HL22.3
Attachment 2

TORONTO

Avoiding the TRAP:

Traffic-Related Air Pollution in Toronto and Options for Reducing Exposure

October 2017

Reference:

City of Toronto. Avoiding the TRAP: Traffic-Related Air Pollution in Toronto and Options for Reducing Exposure. Technical Report. October 2017.

Authors:

Stephanie Bell, Stephanie Gower, Barbara Lachapelle, Christopher Morgan, Kelly Drew, Ronald Macfarlane, and Monica Campbell

Acknowledgments:

We gratefully acknowledge the people who helped shape this report by contributing information or discussing ideas, including:

Mark Bekkering (City of Toronto, Environment & Energy Division)
Sarah Gingrich, Kelly Sabaliauskas, Reg Ayre and Christine Navarro (Toronto Public Health)
Jane Welsh, Steven Dixon, and Shayna Stott (City Planning)
Nazzareno Capano, and Vesna Stefanovic-Briatico (Transportation Services)
Dylan Aster (Toronto Building)
Dawn Cassar, Nino Dodaro, and Shannon Monaghan (Children's Services)
Ontario Ministry of Environment and Climate Change staff
Kevork Hacatoglu (Ontario Ministry of Transportation)
Dr. Michael Brauer (University of British Columbia)
Dr. Deb Niemeier and colleagues (University of California, Davis)

Distribution:

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Phone: 416-338-7600
TTY: 416-392-0658

publichealth@toronto.ca

EXECUTIVE SUMMARY

Toronto's air quality is improving. Policies and programs implemented at all levels of government over the past decade have led to downward trends in pollutant emissions, ambient air pollution levels, and related health impacts (MOECC, 2013). However, progress may be slowing and air pollution still poses a significant burden of illness in Toronto. There is still much work to be done to reduce emissions that are harmful to health.

In 2014, Toronto Public Health (TPH) reported that air pollution from all sources gives rise to 1,300 premature deaths and 3,550 hospitalizations in Toronto each year. Traffic-related air pollution (TRAP) is the major local contributor to air pollution in Toronto. Adverse health impacts attributed to air pollution are amplified for people in close proximity to major highways and roads, where the concentration of common air contaminants (CACs) is significantly increased by local TRAP. In the 2014 assessment, TRAP accounted for 42% of premature deaths and 55% of hospitalizations attributable to locally emitted air pollution each year (TPH, 2014b).

In 2011 TPH and the City's Environment and Energy Division (EED) began conducting local air quality studies in several parts of the city in response to concerns about the potential for cumulative impacts from current and past exposures to pollutants in former industrial areas. In 2015-2016, the local air quality studies were updated with current data and expanded to address the city as a whole. The city-wide modelling led to similar conclusions as the local air quality studies and identified greater city-wide significance of TRAP in Toronto.

Based on the city-wide modelling, traffic is a significant source of air pollution in Toronto, and concentrations are especially high near highways and busy roads. Modelling results indicate that some TRAPs, benzene and PM_{10}, are present at levels that exceed the health benchmarks set by the Ministry of the Environment and Climate Change (MOECC) at times in Toronto. An assessment of the health risks arising from modelled air pollution on a city-wide scale showed elevated risk for respiratory and cardiovascular illness, cancer, and non-cancer outcomes (e.g., adverse immunological, neurological, and developmental outcomes).

As anticipated, modelled levels of TRAP tend to be higher along highways and major arterial roads of Toronto. People who live, work, learn or play near these roads are at greatest risk of adverse health outcomes associated with TRAP. Vulnerable populations, including children, seniors, and people who work or commute in vehicles are at particular risk.

Factors that determine the concentration of TRAP include traffic volumes and their patterns of flow, meteorological conditions, built form, and urban topography. For any given roadway, a key indicator of the presence of TRAP is traffic volume. Numerous Toronto highways and roadways carry high traffic volumes. Highway 401 within Toronto includes the busiest section of highway in North America. The average daily volume of traffic on Toronto's 116 major and minor arterial roads is over 25,000 vehicles. TPH mapped TRAP exposure zones, defined as 500 metres on either side of a highway with an average of 100,000 vehicles or more per day, 150 metres on either side of a highway with an average of 50,000 vehicles or more per day, and 100 metres on either side of a roadway with an average of 15,000 vehicles or more per day. The maps were used to estimate the number of sensitive sites, including schools, child-care centres and long-term care facilities, that are located in TRAP exposure zones and that may benefit from mitigation measures to reduce exposure of sensitive receptors.

A review of the current literature indicates there are a number of strategies that can effectively mitigate exposure to traffic pollutants. Due to the complexity of the issue, an effective TRAP mitigation strategy requires a collaborative, multi-sectoral effort from all orders of government – local/municipal, provincial, and federal. Municipalities can utilize land-use planning and transportation management tools such as official plans, zoning, site plans, and transportation plans for siting new buildings and transportation infrastructure, and influencing site and building design. Provincial regulatory and policy changes can enable transportation and building code interventions. At the federal level, improvements in fuel quality and emission standards can lower car and truck emissions. Priority-setting at the provincial and federal levels can allow for the regulatory requirements, and funding/financing, necessary to stimulate retrofits to existing buildings, and design enhancements to new buildings, that can effectively mitigate traffic emissions from entering the buildings.

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ABBREVIATIONS

AADT	Annual average daily traffic
AAQC	Ambient air quality criterion
AQHI	Air quality health index
B[a]P	Benzo[a]pyrene
CAC	Common air contaminant
CO	Carbon monoxide
CO_2	Carbon dioxide
CWS	Canada-wide standard
EED	Environment & Energy Division
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
MERV	Minimum efficiency reporting value
MOECC	Ontario Ministry of the Environment and Climate Change
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
O_3	Ozone
PAC	Priority air contaminant
$PM_{2.5}$	Particulate matter with a diameter of < 2.5 microns
PM_{10}	Particulate matter with a diameter of < 10 microns
SO_2	Sulfur dioxide
TPH	Toronto Public Health
TRAP	Traffic-related air pollution
$\mu g/m^3$	Micrograms (of contaminant) per cubic metre (or air)
US	United States
US EPA	United States Environmental Protection Agency

AIR QUALITY AND TRAFFIC-RELATED AIR POLLUTION IN TORONTO

Air quality in Toronto is affected by pollution released both within and outside of the city's boundaries. The main sources of air pollution originating within Toronto are traffic; industry; residential and commercial heating; and off-road mobile sources such as rail, air, and marine vehicles (TPH, 2014b). Approximately 36% of Toronto's air pollution is emitted locally with the rest coming from sources elsewhere in Ontario and in the United States (US) (TPH, 2014a). As a major source of both primary emissions and precursors of secondary pollutants, vehicle traffic greatly contributes to the overall impact of outdoor air pollution. Traffic-related air pollution (TRAP) is the source of one third of air pollution emitted within the city boundaries (TPH, 2014a; TPH, 2014b).

TRAP includes some of the common air contaminants (CACs) - sulphur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), and fine particulate matter ($PM_{2.5}$). In addition to these pollutants, vehicle emissions include a range of toxic pollutants such as acrolein, benzene, benzo[a]pyrene, cadmium, chromium, and formaldehyde. Ozone (O_3) is a secondary pollutant that is formed in the atmosphere when CACs, including those emitted by vehicles, and other pollutants react. Carbon dioxide (CO_2) is also emitted in large quantities by vehicles. While CO_2 does not have direct health impacts, it is a greenhouse gas (GHG) that contributes significantly to global climate change, which is expected to lead to a variety of adverse health outcomes (TPH, 2005; WHO, 2016).

HEALTH RISKS ASSOCIATED WITH EXPOSURE TO AIR POLLUTION

Burden of Illness in Toronto

In 2014, Toronto Public Health (TPH) published *The Path to Healthier Air: Toronto Air Pollution Burden of Illness Update*. The report showed that air pollution continues to have a serious impact on health in Toronto, despite improvements in air quality (TPH, 2014b). Estimates updated from a 2004 report found that air pollution from all sources, including those inside and outside of Toronto, gives rise to 1,300 premature deaths and 3,550 hospitalizations related to respiratory and cardiovascular illness each year in Toronto (TPH, 2014b). TRAP accounts for about 280 deaths and 1,090 hospitalizations in the city each year (or about 42% of premature deaths and 55% of hospitalizations due to air pollution emitted within Toronto) (**Table 1**). Residential and commercial sectors are the next most important local contributors to health impacts from air pollution, accounting for about 190 premature deaths and 400 hospitalizations (or 28% of deaths and 20% of hospitalizations arising from pollution emitted in Toronto). While these values represent decreases when compared to 2004 estimates they still represent an important health impact.

Table 1: Burden of illness attributable to air pollution from sources inside and outside Toronto (TPH, 2014b)

Air Pollution Source		Health Outcome	
		Premature Deaths	Hospitalizations
All sources combined[1]		**1,300**	**3,550**
Sources inside Toronto	Traffic (Cars and trucks)	280	1,090
	Residential/Commercial	190	400
	Mobile off-road (e.g., rail, air, marine sources)	80	280
	Industrial	120	200
Sources outside Toronto	Transboundary from United States	390	870
	Transboundary from Ontario	270	740

TPH's burden of illness findings focus on premature deaths and hospitalizations related to respiratory and cardiovascular illness. However, the impacts of air pollution on health also include less severe effects such as chronic bronchitis and asthma symptom days, visits to physicians, and school and work absences (TPH, 2014b). Using updated estimates for premature death and hospitalization numbers from TRAP, the other health outcomes were adjusted using data from an earlier report (TPH, 2007) on TRAP in Toronto that considered additional cardiovascular and respiratory outcomes. It is estimated that air pollution in Toronto from traffic sources currently contributes to 800 episodes of acute bronchitis among children, 42,900 asthma symptom days (also mostly among children), 43,500 days where respiratory symptoms such as chest discomfort, wheeze, or sore throat would be experienced, and 128,000 days when people would stay in bed or otherwise cut back on normal activities as a result of air pollution (TPH, 2014b).

When the proportion of the burden attributable to each individual pollutant is considered, $PM_{2.5}$, NO_2, and O_3 contribute the most to cardiovascular and respiratory ill health. They account for about 69%, 14%, and 13% of premature mortality and about 33%, 35%, and 29% of hospitalizations, respectively. Carbon monoxide and SO_2 contribute relatively little to the overall burden of illness, with CO accounting for 3% of deaths and 2% of hospitalizations, and SO_2 accounting for 1% of deaths and 1% of hospitalizations (TPH, 2014b).

[1] Totals may not sum correctly as a result of rounding

Health Evidence

In 2004, TPH reported on an extensive body of scientific evidence that air pollution adversely affects the health of children and adults (TPH, 2004). The adverse health impacts attributed to air pollution in general are amplified in proximity to major roadways, where the concentrations of some CACs are higher. The health impacts of TRAP are the same as those for air pollution in general. Numerous studies, conducted to assess the impacts on people who live, work, learn, and play near TRAP sources, indicate an increased risk of adverse health outcomes.

Both short- and long-term exposure to TRAP can result in adverse health outcomes. Acute respiratory and cardiovascular effects can be experienced from exposure periods of minutes or hours, whereas chronic illnesses like diabetes, hypertension, and cancer are the result of long-term exposures (Brauer et al., 2012; TPH, 2007; WHO, 2013). Reviews of the health evidence have identified that the strongest association between exposure to TRAP and adverse health outcomes is the onset and exacerbation of respiratory disease, particularly asthma (Brauer et al., 2012). Studies have shown that TRAP may also be associated with heart attack and other cardiovascular disease, wheezing, reduced lung function, childhood cancer, lung cancer, adverse birth outcomes, neurodevelopmental issues, reduced cognitive function, dementia, and chronic conditions such as diabetes (Brauer et al., 2012; Chen et al., 2017; HEI, 2010; WHO, 2013).

ASSESSING LOCAL AND CITY-WIDE AIR QUALITY

Because there is considerable local variation in air pollution concentrations across Toronto, understanding the emissions and concentrations of air pollution is important in helping to understand the health implications of local circumstances, and in setting priorities for pollution prevention. A combination of air quality monitoring and modelling is needed to provide a more accurate picture of the variations in air quality within an urban area.

Air quality monitoring is useful because it provides information about actual concentrations in a specific location, and also allows investigation of trends in air quality over time. As well, most air quality monitors are stationary – they measure air quality at only one location. In Toronto, there are four monitoring stations that measure the most common air pollutants. They cannot always provide accurate information about air pollution concentrations at other locations, or about where the air pollution is coming from.

Air quality modelling results can create a continuous “picture” showing expected air quality everywhere within a community. Models can be used to predict what might happen to air quality if a new source is added to the community, or if an existing source is eliminated. Modelling requires a lot of detailed data about air pollution sources and weather patterns, and modelling predictions are only as good as the data that is used as input. Air quality models are becoming very reliable and sophisticated, and they enable analyses that monitors cannot. For example, they allow prediction of what would happen to local air quality if air pollution emissions were to increase or decrease, or new pollutants were to be introduced.

Local Cumulative Air Modelling Studies and Health Assessments

In 2011, TPH and the City's Environment and Energy Division (EED) began conducting local air quality studies in several parts of the city. These were modelling studies that tackled the spatial distribution of health risk. The first was conducted in 2011 for Wards 30 and 32 (South Riverdale and The Beaches), and the second was conducted in 2014 for Wards 5 and 6 (South Etobicoke and Lakeshore) (City of Toronto, 2011; City of Toronto, 2014). These studies were carried out in response to concerns about the health and environmental impacts of the historical presence of heavy industry in these areas. While many of the facilities are no longer operating, the potential for cumulative impacts from current and past exposures to pollutants remained a question for area residents.

Both local air quality modelling studies provided valuable local information and had similar findings. They revealed that transportation related emissions were the greatest contributor to pollutants that were present in ambient concentrations that were predicted to exceed health benchmarks, including Ontario's Ambient Air Quality Criteria (AAQC) (TPH, 2011a; TPH, 2014a). Health assessments indicated that $PM_{2.5}$, NO_2 and ozone at modelled concentrations were the primary contributors to increased non-cancer (cardiac and respiratory) health risk in both areas, while modelled benzene, chromium, and 1,3-butadiene were the greatest contributors to increased cancer risk (TPH, 2011a; TPH, 2014a).

Air Quality at a City-Wide Scale

In 2015-2016, EED expanded the modelling from the local scale to the city as a whole. EED estimated pollutant levels and created maps depicting average and worst case scenario air quality city-wide. Similar to the local air quality studies, but updated with 2012 data, the modelling used a year's worth of data about emissions from within Toronto and from southern parts of Ontario and the north-eastern US that were expected to have an impact on air quality in Toronto. The modelling accounted for distant and local weather patterns over the course of the year and included emissions from transportation, industrial, commercial, residential, agricultural, and natural sources.

Thirty priority air contaminants were included in the city-wide air quality modelling study; the priority air contaminants include CACs, and other substances that are reported under the City's Environmental Reporting and Disclosure Bylaw, also known as ChemTRAC (**Table 2**). Ozone was modelled separately, since it is a secondary pollutant and has impacts at the regional rather than local scale. As seen in Table 2, many of the modelled substances are associated with traffic sources.

Table 2: Substances included in city-wide air quality modelling

Substances associated with traffic emissions	Substances not associated with traffic emissions
Acetaldehyde Acrolein Benzene 1,3-Butadiene Cadmium Chromium Chromium VI Formaldehyde Manganese Nickel Nitrogen oxides (NO_X) Nitrogen dioxide (NO_2) Nitric oxide (NO) $PM_{2.5}$ PM_{10} Polyaromatic hydrocarbons (as benzo[a]pyrene) Total suspended particles	Carbon tetrachloride Chloroform 1,4-Dichlorobenzene 1,2-Dichloroethane Dichloromethane Ethylene dibromide Lead Mercury Ozone[2] (O_3) Tetrachloroethylene Trichloroethylene Vinyl Chloride Volatile organic compounds (originating from human activity and nature)

The conclusions drawn from city-wide modelling significantly enhanced the conclusions of the local air quality studies. City-wide modelling indicates that traffic is a significant source of air pollution in Toronto, and concentrations are especially high near highways and busy roads. Results indicate that some TRAPs, benzene and PM_{10}, are present at levels that may exceed the health benchmarks set by the Ministry of the Environment and Climate Change (MOECC) at times in Toronto. AAQCs and Canada-Wide Standards (CWSs) are benchmarks that represent an upper limit of desirable concentrations of contaminants in air, and are intended to be protective of health and/or environmental effects.

In the local air quality studies, benzene, benzo[a]pyrene, PM_{10}, and $PM_{2.5}$ – all of which are important vehicle emissions – were identified as exceeding the relevant health benchmarks.[3] The city-wide modelling also suggests that additional substances may exceed AAQCs in some parts of Toronto, including cadmium, chromium, and vinyl chloride (**Table 3)**. While the modelling suggests possible exceedances of these

[2] Ozone (O_3) is a secondary pollutant that is formed in the atmosphere when air pollutants from transportation and other sources react.

[3] Overall the modelled data shows a slight over-prediction of most CACs when compared to MOECC monitored values. However, most modelled CACs are within the expected monitored values. Generally, the modelled average CAC levels are within a factor of two of the monitored average data and within the variability of the monitoring data. This equivalence is regarded as being normal among dynamic, rather than regulatory, air quality modelling assessments.

substances, exceedances were not observed in air quality monitoring, and this issue merits further exploration. Cadmium and chromium may be present in road dust[4], railway emissions, and in emissions from industrial sources, while vinyl chloride is more likely to be emitted from a point source, such as an industrial location.

Table 3: Substances whose modelled concentrations exceeded health benchmarks in at least one part of Toronto[5]

Substances exceeding an annual average health benchmark	Substances exceeding a 24-hour average health benchmark
Benzene Benzo[a]pyrene Cadmium Chromium (VI) Vinyl chloride	Benzene Benzo[a]pyrene Cadmium Chromium (VI) PM_{10}[6] $PM_{2.5}$[7] Vinyl chloride

Figures 1 and **2,** below, were selected to illustrate the spatial patterns of pollution concentrations across Toronto for two substances, benzene and PM_{10}. The maps both illustrate the impacts of vehicle emissions from major transportation corridors on air quality in the city.[8]

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[4] A limitation of the air quality model used is that cadmium from road dust may not be fully accounted for. As a result, the findings underestimate the cadmium contribution arising from busy roadways.

[5] Unless otherwise noted, health benchmarks in Table 3 are AAQCs based on health as the limiting effect.

[6] The benchmark is Ontario's interim 24-hour AAQC for PM_{10}.

[7] The benchmark is the 24-Hour CWS for $PM_{2.5}$.

[8] Pollutant levels are somewhat over-estimated in Figures 1 and 2 and would benefit from further refinement. However, in keeping with standard modelling procedures, the current level of refinement is considered adequate for indicating appropriate policy directions. There is only one MOECC air quality monitoring station located immediately adjacent to a major TRAP producing highway. Air quality data has been collected at that site since the Pan Am games in 2015 and will be valuable to modellers and policy-makers, but none has yet been publically released.

Figure 1: Modelled annual average benzene concentrations across Toronto (based on 2012 data)

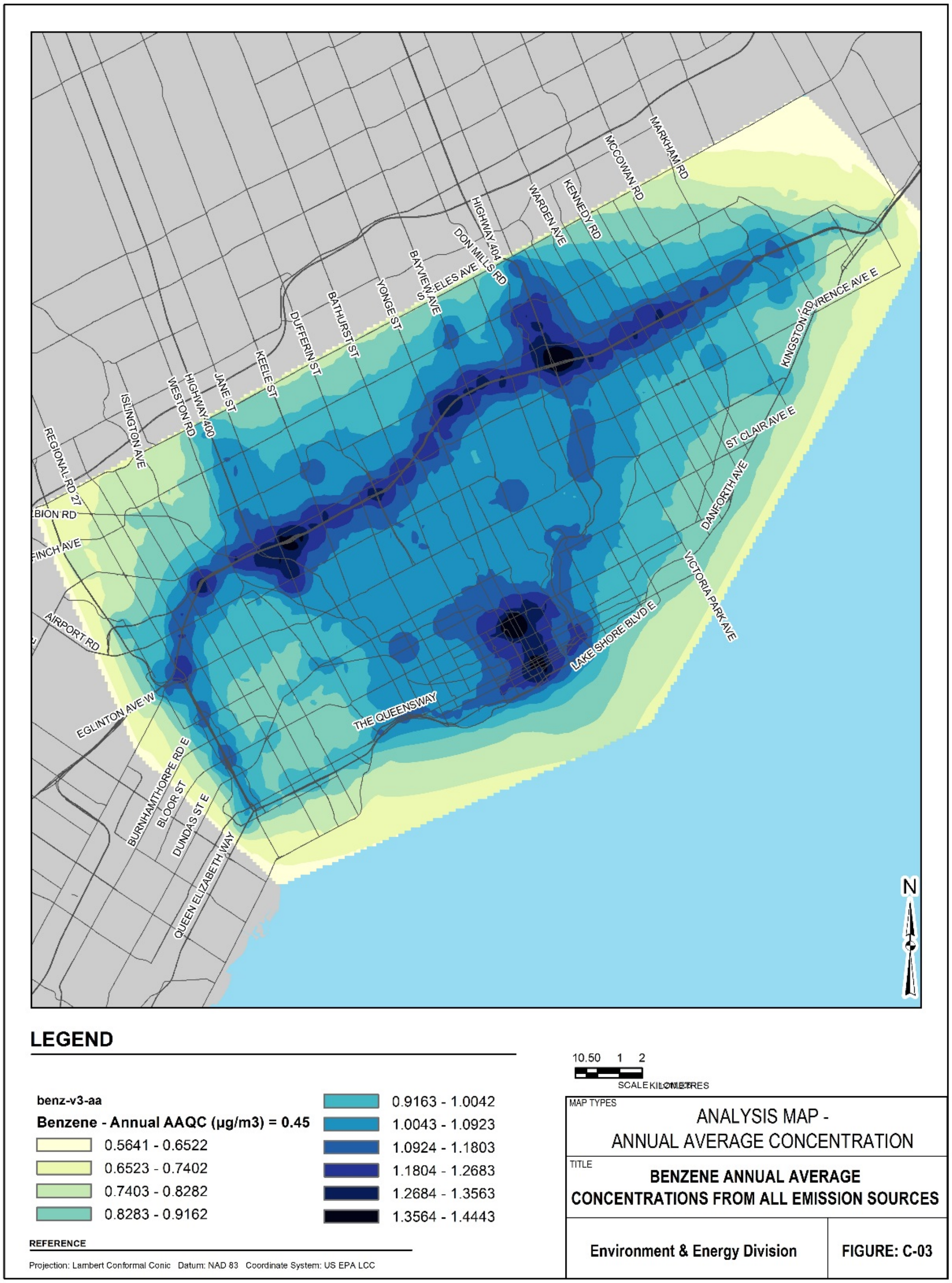

Figure 2: Modelled annual average PM_{10} concentrations across Toronto (based on 2012 data)

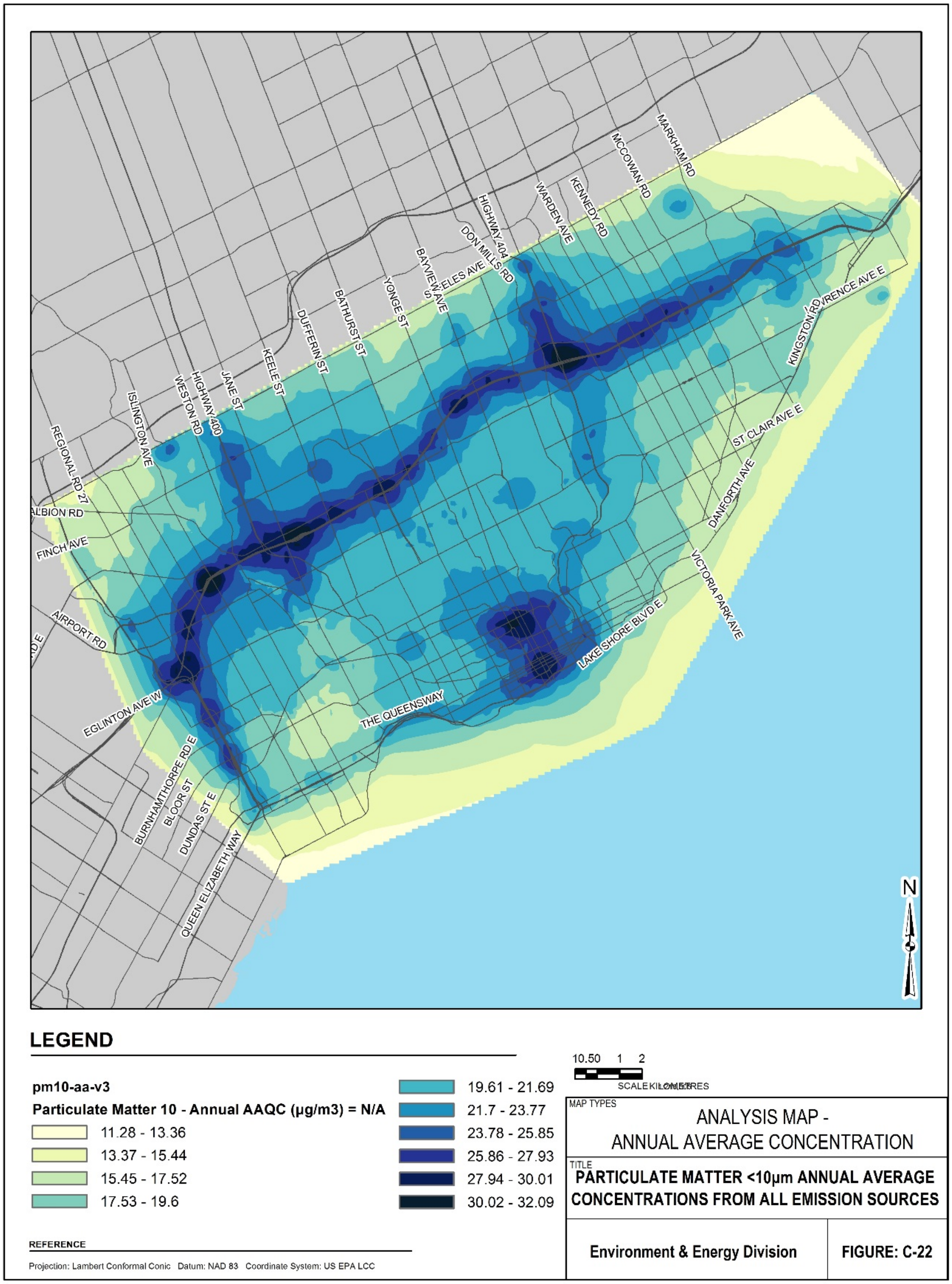

Figure 1 shows modelled annual average concentrations of benzene. The influence of transportation emissions is clear along Highway 401 and other major highways, including the additional traffic on ramps and at highway crossings and interchanges, as well as the congested downtown area. While the provincial annual AAQC for benzene is 0.45 μg/m^3, the modelled concentrations range from 0.56 to 1.44 μg/m^3, depending on the specific location within Toronto.[9]

Figure 2 shows modelled annual average concentrations of PM_{10} in Toronto. As for benzene, the influence of traffic sources on PM_{10} concentrations can be clearly seen along major highways.[10]

Cumulative Health Risks from Air Pollution

As a complement to the city-wide air modelling study TPH prepared a health assessment estimating the cumulative health impacts of air pollution across Toronto. The analysis recognizes that people are exposed to a mixture of pollutants at any given time and that the effects may accumulate. The science for assessing the health impacts of mixtures of chemicals continues to evolve. Currently, there is no common approach to assessing health risks arising from combined exposures from the complete range of substances considered in this study. TPH grouped pollutants according to similar mechanisms of action, resulting in three categories of health effects, with cumulative impact estimated for each group of pollutants separately. The categories were:

1. Substances associated with non-cancer effects, for which there is an assumed health threshold;
2. Substances associated with cancer; and
3. CACs, which are mainly associated with cardiovascular and respiratory diseases, and which are assumed to have no health threshold.

Many of the findings from the city-wide health assessment are similar to those from the previous local air quality health assessments (TPH, 2011a; TPH, 2014a). **Table 4** shows the calculated cumulative health risks based on the city-wide modelled air pollutant concentrations, for non-cancer, cancer, and respiratory and cardiovascular health outcomes.

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[9] The MOECC's and the University of Toronto's Gage Institute monitored data for 2012 show 0.497 μg/m^3 +/- 0.312 and 0.622 +/- 0.264, both of which are approximately half of the City's modelled estimates of 0.9 and 1.6 respectively. This 2x comparison is regarded as a good fit and very acceptable by professional air quality modellers for policy development purposes.

[10] The MOECC no longer monitors PM_{10}. A comparison with the Gage Institute monitored PM_{10} annual mean of 12.87 μg/m^3 +/- 9.13 again shows strong acceptability of the City's modelled data, 25.67 μg/m^3, at that location. The city-wide PM_{10} modelled data of 13.7 minimum, 18.9 mean, and 32.5 maximum is also considered within standard acceptable 2x modelling parameters.

Table 4: Summary of health risks estimated from city-wide modelling study

Health outcome	Health risk estimated from model results
Non-cancer (e.g. immunological, neurological, developmental)	Some health risk arising primarily from acrolein and cadmium
Cancer[11]	110 in one million
Respiratory and cardiovascular	9% increase

In the case of carcinogens, benzene, chromium, polyaromatic hydrocarbons, and 1,3-butadiene are all among the top contributors to health risk based on modelled levels. Among the CACs, $PM_{2.5}$, O_3, and NO_2 are the primary contributors to excess risk of premature death. As well, maps of health risk (not shown) suggest that for many of these key pollutants, transportation is an important source of pollution and related health risk across Toronto. While more detailed interpretation of these findings is available in previous reports, the estimated health risk attributable to these substances warrants continued action to reduce exposure, especially for the CACs (TPH, 2011a; TPH, 2014a). The city-wide study also suggests that action is warranted to reduce exposures to some substances in Toronto's air based on their non-carcinogenic health endpoints; in particular, acrolein and cadmium.

The non-cancer health effects of the substances modelled in this study include neurological, immunological, and developmental health impacts. In general, for non-cancer effects it is assumed that there is a threshold of effect – a level below which exposure to the substance will have no adverse health impacts. By comparing an exposure level to the threshold, it is possible to assess whether a health impact is expected.

Each pollutant considered in the health assessment has a different threshold. To be able to compare them all on the same scale, a measure called the hazard ratio is obtained for each pollutant by dividing the exposure level for that pollutant by its health threshold. If the hazard ratio is less than one, then a person or community is being exposed at a level which current knowledge suggests is not a concern. As well, hazard ratios for multiple substances can be added to estimate a cumulative hazard.

Of the substances included in EED's modelling study, 20 are potentially associated with non-cancer health effects. When the hazard ratios for the 20 pollutants are added together, the cumulative hazard index is 3.45. This suggests that there may be an

[11] The cancer risk results are not directly comparable between neighbourhoods, as the city-wide findings and those from South Riverdale and The Beach include the contribution of B[a]P, while those from Etobicoke-Lakeshore do not. TPH excluded the B[a]P findings from the Etobicoke-Lakeshore studies as a result of concerns about the accuracy of the modelled concentrations.

elevated risk for non-cancer health effects that arises from the accumulation of exposures that occurs in the modelled ambient urban air pollution mix[12].

Based on the modelling results, the substances that appear to contribute most to this non-cancer health risk are acrolein and cadmium. The hazard ratio values for the remaining 18 individual non-carcinogenic substances are all less than one, most by a very large margin. This indicates that there is little or no risk of adverse non-cancer health effects from exposures to these substances individually.

The hazard ratio for acrolein was estimated to be 1.6. A major reason for the elevated hazard ratio seen in the city-wide study is the adoption of an updated, more stringent threshold for health effects based on information from the MOECC. That is, while the concentrations of acrolein across Toronto are not much different from what was modelled in previous studies, our understanding of the risk associated with acrolein has changed.

While the hazard ratio for acrolein appears to be elevated, monitoring data suggests that the levels predicted by the modelling are not unusual. Data collected by Canada's National Ambient Pollutant Surveillance Network between 2009 and 2013 suggests that acrolein concentrations are routinely above guideline levels at sites across Canada, and indicated concentrations could commonly be in the range of 0.1-1 µg/m^3 or greater (Galarneau et al., 2016). For comparison, the modelling for the City of Toronto predicted concentrations ranging from 0.02 µg/m^3 – 0.05 µg/m^3. Depending on the level of exposure, acrolein may cause irritation of the eye and respiratory system, and may lead to reduced lung function. While the hazard ratio was developed under conservative assumptions and is still relatively close to one, the findings indicate a need for further consideration and action. Acrolein is primarily emitted by transportation sources, and the highest risks are predicted to be along the busy highways and congested areas of Toronto.

Exposure to cadmium is typically associated with impacts to the lung and kidney. The source of cadmium in the model is primarily railway lines. Similar emissions are clearly generated by diesel fuel used in trucks and other vehicles. While it is possible to utilize federal data to determine cadmium emissions from diesel trains, it is not possible, given the lack of equivalent data or emission factors for diesel emissions from road vehicles, to assess cadmium emissions along highways and city roads. However, elevated levels of cadmium are to be expected along the major transportation corridors. While the modelling study indicated the potential for elevated cadmium levels, exceedances of the AAQC benchmark are not seen in air quality monitoring. The issue of potentially

[12] There are limitations to this approach. It assumes that the effect of the individual pollutants is in direct proportion to the level of exposure and the effect of each pollutant is additive. In some circumstances, this could overestimate the risk since it does not take into account that different pollutants affect different parts of the body and ignores the natural mechanism of the body to eliminate or detoxify these substances. At the same time, the approach could underestimate the risk since it does not take into account potential interactions between these pollutants that could increase the health impacts.

elevated cadmium levels near transportation sources requires further investigation, and cooperation from other orders of government. The average hazard ratio for cadmium was one, suggesting that it is unlikely to be a health concern at present. However, action is warranted in areas where ambient concentrations are above average, and because cadmium could become a concern more broadly if ambient concentrations were to increase or be better recognized by air quality modelling.

Overall, the study findings suggest that the substances that contribute most to health risk are components of TRAP. Therefore, efforts to reduce exposure to TRAP will yield health benefits.

THE IMPORTANCE OF TRAFFIC-RELATED AIR POLLUTION

Although air quality in Toronto has generally improved over time, certain populations may experience increased exposure to TRAP as a result of urban intensification and greater traffic volumes in the city (Brauer et al., 2012; TPH, 2007).

Populations Most Vulnerable to Adverse Health Outcomes Related to TRAP

As anticipated, results of the air quality modelling indicate that the levels of air pollutants tend to be higher along highways and major arterial roads of Toronto. People who live, work, learn or play near these roads are therefore at greatest risk of adverse health outcomes associated with TRAP (Brauer et al., 2012; PHO, 2016). Specific populations most affected include:

- Children: Children are especially sensitive to TRAP because they have a faster respiration rate and developing lungs (PHO, 2016). They may also spend more time than adults engaging in physical activity outdoors, and are at increased risk if they attend schools or child care centres that are located near highways or major roadways (Janssen et al., 2001; Reis et al., 2010).

- Seniors: Seniors often have existing cardiovascular or respiratory disease which can increase their vulnerability to TRAP (Simoni et al., 2015). Additionally, seniors who live in facilities that are located near highways or major roadways are at increased risk.

- People who work or commute in vehicles: Risk of adverse health outcomes related to TRAP exposure is elevated for taxi, bus, and truck drivers, as well as people who commute on major roadways in personal vehicles on a regular basis (TPH, 2007; Weichenthal et al., 2015). Spending longer amounts of time in vehicles and traveling during rush hour are also associated with increased risk of exposure (Peace et al., 2004).

Other populations at greater risk of adverse health outcomes related to TRAP exposure include people who work or exercise near highways or major roadways (TPH, 2007). In addition people of lower socioeconomic status may be more likely to live, work, learn, or play near highways or major roadways or be exposed to indoor settings with poorer ventilation systems, which can lead to an inequitable distribution of adverse health outcomes (CIHI, 2011).

Factors Influencing Dispersion Patterns of Common Air Pollutants

Many factors influence how pollutants move and concentrations change and therefore the potential for exposure. The concentration of pollutants varies both spatially (by location) and temporally (by time) (WHO, 2013). The concentration of pollutants in air along highways and major arterial roads decreases as the distance from the roadway increases (HEI, 2010; Karner et al., 2010; WHO, 2013). The concentrations of primary pollutants (those emitted directly from vehicles) tend to decrease rapidly as the distance from the roadway increases, whereas secondary pollutants (those that can be formed in the atmosphere) dissipate more slowly (Brauer et al., 2012; HEI, 2010; TPH, 2004). . Although different studies report slightly different ranges, there is consensus that the concentration of pollutants generally decreases to background levels within 100 metres of the edge of major arterial roads and 500 metres of the edge of highways when there are no major meteorological, topographical, or structural interferences (Brauer et al., 2012; HEI, 2010; TPH, 2004).

Concentrations of TRAP are influenced not only by the distance from the roadway, but also by traffic volumes and patterns, meteorology, topography, and the built environment (Brauer et al., 2012; PHO, 2016):

Traffic volumes

The greater the traffic volume, measured as annual average daily traffic (AADT) volumes, the greater the concentration of pollutants. Highways are typically defined as having an AADT of greater than 100,000 vehicles and major arterial roads typically have an AADT of greater than 15,000 vehicles (Brauer et al., 2012). Highway 401 is one of the busiest highways in North America and can exceed 400,000 vehicles at peak times. **Tables 5** and **6** show the mean and maximum daily traffic volumes on Toronto expressways, highways, and major arterial roads.

Table 5: Mean and maximum daily traffic volumes on Provincial highways and City expressways[13]

Expressways & Highways	Mean	Maximum
Highway 401 *(Renforth Dr. to Kingston Rd.)*	331,246	410,000
Highway 427 *(South of the 401 only)*	364,550	382,200
Highway 404	255,600	285,100
Highway 400	141,800	231,000
Gardiner Expressway	150,662	222,894
Don Valley Parkway	148,286	180,303
Queen Elizabeth Way	171,900	175.000
Highway 409	89,125	114,600

[13] All data in table derived from Ontario Ministry of Transportation, 2013, with the exception of data taken from City of Toronto, Transportation Services, 2010, for the Gardiner Expressway and the Don Valley Parkway.

Table 6: Mean and maximum daily traffic volumes on major arterial roads with maximum daily traffic volumes greater than 50,000 vehicles per day[14]

Major Arterial Road	Mean	Maximum
Bayview Ave	36,610	64,070
Black Creek Dr	39,242	51,364
Bloor St E	35,972	57,300
Don Mils Rd	34,837	52,574
Dufferin St	30,043	56,642
Dundas St W	25,581	60,530
Eglinton Ave E	39,825	64,778
Eglinton Ave W	29,090	57,970
Finch Ave	35,610	77,432
Islington Ave	26,917	51,762
Keele St	32,806	60,022
Kennedy Rd	36,799	71,796
Lake Shore Blvd E	28,673	65,546
Lake Shore Blvd W	26,072	69,046
Lawrence Ave E	33,897	51,618
Lawrence Ave W	31,349	52,830
Leslie St	35,212	64,346
Markham Rd	40,085	61,946
McCowan Rd	37,930	67,500
Sheppard Ave E	33,947	57,632
Sheppard Ave W	42,750	74,660
Steeles Ave E	39,579	60,446
Steeles Ave W	38,017	53,778
University Ave	30,969	67,256
Warden Ave	33,878	59,090
William Allen Rd	55,900	66,044
Yonge St	35,184	78,892
Average of 27 major arterials (as above)	**35,066**	**62,180**
Average of 116 arterials across Toronto[15]	**26,332**	**38,214**

Traffic types and patterns

The concentration of TRAP is greatest when there is a greater volume of older vehicles and heavy-duty diesel trucks (TPH, 2014b; TPH, 2007). Although diesel trucks comprise only 1.5% of Canada's vehicle fleet, they are responsible for nearly 80% of all traffic-related $PM_{2.5}$ emissions and more than half of the emissions of nitrogen oxides (NO_x) from vehicles in Ontario (Environment Canada, 2014; NRCan, 2009).

[14] City of Toronto, Transportation Services, 2010

[15] 116 Arterial roads include 13 roads that are counted twice for their eastern and western portions. For example, King Street West and King Street East are considered two separate arterials. The figure of 116 includes 27 major arterials and 89 minor arterials.

Vehicles also emit more pollutants when traffic moves in a stop-and-go pattern rather than in a continuous flow (Brauer et al., 2012). Ryan and colleagues (2005) reported that stop-and-go traffic patterns may be a more important predictor of adverse health impacts than total traffic volumes.

Meteorological conditions

Wind direction and velocity can impact TRAP concentrations near the roadway. Concentrations of pollutants downwind will decline more slowly than those upwind (Brauer et al., 2012; HEI, 2010; PHO, 2016; Beckerman et al., 2008). Other influential meteorological conditions include solar radiation, which influences the formation of secondary pollutants in the atmosphere, and seasonal conditions – for example, summer rain events can accelerate the deposition of particulate matter (Brauer et al., 2012).

Built form and urban topography

Long rows of buildings with continuous form on either side of a busy urban street can form "street canyons" that trap pollutants and prevent them from dispersing (Brauer et al., 2012). Similar natural topography formed by valleys can have the same effect on the concentration of pollutants (Brauer et al., 2012; PHO, 2016).

Sensitive Uses in TRAP Exposure Zones

Based on this information, TPH set out to estimate how many sites with sensitive users are located in zones with potentially high exposure to TRAP.

To gain this understanding, TPH mapped "TRAP zones" where levels of TRAP in the air are expected to be higher than background levels in Toronto. The literature indicates that TRAP exposure zones extend 500 metres from highway with an average of 100,000 vehicles or more per day, and 100 metres from roads with an average of 15,000 vehicles or more per day (Brauer et al., 2012). For this analysis, TRAP exposure zones were defined as 500 metres on either side of a highway with an average of 100,000 vehicles or more per day, 150 metres on either side of a highway with an average of 50,000 vehicles or more per day, and 100 metres on either side of roadways with an average of 15,000 vehicles or more per day. As indicated in the literature, beyond these zones it is expected that TRAP is at background levels.

Locations of facilities with sensitive users were then compared to locations of estimated TRAP zones. Sites with sensitive users included schools, child-care centres, long-term care centres and seniors' residences. It should be noted that in this analysis, schools include public and private, large and small schools. The purpose of the analysis was to understand how many facilities are affected by TRAP and may benefit from measures to mitigate exposure of sensitive users.

Table 7 summarizes the number of child care centres, schools, and long-term care centres and seniors' residences that are located in TRAP zones in Toronto, and their level of TRAP exposure. These facilities are categorized as:

- Sites with the greatest TRAP exposure: located near multiple major highways with an AADT volume of 100,000 vehicles or more, within 500 metres;
- High exposure sites: located near one major highway with an AADT volume of 100,000 vehicles or more, within 500 metres;
- Medium-high exposure sites: located near one highway with an AADT volume of 50,000 vehicles or more, within 150 metres;
- Medium exposure sites: located near one arterial road with an AADT volume of 15,000 vehicles or more, within 100 metres; and
- Sites outside TRAP zones: located farther away from highways and high-volume arterial roads.

The results (**Table 7**) indicate that a large proportion of sites with vulnerable users are located within TRAP exposure zones. It is estimated that approximately 50% of child care centres, 43% of schools, and 63% of seniors' facilities identified in the analysis are located near major roads and highways where TRAP levels are expected to be elevated. Eleven child care centres and 20 schools are located close to multiple highways. The large number of sensitive sites near highways and major roads highlights the need to consider mitigation measures to reduce the exposure of building occupants to TRAP.

Table 7: Number and percentage of vulnerable sites in TRAP zones and level of TRAP exposure in Toronto[16]

	Greatest exposure	**High exposure**	**Medium-high exposure**	**Medium exposure**	**Outside TRAP zones**
Location	Within 500 metres of multiple major highways	Within 500 metres of one major highway	Within 150 metres of a highway with AADT > 50,000 vehicles	Within 100 meters of one or more arterial roads with AADT > 15,000 vehicles	Farther from highways & high-volume arterial roads
Facilities	Number (%)	Number (%)	Number (%)	Number (%)	Number (%)
Child care centres	11 (1%)	129 (13%)	2 (0.2%)	367 (36%)	497 (49%)
Schools	20 (2%)	131 (12%)	2 (0.2%)	333 (29%)	644 (57%)
Long-term care centres and senior's homes	0 (0%)	27 (16%)	0 (0%)	80 (47%)	65 (38%)

MITIGATION STRATEGIES FOR TRAFFIC-RELATED AIR POLLUTION

TPH estimates that approximately 35 percent of Toronto's residential land-use is located within 100 metres of a major arterial road, within 150 metres of a highway with AADT of more than 50,000 vehicles, or within 500 metres of a highway. Research suggests that people that live close to busy roadways are also more likely to experience unemployment, education, and ill health (CIHI, 2011). A review of the current literature indicates there are numerous strategies that can effectively mitigate exposure to traffic pollutants. These are interventions that address the source (reduction measures for vehicles, fuel, and congestion), address the pathway (the natural and built environment) or strengthen the receptor's ability to withstand the impacts (behavioural interventions) (**Table 8**).

[16] Data sources for table: Based on road data and traffic volumes, Ministry of Transportation, 2013; City of Toronto Transportation Division, 2010. Facilities information, Open Data. Schools 2014, child-care centres 2016, long-term care 2012, seniors' homes 2008.

Table 8: TRAP exposure risks (Adapted from Metro Vancouver, 2013)

Source (Traffic)	**Pathway (Environment)**	**Receptor (Person)**
• Vehicle type • Fuel quality • Emissions • Vehicle speed & volumes • Congestion	• Built environment • Distance between people & traffic • Topography & environmental conditions	• Time spent in proximity to traffic • Transportation mode • Activity level • Physiological & social characteristics

Due to the complexity of the issue, an effective TRAP mitigation strategy requires a collaborative, multi-sectoral effort among all orders of government – local/municipal, provincial, and federal. Municipalities can utilize land-use planning and transportation management tools such as official plans, site plans, and transportation plans for siting new buildings and transportation infrastructure, and influencing site and building design. Provincial regulatory and policy changes can enable transportation and building code interventions. At the federal level, improvements in fuel quality and emission standards can lower car and truck emissions. Decisions at the provincial and federal levels can allow for the regulatory requirements, and funding/financing, necessary to stimulate retrofits to existing buildings, and design enhancements to new buildings, that can effectively mitigate traffic emissions from entering.

In order to be effective, mitigation strategies must be accompanied by education and outreach activities. Reductions in exposure to TRAP can be achieved through behavioural changes at the institutional and even the individual level, such as management of outdoor activities, retrofitting of existing building and facilities, and changes to current practices such as street sweeping.

Land-Use Planning at the City-Wide and Neighbourhood Level

Separation distances

There is an existing body of literature that links the built environment to health outcomes. Land use and urban design characteristics can influence walkability, bikeability and the level of physical activity, all factors that impact exposure to TRAP (TPH, 2011b). Municipalities have a number of tools at their disposal such as official plans, zoning, and other planning policies that allow them to modify the built environment in order to separate vehicular traffic from places where people spend their time (Brauer et al., 2012).

The most widely reported mitigation strategy is the implementation of separation distances, or buffer zones. In 2005, the California Environmental Protection Agency provided some of the earliest guidance on siting new sensitive land uses near various polluting sources, including roadways. The recommendation was for a setback of 500 feet (150 metres) from urban roads with traffic counts of 100,000 vehicles per day or more (Cal EPA, 2005).

In 2012, based on more up-to-date evidence, Brauer and colleagues recommended a separation distance of 100 metres from roads with 15,000 or more AADT. The British Columbia Ministry of the Environment recommends a setback of 150 metres from busy roads for sensitive uses such as schools, hospitals, long-term care facilities and residences (BC MOE, 2012). It further recommends special consideration for truck routes as elevated air pollutant concentrations have been measured up to 750 metres from such routes.

Separation distances are most practically applied to new buildings and roads, and Toronto is a mature, largely built out city. In Toronto, more than 116 arterial roads have an AADT of 15,000 vehicles or more, with the counts likely to increase in future. It would not be feasible to restrict development within the proposed buffer zones and meet Toronto's growth projections. The available evidence, however, suggests that sensitive facilities that are not able to meet prescribed separation distances could benefit from the implementation of TRAP mitigation measures (Halton Region, 2012; SMAQMD, 2011).

Urban street canyons

Urban canyons are found in areas of Toronto where tall buildings are built on the existing narrow road network. They occur where multiple buildings on opposite sides of a road face each other and where the buildings are taller than the road is wide. As a result, traffic emissions into air do not disperse as readily and become entrapped at street level which results in an accumulation of pollutants at ground level (City of Toronto, 2016). This phenomenon can be mitigated by design measures, primarily for new buildings, that encourage greater street ventilation, create fewer confined areas, require step-backs of upper stories and encourage a variety of building heights (GSA, 2012; LASC, 2014).

In 2016 EED completed The Urban Ventilation Study, which quantified the changes to local air quality due to impacts of intensification in combination with the existing urban layout. EED developed an equation to help evaluate streets and identify the level of severity of poor air quality. The approach can be used to identify streets where changes to existing and future building structure could be used to alleviate air quality impacts due to the street canyon effects. To address the issue, EED also identified options for new-build and existing buildings, in keeping with present urban design guidelines.

Congestion reduction

A number of studies have examined the relationship between traffic congestion and adverse health impacts. Brauer and colleagues (2012) reported that reduction in traffic congestion was associated with significant decreases in premature birth and low birth weight in infants. They further reported that "stop-and-go" traffic may be a more important predictor of adverse health impacts than total traffic volumes. Stop-and-go traffic, or brake-and-accelerate traffic, pollutes a lot more than steady flow traffic (Berry, 2010). Measures to encourage steady flow by variable speed limits on highways and by synchronizing traffic lights on city streets are utilized in cities such as Munich, Germany and London, UK, primarily to reduce congestion. Experience in Catalonia, Spain, and model estimates from the literature, indicate that a variable speed policy can be effective in reducing traffic pollution (Bel and Rosell, 2013; Zegeye et al., 2009).

A number of other strategies have been proposed and implemented to alleviate traffic congestion, most notably in London, England and Paris, France, cities that have traditionally experienced high levels of congestion. These strategies typically include restrictions on vehicles entering high congestion zones, implementation of low emission zones, and congestion charges (Brauer et al., 2012).

In November 2015, City Council endorsed the updated Congestion Management Plan for the period 2016-2020. The plan proposes a number of measures to improve management of traffic congestion on Toronto's streets and expressways, including development of action plans for "hot-spots" across Toronto, upgrading the City's "smart" traffic signal system, developing a comprehensive curbside management strategy, expanding the existing Smart Commute program (City of Toronto, 2017a). In 2017, the City also adopted the Vision Zero Road Safety Plan.

In order to explicitly address traffic pollution, implementation of congestion management strategies should prioritize high traffic emission zones where vulnerable populations live, work, learn and play. Exploring and implementing measures on major roadways may decrease congestion and "stop-and-go" traffic, thus leading to reduction in traffic emissions and exposure to traffic pollutants.

Transportation planning

Most existing traffic management guidance focuses on reducing congestion rather than reducing TRAP (PHO, 2017; Brauer et al., 2012). Cities and regions, including the City of Ottawa and the York Region, have drafted or implemented Transportation Master Plans that provide guidance for planning and development of future transportation infrastructure (PHO, 2017). These plans recognize the contribution of active transportation, improved transit infrastructure, and connectivity to improved health, (TPH, 2011b; Brauer et al., 2012; TPH, 2012). Depending on their impact on total traffic volumes, these interventions may contribute to a reduction in TRAP.

The City of Toronto already has a wide range of transportation policies, programs, and initiatives in place to support Toronto's continuing growth and health. Toronto's Official Plan sets out broad policies for transportation planning. In addition, the recently adopted Cycling Network Plan sets out a ten year work plan for the development of Toronto's cycling network, and the Pedestrian Charter sets out the principles necessary to ensure that walking is a safe and convenient mode of urban travel (City of Toronto, 2017b). To ensure these initiatives are effective in reducing exposure to TRAP, current plans and policies need to also explicitly take into account reduction of exposure to emissions from vehicles.

Many active transportation policies aim to separate vehicular traffic from pedestrian and cycling routes in order to increase user safety and encourage walking and cycling (TPH, 2012). While such an approach will help decrease collision rates, it can still place pedestrians and cyclists in close proximity to traffic emissions. In their study, Hankey and colleagues (2017) report that approximately 20 – 42% of active travel occurs in areas with high exposure levels. They further estimate that shifting active travel one block to a lower traffic road could decrease individual's exposure to ultrafine particulate matter by 11%, black carbon (a component of particulate matter) by 19%, and fine particulate matter by 3%. When the shift is not feasible, measures such as physical and vegetative barriers can provide a separation between vehicular traffic and cyclists or pedestrians, where space is available (GSA, 2012; US EPA, 2016; Hagler et al., 2012).

Land-Use Planning at the Site Level

Site layout

There are a number of measures available at the site level to mitigate the impact of traffic emissions, most notably the location and orientation of individual buildings and outdoor play areas. Ideally, both should be located as far as possible away from roadways and be buffered by transitional uses, thereby increasing the physical distance from traffic emissions. Special consideration should be given to outdoor recreation areas and courtyards that are designed for individuals to spend prolonged periods of time outside. Consideration should also be given to site open spaces in the interior of "U" or "L" shaped buildings, to create open spaces that are located away from the roadways as this provides a physical barrier between traffic emissions and people using the space (GSA, 2012; LASC, 2014).

Vegetation and landscaping

It is well known that urban green spaces provide numerous ecological, social, cultural and economic benefits. The ecological services, such as cooling, provided by Toronto's approximately 10.2 million trees are valued at $28.2 million annually (City of Toronto, 2013). In its recent report, TPH summarized that the presence of green space is associated with reduced health outcomes such as mortality and cardiovascular disease, increased activity levels, improved health and wellbeing, and various environmental health benefits such as improved air quality, relief from extreme heat, and lessening of the urban heat island effect (TPH, 2015). Recently, there has also been much attention given to vegetation and green spaces as sinks for traffic pollutants; however, there is still only limited evidence of the effectiveness of such approaches for reducing exposure to TRAP (Brauer et al., 2012; BC MOE, 2012; Baldauf et al., 2011).

The US Environmental Protection Agency indicates that vegetation can reduce near road traffic impacts by acting as a physical barrier between the traffic emissions and the receptor by affecting pollutant transport and dispersion, and by intercepting the particles as they pass through and accumulate on leaf surfaces (US EPA, 2016; US EPA, 2015). There have been some studies examining the uptake of pollutants by various vegetative species, but they have been inconclusive in terms of the magnitude of pollution reduction and value as a TRAP reduction measure (Brauer et al., 2012)

The efficacy of vegetation as a traffic pollution mitigation strategy is highly dependent on many factors including plant species and their characteristics, the height, thickness, and porosity. Vegetation that is not designed as a barrier has negligible reduction of traffic emissions (Sonoma, 2010). The US EPA (2016) notes that vegetation can be a diluting complement to the other emission reduction efforts and should be considered as part of an overall TRAP reduction strategy.

Physical barriers

Physical barriers, such as sound walls, can have a significant influence on pollutant concentrations downwind from the wall by affecting wind flow and dispersion. The resulting dilution of traffic pollutants is variable and highly dependent on wall height and length, wind speed and direction, as well as roadway configuration (Sonoma, 2010; Brauer et al., 2012; US EPA, 2016). The US EPA (2015) states that a well-designed sound wall can reduce downwind pollutant concentrations by 15% to 50%.

Prevalent wind direction and the length and height of the wall are perhaps the most critical factors that influence a barrier's pollutant reduction capability. Most studies examining the efficacy of sound walls in mitigating TRAP focused on scenarios in which winds are perpendicular to the roadway direction. It is unclear whether the same dilution could be achieved under different wind conditions (Sonoma, 2010; Brauer et al., 2012). The length and height of the wall can also greatly affect pollutant concentrations. The higher the wall, the greater the pollutant concentration reduction downwind from the barrier. The length of the wall must be sufficient so that it will prevent emissions from meandering around the edges (US EPA, 2016).

Building design

Good building design and operation, with the appropriate ventilation and filtration, can effectively mitigate traffic emissions from entering the building. When designing a building near a busy roadway, the installation of a mechanical heating, ventilating, and air conditioning (HVAC) system is recommended rather than depending on passive ventilation. In an HVAC system, air is mechanically circulated throughout the building by air intakes and/or exhaust fans, whereas in a passively ventilated building air is supplied through the opening of windows or doors. Mechanical ventilation allows greater control over the timing of the ventilation and pressurization of the building. For example, by providing more make-up air than is mechanically exhausted, the building becomes slightly positively pressurized thus minimizing infiltration of polluted air through the building envelope (Brauer et al., 2012; Sonoma, 2010; US EPA, 2015).

Air filtration is the most effective measure to reduce exposure to TRAP indoors. The US EPA (2015) reports that filtration in schools can improve air quality by reducing particle concentrations by as much as 97% in comparison to outdoor levels. The efficacy of the filtration system is largely dependent on the filter's Minimum Efficiency Reporting Value (MERV). In general, the higher the MERV rating the higher the removal efficiency of the filter. Filters rated MERV 6-7 can reduce particle concentrations by 20% to 65%, whereas MERV 11 to 16 can reduce particle concentrations by 74% to 98% (Brauer et al., 2012; US EPA, 2015). MERV filters 5-8 are deemed appropriate for "Commercial

Buildings" and "Better Residential Buildings". MERV 9-12 are deemed appropriate for "Better Commercial Buildings" and "Superior Residential Buildings". Typically, all filters are much less effective in the removal of gaseous particles and completely ineffective in removing gaseous pollutants. To provide maximum benefits, air intakes should be located away from known pollution sources and roads. High efficacy filters must also be accompanied by increased flow pressures in order to maintain appropriate air circulation levels.

Operational and Behavioural Strategies in Buildings

Operational changes for existing facilities

For existing facilities, one of the most effective measures of mitigating TRAP is upgrading from a passive ventilation system to a mechanical system, or upgrading the MERV rating on the existing filtration system.

When retrofits are not immediately feasible or are cost prohibitive, operational changes can also have a significant impact on the air quality within the building. For example, US EPA (2015) notes that in passively ventilated schools strategies include reducing indoor sources of pollutants and the timing of opening and closing windows and doors (i.e. avoiding peak pollution times). Relying, where possible, on only opening windows on the side of buildings that face away from TRAP sources, can have a positive impact on indoor air quality. Similarly for mechanically ventilated buildings, optimizing the operation of the HVAC system can be effective as well. A 2015 Health Canada and Ottawa-Carleton District School Board study found that altering the timing of the ventilation so that it does not correspond to rush hour traffic can result in air quality improvements (Health Canada, 2015).

When centralized filtration is not an option, portable air filters are also quite effective in reducing outdoor-generated particle concentrations. Portable stand-alone room air cleaners with filters can remove significant levels of $PM_{2.5}$ as compared to air cleaners that were not equipped with filters (Barn, 2010). The major limitation is that portable filtration systems can only clean a limited volume of air, thus appropriate room sizing and air exchange rates are critical in order for them to be effective (Barn, 2010).

Management of outdoor activities

Evidence suggests that modification of outdoor activities can be an effective TRAP reduction strategy (Brauer et al., 2012; Sonoma, 2010). Sonoma (2010) notes a 50% reduction in peak hourly exposure to traffic pollution is possible when avoiding outdoor activities during the rush hour. This implies that schools and children's facilities near busy roads should avoid scheduling outdoor activities during peak traffic hours. Use of the Air Quality Health Index to inform outdoor activity time may also help reduce exposure to air pollution (Brauer et al., 2012; Environment Canada, 2016). However, the index was not designed to predict health risk at the microenvironment level.

Emission and Fuel Standards

Improvements to fuel standards and emission controls have direct impact on public health and the environment. However, older vehicles and deterioration of in-vehicle pollution control devices can result in a significant increase in tailpipe emissions (Brauer et al., 2012).

Emission control regulations and fuel standards are set by the federal government, through the *Canadian Environmental Protection Act, 1999* (Government of Canada, 2017). For instance, the *On-Road Vehicle and Engine Emission Regulations* establish the allowable levels of pollutant emissions for various on-road vehicles. They are closely aligned with the corresponding US federal emission standards. As a result of a history of concerns related to air pollution, the state of California is allowed to promulgate more stringent vehicle emissions standards, and other states can choose to follow either the US federal or California standards. The Canadian government could choose to align with California standards which would allow reductions in TRAP emissions in Canada to occur sooner.

Environment and Climate Change Canada is currently developing a Clean Fuel Standard. While commendable for its focus on reducing greenhouse gas emissions, the proposal does not currently consider other air pollutants. Given that the concept of "clean fuels" normally implies minimizing air pollution impacts broadly, it would be beneficial for this GHG-reduction effort to be combined with TRAP-reduction efforts regarding common air contaminants and air toxics. Limiting emissions of air pollutants from the burning of transportation fuels is especially important in urban areas with high traffic densities.

Vehicle fuel types offer different benefits with regards to GHG emissions and air pollution. When compared to gasoline-powered vehicles diesel engines have lower CO_2 emissions but significantly higher emissions of NO_X and particulate matter. It is important for emission standards be set to address both air quality and climate change impacts.

Canada has established the Company Average Fuel Consumption targets and harmonized them with similar standards in the US. The main difference between the two programs is that Canada's standards have remained essentially voluntary for 25 years, albeit automotive manufacturers routinely produce cross-border compliant vehicles. Canada first enacted regulations in September 2014, which came into effect for 2017 and subsequent model year vehicles.

As electric vehicles (EVs) become more widespread, TRAP will be reduced. While adoption of electric light-duty (personal) vehicles is occurring relatively quickly, conversion of the heavy-duty vehicle fleet will be slower, in part because of their longer life and slower turnover. Heavy-duty diesel trucks are associated with much higher emissions than light-duty vehicles. To reduce TRAP, particularly along Toronto's major highways, special attention is needed to accelerate the transition of heavy-duty trucks to new, cleaner technology.

The Province of Ontario is currently developing a Green Commercial Vehicle Program that aims to accelerate adoption of low-carbon technologies. Many of these technologies, including EVs, auxiliary power units, and cab heaters/coolers, reduce emissions of both GHGs and TRAP by reducing fuel consumption or switching to cleaner energy sources. Numerous options are available for reducing emissions from the heavy-duty vehicle fleet (ICF International, 2015). Additional emission-reduction programs and more stringent standards targeted at heavy-duty vehicles are needed to accelerate emission reductions from this sector.

Regional increases in population are expected to result in larger traffic volumes and increasing proximity between pollution sources and sensitive uses. Therefore, it is increasingly important to reduce TRAP emissions through cleaner transportation, and to mitigate occupants' exposure using effective building design and management practices.

ADDRESSING TRAP IN TORONTO

TransformTO, the City's climate action plan, invites Torontonians to imagine what a low-emission future can look like. *TransformTO* outlines a long-term approach to reducing greenhouse gas (GHG) emissions in Toronto by 80% by 2050 while also improving health, prosperity and equity. It establishes long-term, low-carbon goals for Toronto including that all trips - including those by public transit and personal vehicles - use low or zero-carbon energy sources, and that 75% of all trips of 5 km or less are walked or cycled. Achieving these goals requires sustained investment in transit and active transportation infrastructure, and efforts to electrify and switch to low-carbon fuels for all types of vehicles.

Since many initiatives that reduce transportation-based carbon emissions will also reduce TRAP, achieving a low-carbon future could dramatically improve air quality and health across Toronto. However, since these changes are driven by an effort to reduce GHGs, it will be important to ensure that air quality benefits are also addressed and improved as decisions about the transportation system are made. One of the guiding principles of *TransformTO* is to "improve public health". This will help align transportation-related GHG reduction activities with efforts to improve air quality and increase active transportation rates.

To promote walking, cycling, and transit as the best ways to get around, Toronto has introduced the Walking Strategy, the Toronto Complete Streets Guidelines, and the 10-year Cycle Network Update and made some improvements to transit. The City will build on the efforts already underway to enable Toronto to move to a future where levels of TRAP are nearly eliminated.

While a vision for the future offers inspiration that significant reduction in TRAP emissions is possible, there is also a need to address exposure experienced by many Toronto residents in the near term. A co-ordinated effort to limit exposures to people who live, work and play near busy roads in Toronto, including continued collaboration with the other municipalities in the Greater Toronto and Hamilton Area, will foster collective action.

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