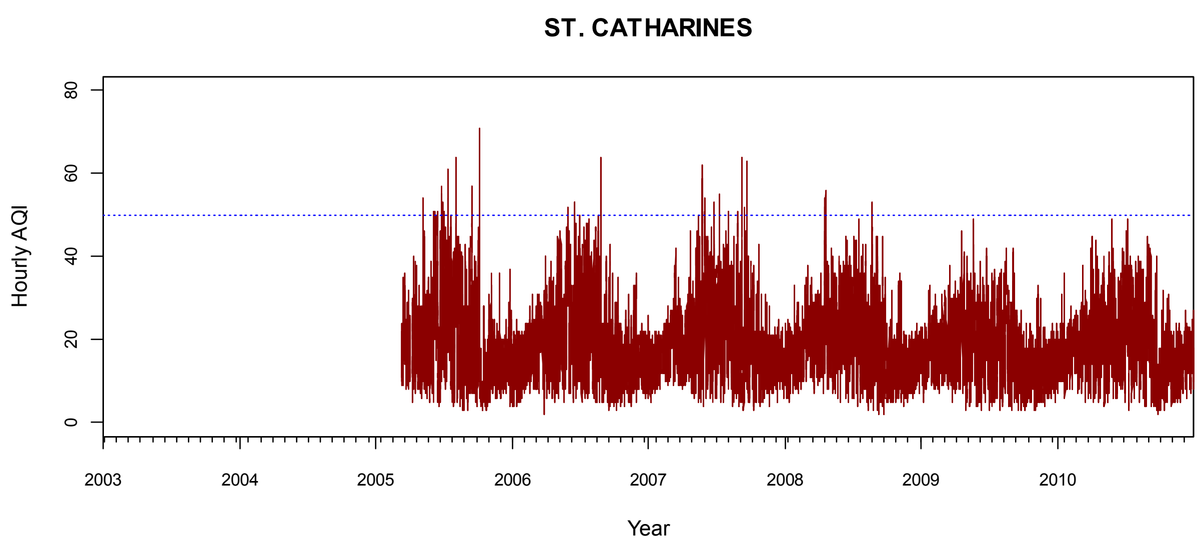


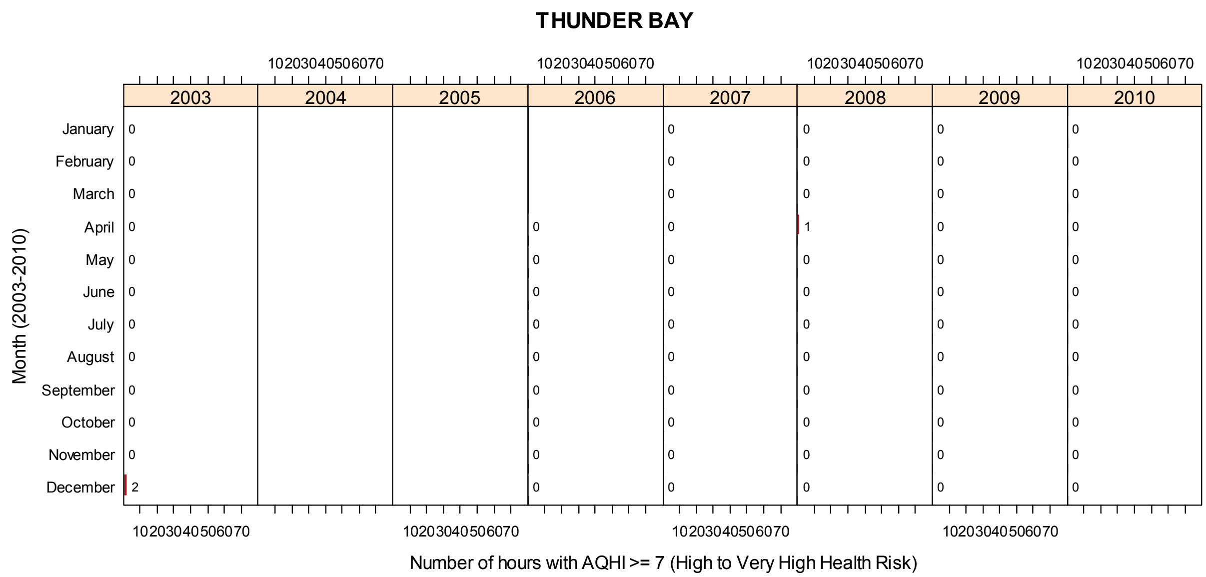
Figure 6. continued





* AQHI was not available from 2003 to 2004 and from January to February, 2005 in St. Catherines, Ontario as indicated by blank space

Figure 6. continued



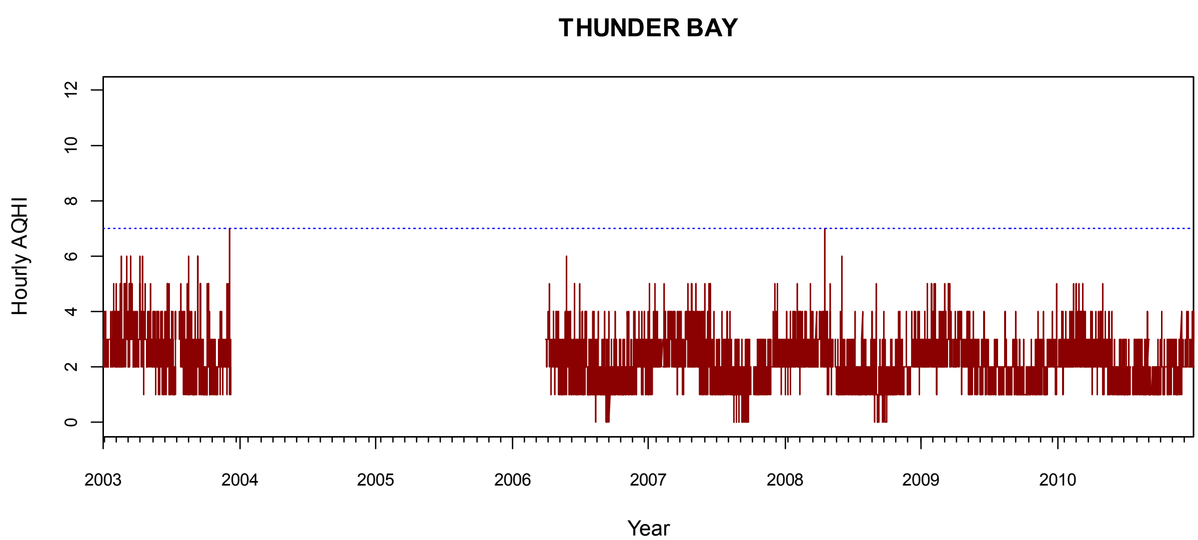
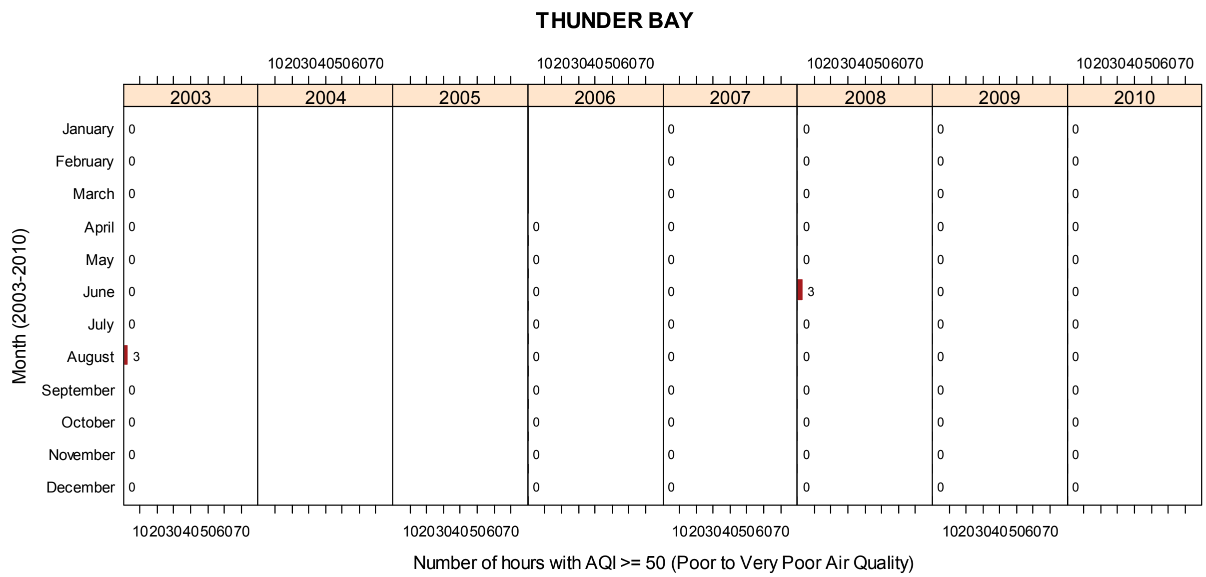
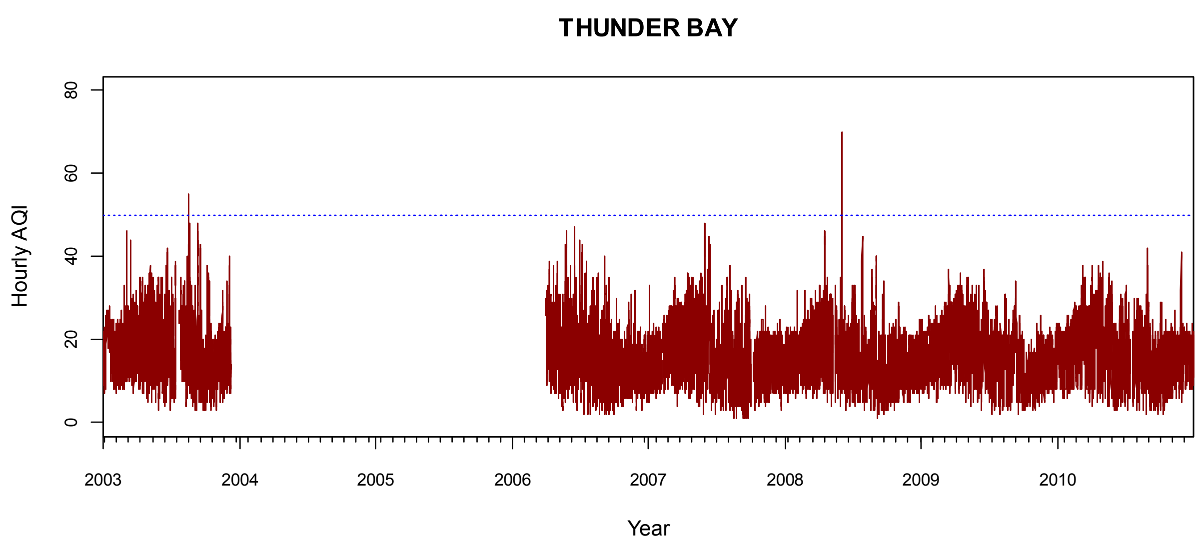


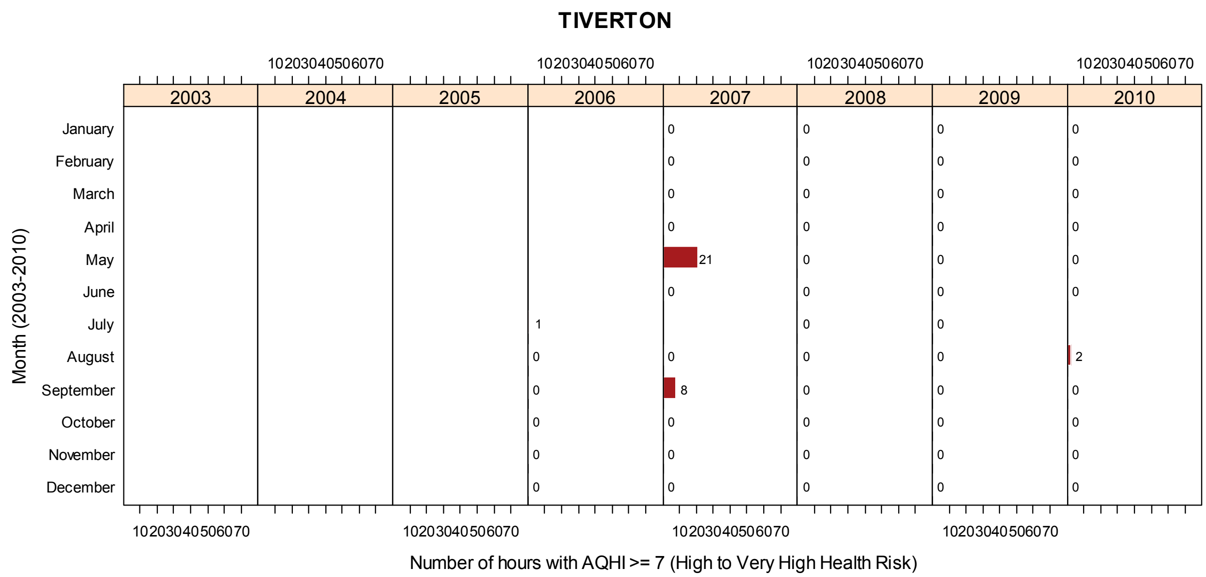
Figure 6. continued

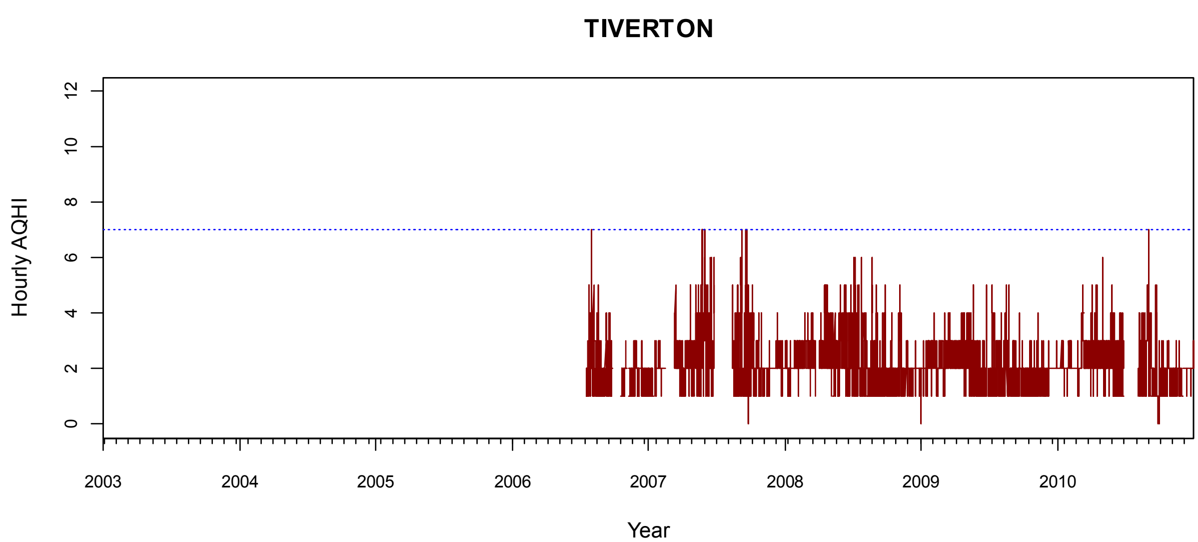




* AQHI was not available from January, 2004 to March, 2006 in Thunder Bay, Ontario as indicated by blank space

Figure 6. continued





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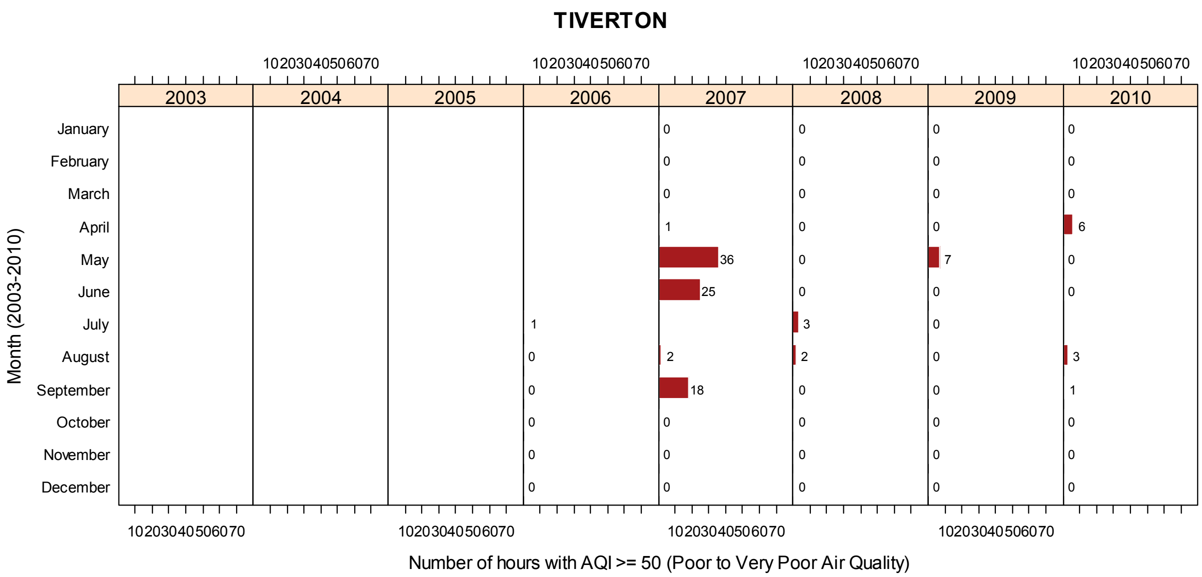
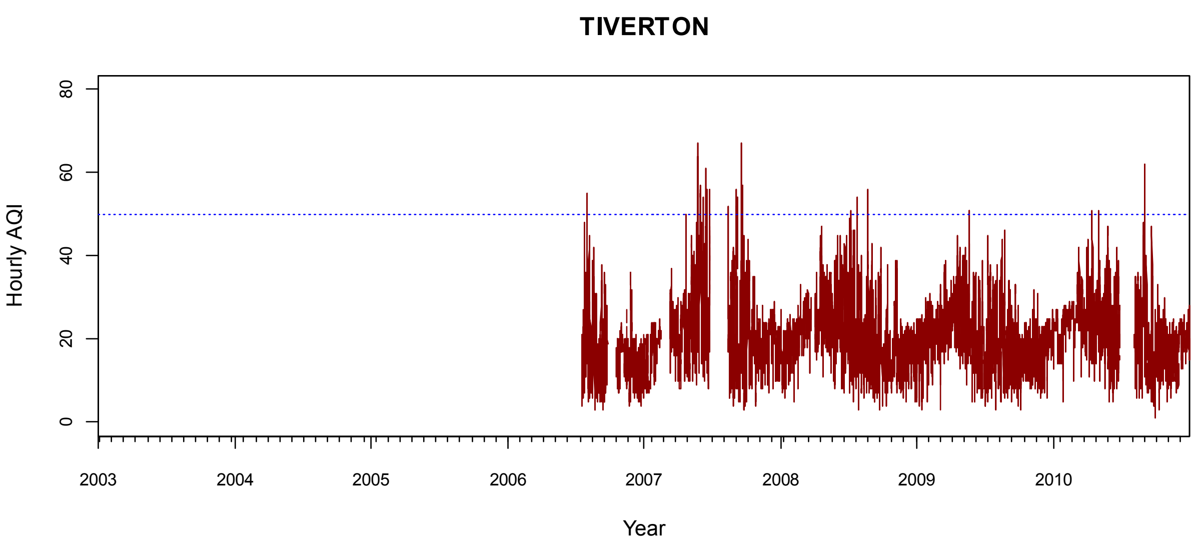
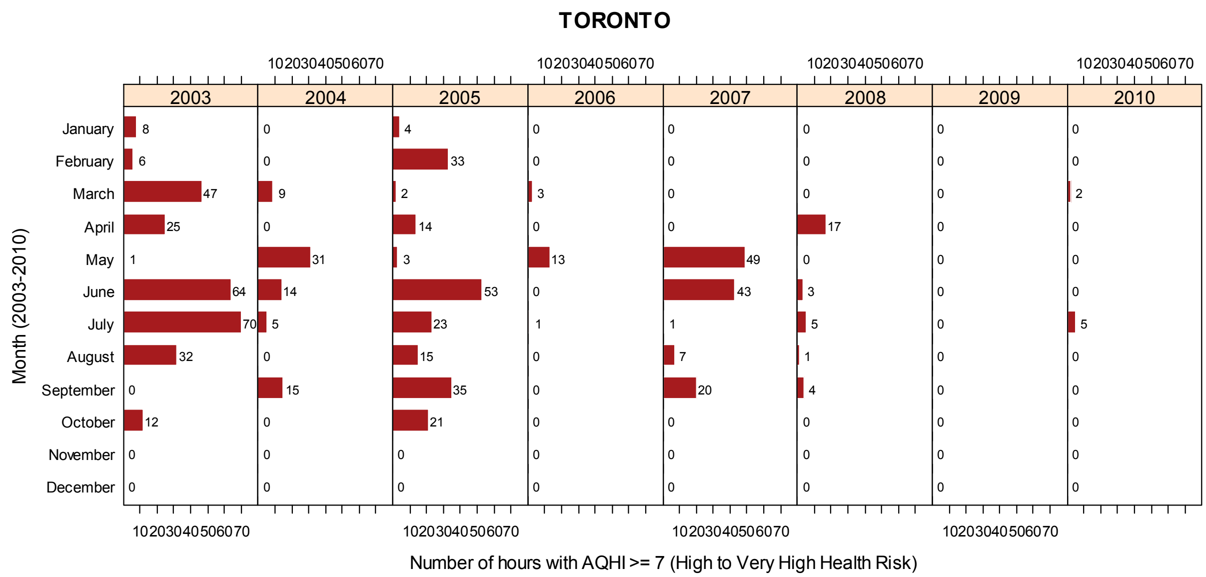
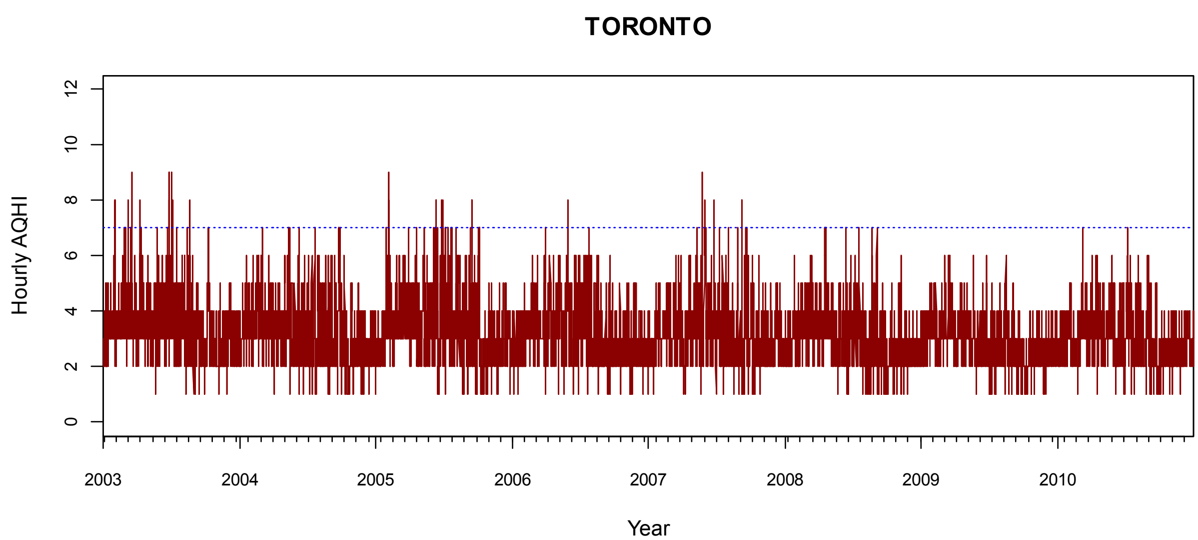




* AQHI was not available from January, 2003 to June, 2006 in Tiverton, Ontario as indicated by blank space

Figure 6. continued





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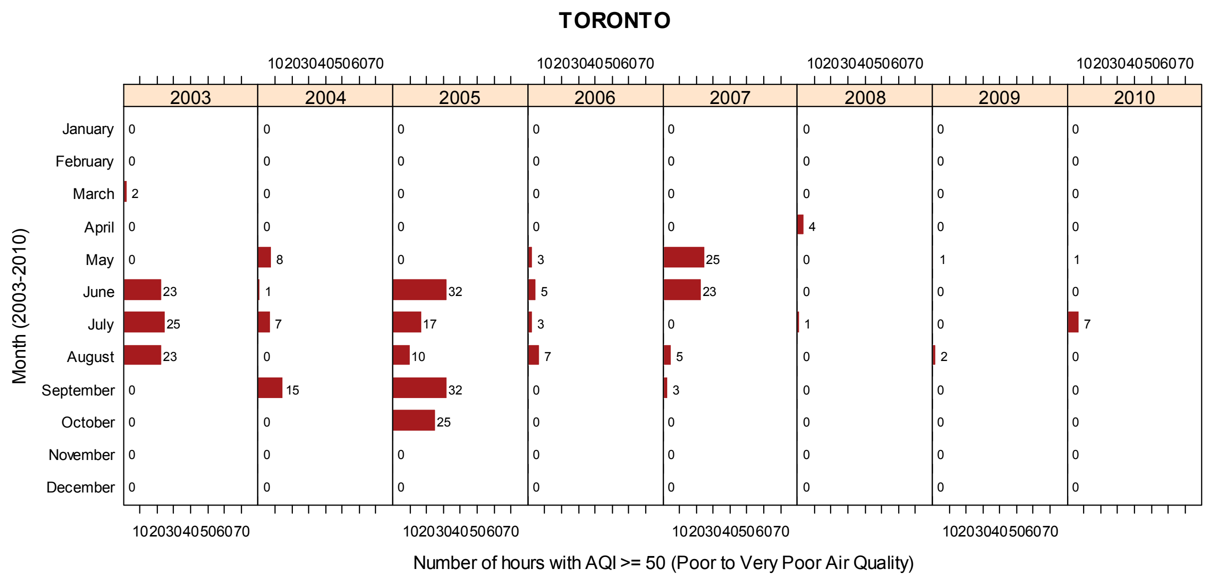


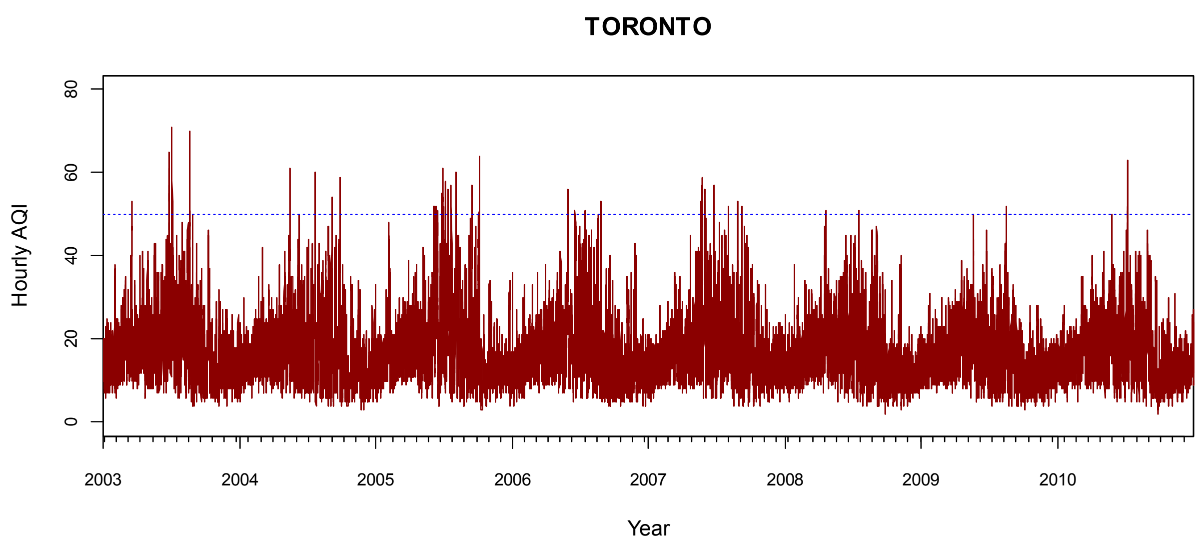
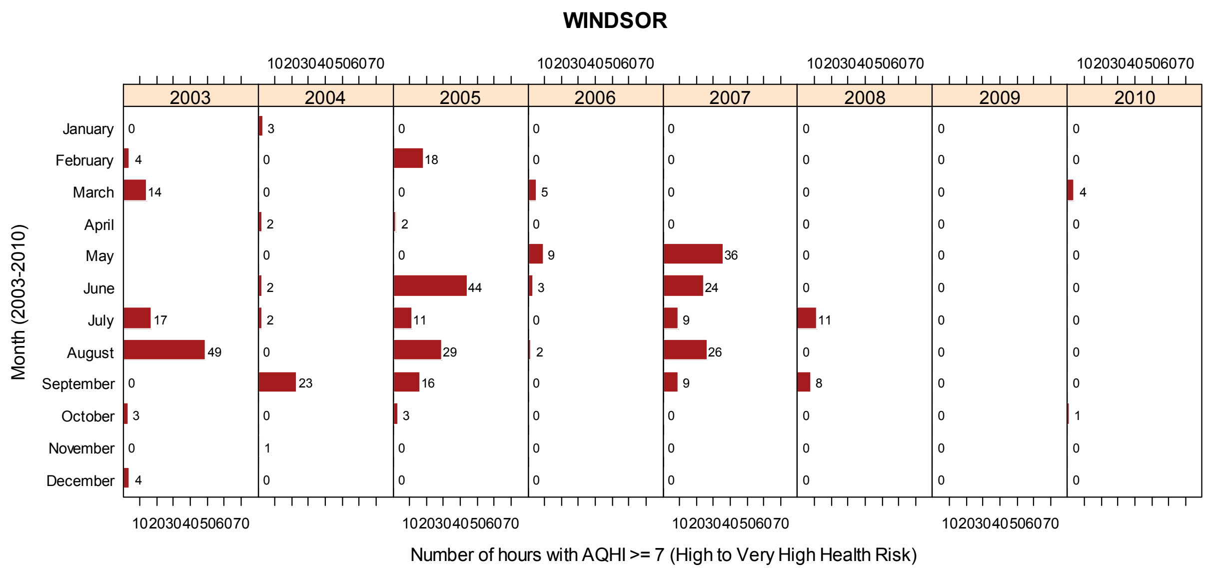


Figure 6. continued



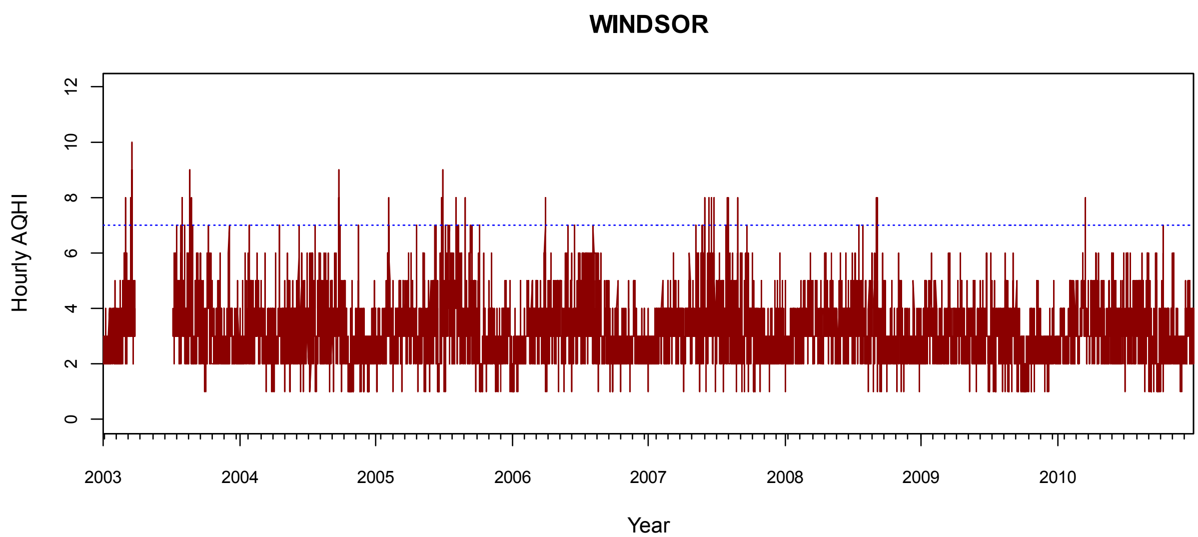
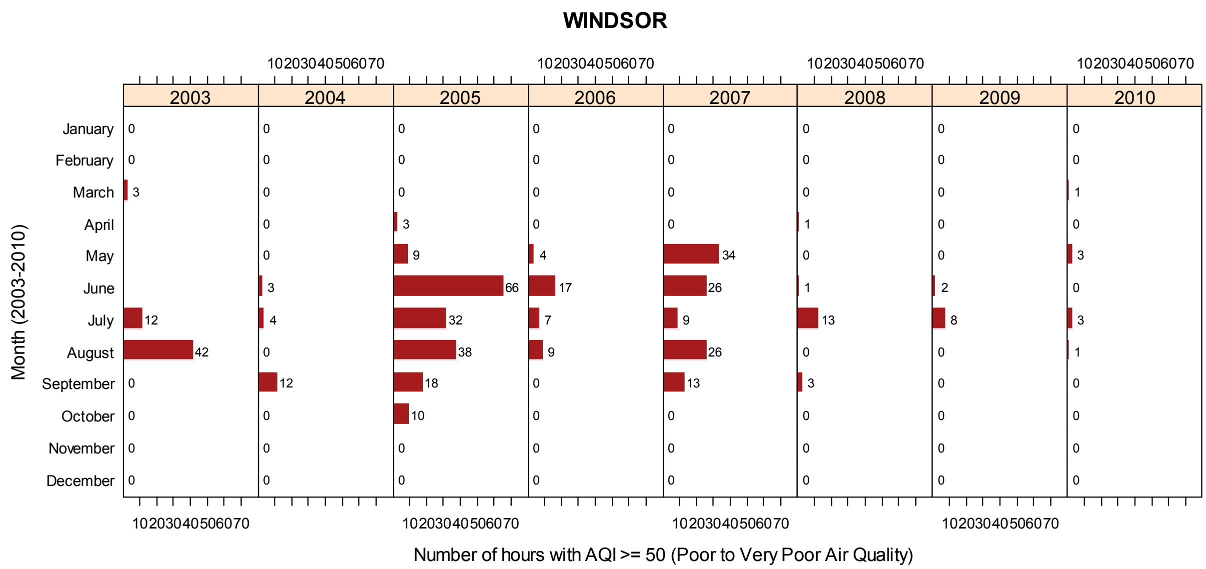
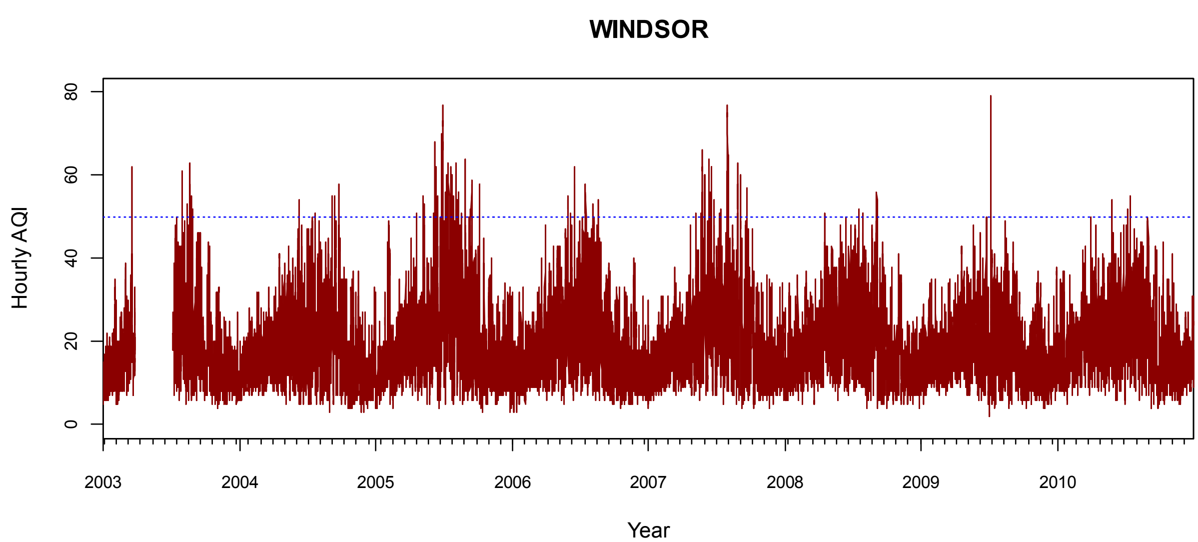


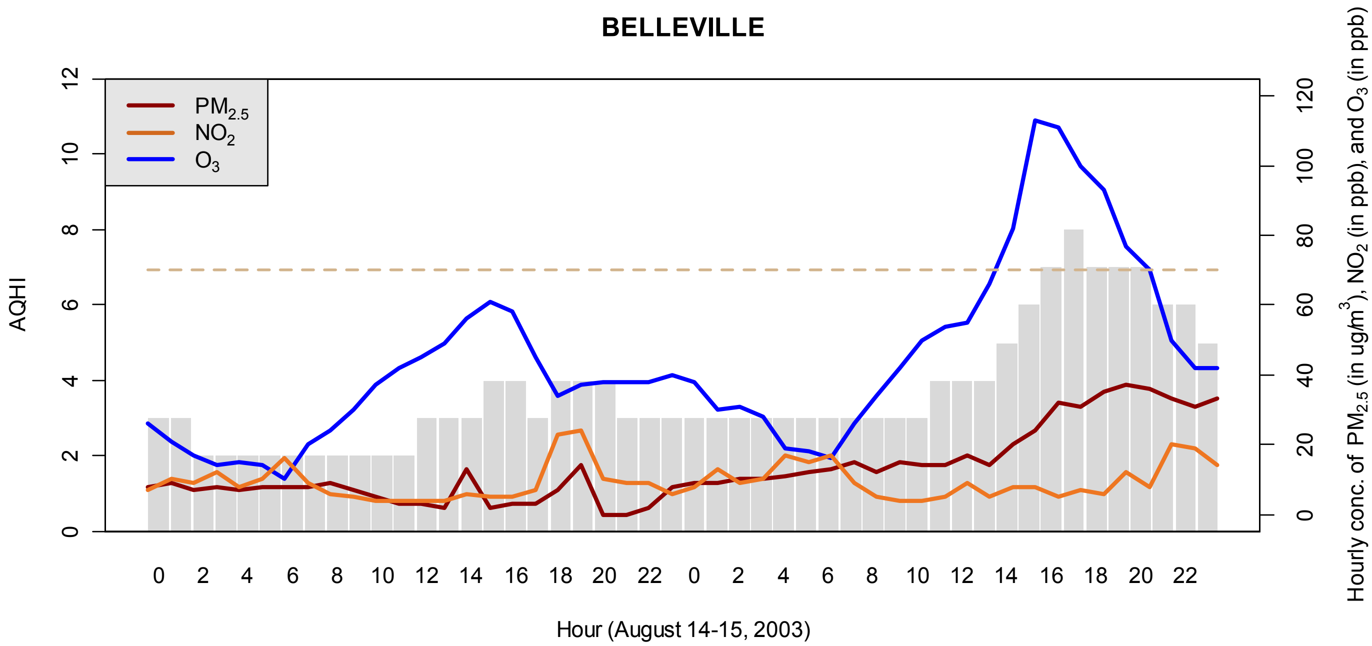
Figure 6. continued





* AQHI was not available from April to June, 2003 in Windsor, Ontario as indicated by blank space

Figure 7 (A). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Belleville, August 14-15, 2003. For any hour in which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



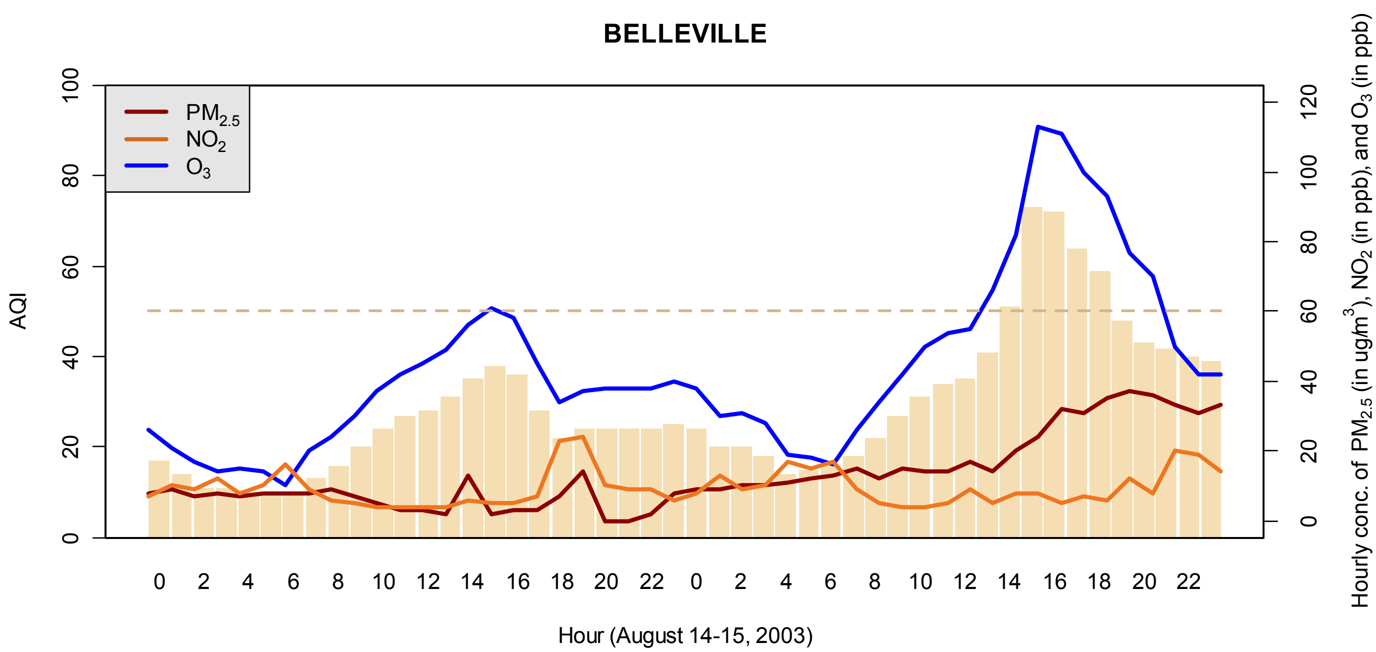
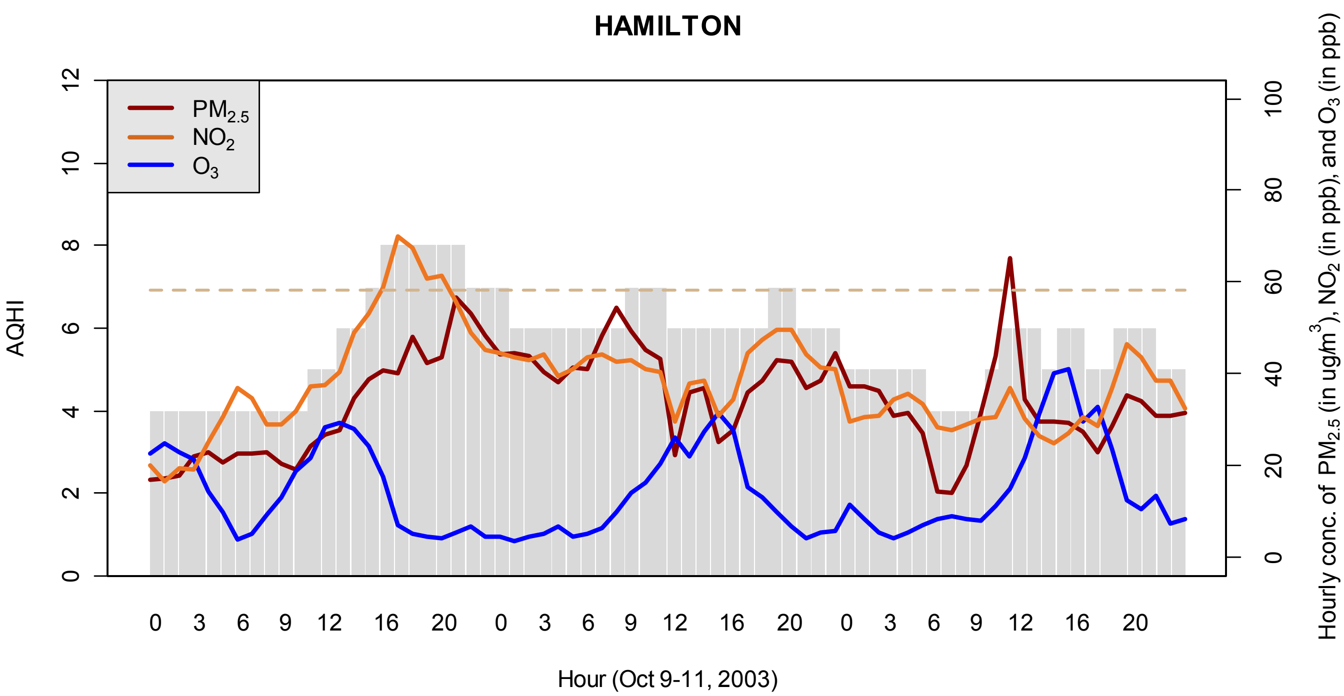


Figure 7 (B). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Hamilton, October 9-11, 2003. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



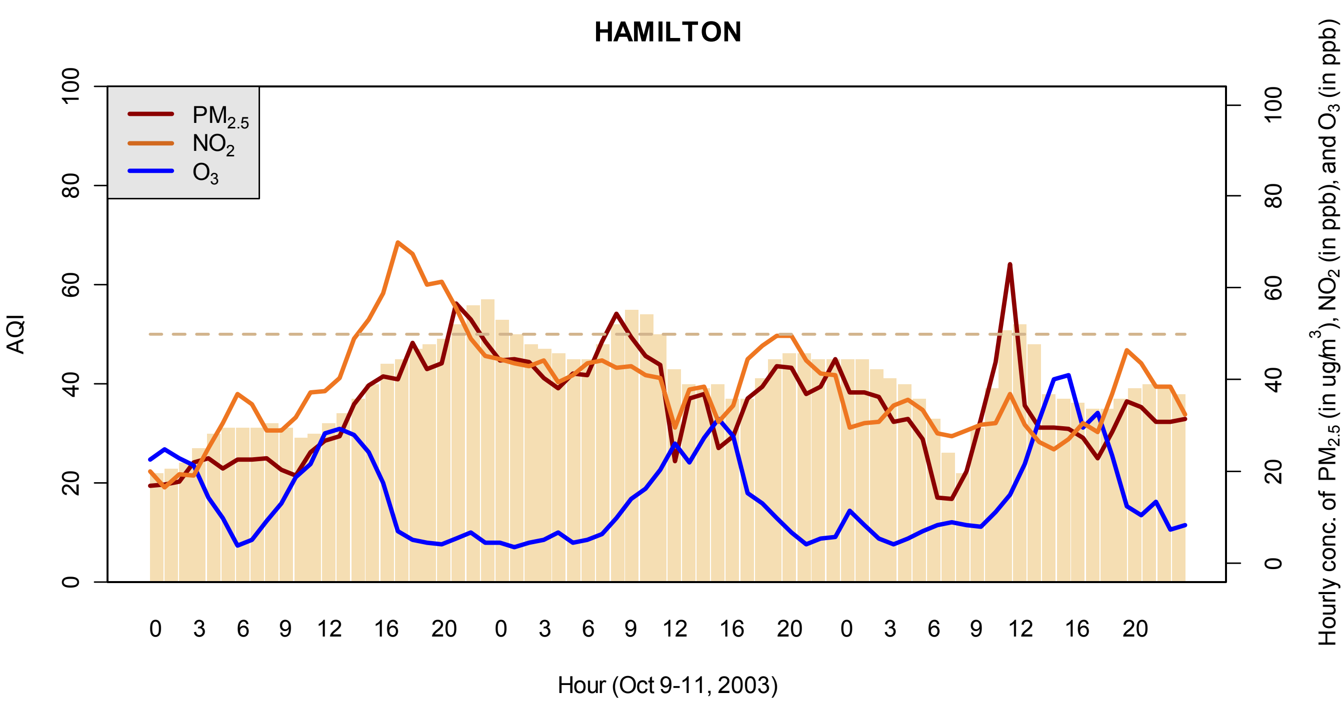
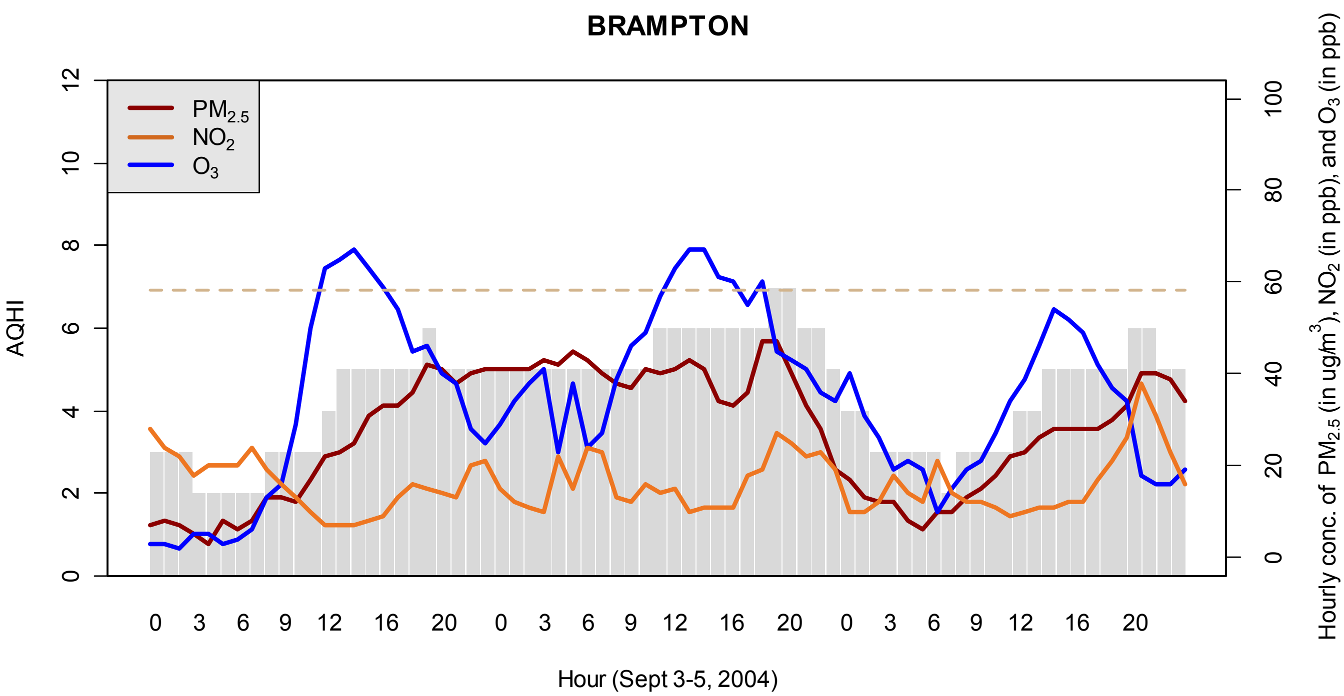


Figure 7 (C). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Brampton, Brantford, and Sarnia, September 3-5, 2004. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



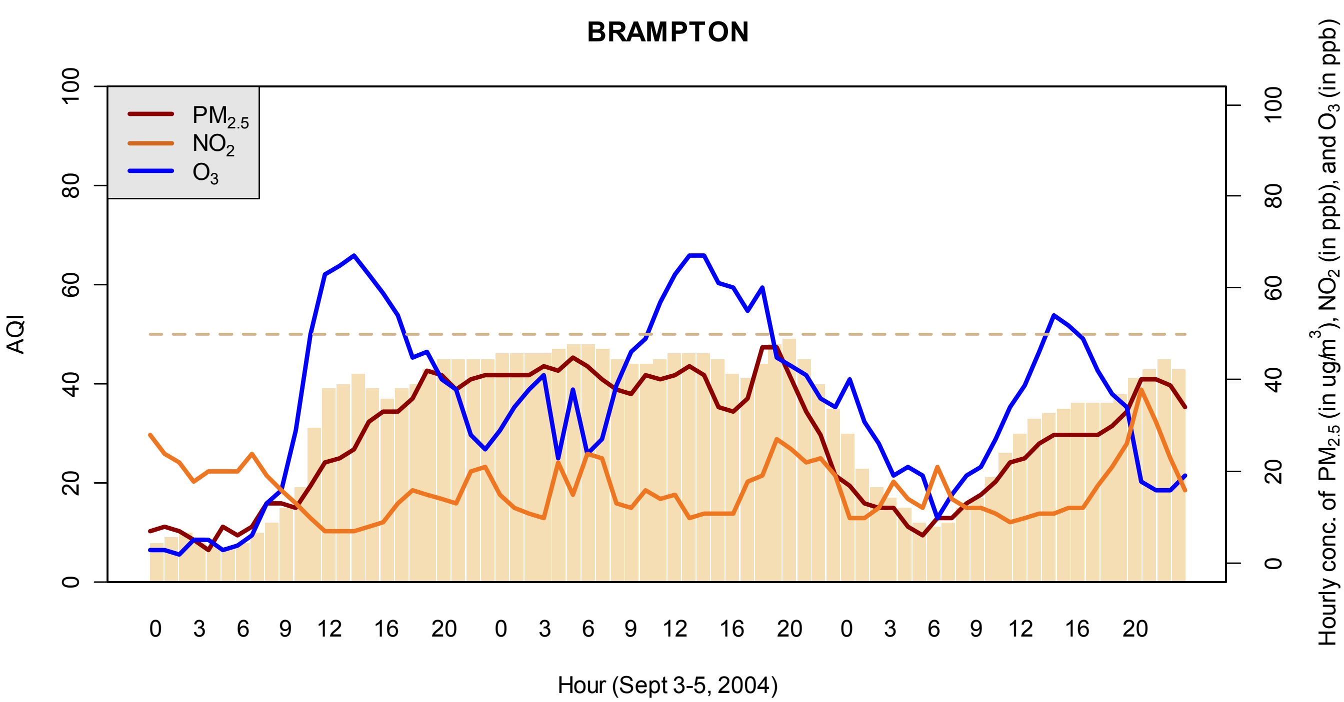
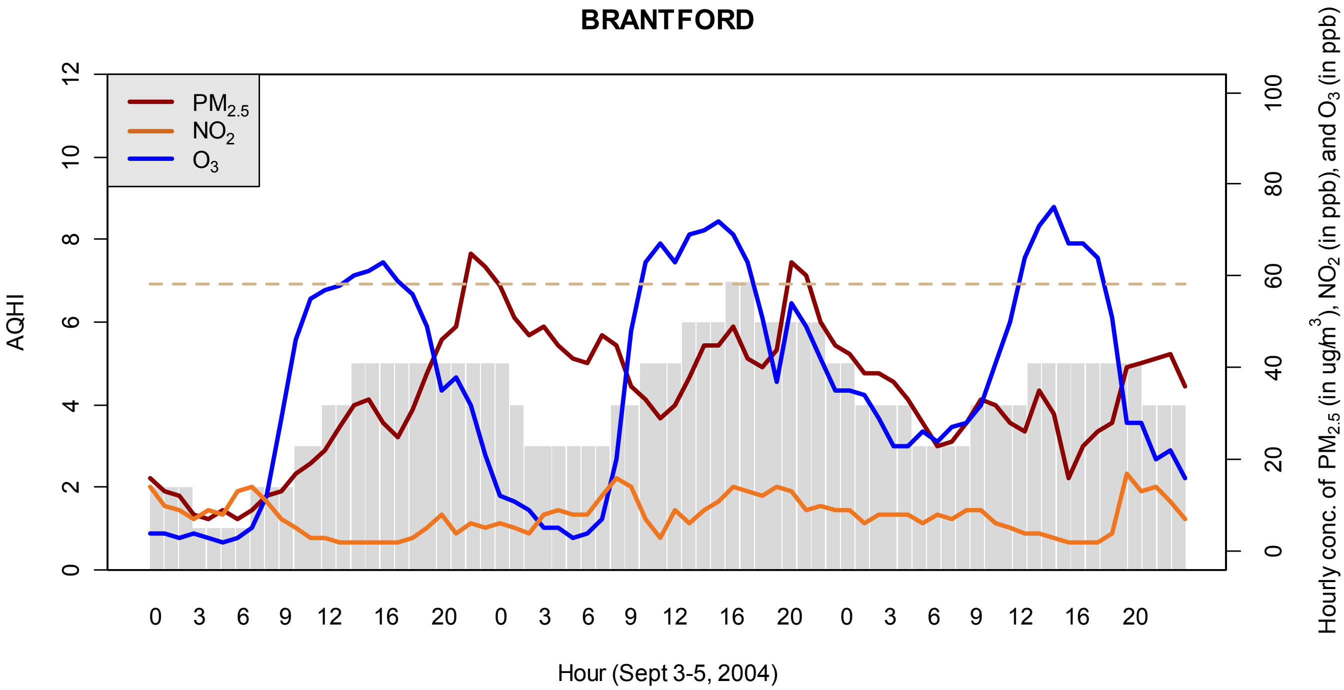


Figure 7(C). continued



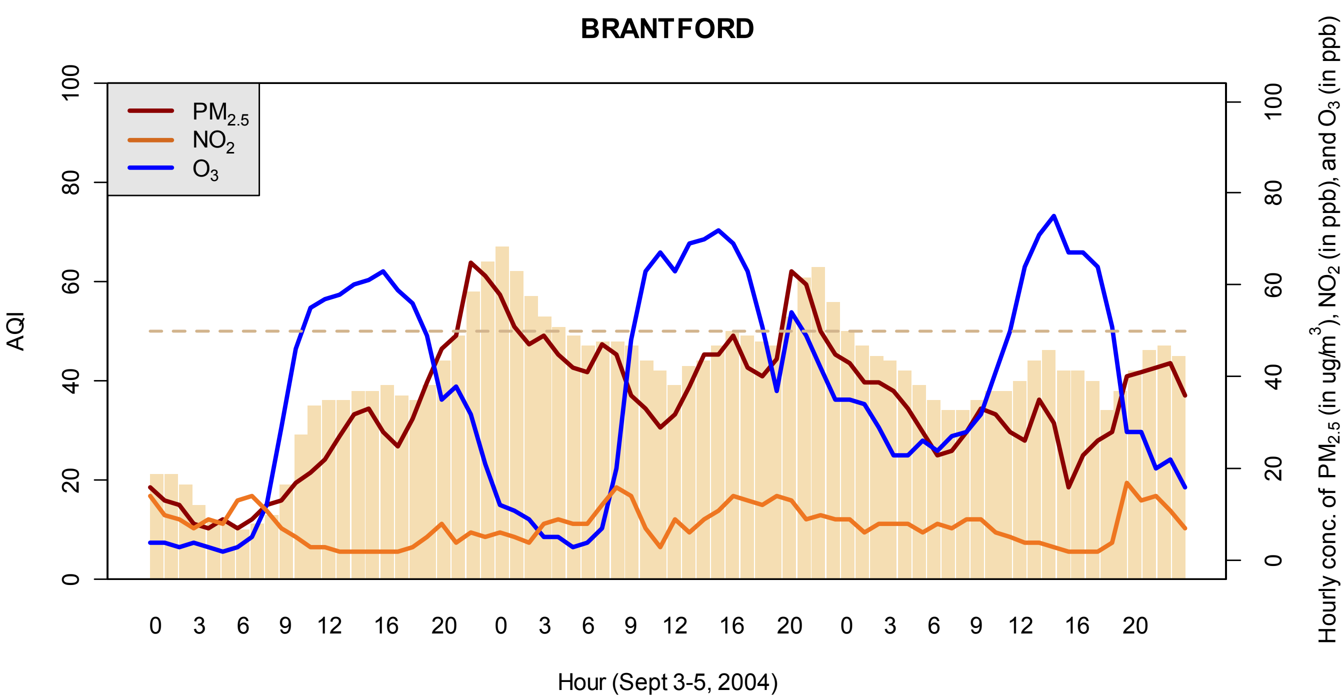
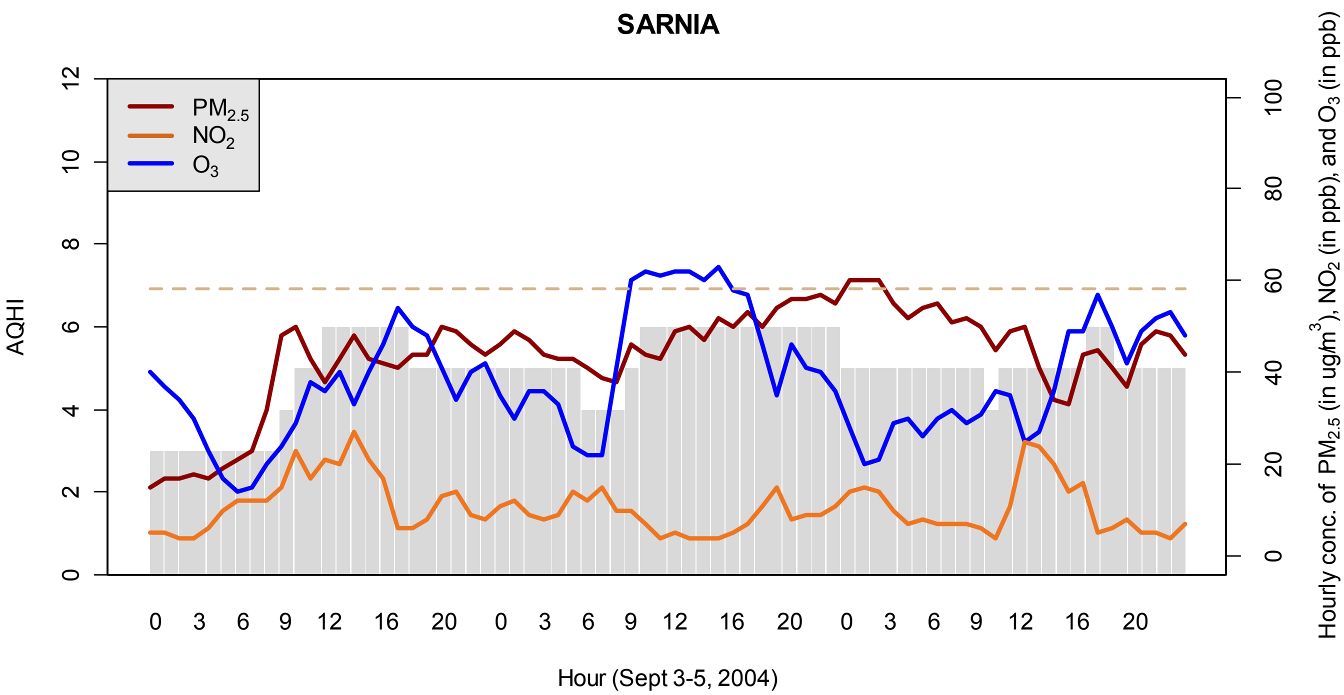


Figure 7(C). continued



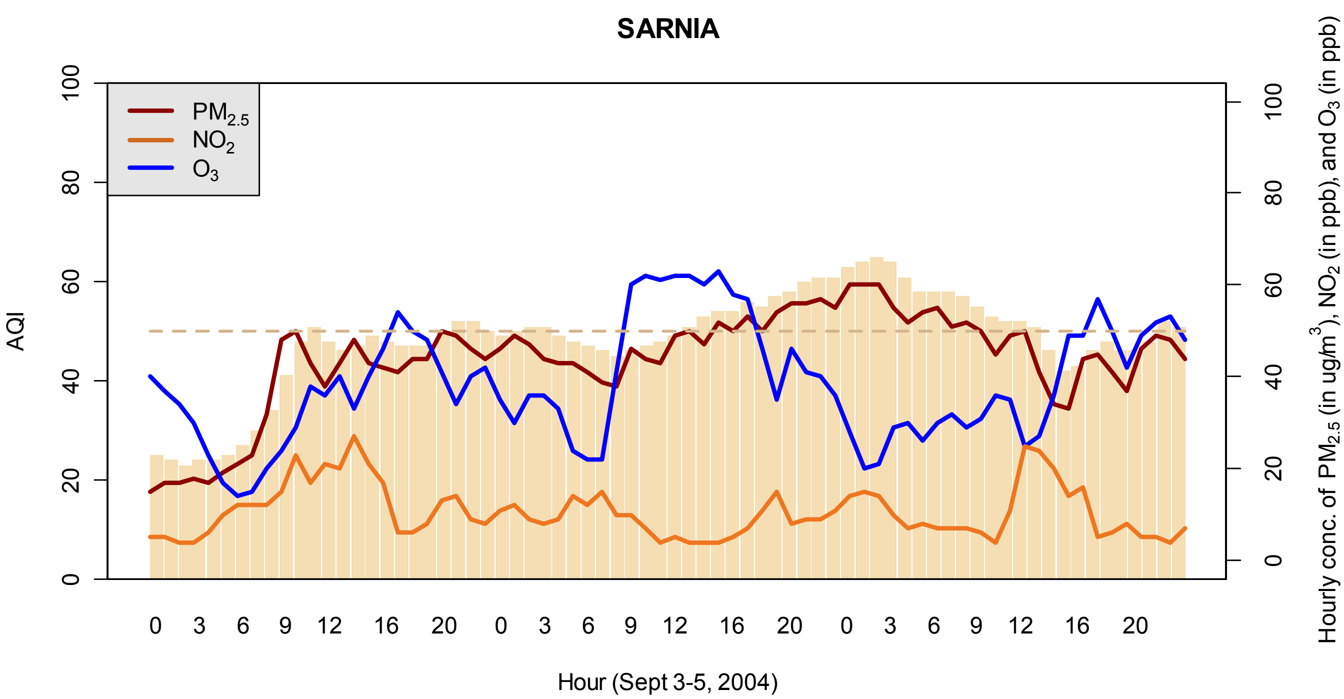
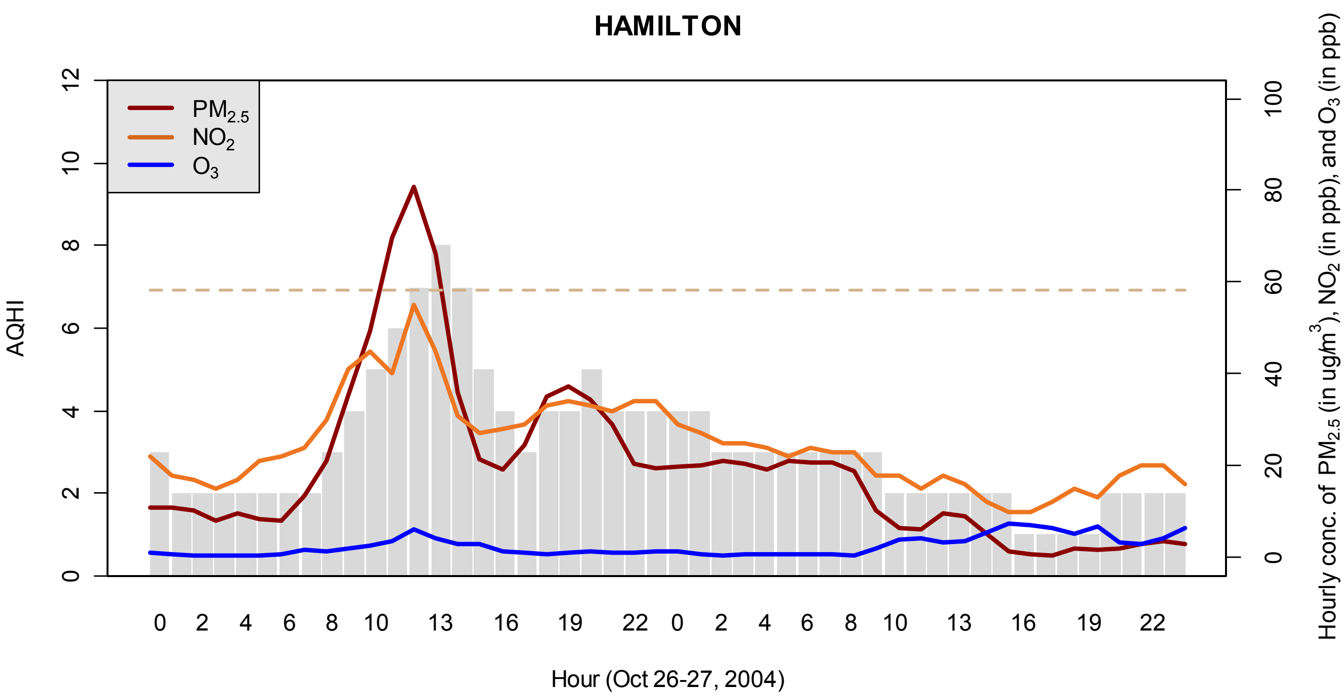


Figure 7 (D). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Hamilton, October 26-27, 2004. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



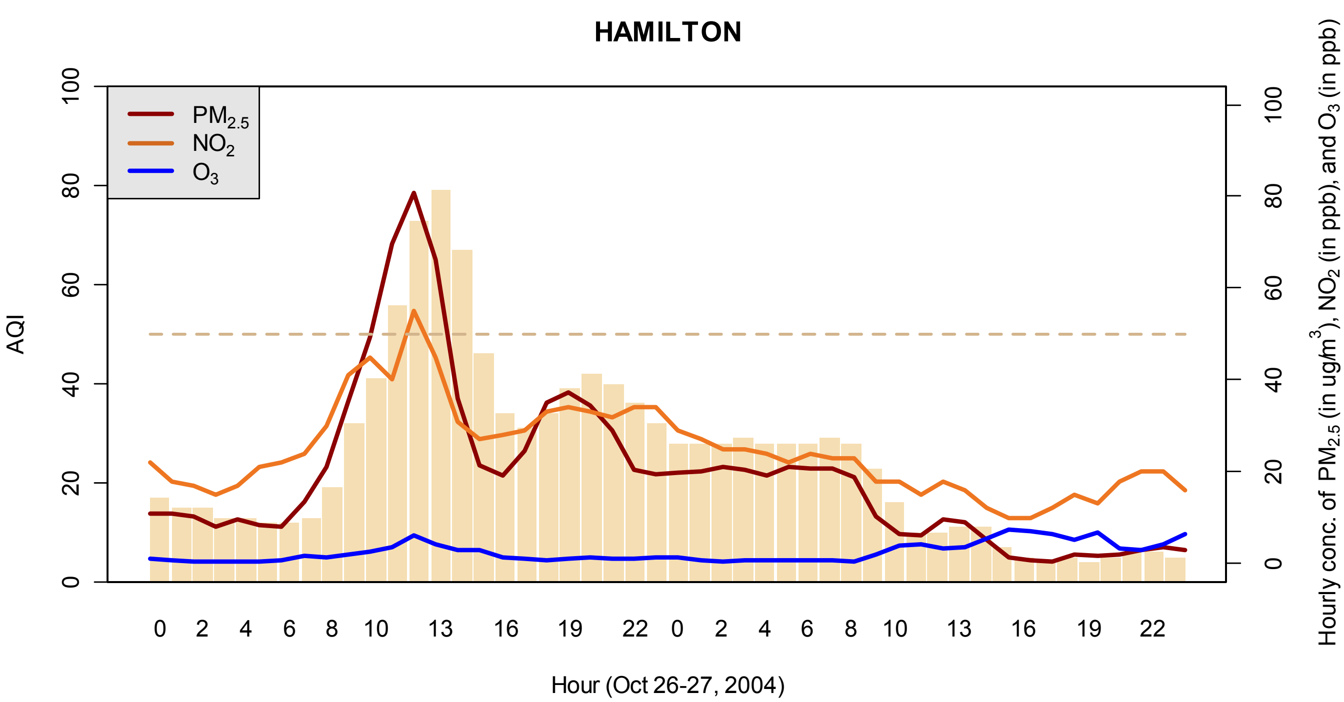
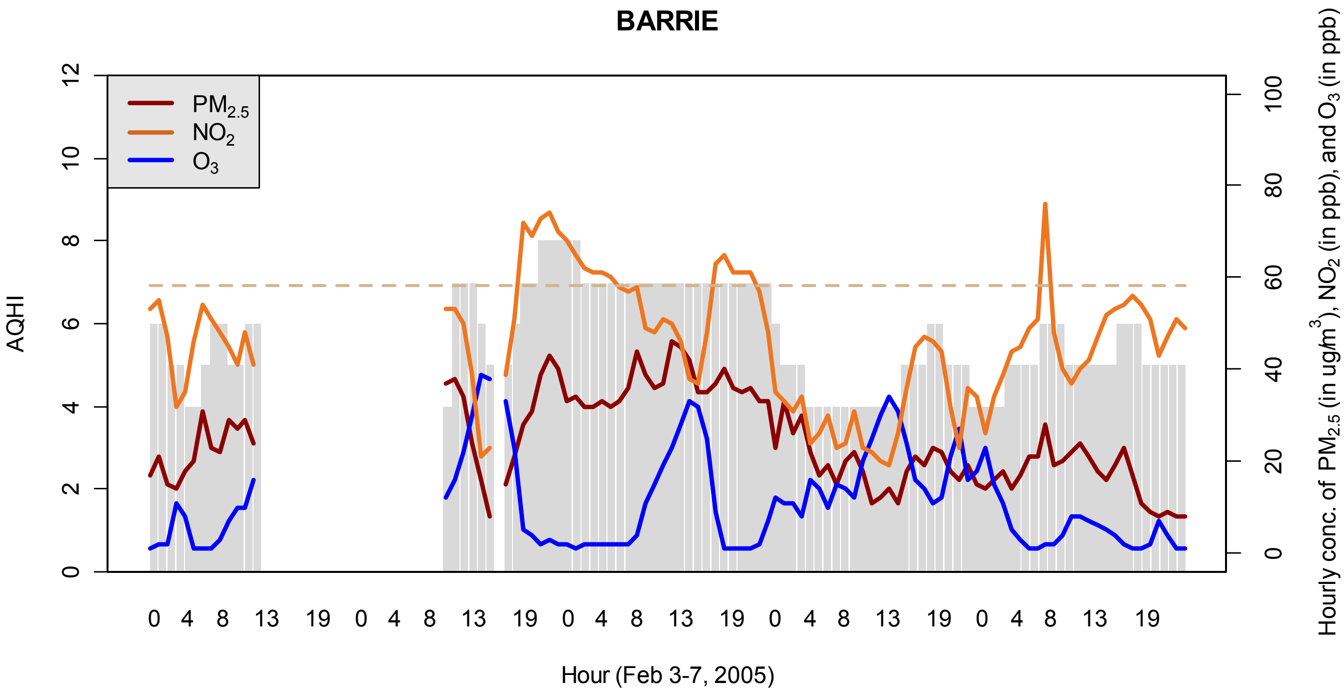
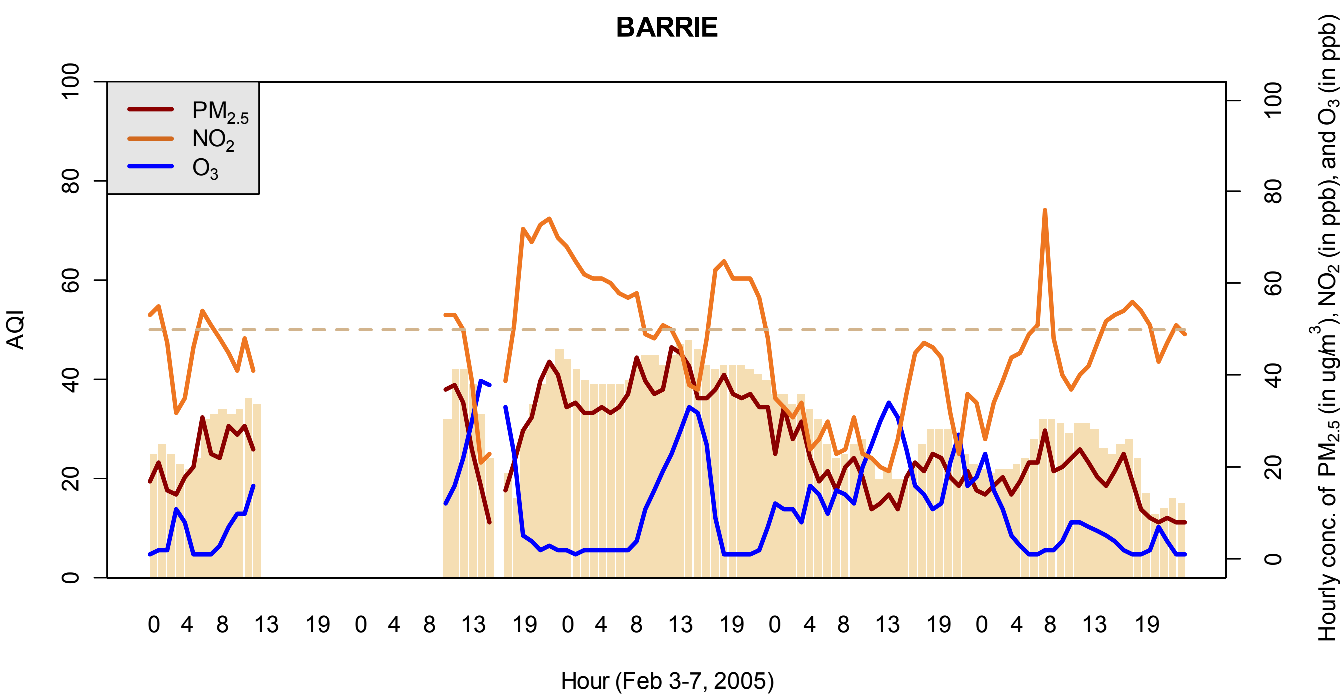


Figure 7 (E). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Barrie, Toronto, and Sarnia, February 3-7, 2005. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.





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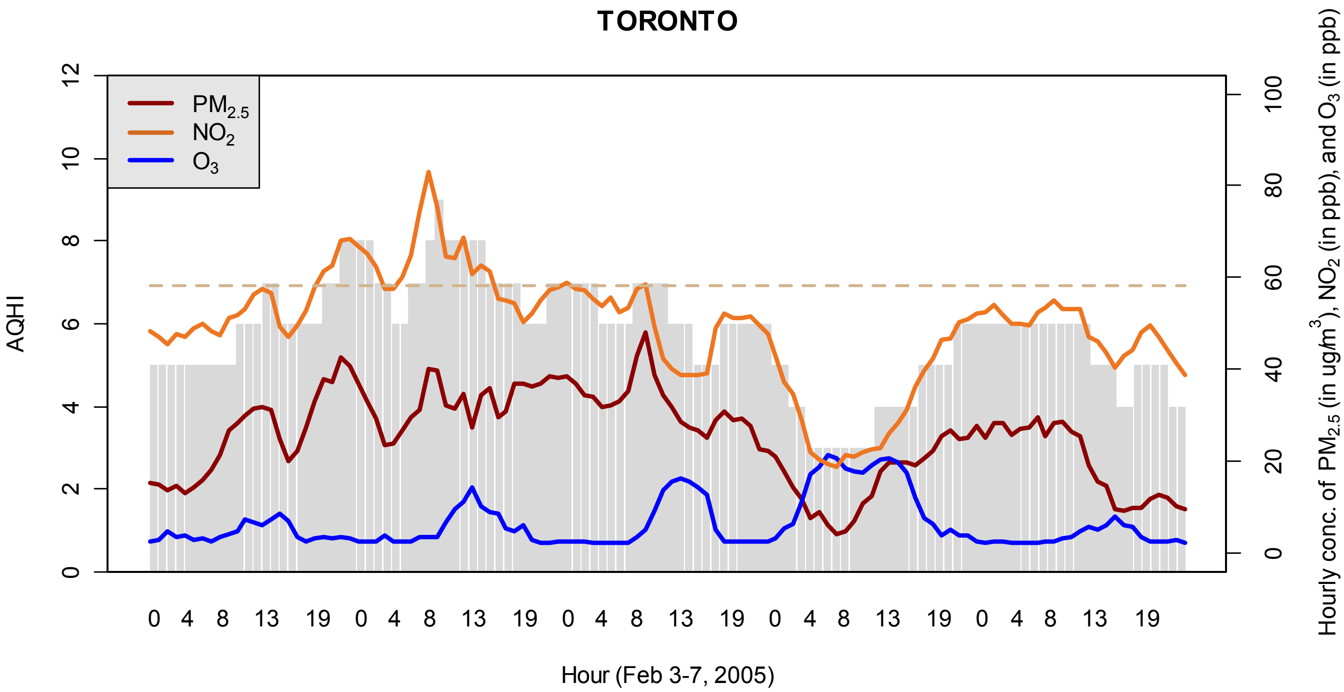

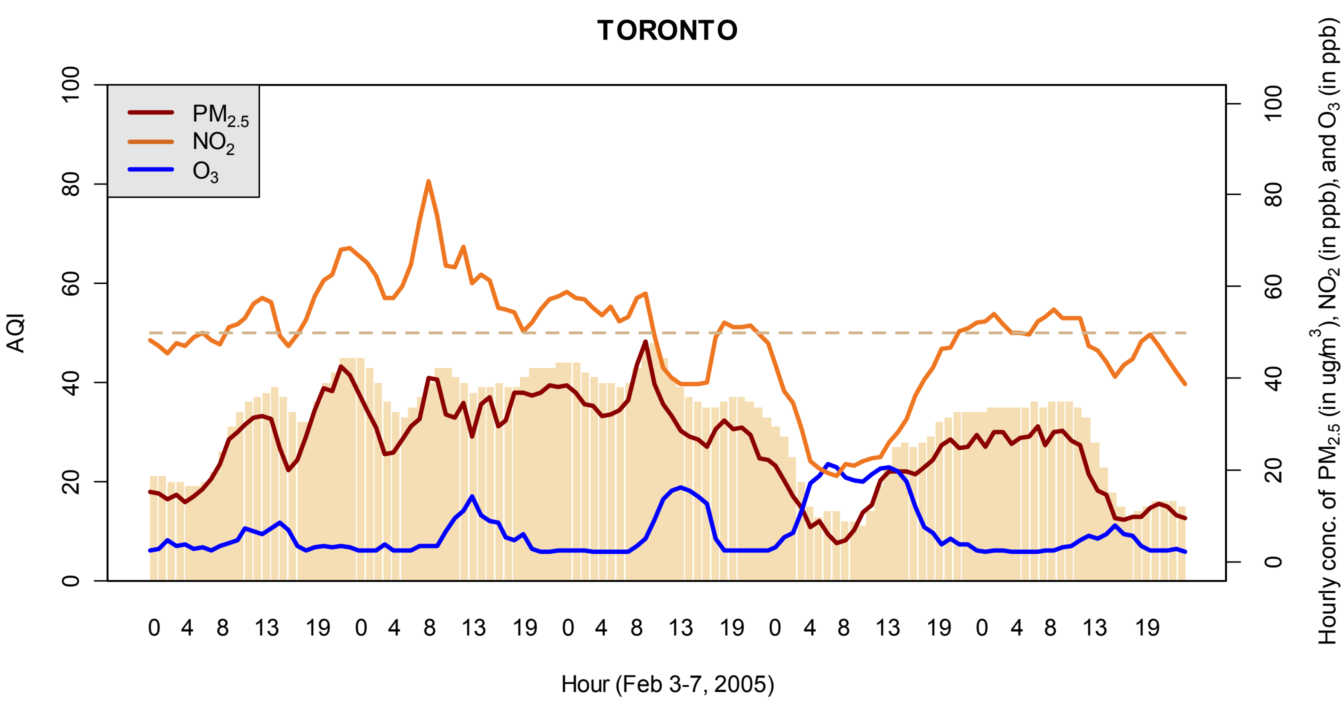

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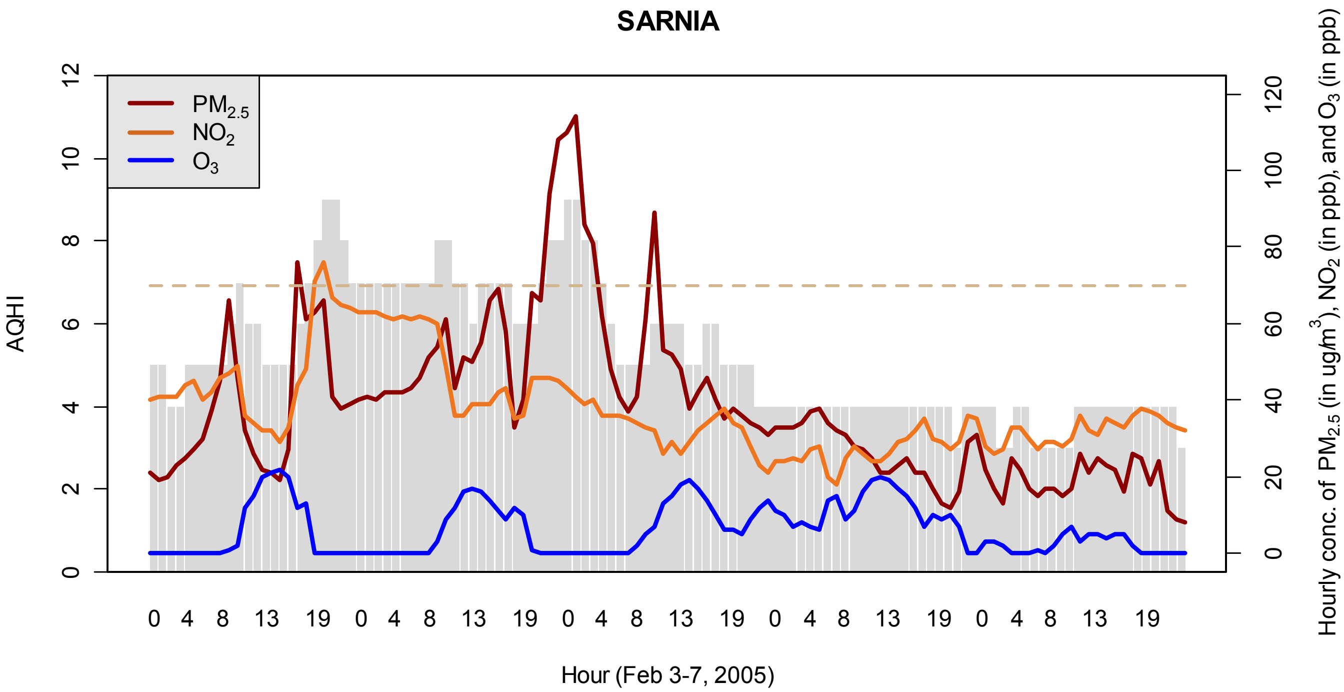


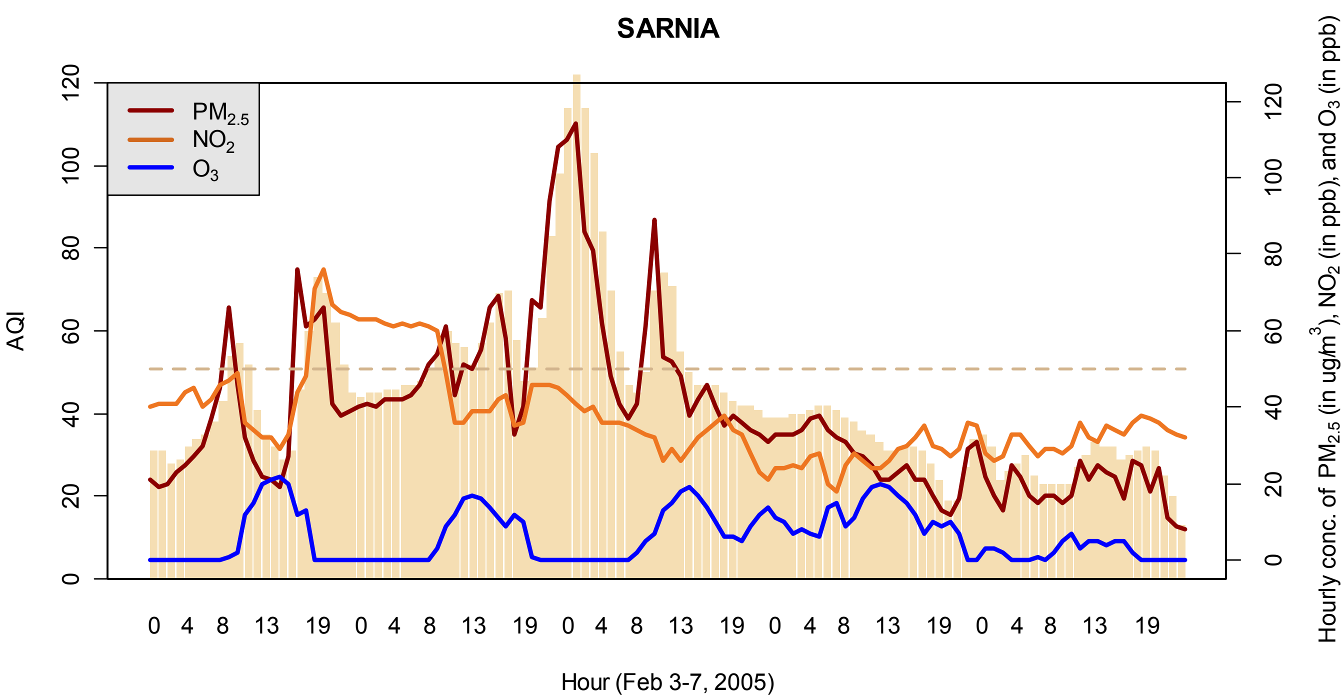
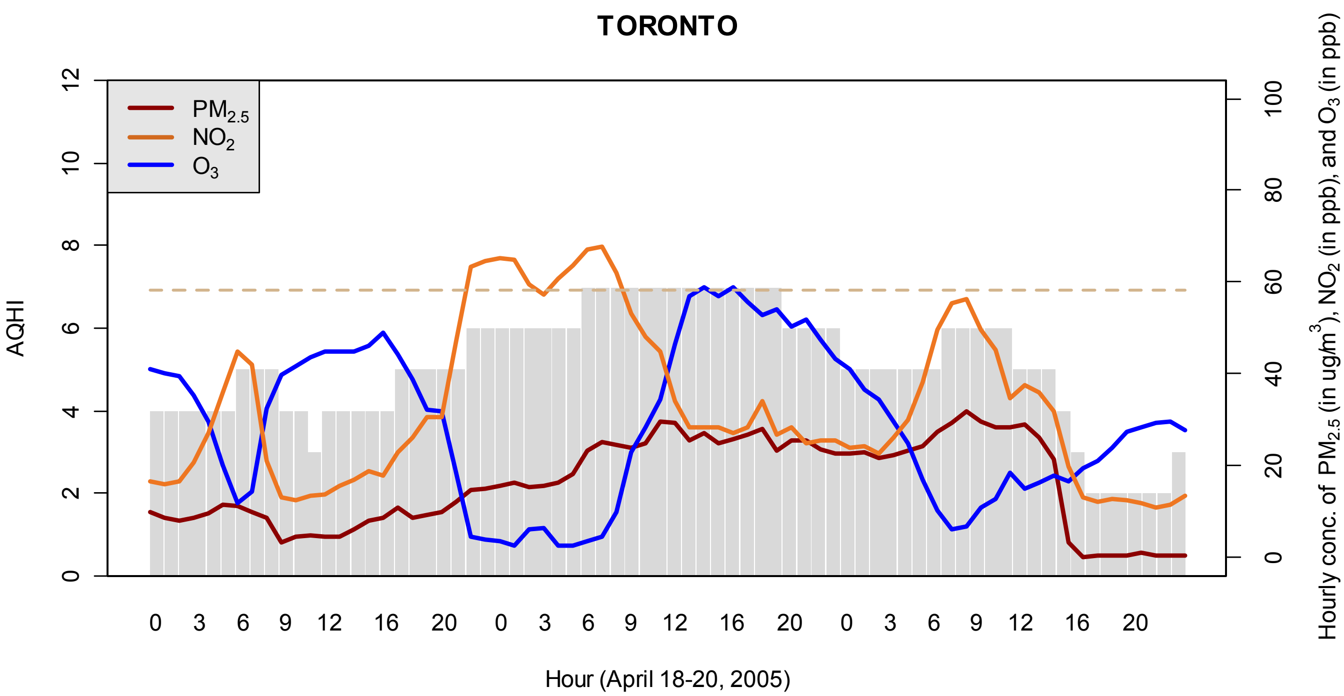


Figure 7 (F). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Toronto, April 18-20, 2005. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



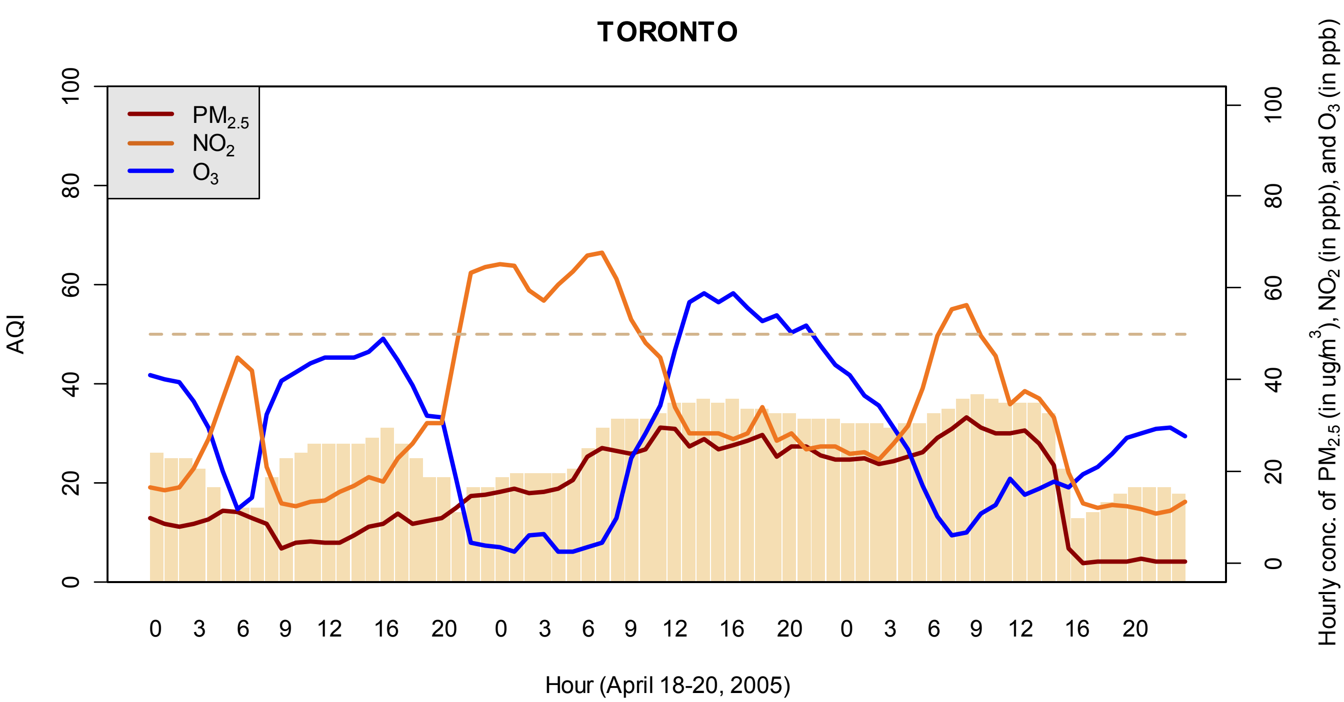
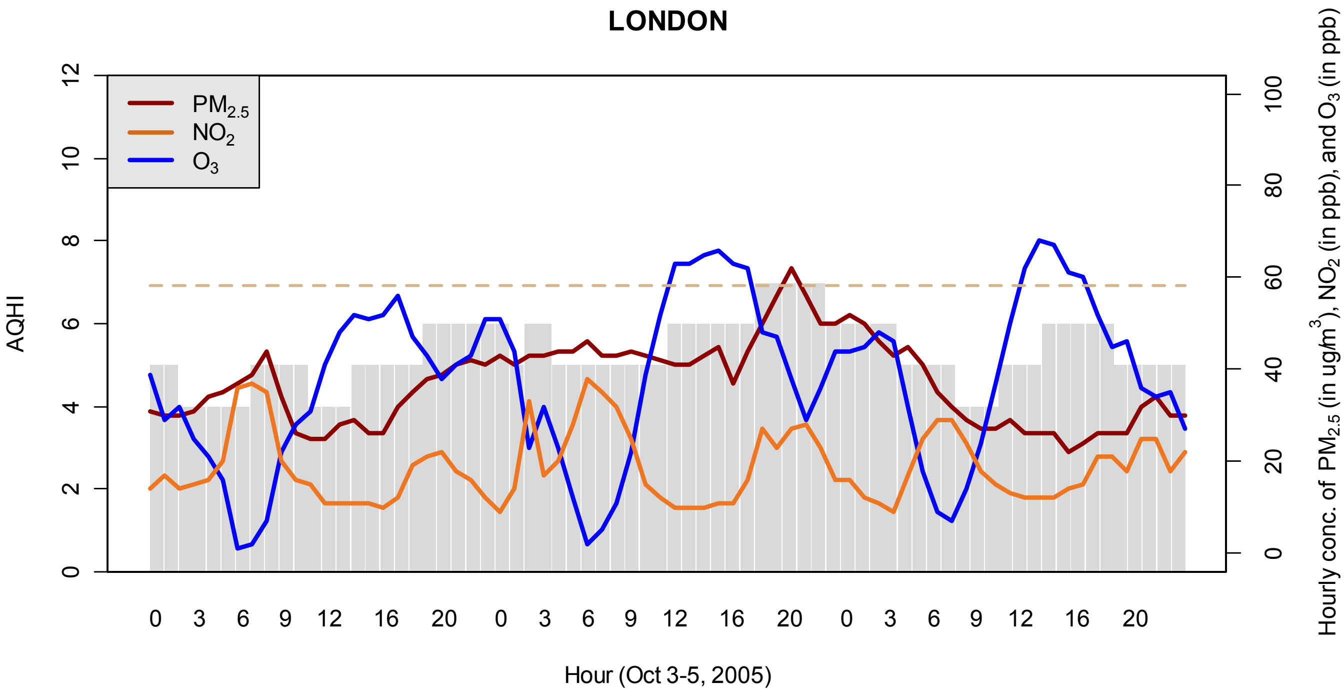


Figure 7 (G). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in London, October 3-5, 2005. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



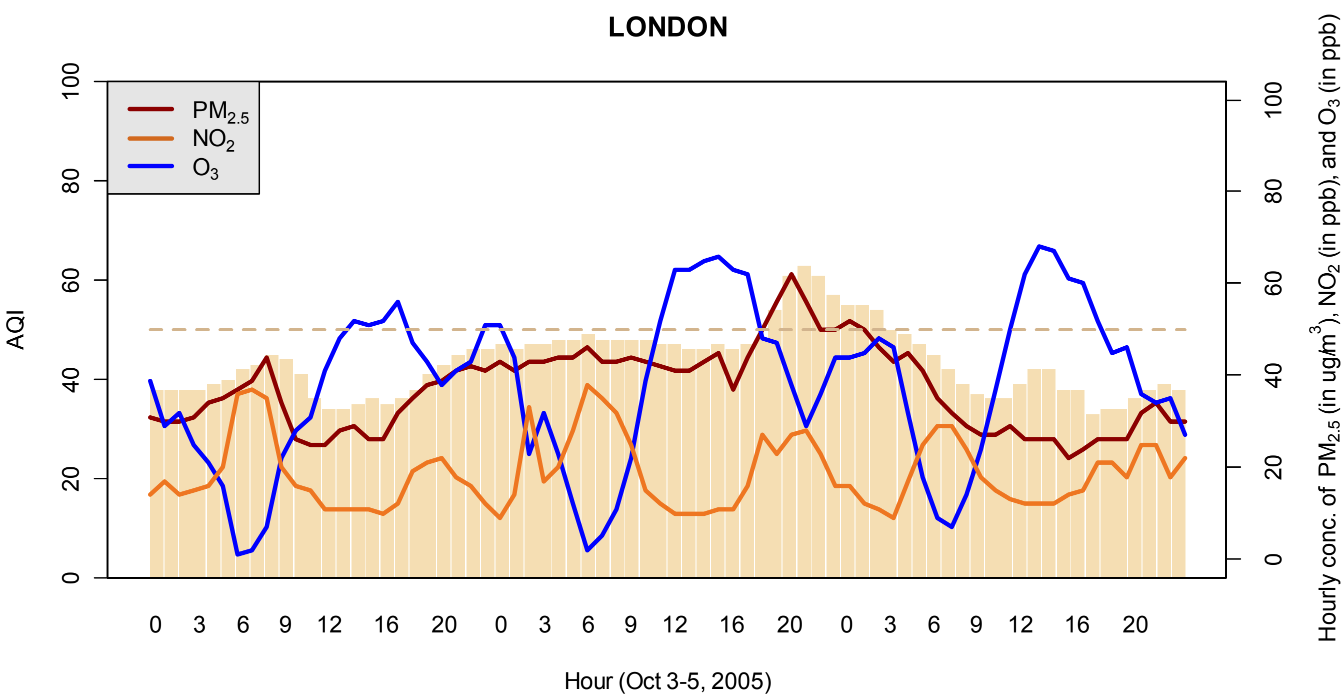
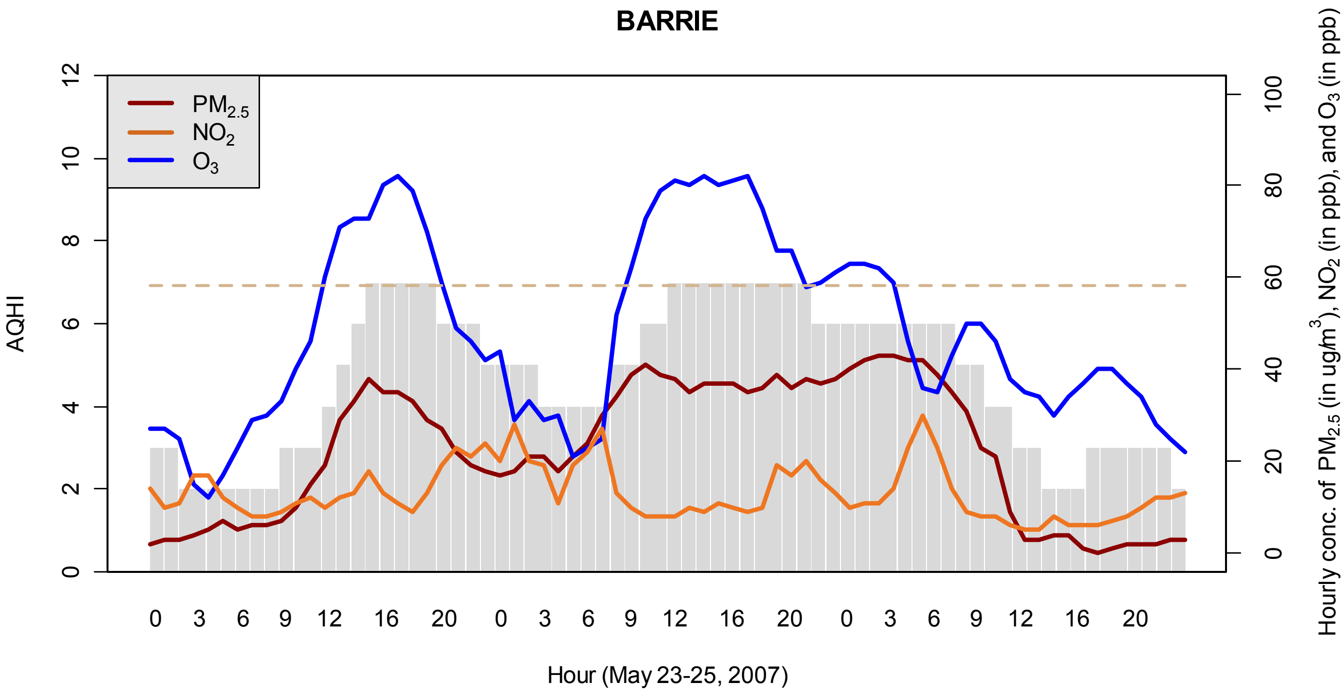


Figure 7 (H). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Barrie, Tiverton, and Sarnia, May 23-25, 2007. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



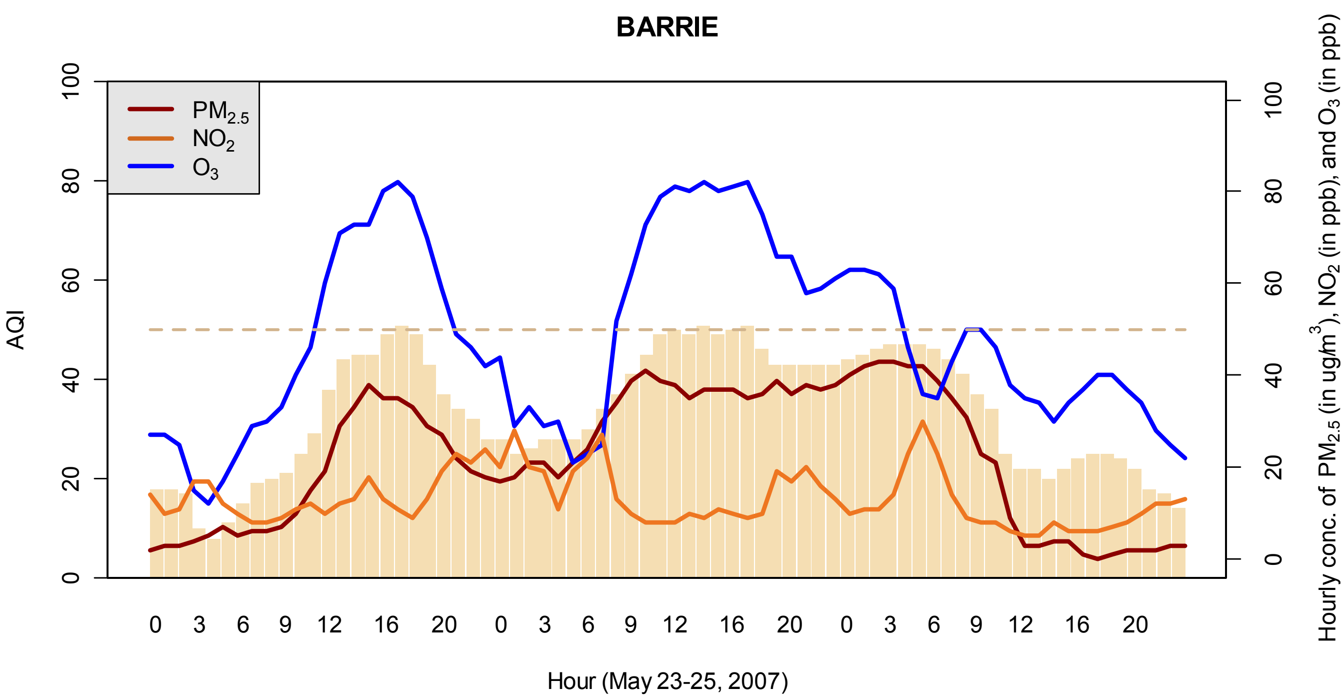
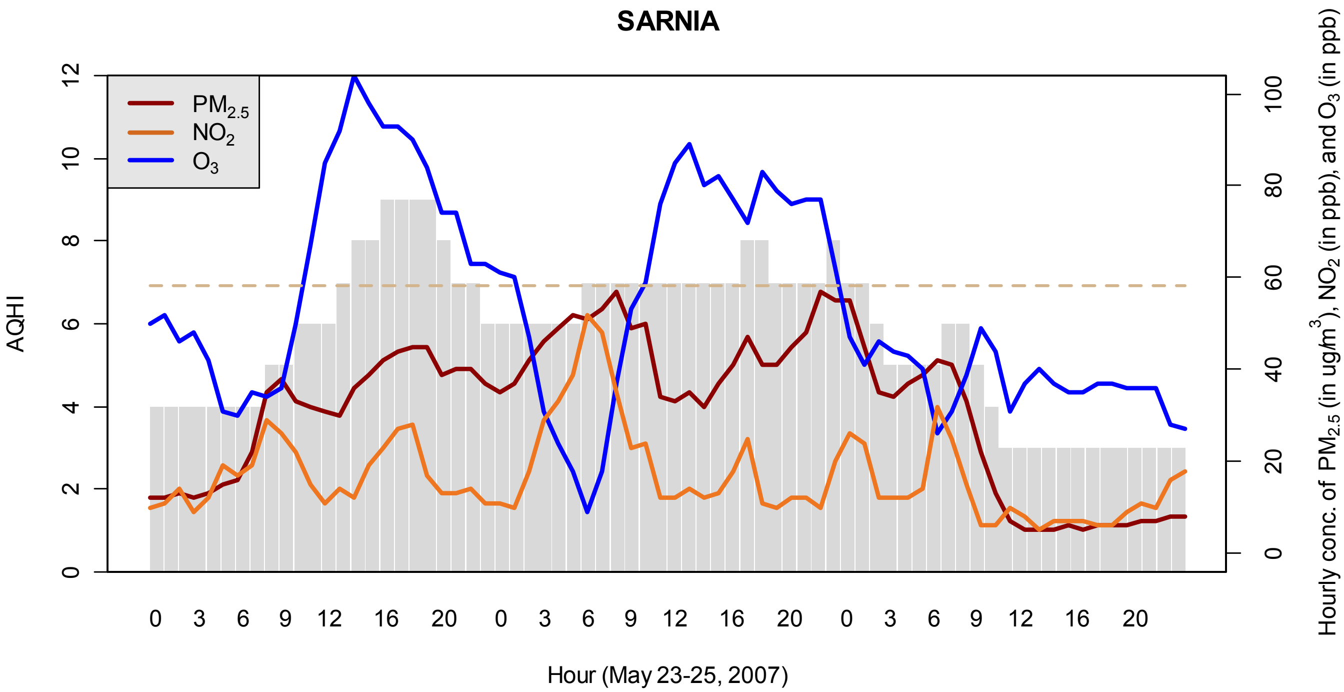
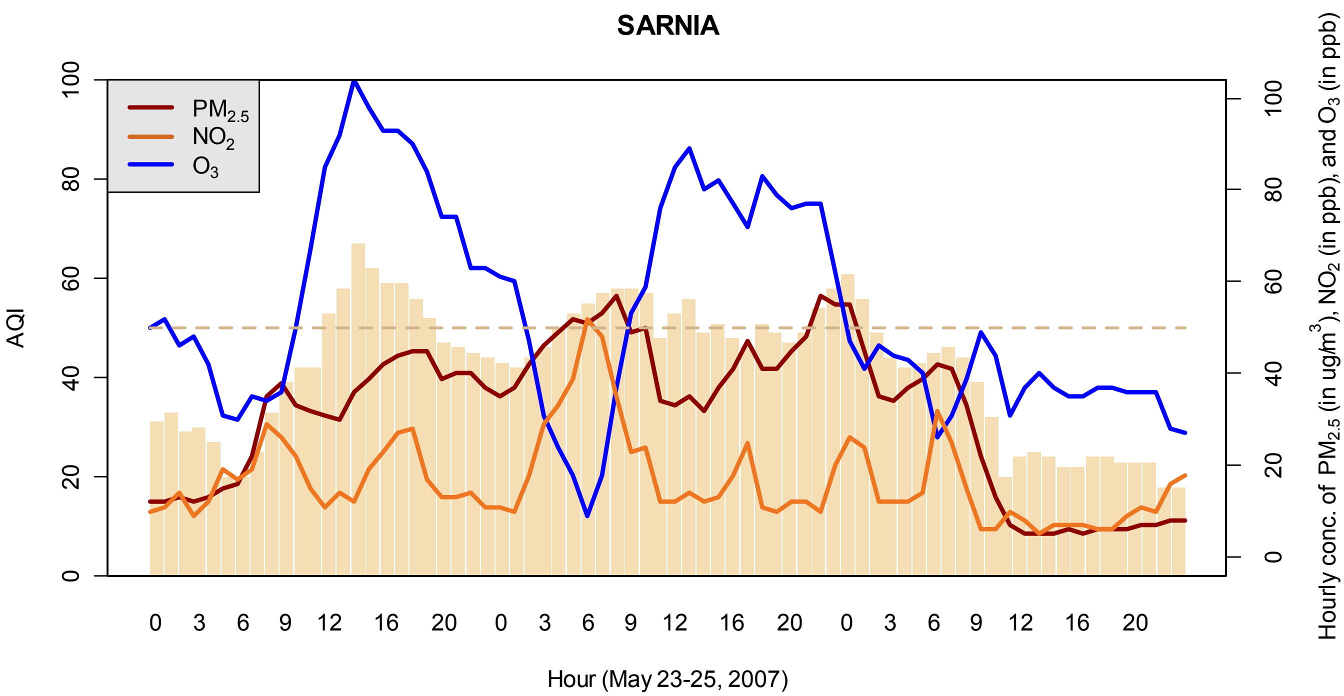


Figure 7 (H). continued





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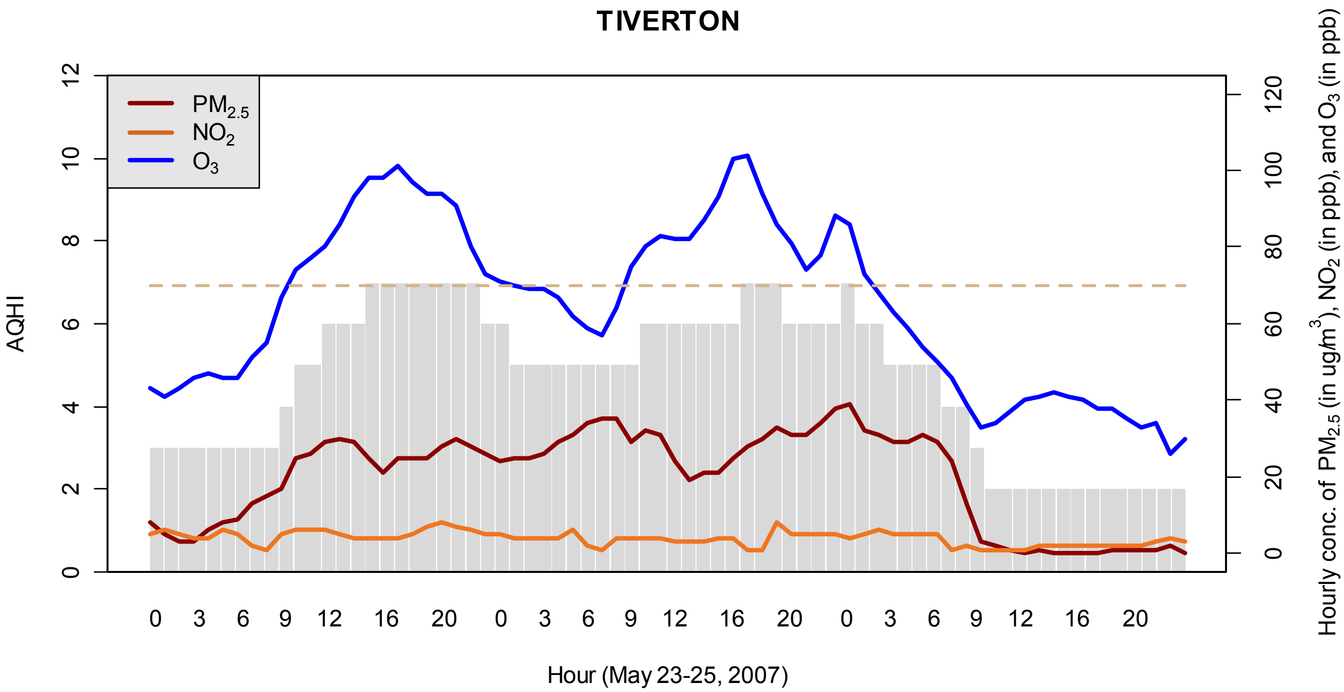


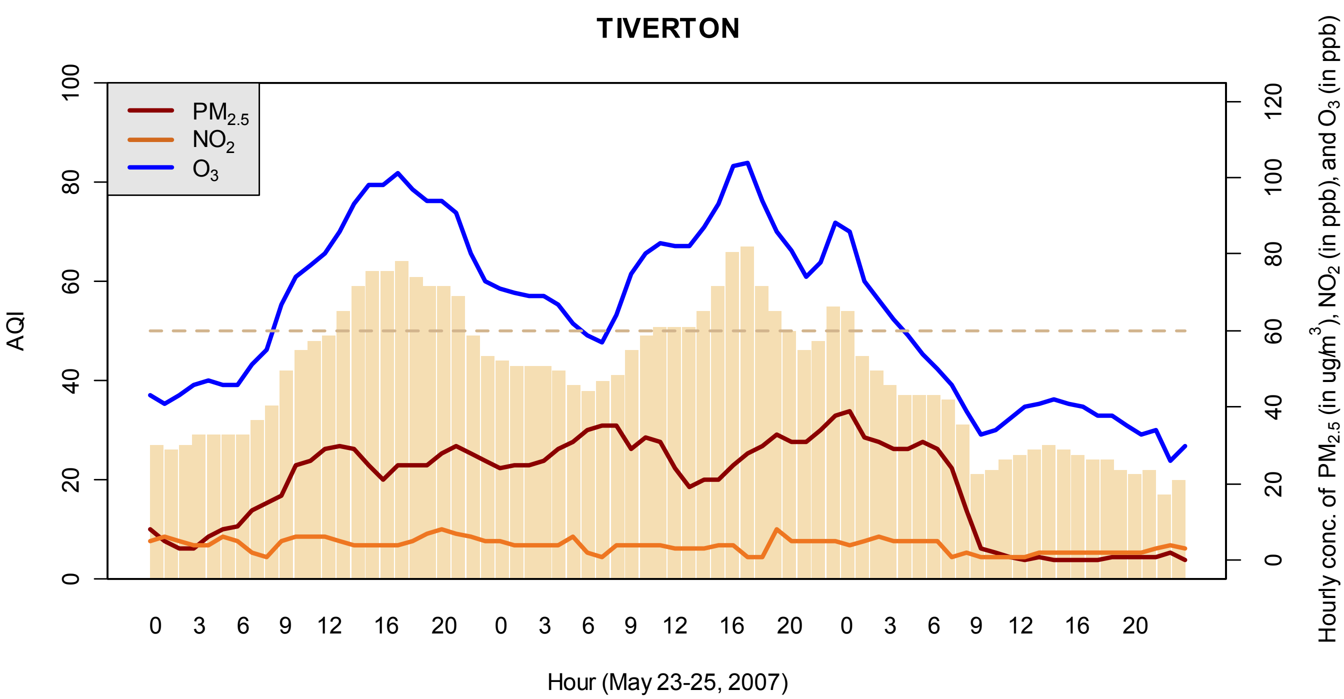
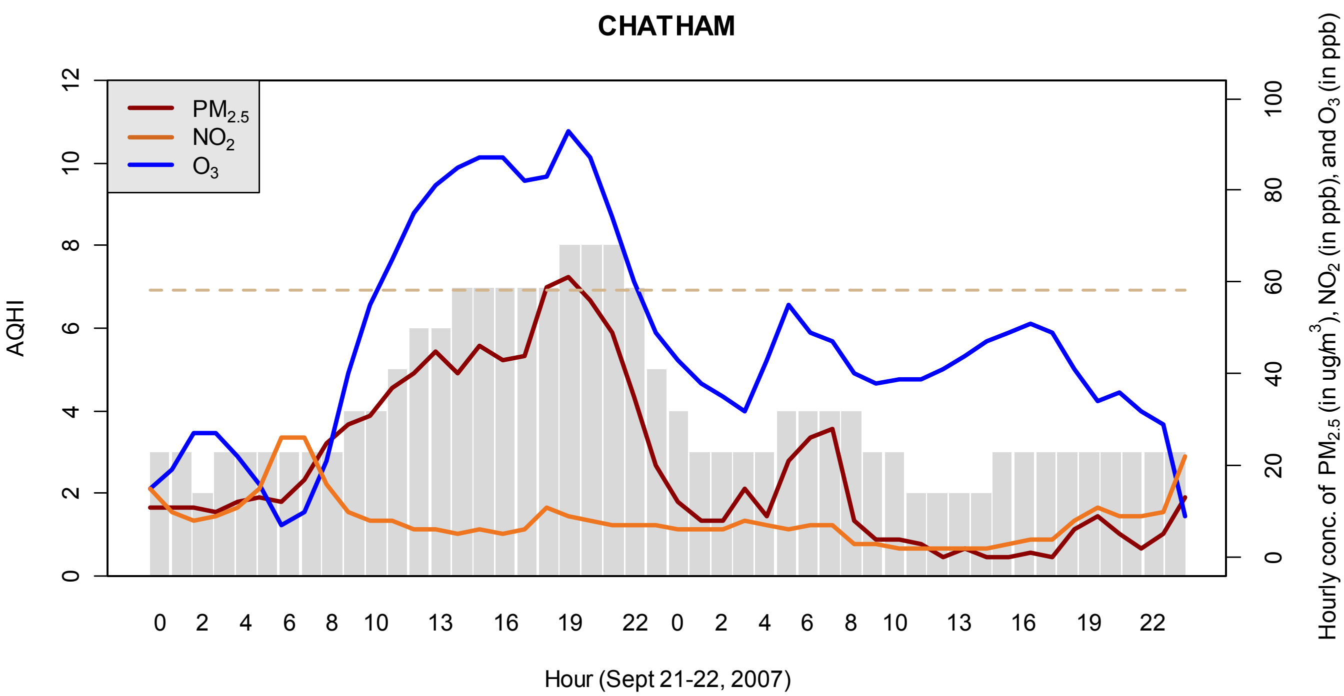


Figure 7 (I). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Chatham and Burlington, September 21-22, 2007. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



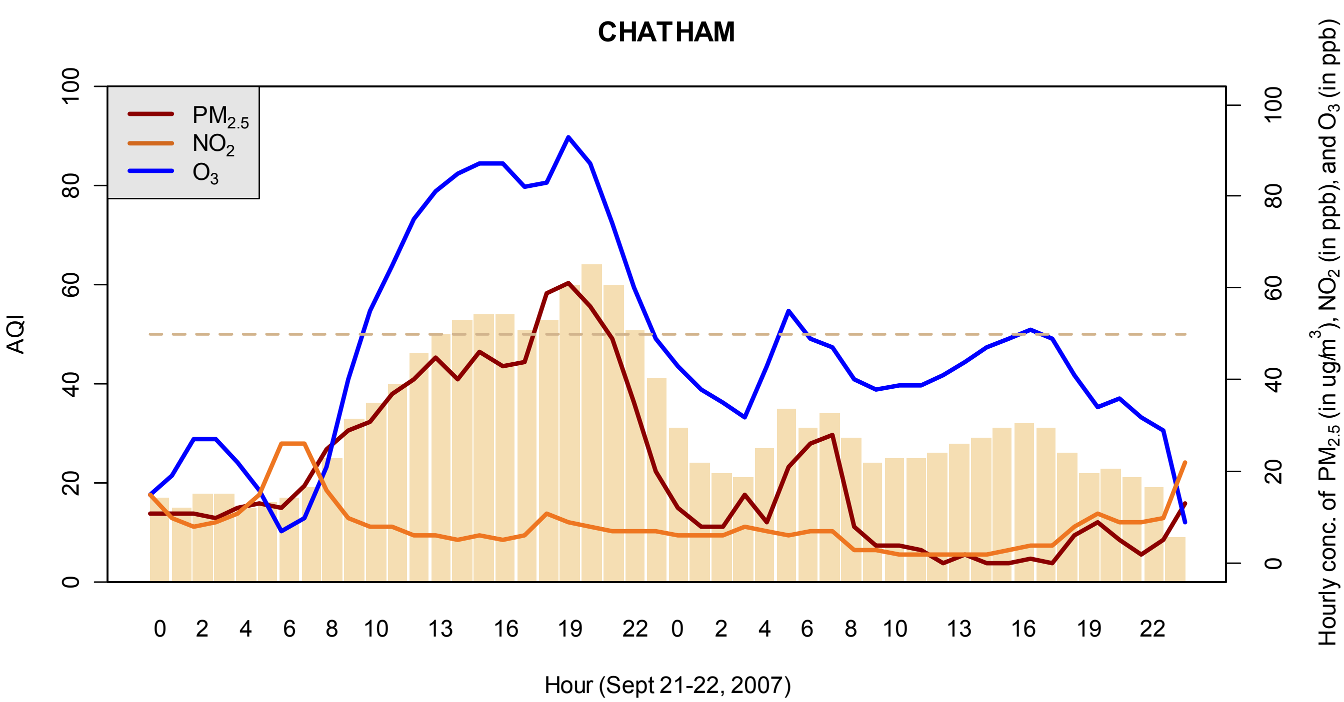
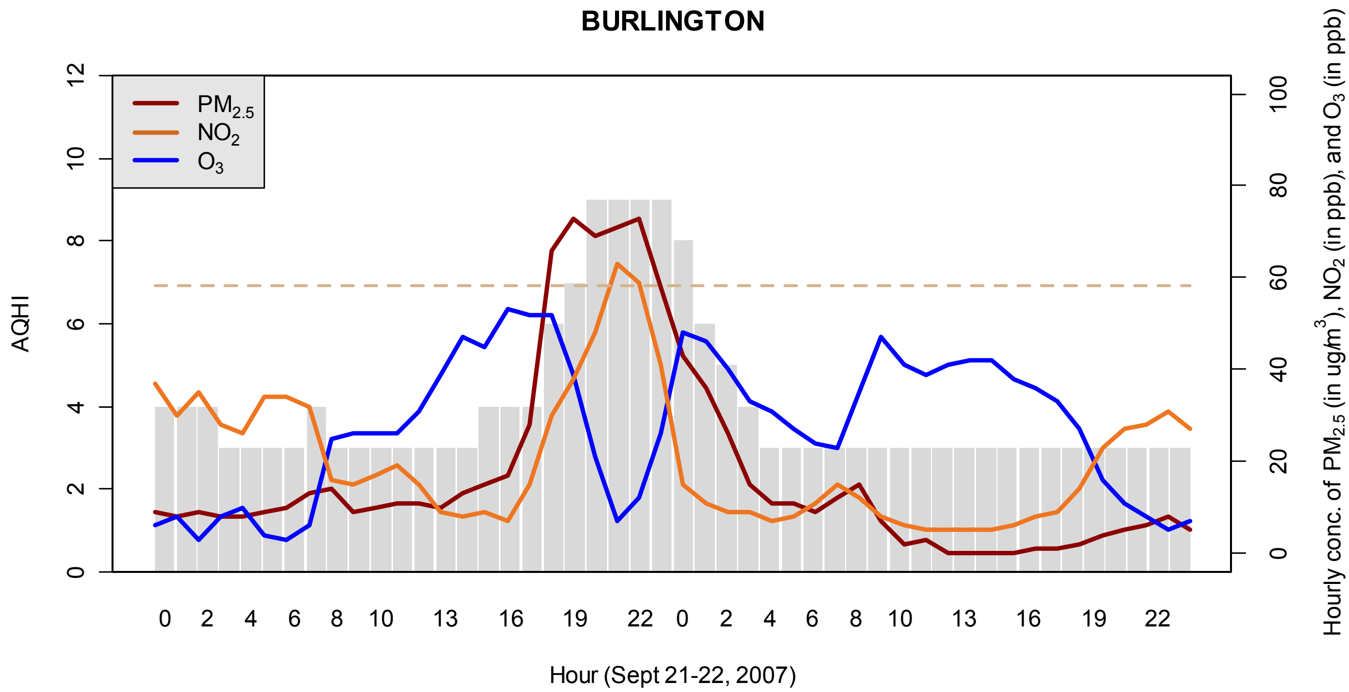


Figure 7 (I). continued



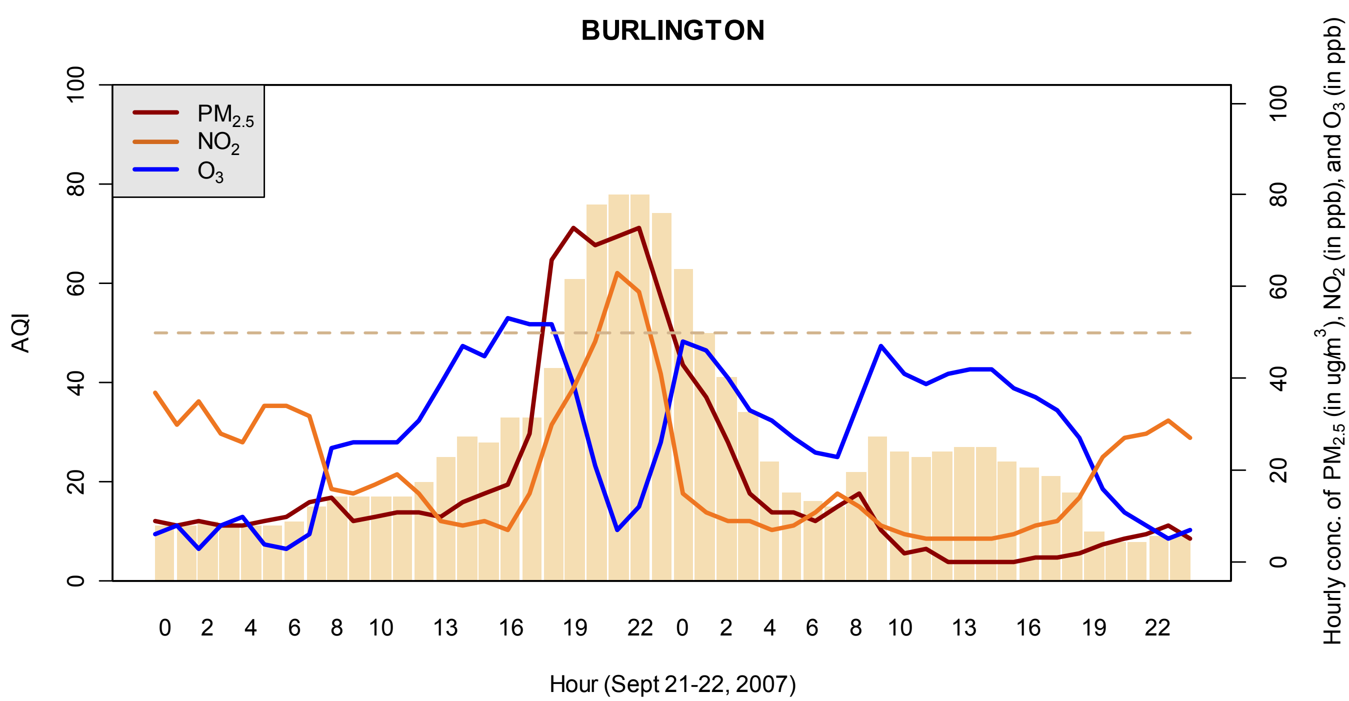
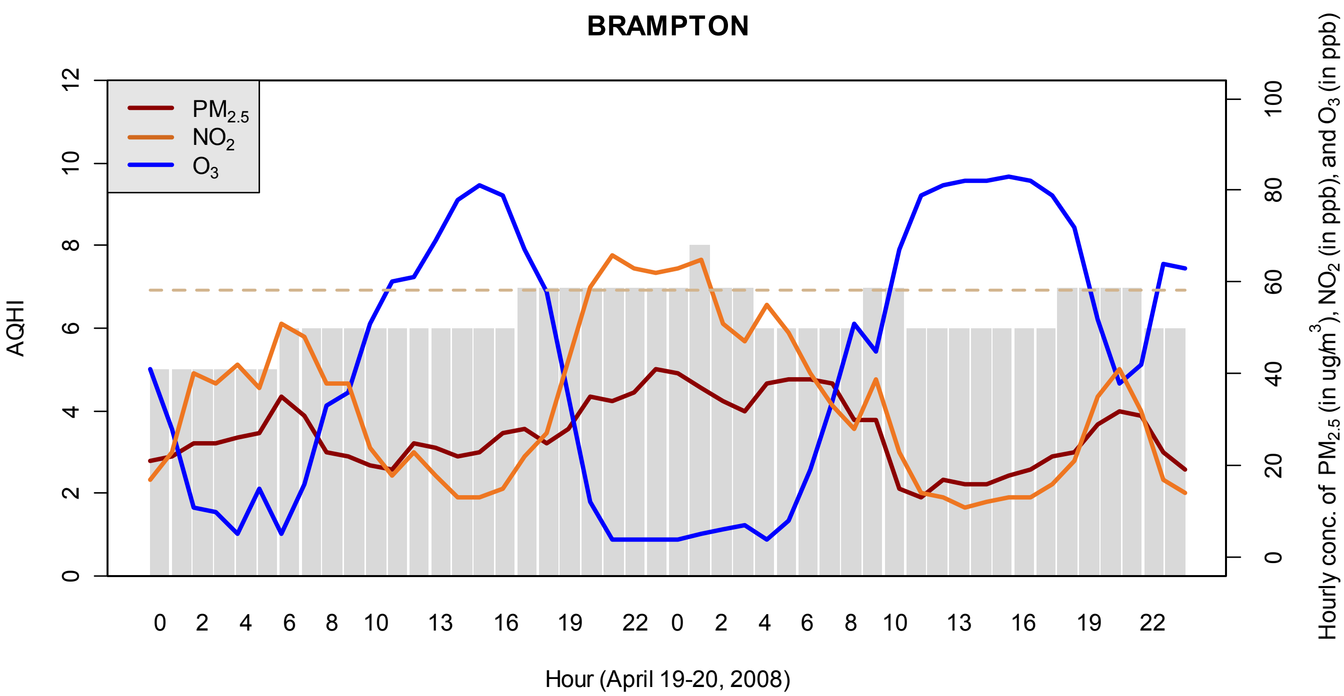


Figure 7 (J). Temporal variability of hourly AQHI, AQI, $PM_{2.5}$, O_3, and NO_2 during an extreme air pollution episode occurred in Brampton, Hamilton, Kingston, and Toronto, April 19-20, 2008. For any hourin which AQHI was unavailable, AQI, $PM_{2.5}$, O_3, and NO_2 were assigned blank space.



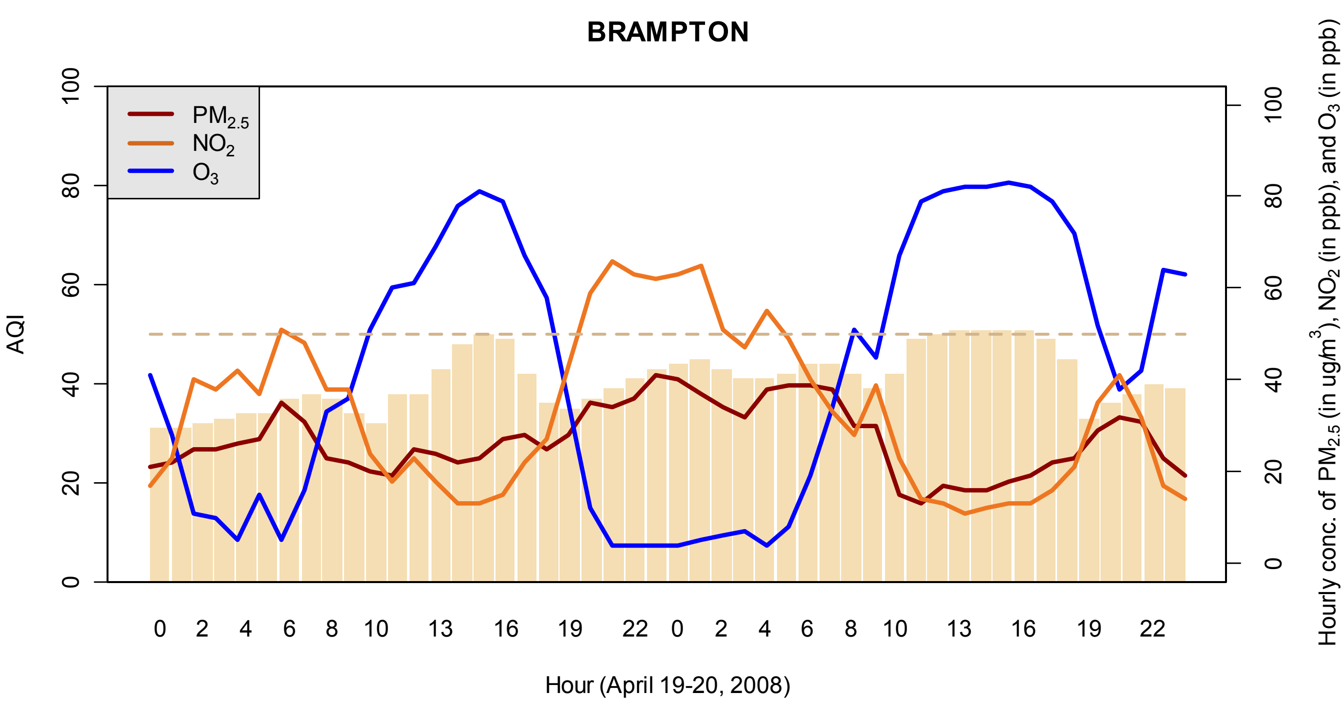
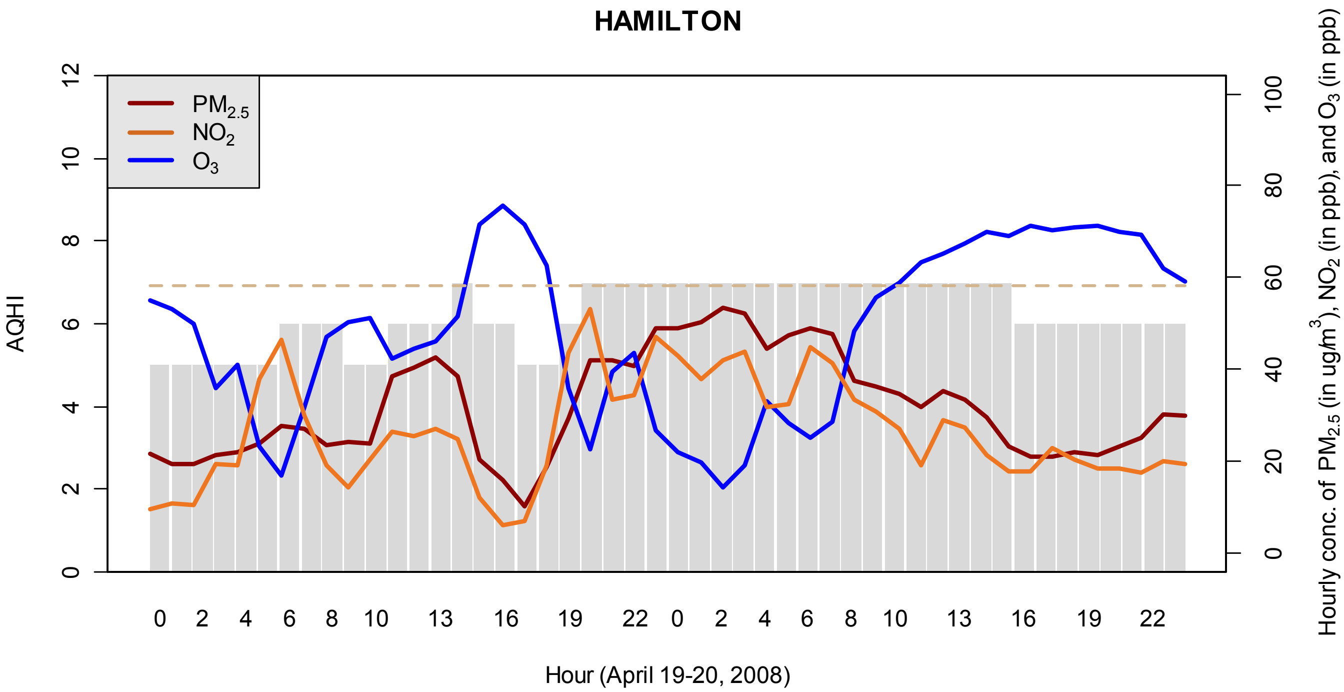


Figure 7 (J). continued



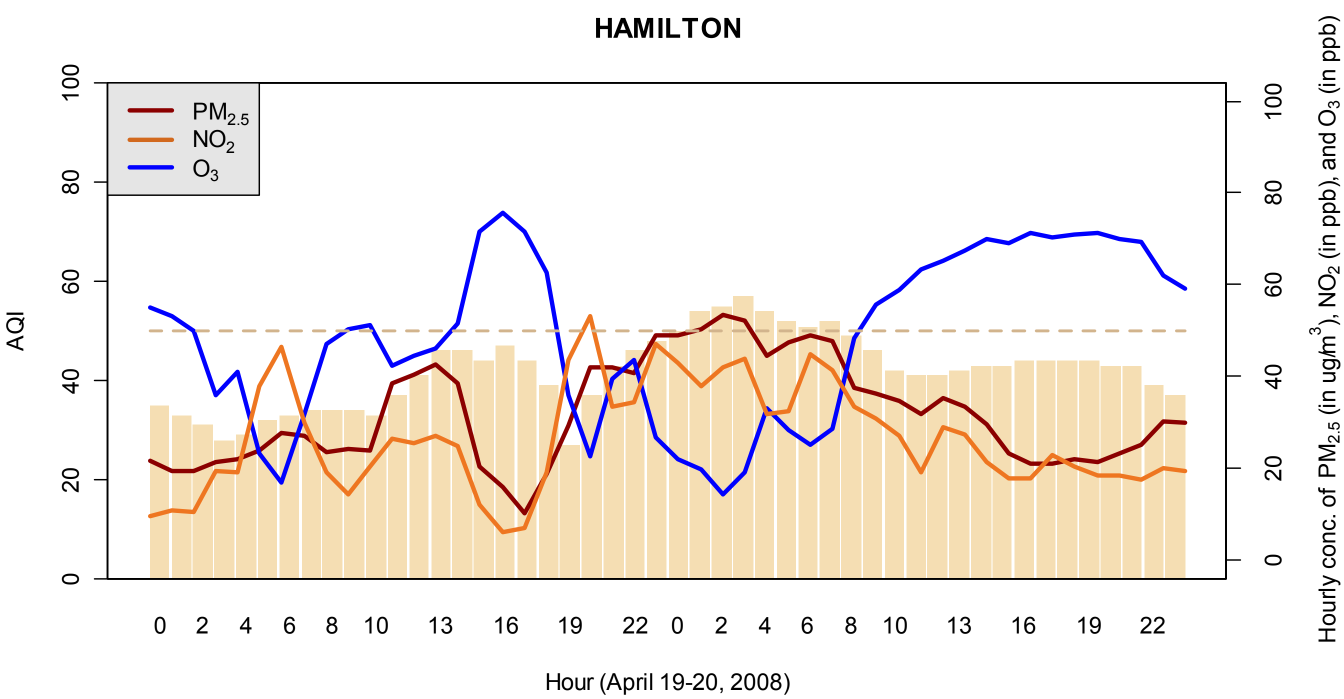
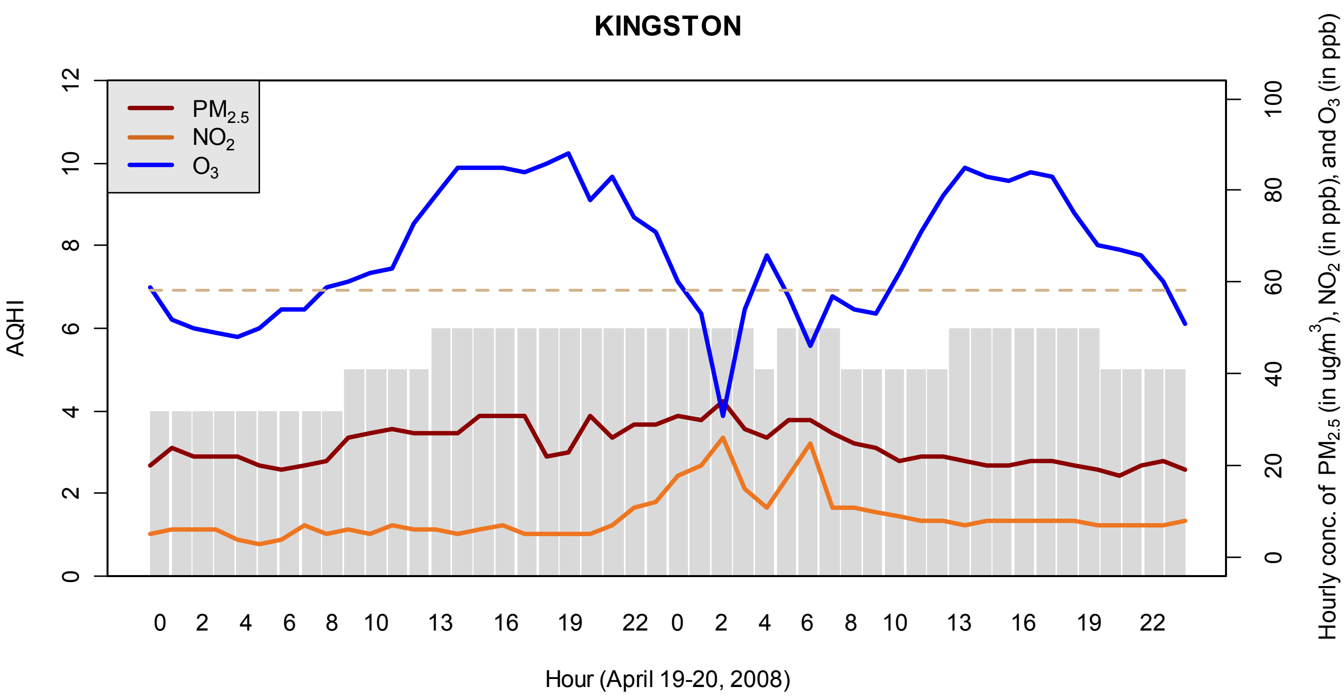


Figure 7 (J). continued



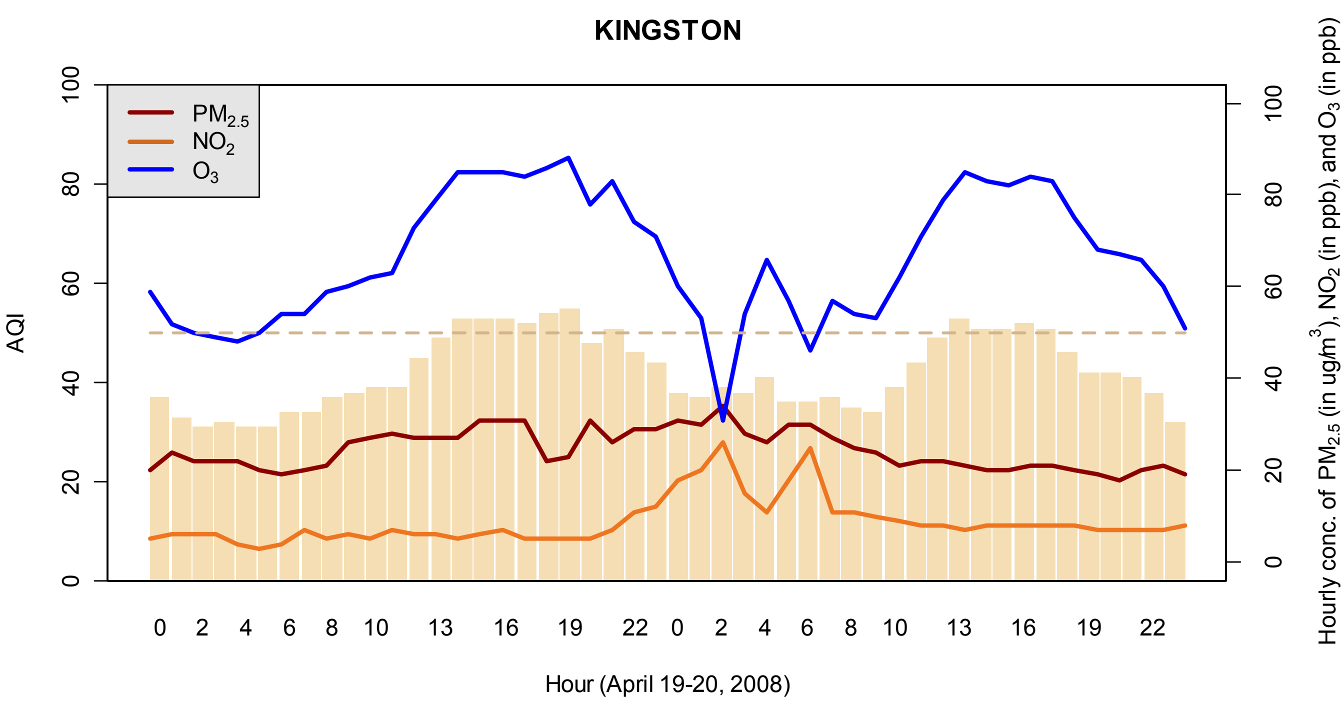
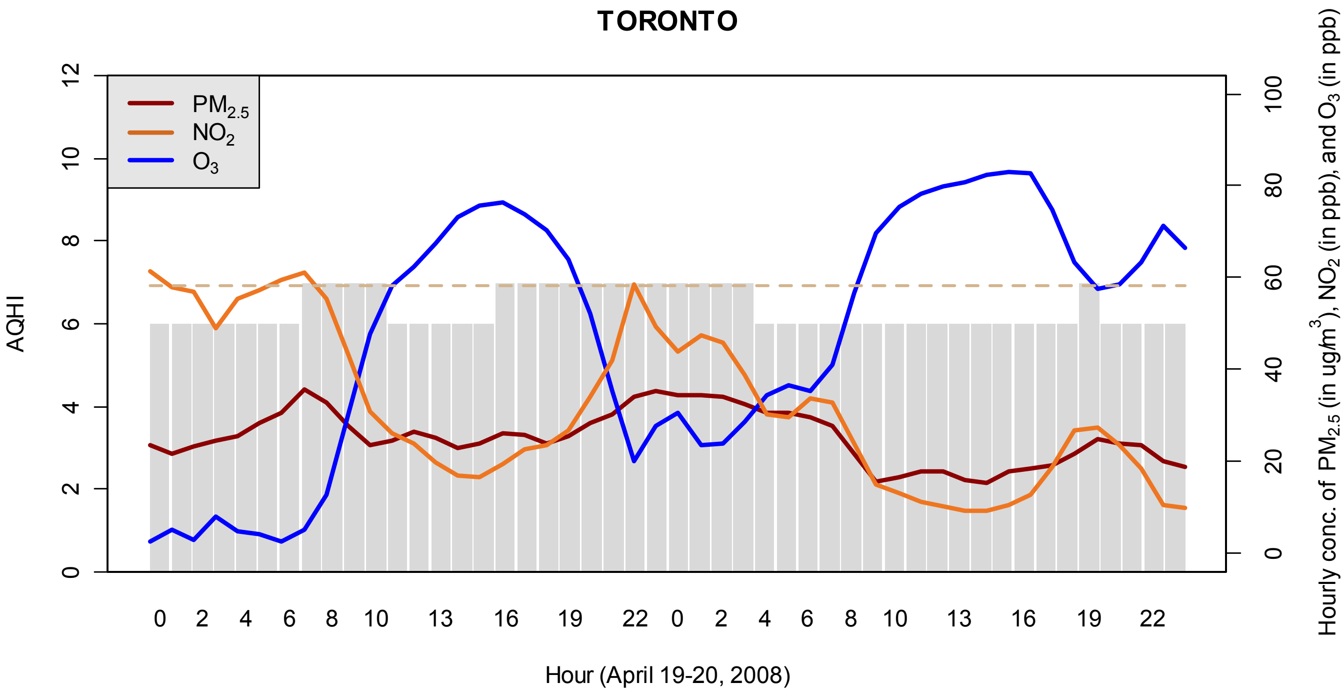


Figure 7 (J). continued



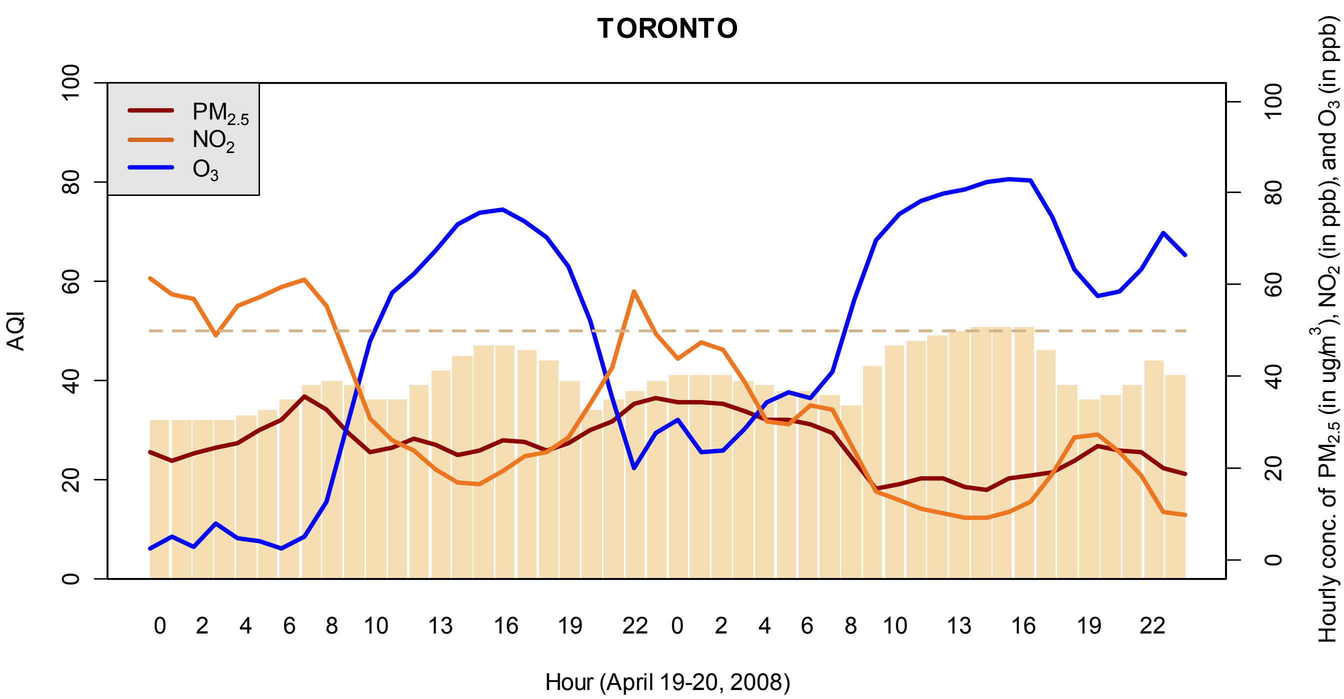
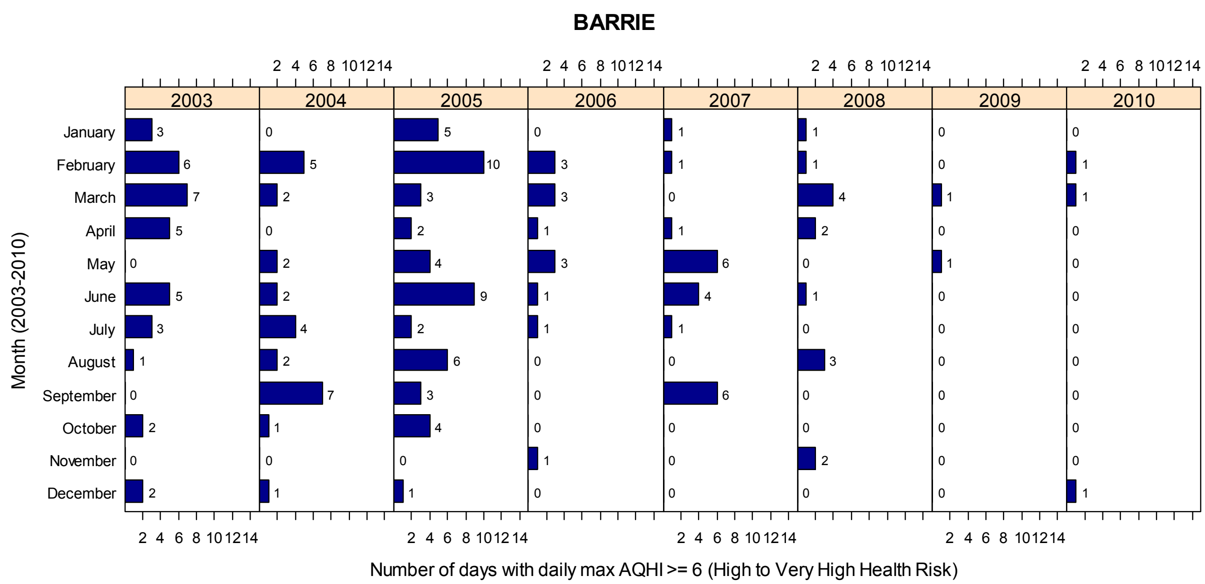


Figure 8. Sensitivity analysis on reclassifying high AQHI days according to AQHI $\geq$ 6: monthly distribution of high AQHI days (daily maximum AQHI $\geq$ 6) and high AQI days (daily maximum AQI $\geq$ 50) across Ontario from 2003 to 2010. AQI data were restricted to the months in which AQHI was also present in order to facilitate comparison. For any month where AQHI data were absent, the number of high AQHI and high AQI days were assigned blank space. Five cities (Dorset, Morrisburg, Parry Sound, Petawawa, and Port Stanley) with air quality monitoring stations are not shown here because data were missing from 2003 to 2010 for one or more air pollutant required for calculating AQHI.



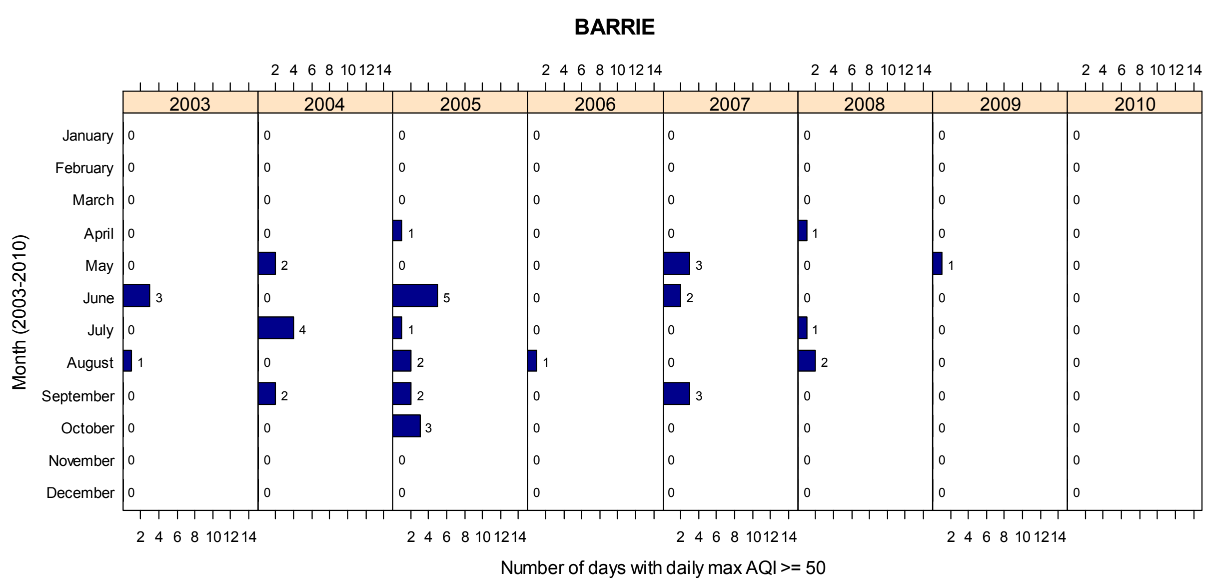
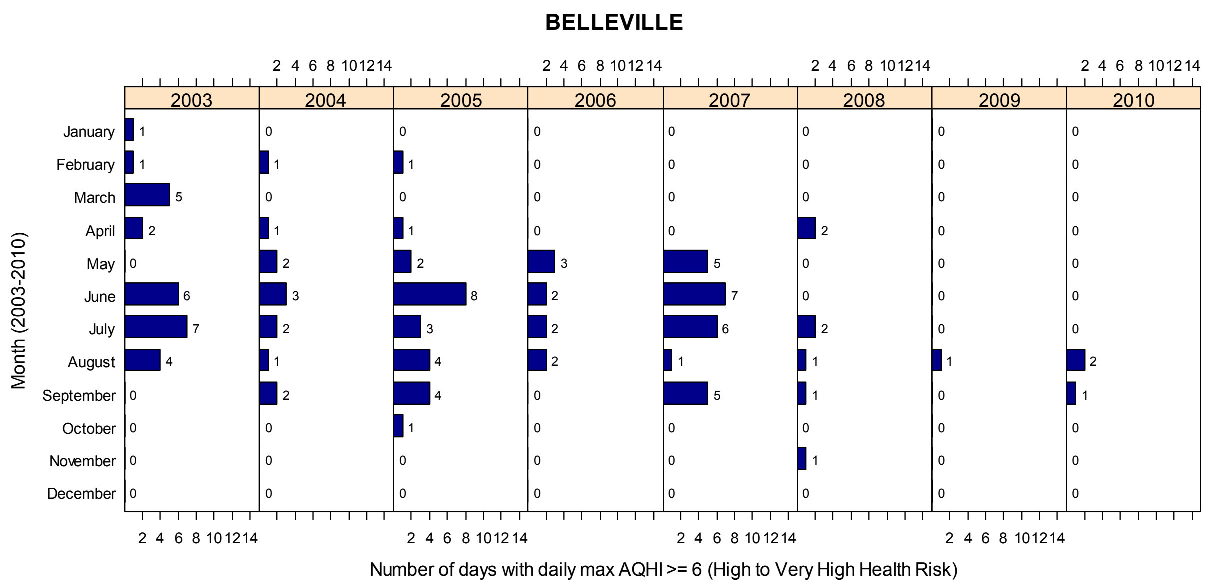


Figure 8. continued



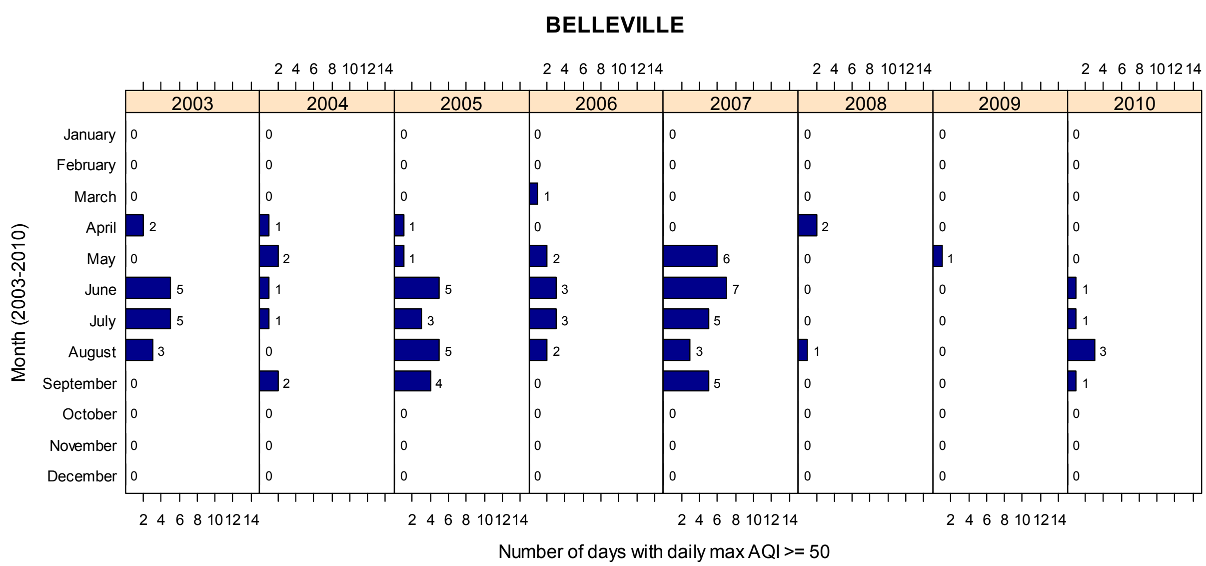
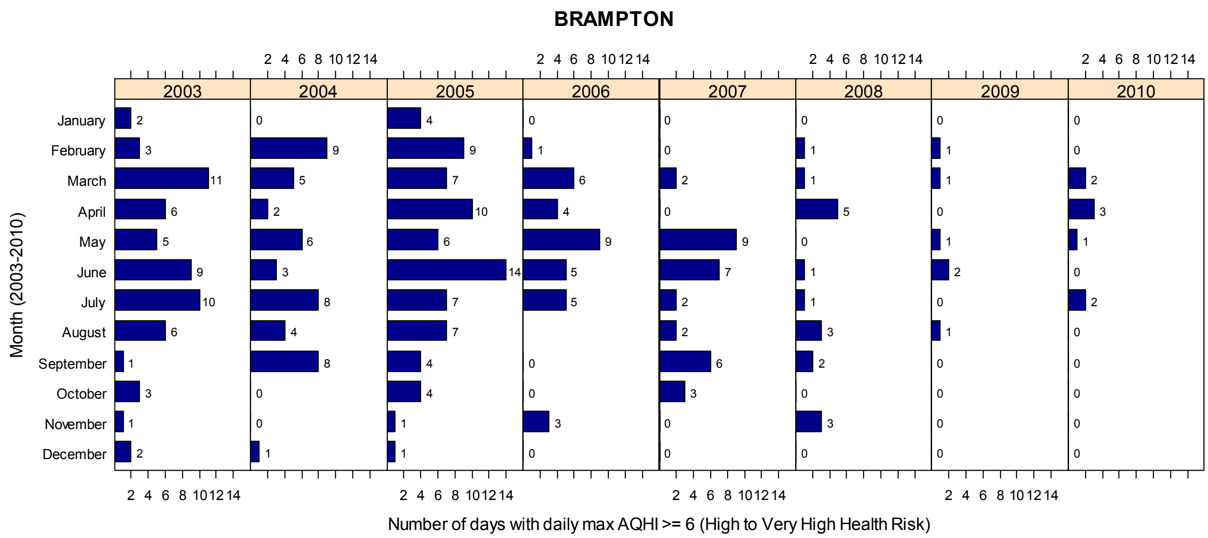
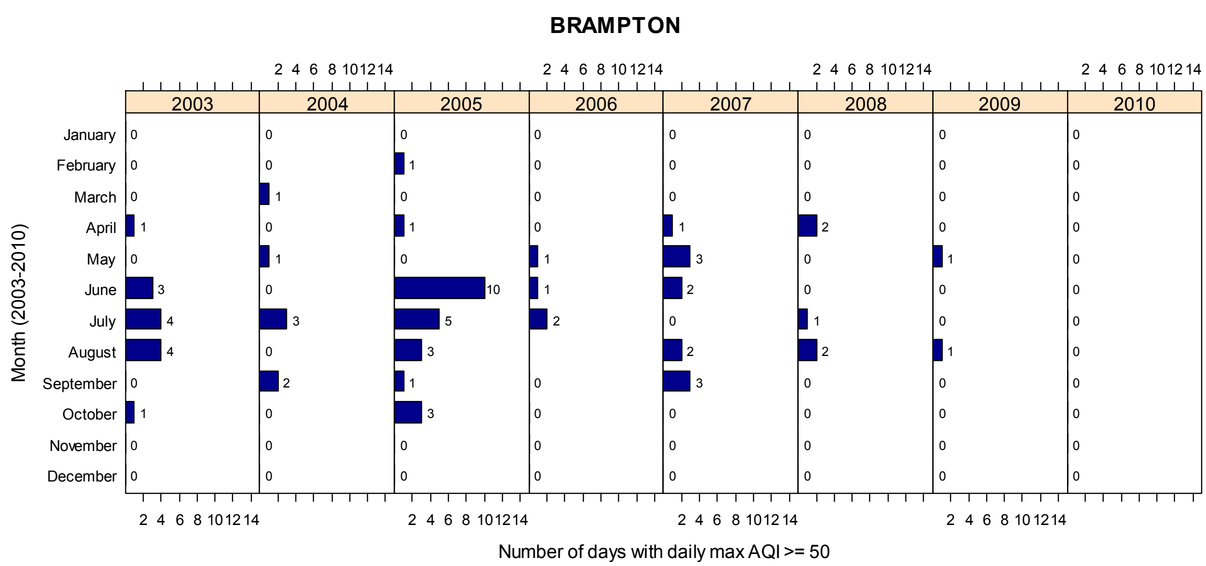


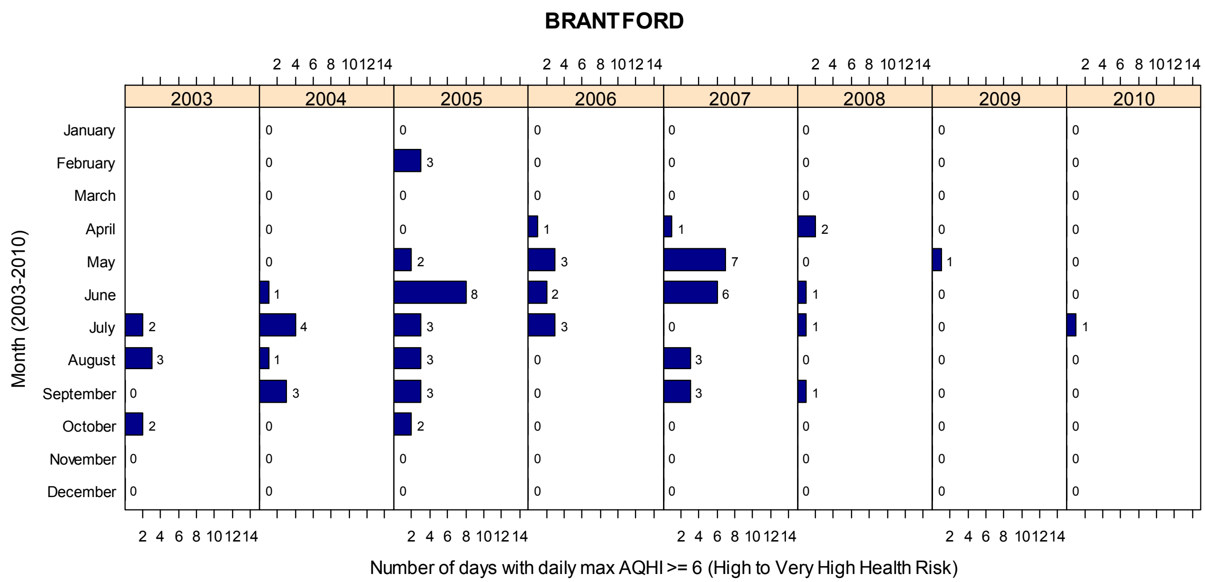
Figure 8. continued

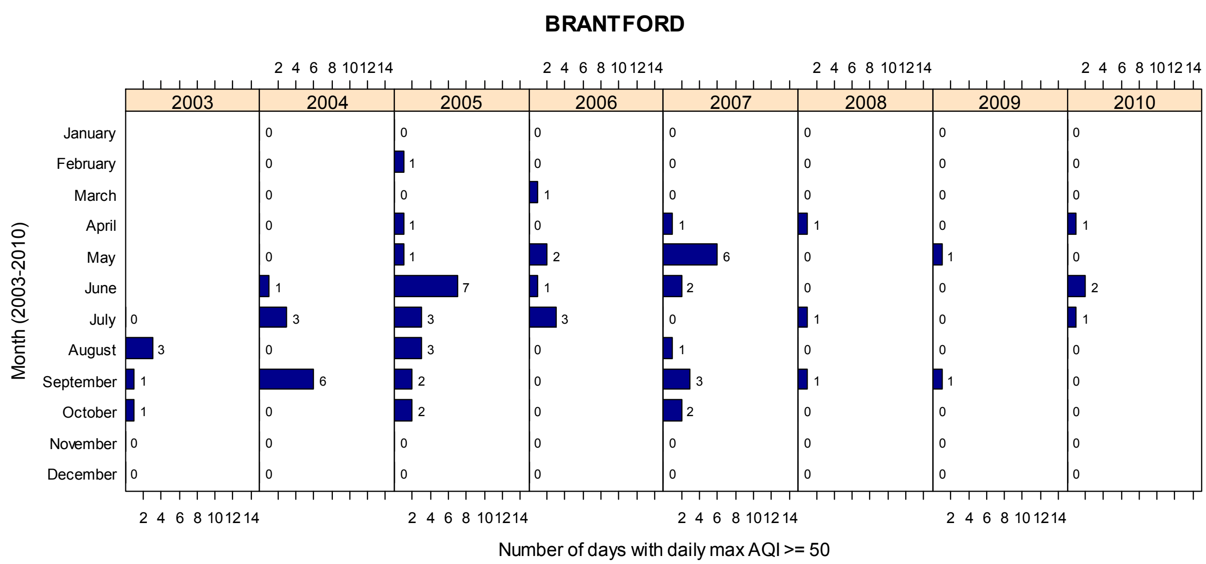




* AQHI was not available in August 2006 in Brampton, Ontario as indicated by blank space

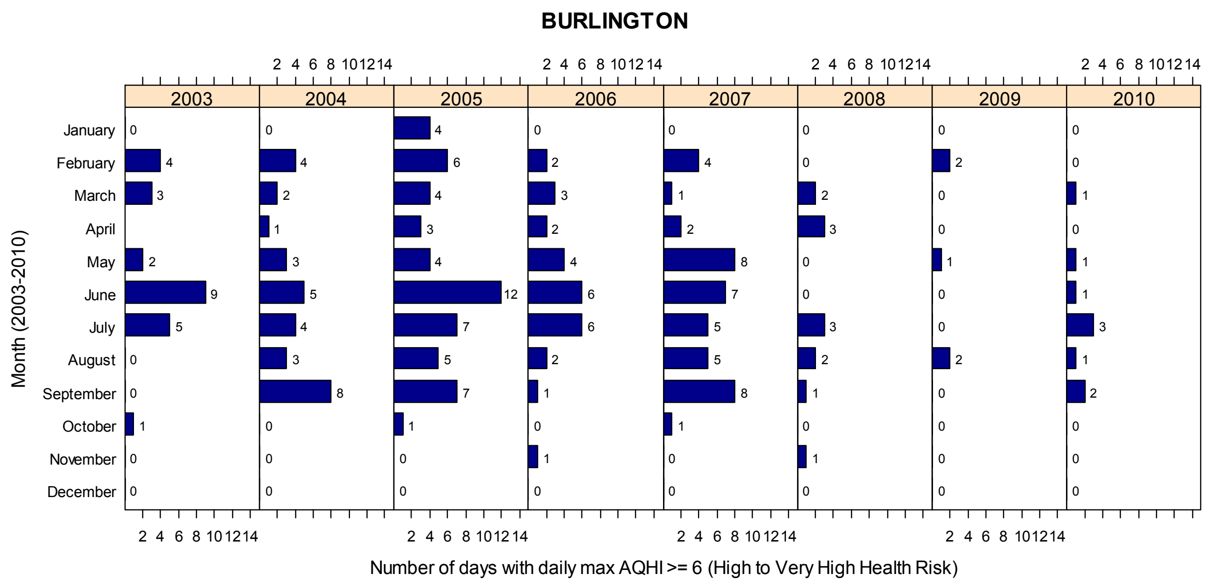
Figure 8. continued

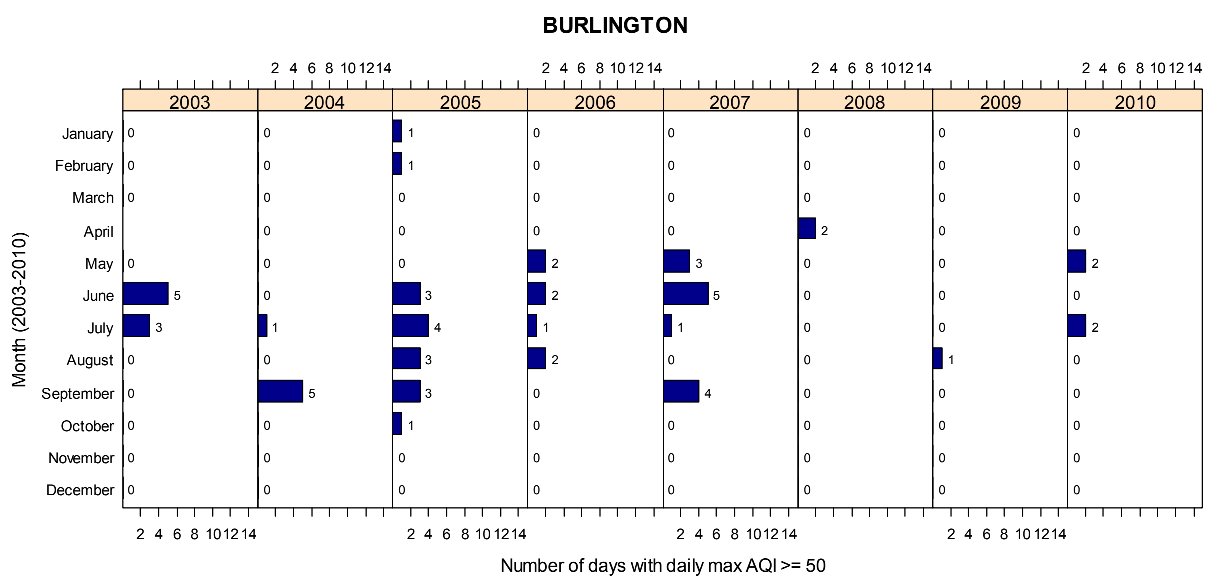




* AQHI was not available from January to June 2003 in Brantford, Ontario as indicated by blank space

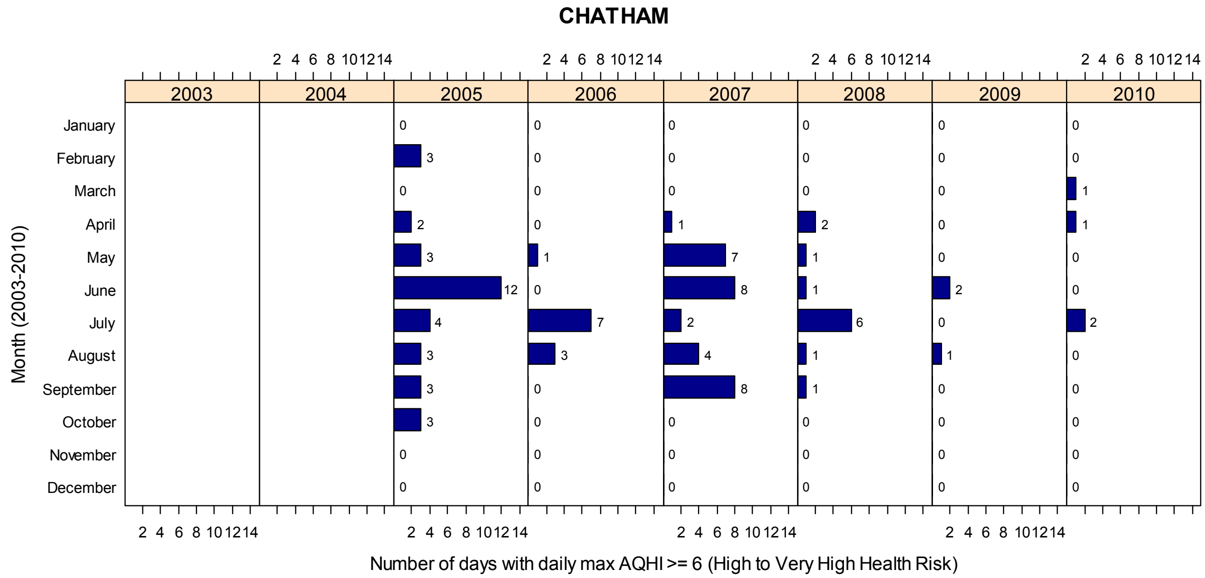
Figure 8. continued

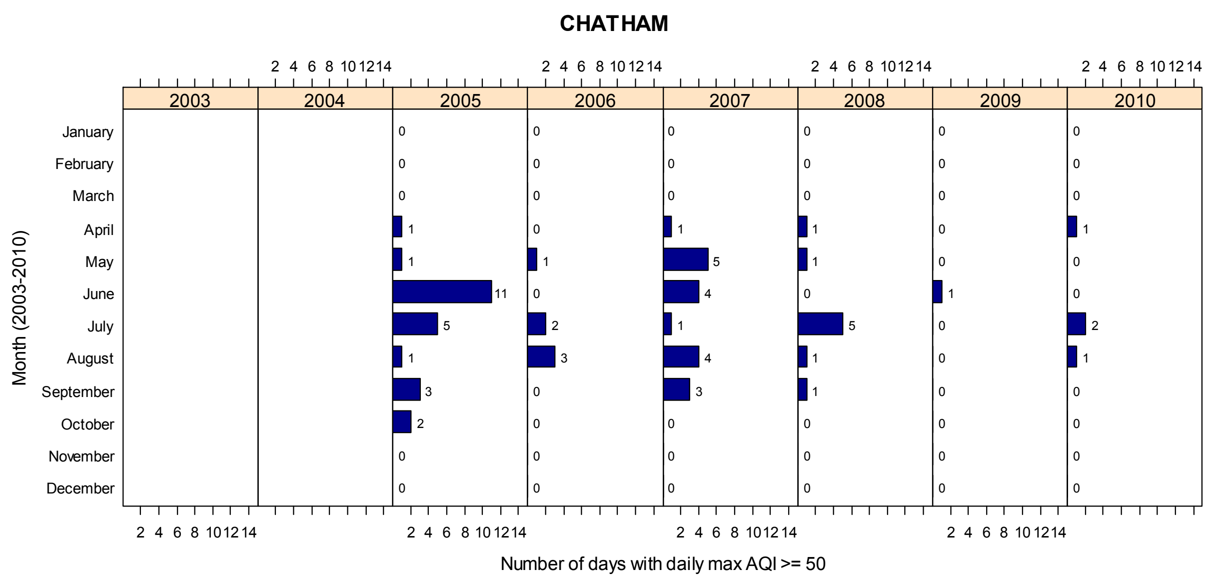




* AQHI was not available in April, 2003 in Burlington, Ontario as indicated by blank space

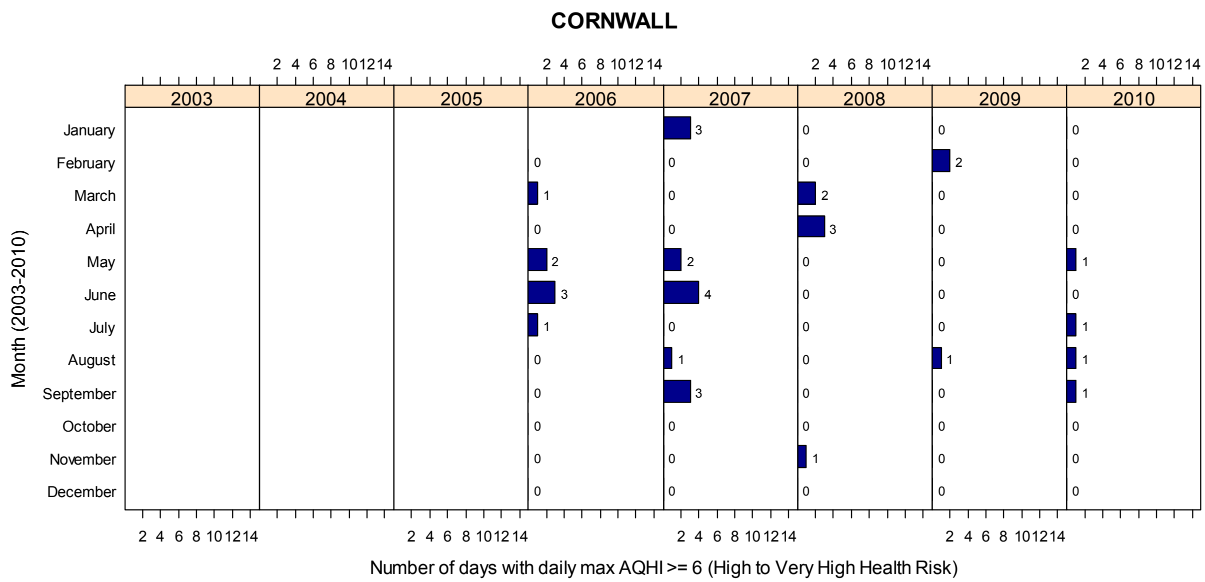
Figure 8. continued

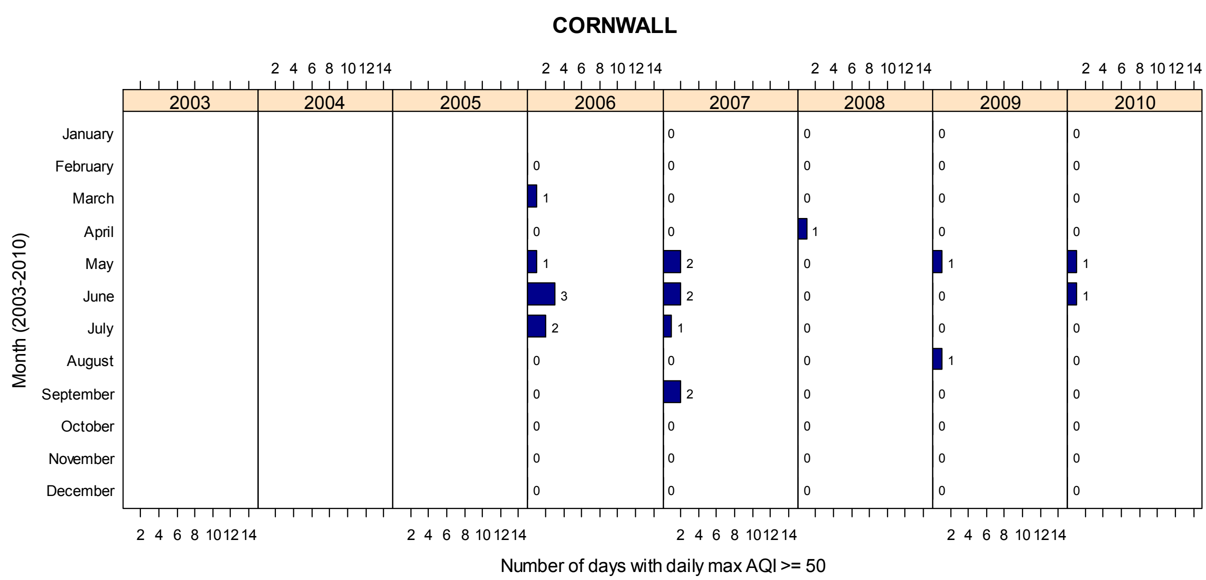




* AQHI was not available from 2003 to 2004 in Chatham, Ontario as indicated by blank space

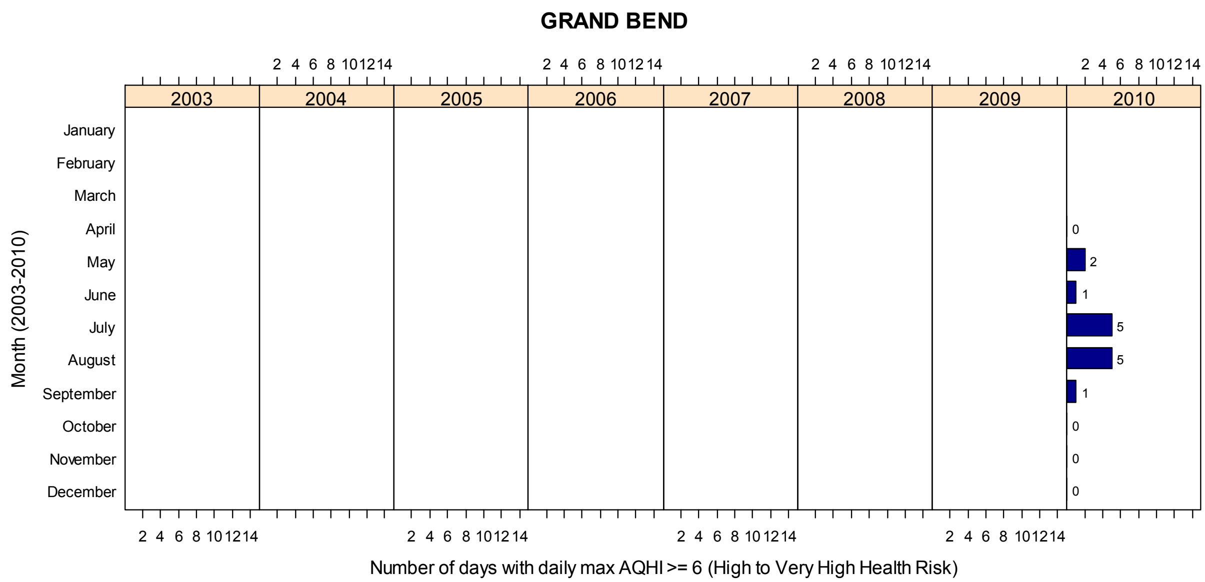
Figure 8. continued

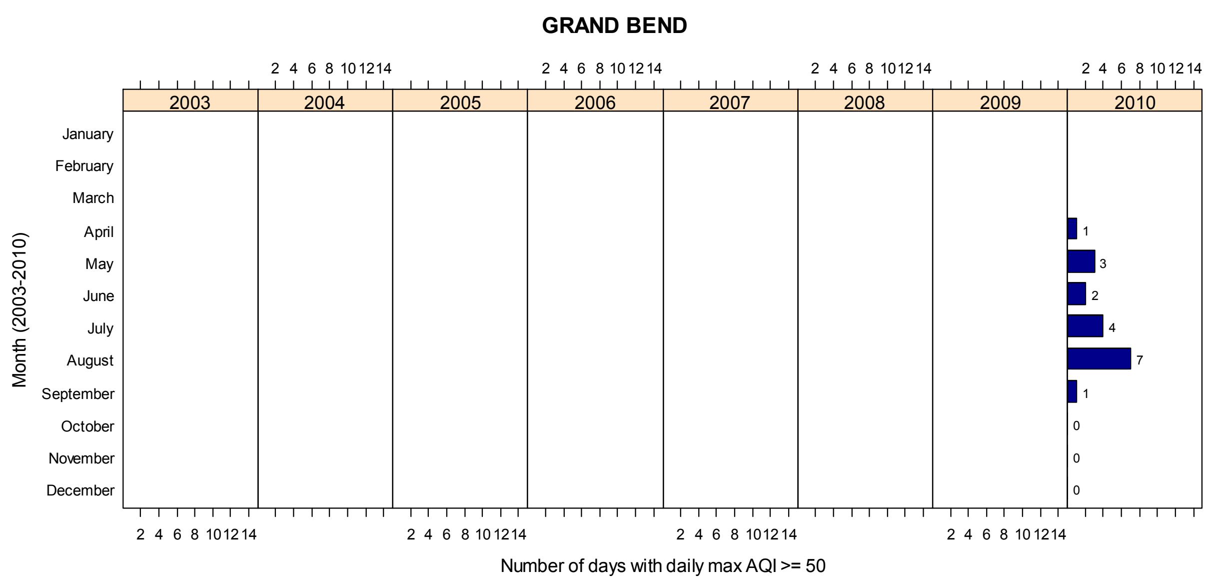




* AQHI was not available from 2003 to January, 2006 in Cornwall, Ontario as indicated by blank space

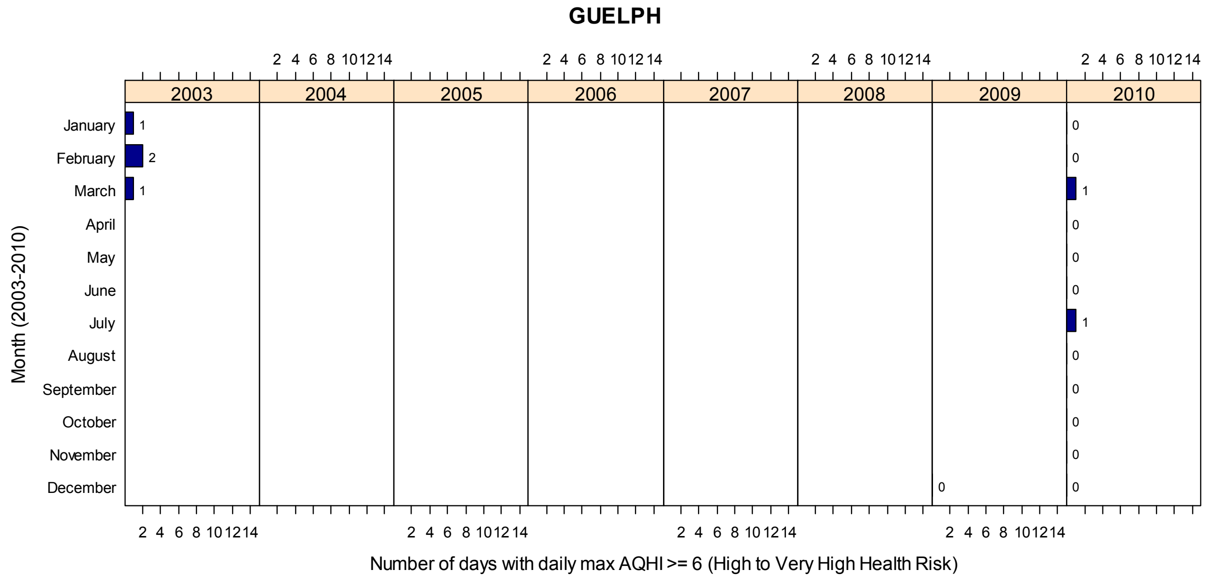
Figure 8. continued

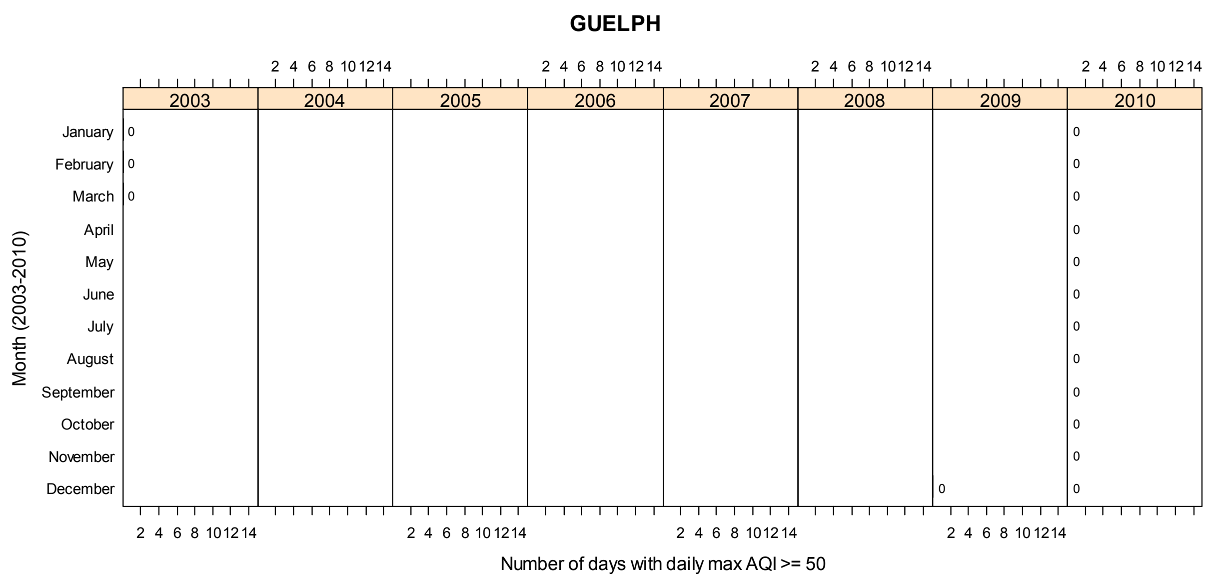




* AQHI was not available from January, 2003 to March, 2010 in Grand Bend, Ontario as indicated by blank space

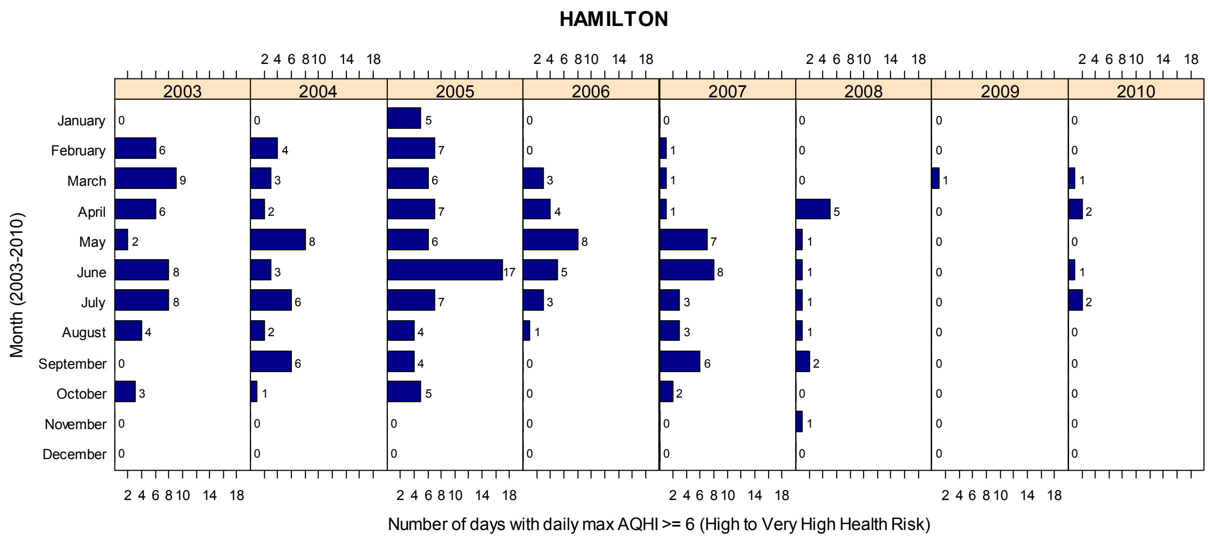
Figure 8. continued





* AQHI was not available from April, 2003 to November, 2009 in Guelph, Ontario as indicated by blank space

Figure 8. continued



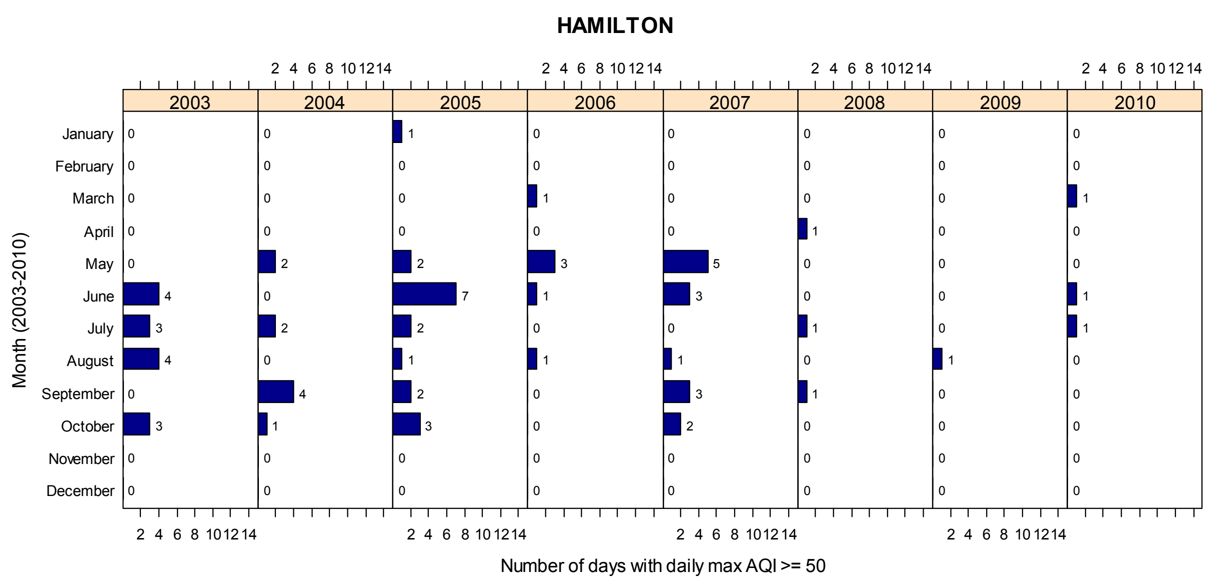
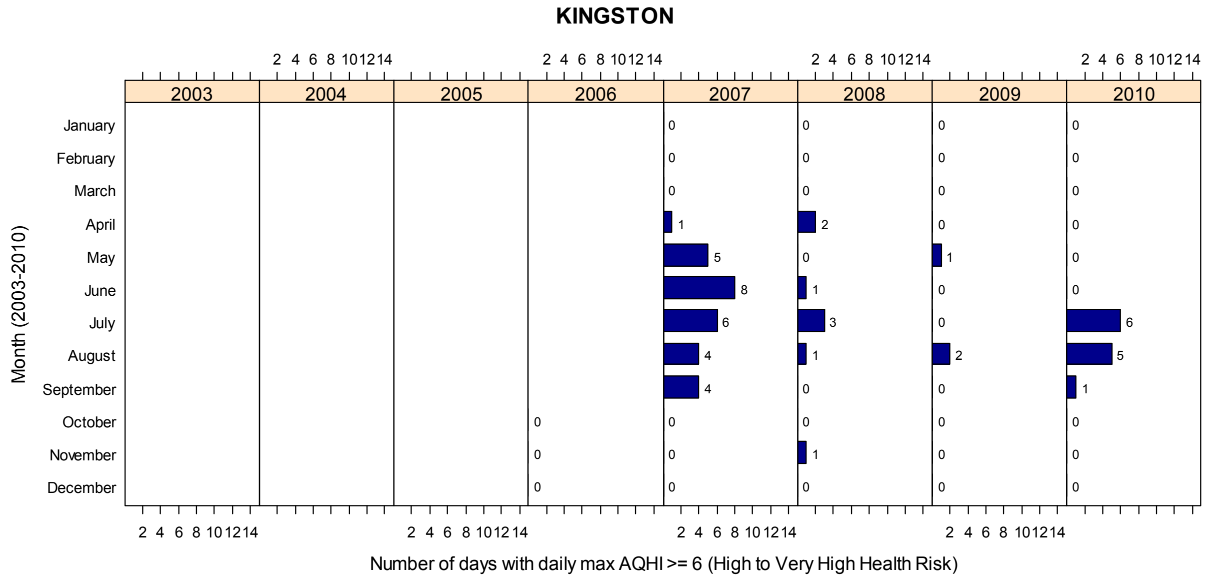
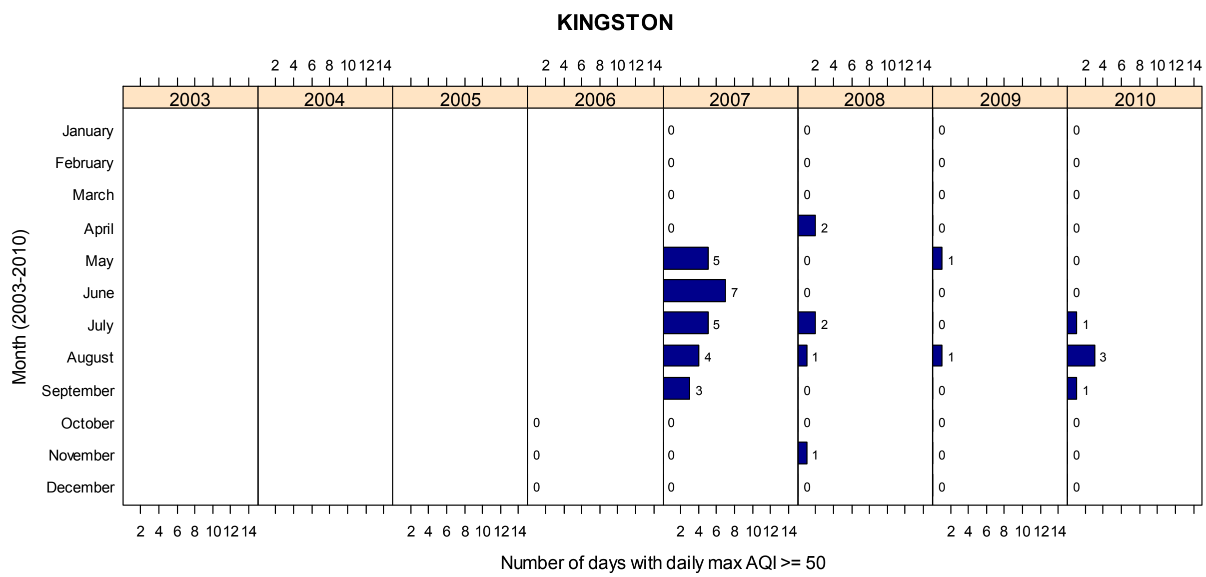


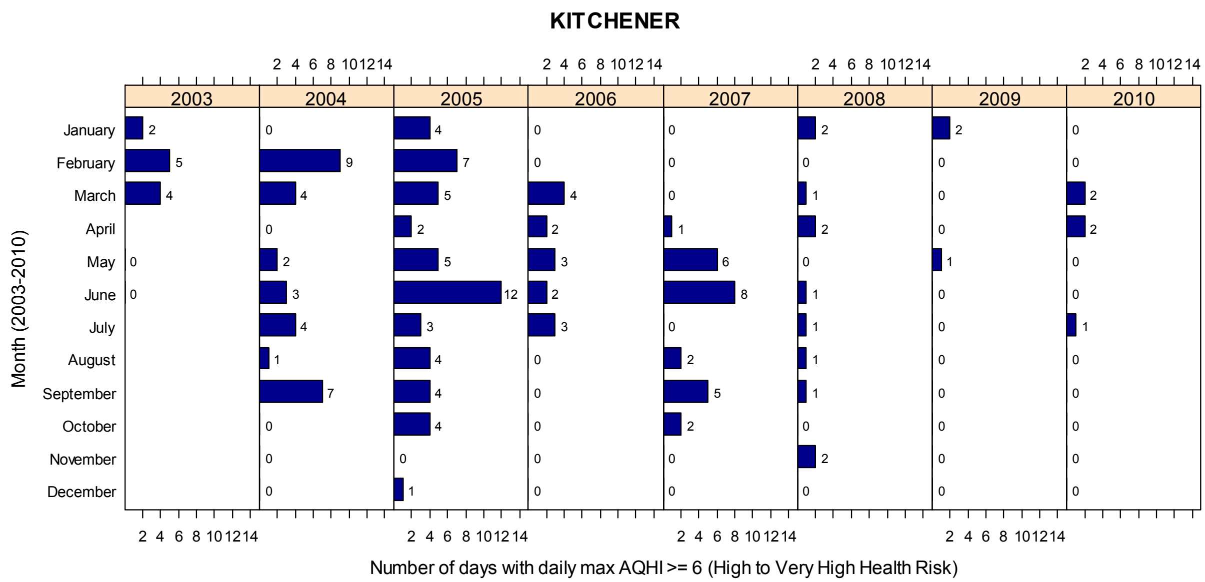
Figure 8. continued

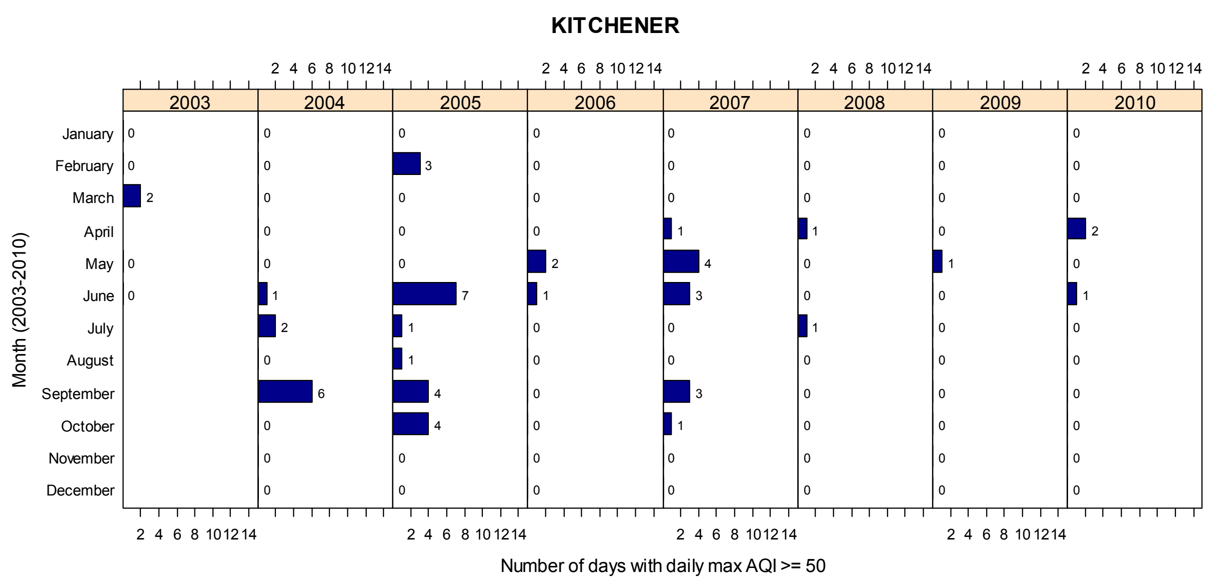




* AQHI was not available from January, 2003 to September, 2006 in Kingston, Ontario as indicated by blank space

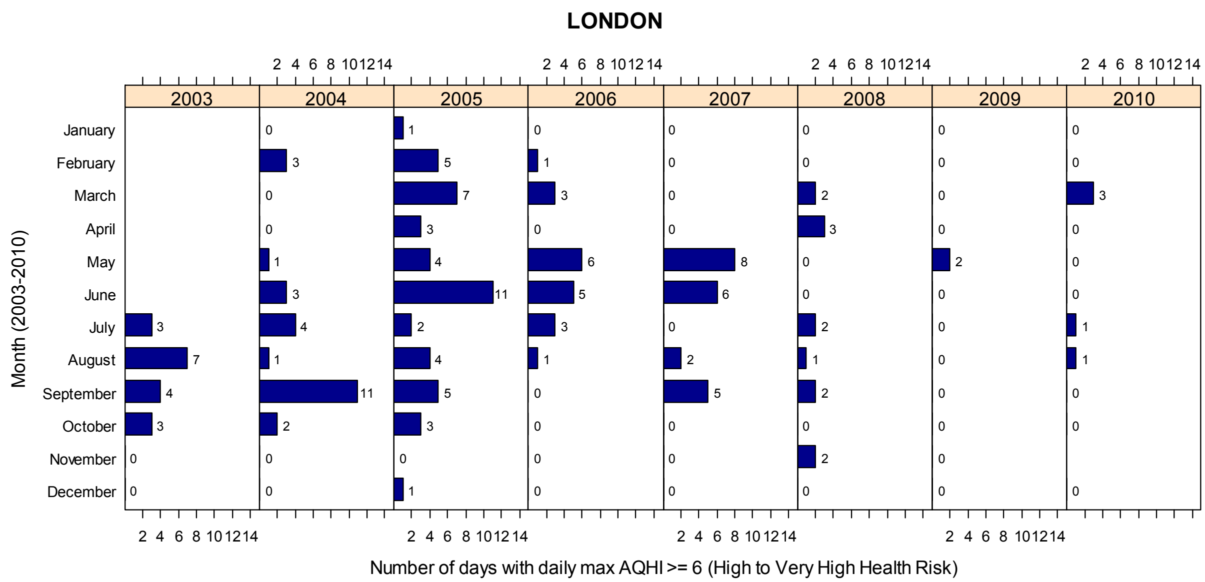
Figure 8. continued

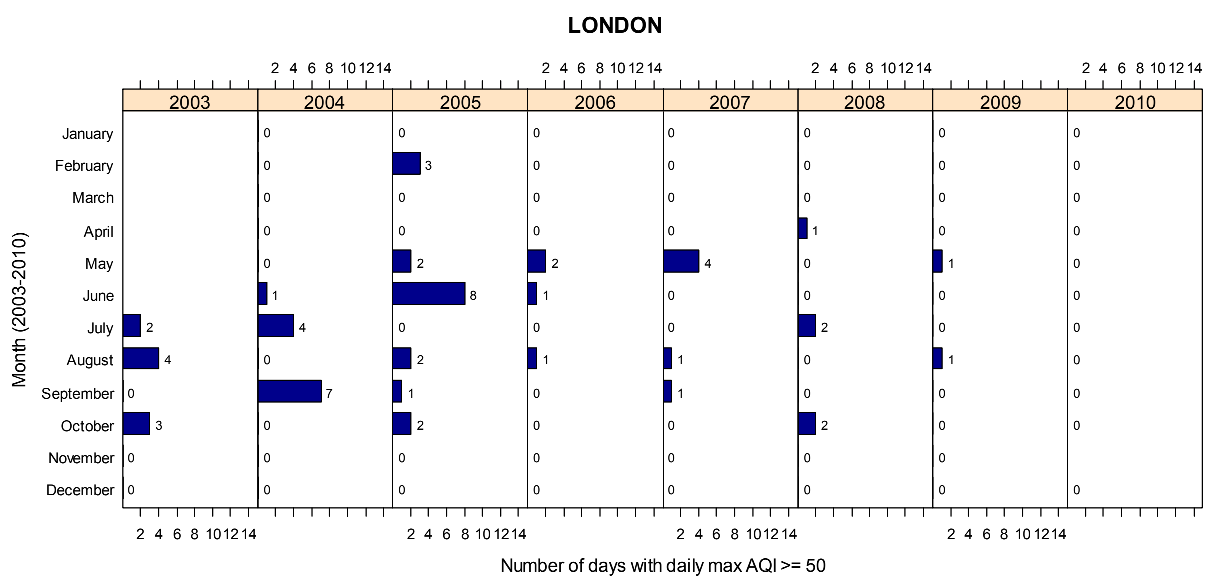




* AQHI was not available in April, 2003 and from July to December, 2003 in Kitchener, Ontario as indicated by blank space

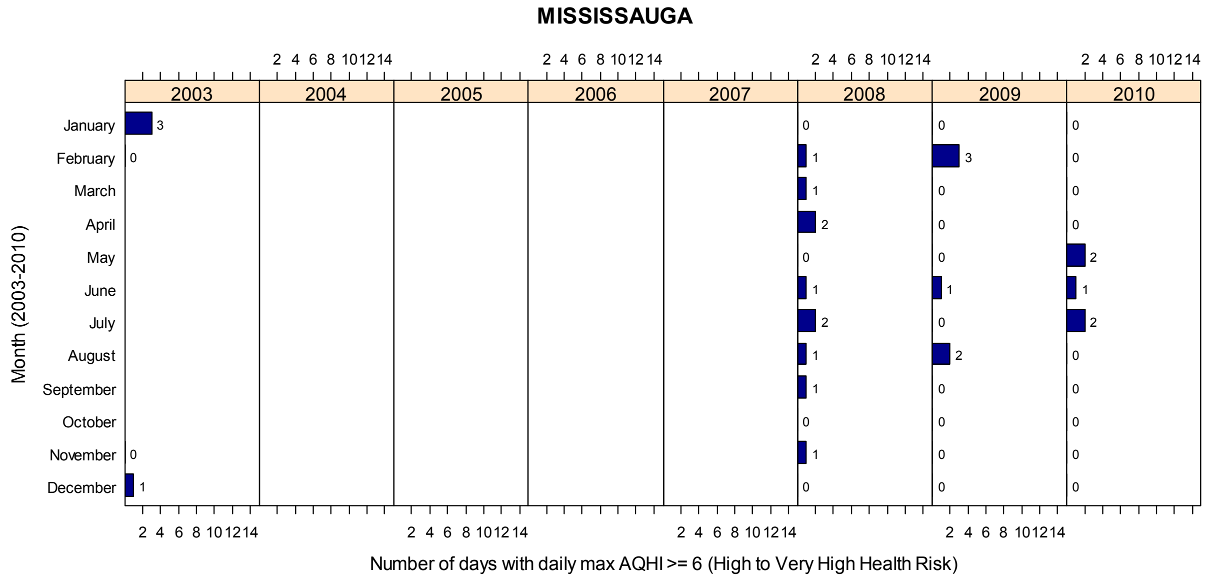
Figure 8. continued

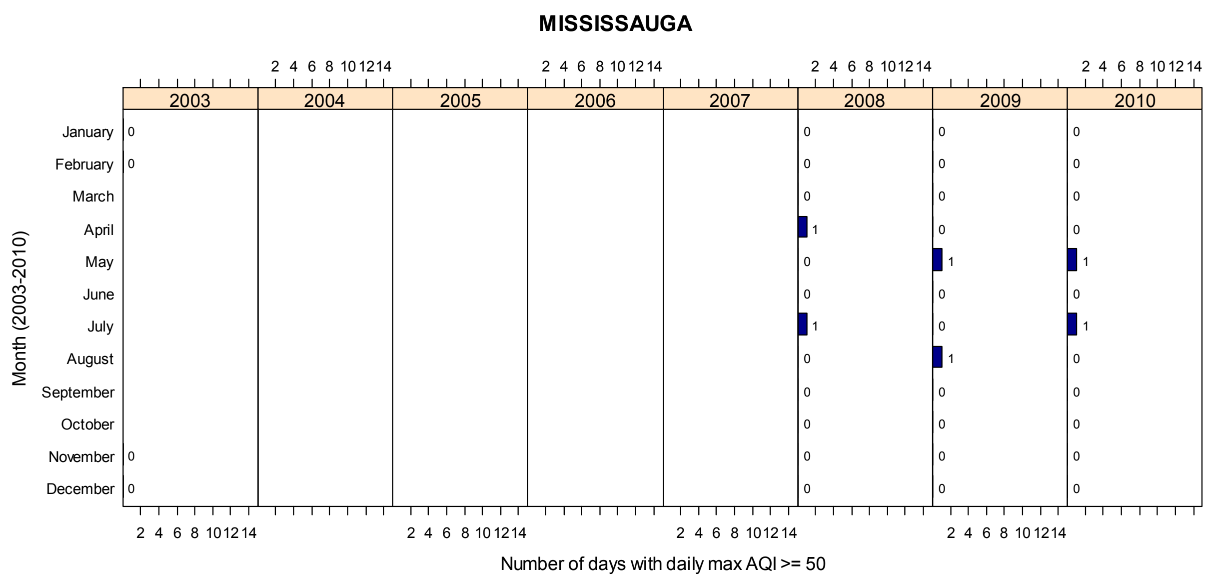




* AQHI was not available from January to June, 2003 and in November, 2010 in London, Ontario as indicated by blank space

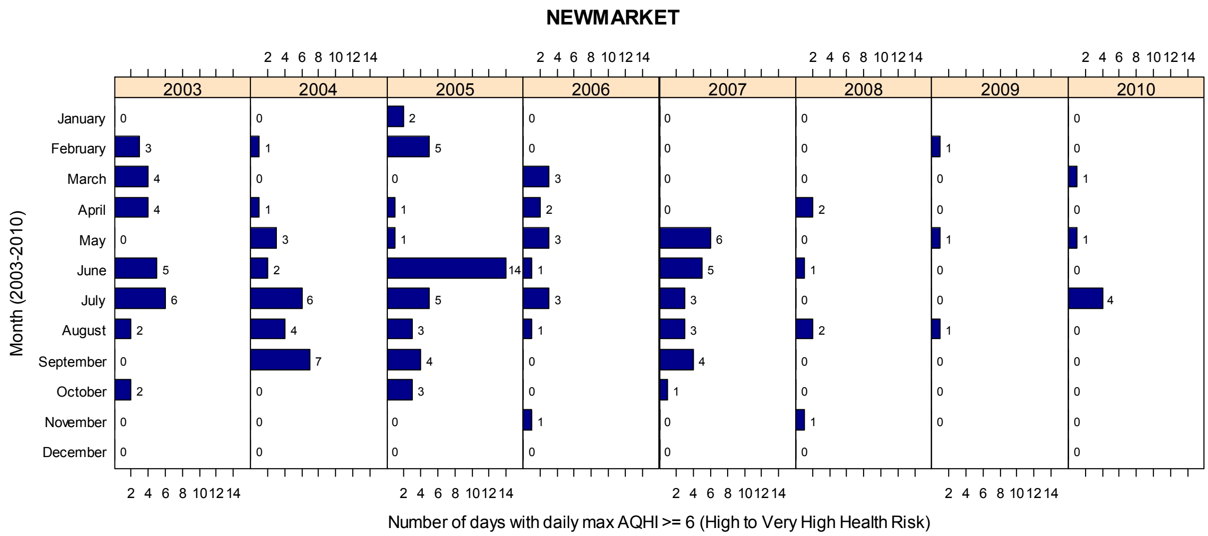
Figure 8. continued

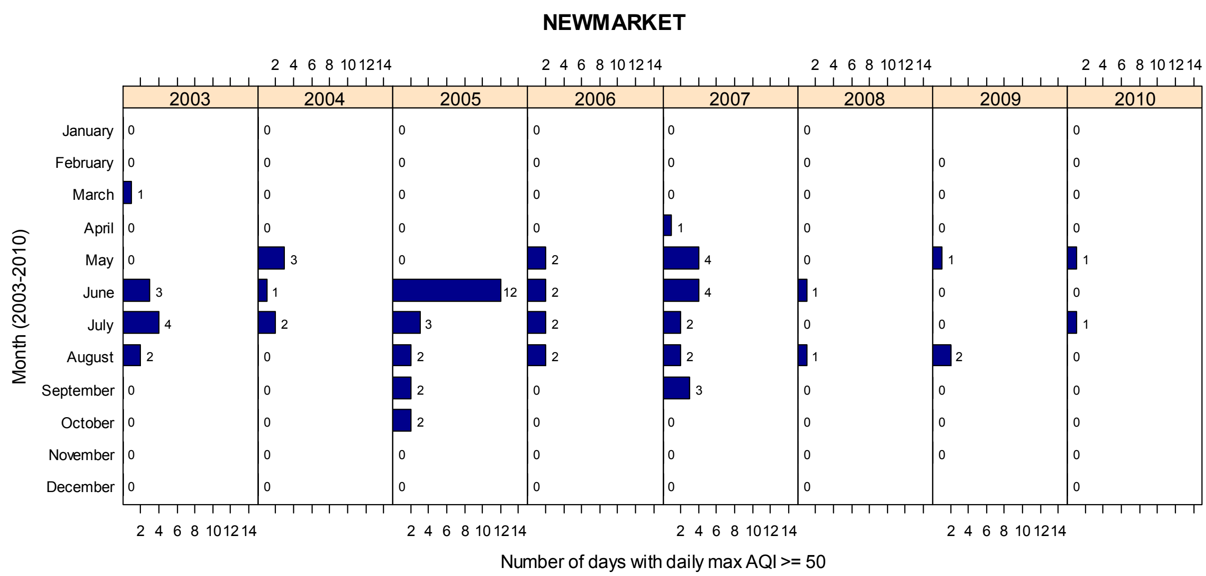




* AQHI was not available from March, 2003 to December, 2007 due to missing NO_2 data in Mississauga, Ontario as indicated by blank space

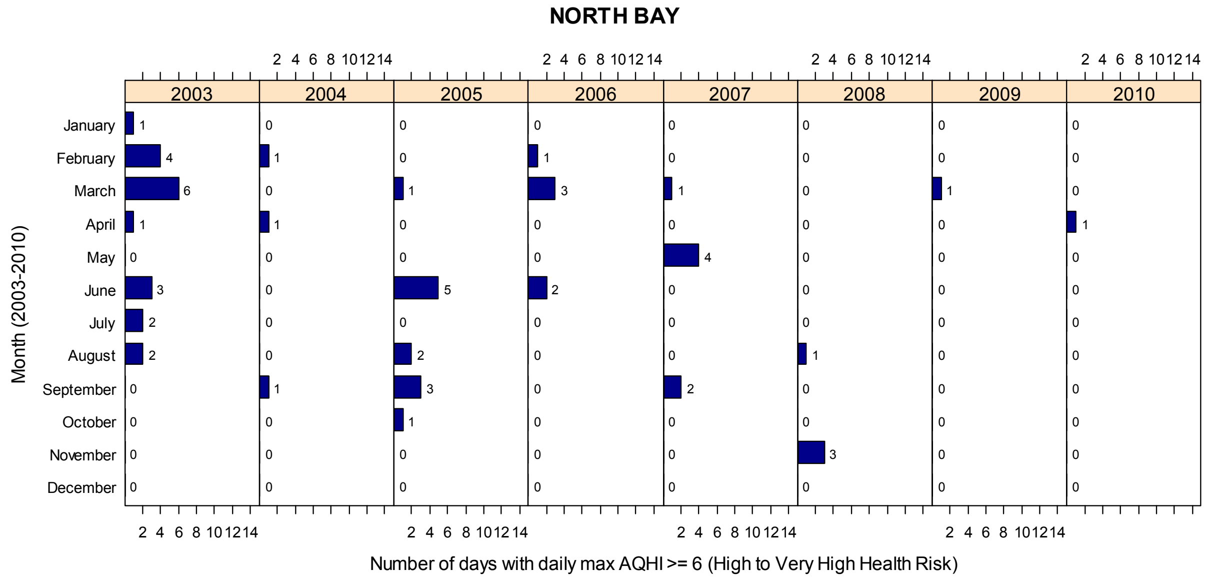
Figure 8. continued





* AQHI was not available in January and December, 2009 in NewMarket, Ontario as indicated by blank space

Figure 8. continued



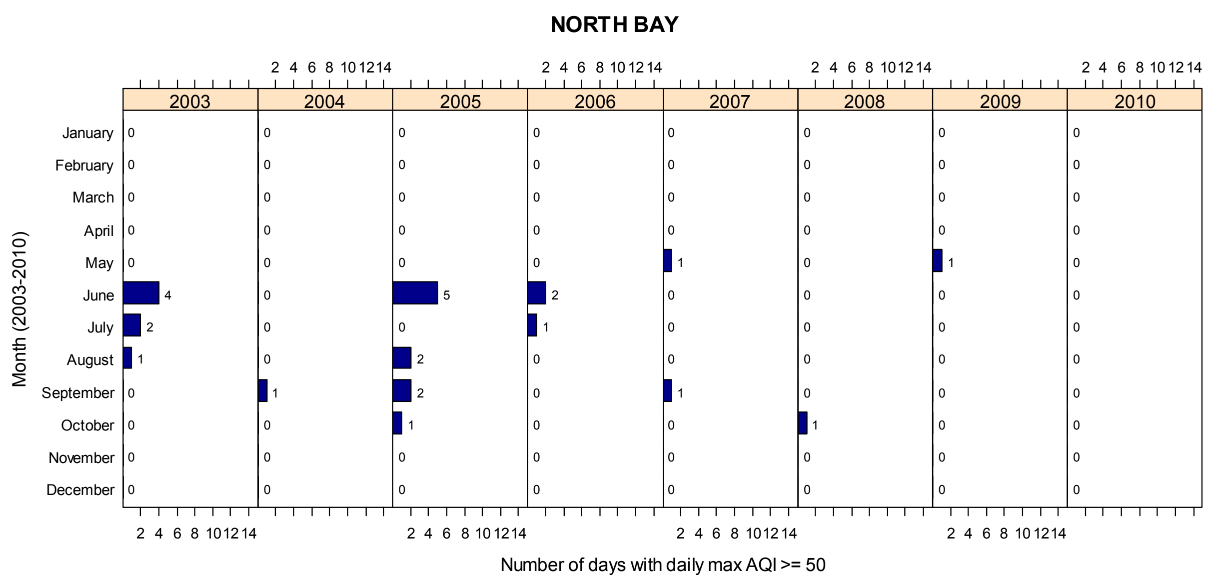
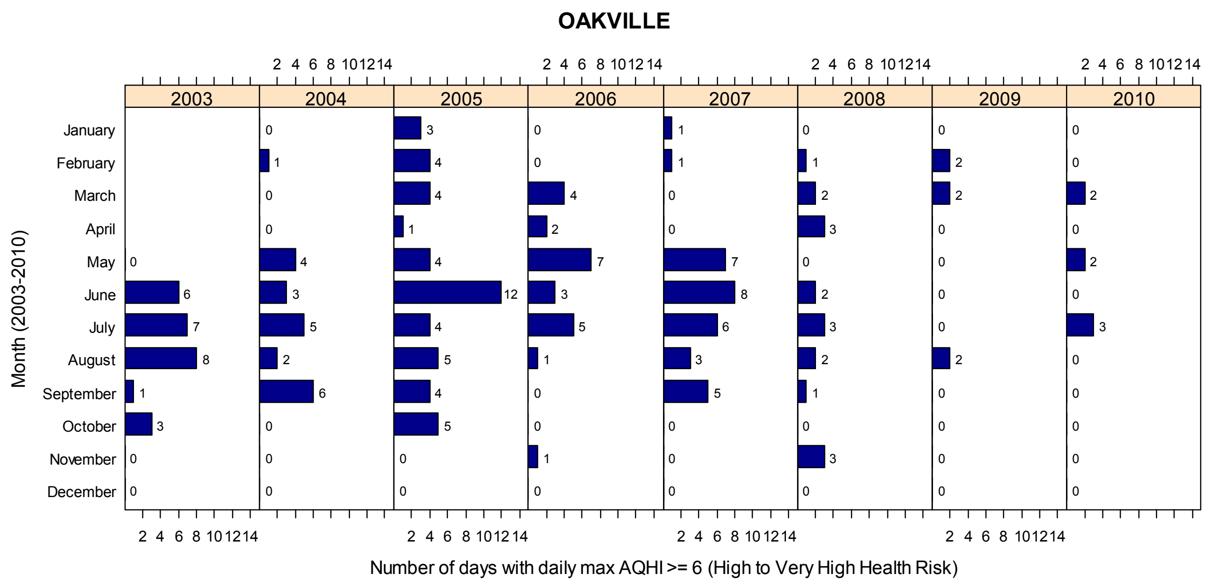
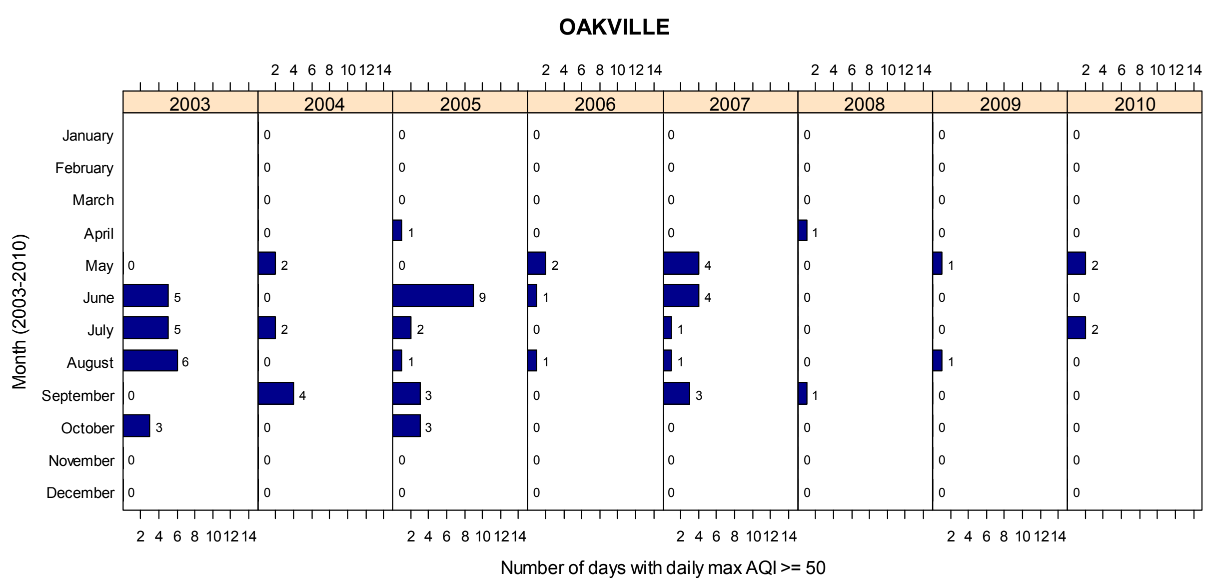


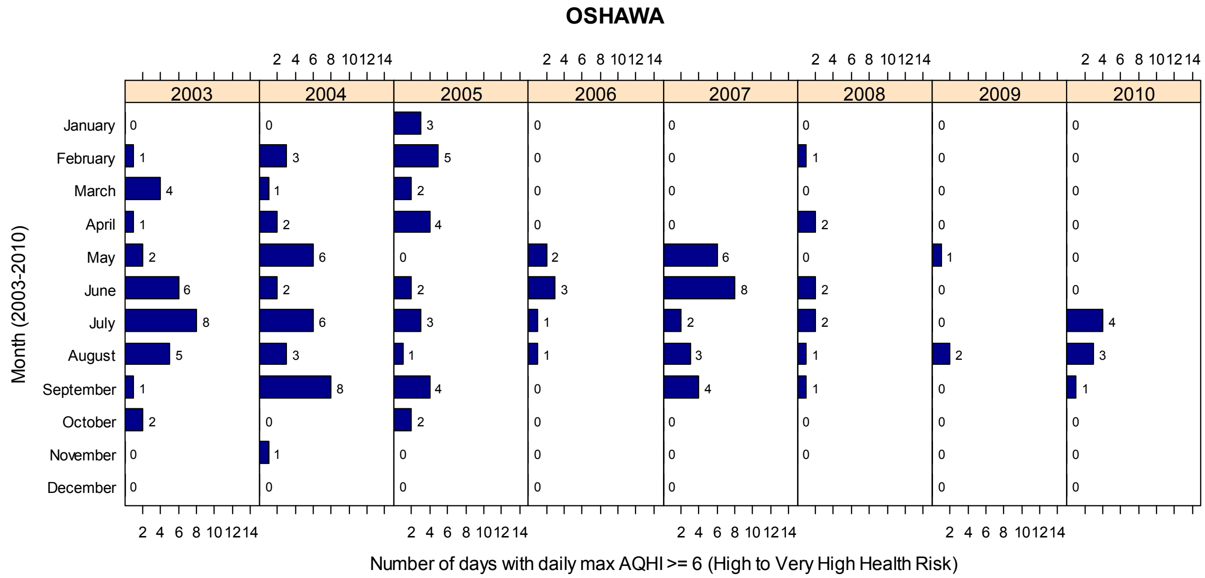
Figure 8. continued

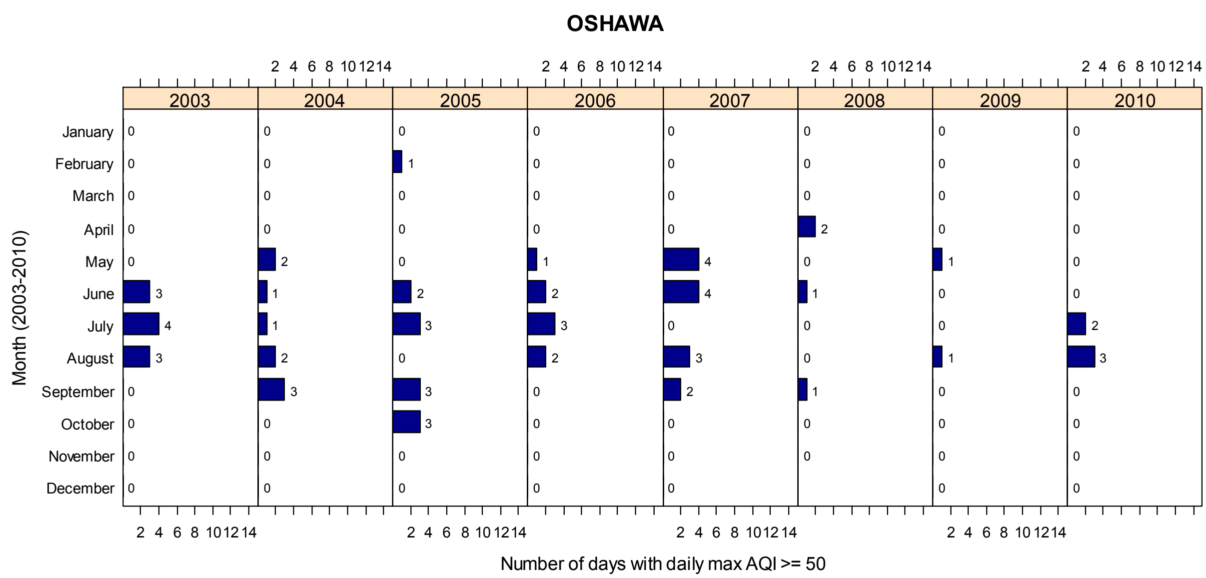




* AQHI was not available from January to April, 2003 in Oakville, Ontario as indicated by blank space

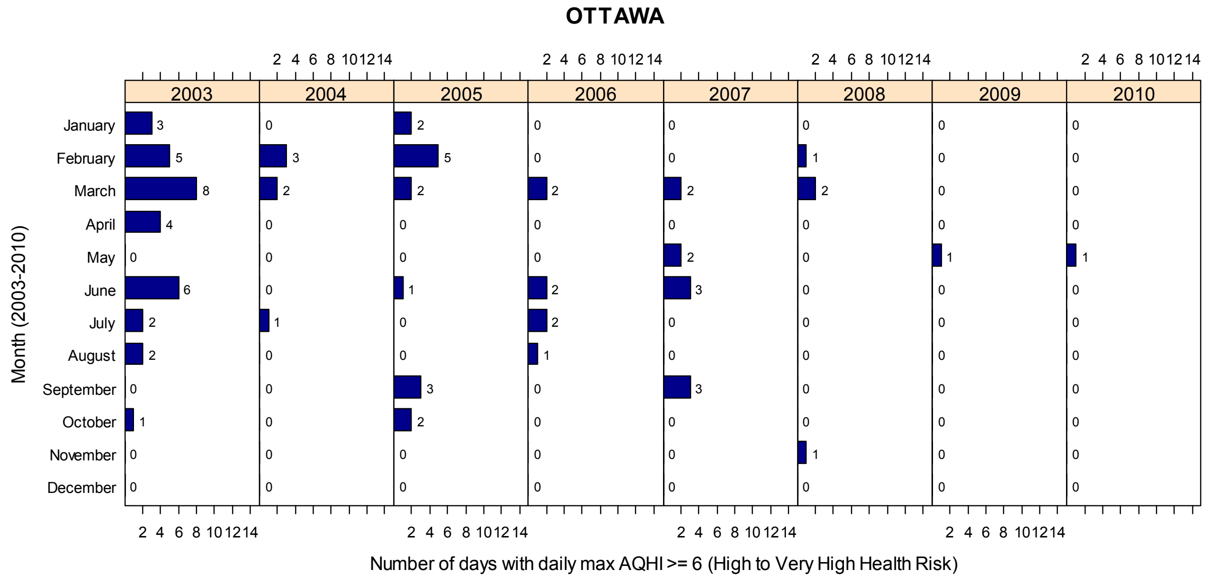
Figure 8. continued





* AQHI was not available in December, 2008 in Oshawa, Ontario as indicated by blank space

Figure 8. continued



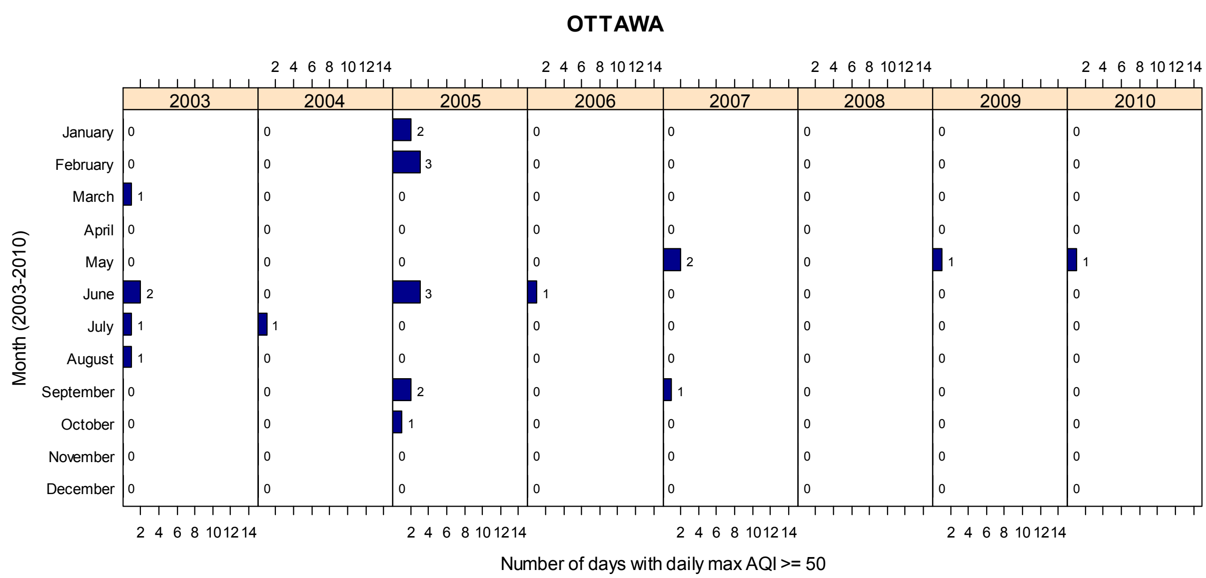
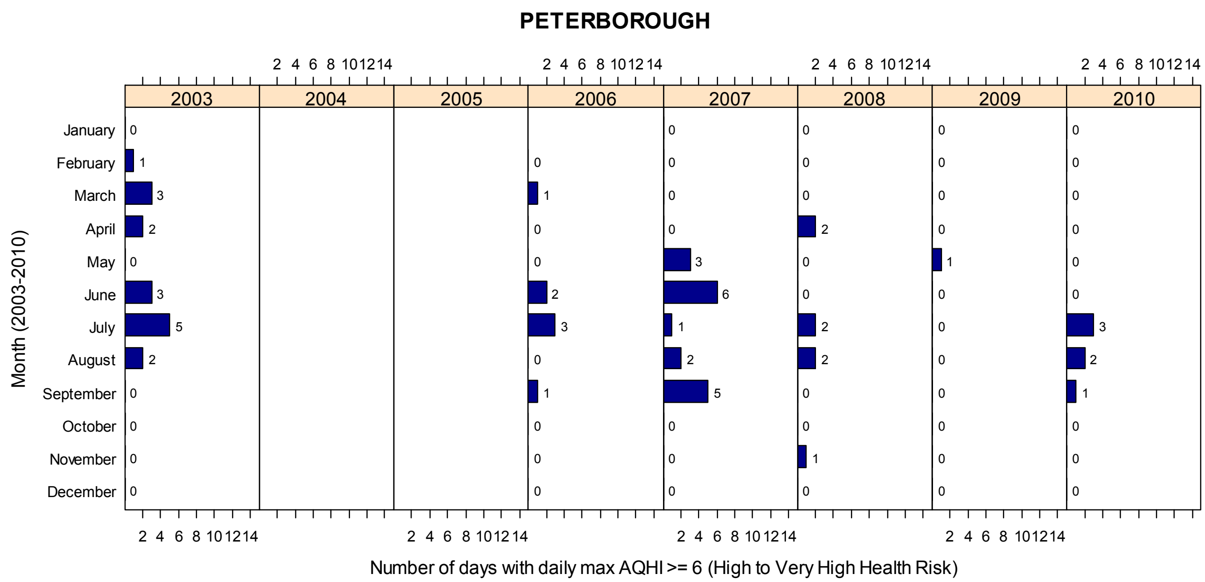
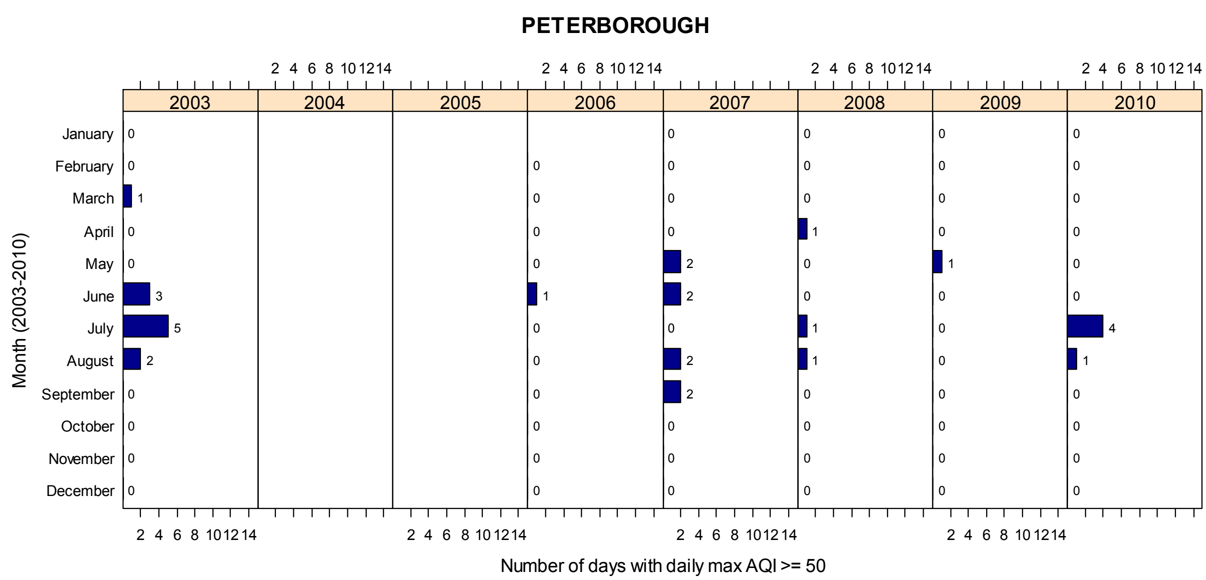


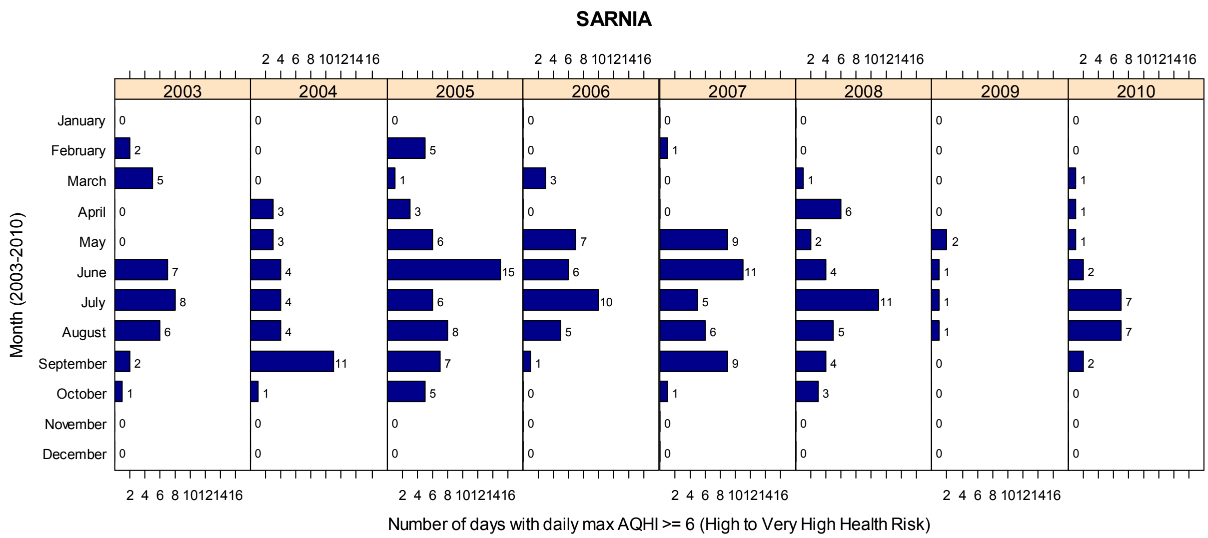
Figure 8. continued





* AQHI was not available from January, 2004 to January, 2006 in Peterborough, Ontario as indicated by blank space

Figure 8. continued



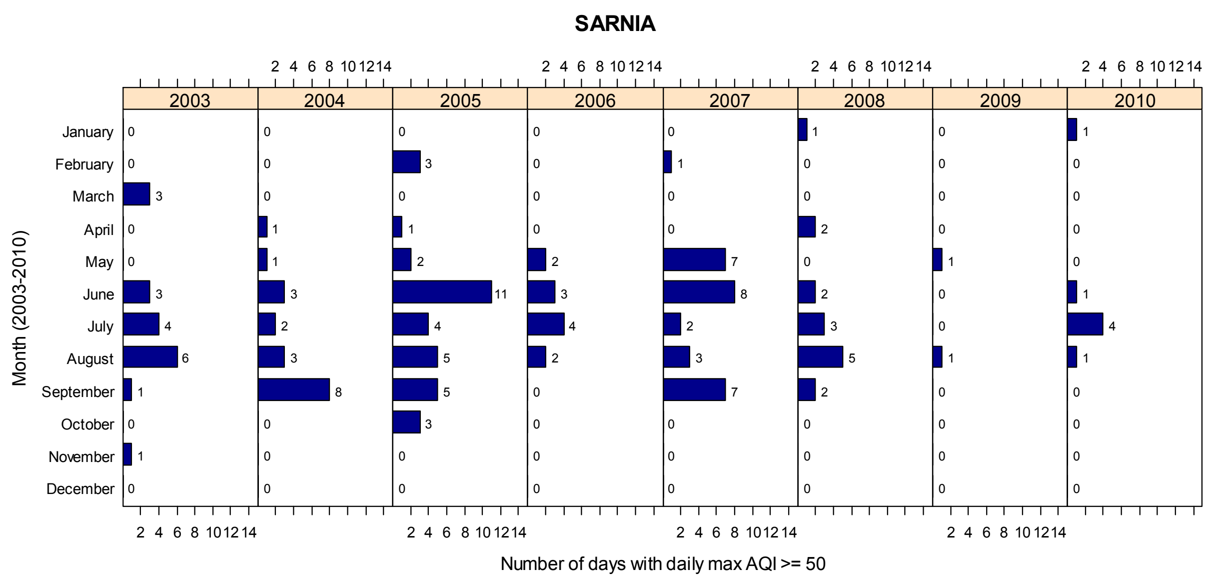
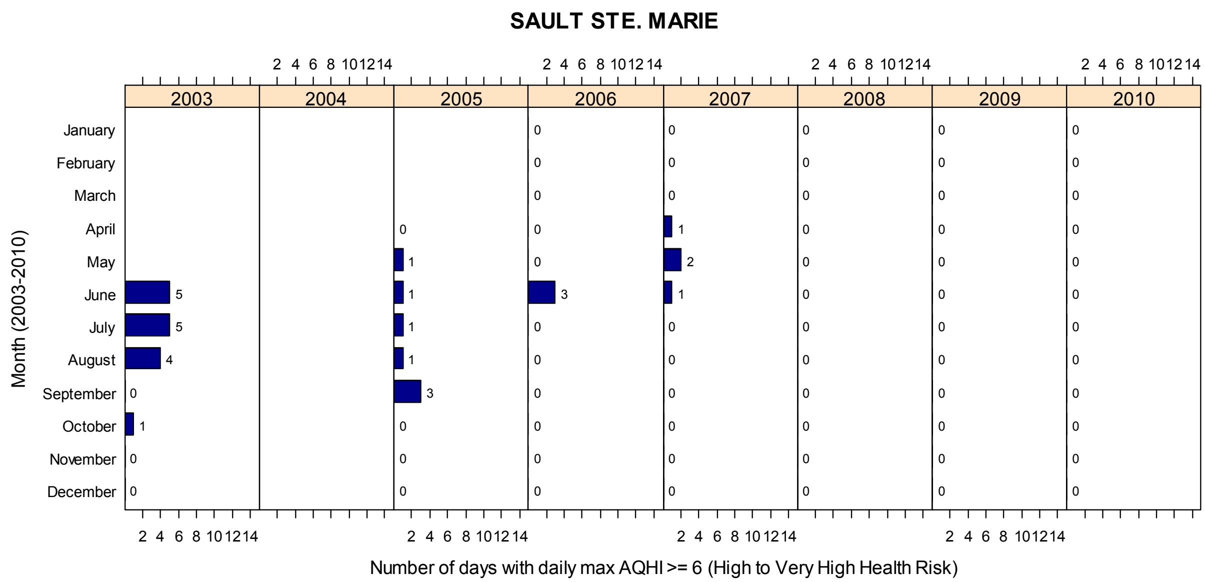
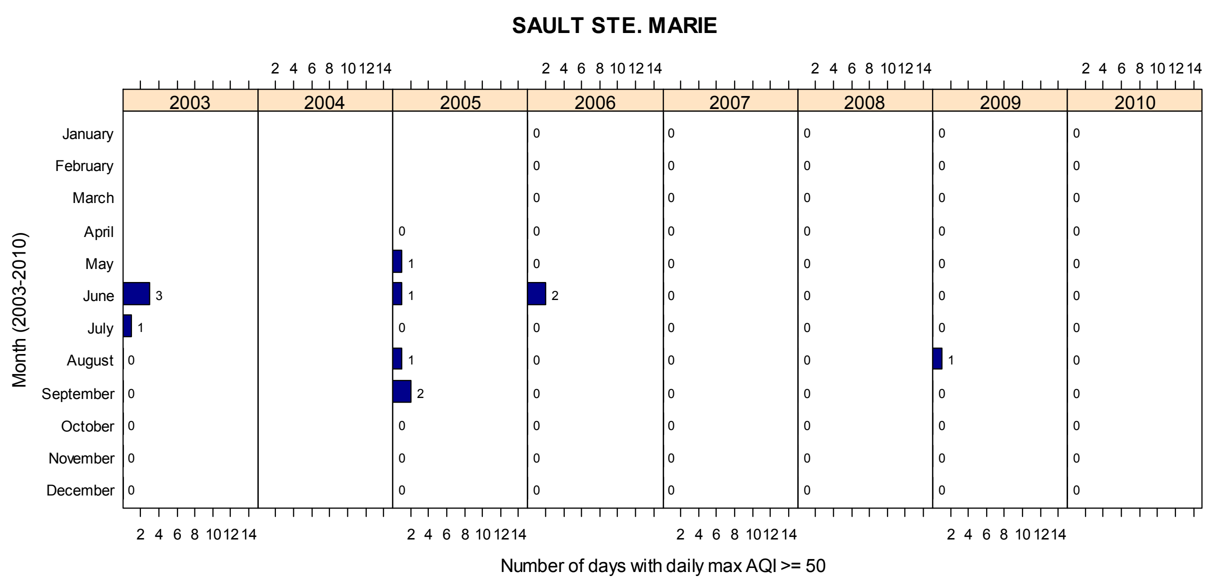


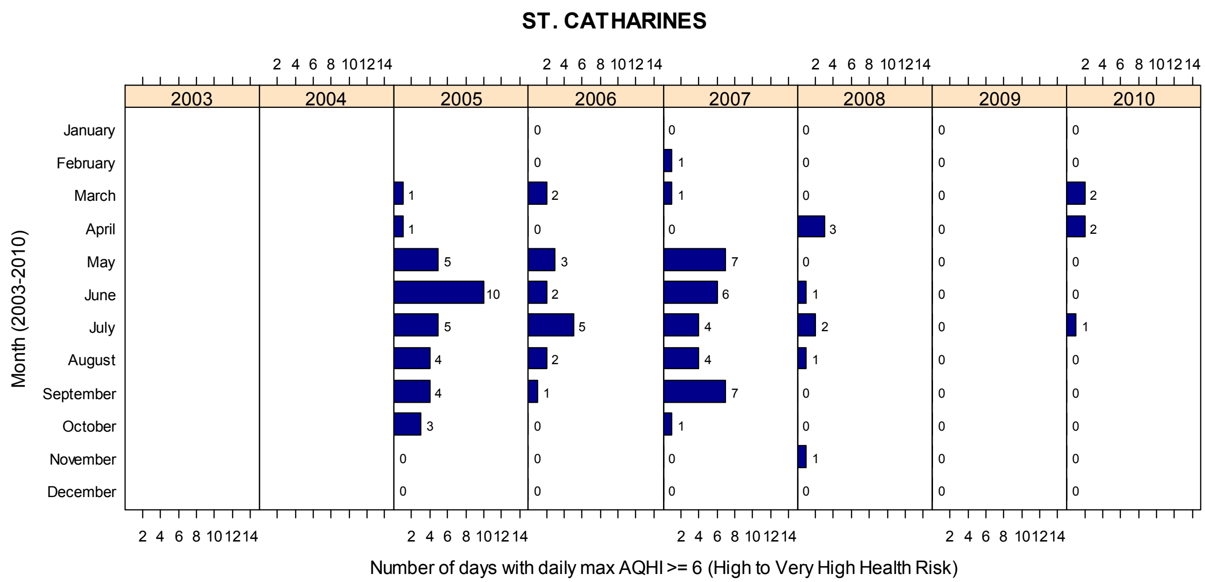
Figure 8. continued

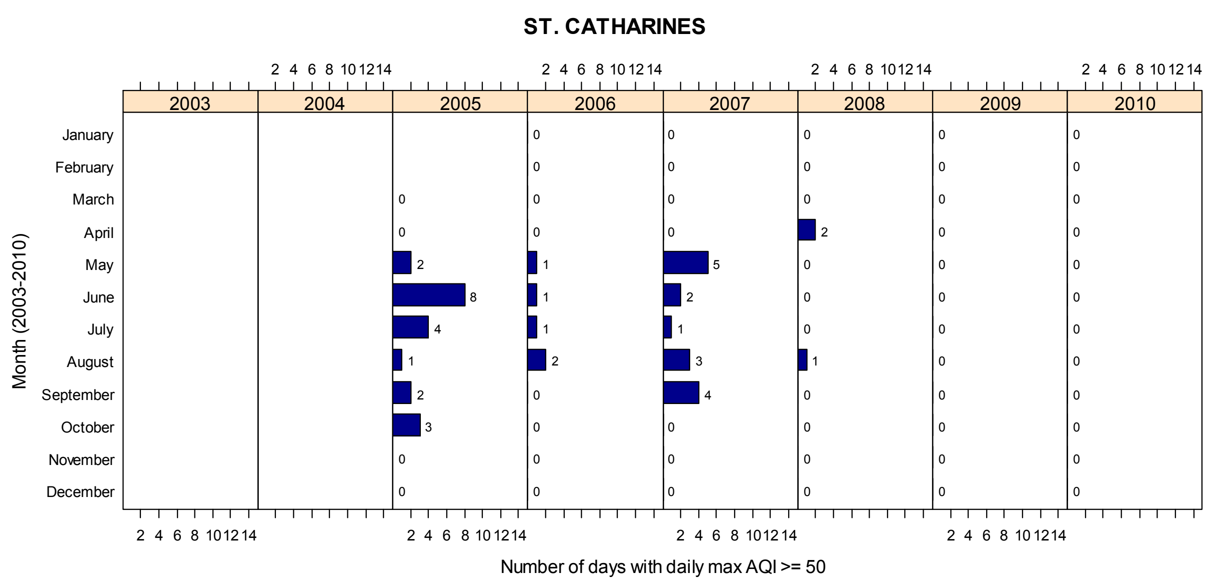




* AQHI was not available from January to May, 2003 and from January, 2004 to March, 2005 in Sault Ste. Marie, Ontario as indicated by blank space

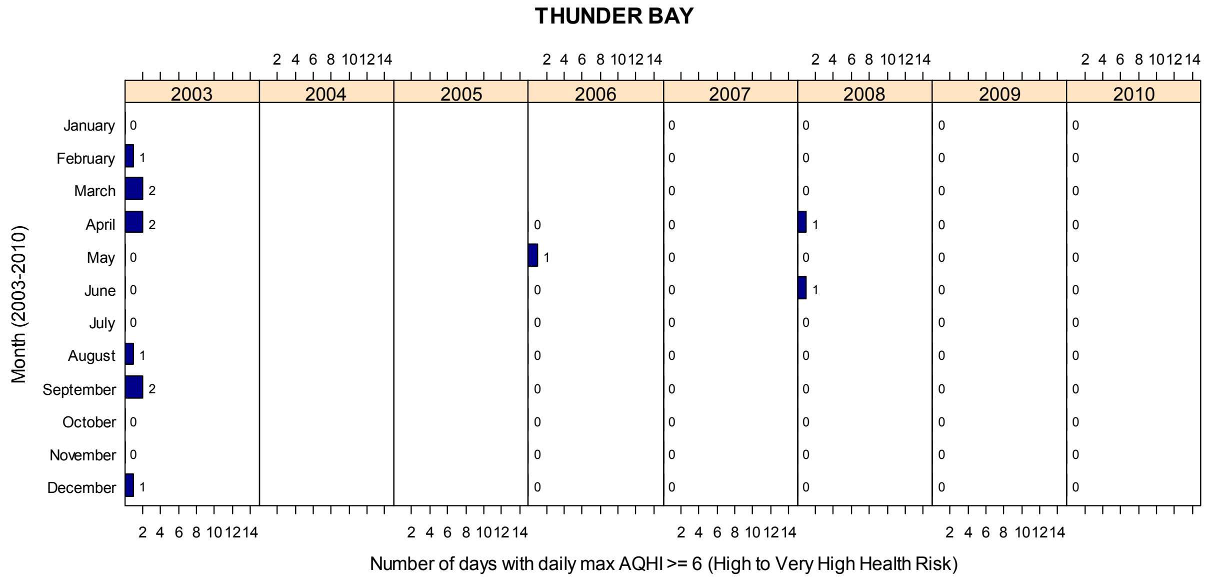
Figure 8. continued

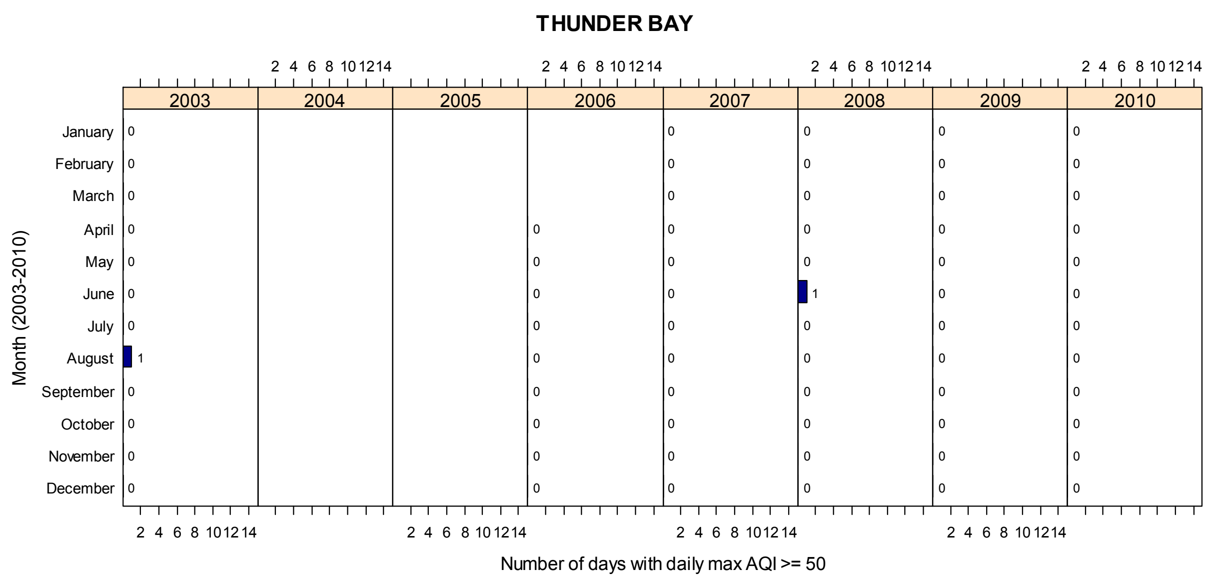




* AQHI was not available from 2003 to 2004 and from January to February, 2005 in St. Catherines, Ontario as indicated by blank space

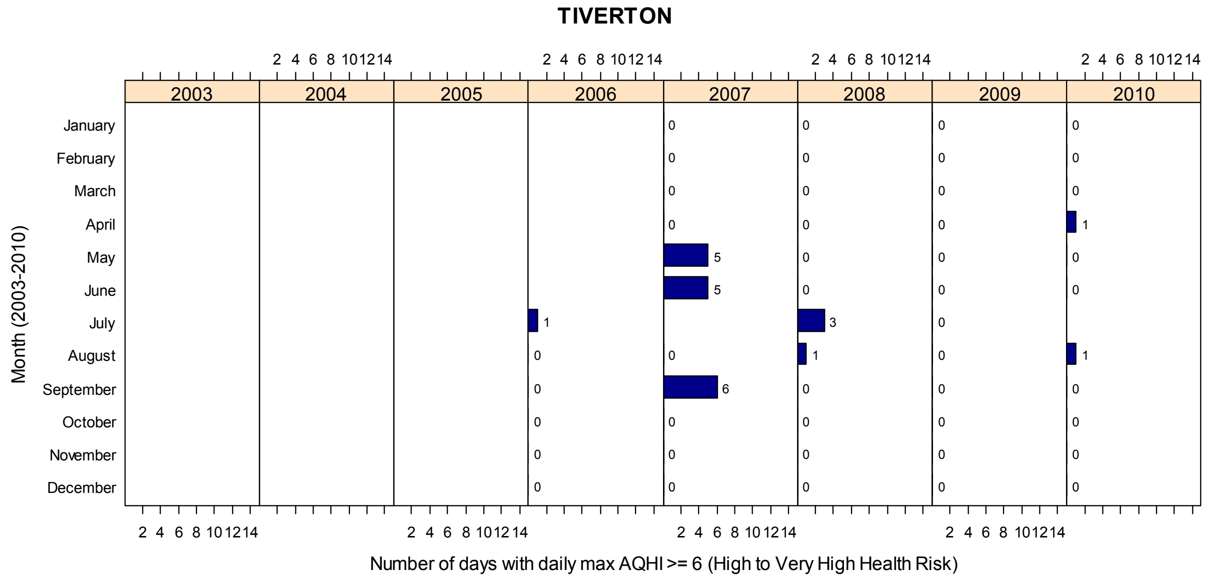
Figure 8. continued

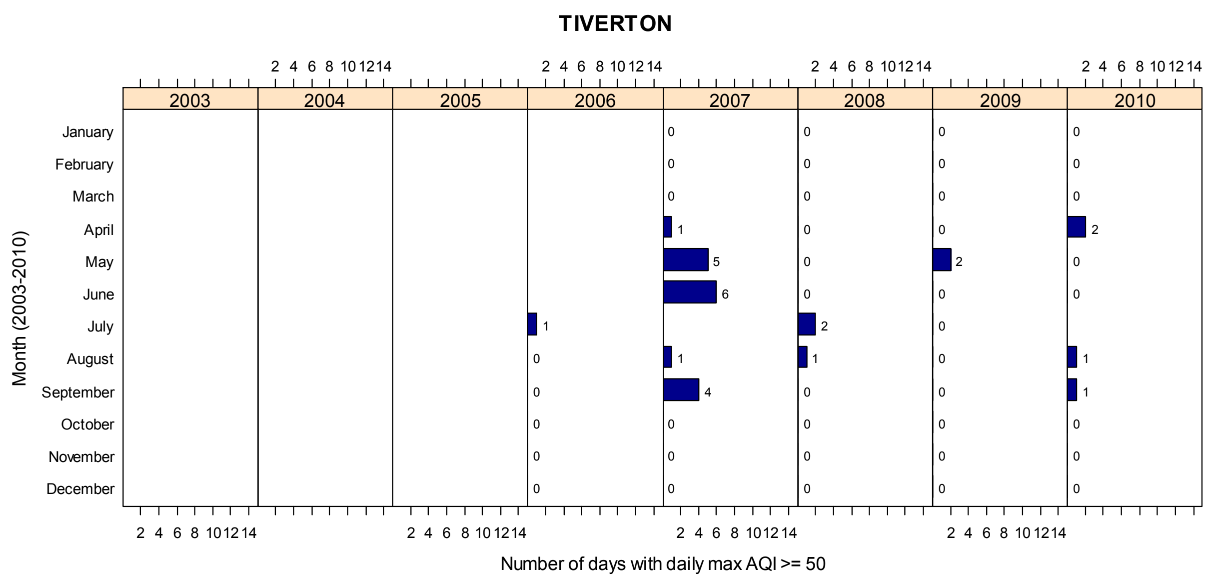




* AQHI was not available from January, 2004 to March, 2006 in Thunder Bay, Ontario as indicated by blank space

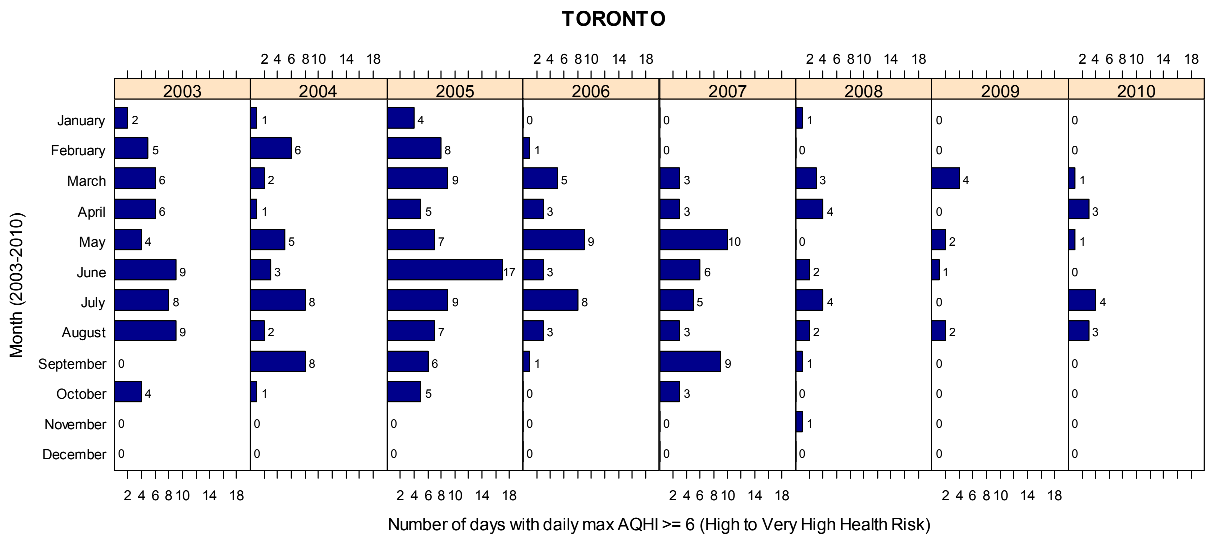
Figure 8. continued





* AQHI was not available from January, 2003 to June, 2006 in Tiverton, Ontario as indicated by blank space

Figure 8. continued



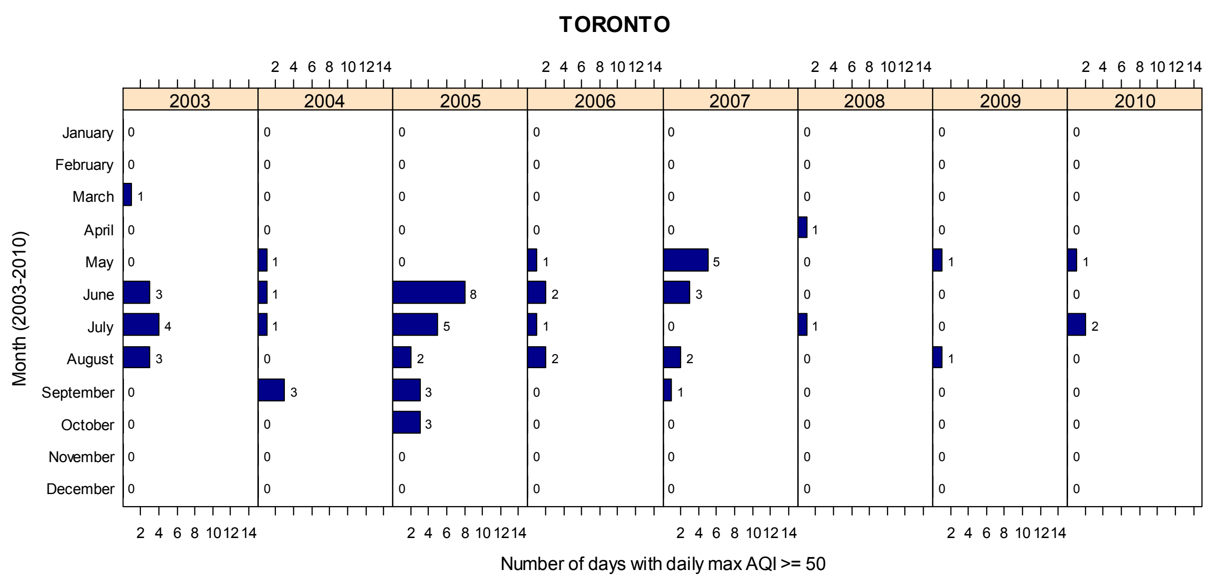
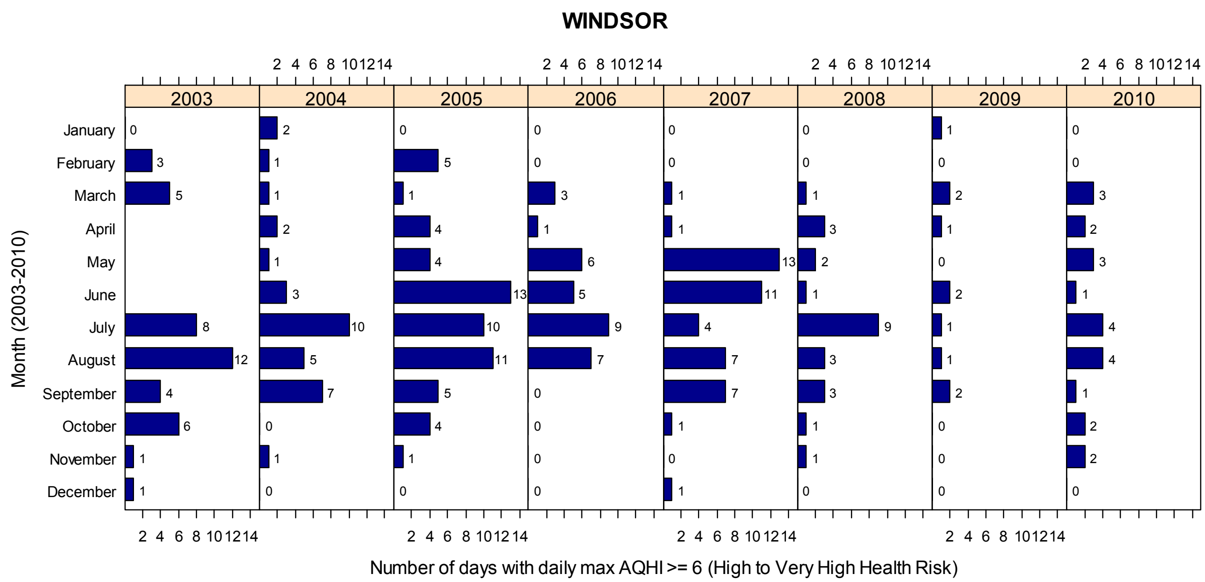
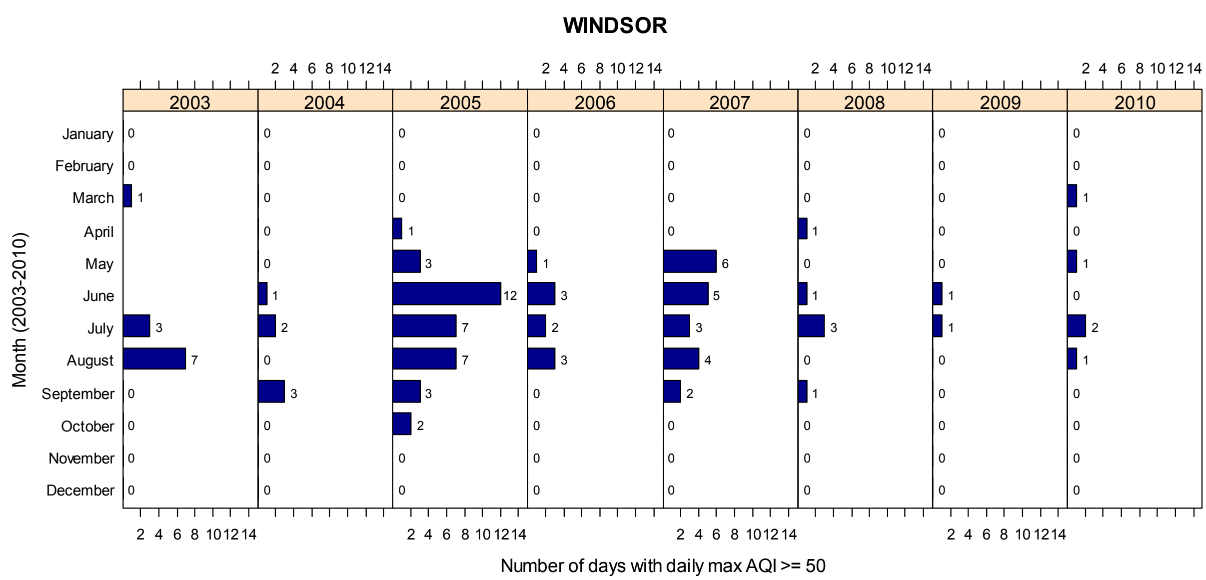


Figure 8. continued





* AQHI was not available from April to June, 2003 in Windsor, Ontario as indicated by blank space

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