Air Pollution Burden of Illness from Traffic in Toronto

Problems and Solutions

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The views expressed in this report are the sole responsibility of the Toronto Public Health staff involved in this study.

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Executive Summary

This report summarizes new work completed by Toronto Public Health, with assistance from the Toronto Environment Office, to assess the health impacts of air pollution from traffic in Toronto. The study has two major components: a comprehensive review of published scientific studies on the health effects of vehicle pollution; and, a quantitative assessment of the burden of illness and economic costs from traffic pollution in Toronto. This report also examines air pollution and traffic trends in Toronto, and provides an overview of initiatives underway or planned by the City to further combat vehicle-related air pollution.

Burden of illness studies provide a reliable and cost-effective mechanism by which local health authorities can estimate the magnitude of adverse health impacts from air pollution. In 2004, Toronto Public Health (TPH) estimated that air pollution (from all sources) is responsible for about 1,700 premature deaths and 6,000 hospitalizations each year in Toronto. The study indicated that these deaths would not have occurred when they did without chronic exposure to air pollution at the levels experienced in Toronto.

Since that time, Health Canada has developed a new computer-based tool, called the *Air Quality Benefits Tool* (AQBAT) which can be used to calculate burden of illness estimates. TPH staff used this tool in the current study to determine the burden of illness and economic impact from traffic-related air pollution.

Toronto Public Health collaborated with air modelling specialists at the Toronto Environment Office to determine the specific contribution of traffic-related pollutants to overall pollution levels. Data on traffic counts and flow, vehicle classification and vehicle emission factors were analysed by Toronto Environment Office and Transportation Services for input into a sophisticated air quality model. The air model takes into account the dispersion, transport and transformation of compounds emitted from motor vehicles. Other major sources of air pollution in Toronto are space heating, commercial and industrial sources, power generation and transboundary pollution.

The current study determined that traffic gives rise to about 440 premature deaths and 1,700 hospitalizations per year in Toronto. While the majority of hospitalizations involve the elderly, traffic-related pollution also has significant adverse effects on children. Children experience more than 1,200 acute bronchitis episodes per year as a result of air pollution from traffic. Children are also likely to experience the majority of asthma symptom days (about 68,000), given that asthma prevalence and asthma hospitalization rates are about twice as high in children as adults.

This study shows that traffic-related pollution affects a very large number of people. Impacts such as the 200,000 restricted activity days per year due to

days spent in bed or days when people cut back on usual activities are disruptive, affect quality of life and pose preventable health risk.

This study estimates that mortality-related costs associated with traffic pollution in Toronto are about $2.2 billion. A 30% reduction in vehicle emissions in Toronto is projected to save 189 lives and result in 900 million dollars in health benefits. This means that the predicted improvements in health status would warrant major investments in emission reduction programs. The emission reduction scenarios modelled in this study are realistic and achievable, based on a review by the Victoria Transport Policy Institute of policy options and programs in place in other jurisdictions. Taken together, implementation of comprehensive, integrated policies and programs are expected to reduce total vehicle travel by 30 to 50% in a given community, compared with current planning and pricing practices.

Given there is a finite amount of public space in the city for all modes of transportation, there is a need to reassess how road space can be used more effectively to enable the shift to more sustainable transportation modes. More road space needs to be allocated towards development of expanded infrastructure for walking, cycling and on-road public transit (such as dedicated bus and streetcar lanes) so as to accelerate the modal shift from motor vehicles to sustainable transportation modes that give more priority to pedestrians, cyclists and transit users.

Expanding and improving the infrastructure for sustainable transportation modes will enable more people to make the switch from vehicle dependency to other travel modes. This will also benefit motorists as it would reduce traffic congestion, commuting times and stress for those for whom driving is a necessity. Creating expanded infrastructure for sustainable transportation modes through reductions in road capacity for single occupancy vehicle use will require a new way of thinking about travelling within Toronto and beyond. To be successful, it will require increased public awareness and acceptance of sharing the road in more egalitarian ways, as well implementation of progressive policies and programs by City Council.

This study provides a compelling rationale for investing in City Council's plan to combat smog and climate change, and for vigorously pursuing implementation of sustainable transportation policies and programs in Toronto. Fostering and enabling the expansion and use of public transit and active modes of transportation, such as walking and cycling, are of particular benefit to the public's health and safety.

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Abbreviations

AQBAT	Air Quality Benefits Assessment Tool
AQHI	Air Quality Health Index
CO	Carbon Monoxide
COPD	Chronic Obstructive Pulmonary Disease
CRF	Concentration Response Function
GHG	Greenhouse Gases
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides
O_3	Ozone
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter < 2.5 µm in diameter
PM_{10}	Particulate Matter < 10 µm in diameter
ppb	parts (of contaminant) per billion (parts of air) by volume
ppm	parts (of contaminant) per million (parts of air) by volume
SES	Socioeconomic Status
SO_2	Sulphur Dioxide
TSP	Total Suspended Particulate
$\mu g/m^3$	micrograms (of contaminant) per cubic metre (of air) by weight
VOC	Volatile Organic Compound

Introduction

This report summarizes new work undertaken by Toronto Public Health, with assistance from the Toronto Environment Office, to assess the health impacts of air pollution from traffic in Toronto. The study is comprised of two major components: a comprehensive review of published scientific studies throughout the world on the health effects of vehicle pollution; and, a quantitative assessment of the burden of illness and economic costs from traffic pollution in Toronto. This report also examines air pollution and traffic trends in Toronto, and provides an overview of initiatives underway or planned by the City to further combat vehicle-related air pollution.

Burden of illness studies provide a cost-effective and reliable approach to estimating the magnitude of the health impact associated with air pollution conditions in a given community, based on the most current health outcome and pollution data available. In 2004, Toronto Public Health released a study that calculated the burden of illness associated with ambient (outdoor) levels of air pollution in Toronto. The study estimated that smog-related pollutants from *all* sources contributed to about 1,700 premature deaths and 6,000 hospitalizations each year in Toronto. The study indicated that these deaths would not have occurred when they did without chronic exposure to air pollution at the levels experienced in Toronto.

An estimated 1,700 Toronto residents die prematurely each year from exposure to outdoor air pollution in the city

Since that time, Health Canada scientists have developed and made available a computer-based tool to enable local health units to estimate air-related burden of illness in their respective communities. This tool, known as the *Air Quality Benefits Assessment Tool* (AQBAT), was used in the current study to quantify the health and economic impacts of traffic pollution in Toronto.

While it is recognized that bicycles are a type of vehicle, the word 'vehicle' is used in this report to refer to only motorized vehicles such as cars, vans, sport utility vehicles, trucks and so on.

In the preparation of this report, Toronto Public Health collaborated with many people and organisations. The literature review was prepared in with guidance from researchers at the University of Toronto and the Health Professionals Task Force of the International Joint Commission. The Toronto Environment Office provided the estimates of the contribution of traffic-related emissions to concentrations of pollutants, which were then entered into AQBAT. Health Canada experts provided guidance on the use of their model and then reviewed the results of the AQBAT calculations.

Health Effects of Air Pollution from Traffic:
A Review of the Scientific Literature

There is clear evidence that air pollution gives rise to adverse effects on human health. 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. Despite the diversity of regulations that have been imposed to reduce vehicle emissions, several indicators suggest that they have only been partially effective. Traffic emissions are associated with morbidity (illness) and premature mortality (early death), and hence continue to be a very significant urban health concern.

Traffic emissions continue to be a very significant urban health concern

This review of the scientific literature presents the broad diversity of inhalation-related health effects caused by traffic. It synthesizes multiple lines of evidence of effects that range from immediate to transgenerational ones, and from those seen in infants to the elderly. Various exposure scenarios are described that illustrate the influence of geographic, individual, and environmental factors on the effects of traffic-related pollution. Finally, intervention studies that demonstrate the immediate health benefits of reducing vehicle emissions are described to illustrate the positive public health impact from reductions in vehicle emissions.

Nature of Traffic-Related Pollution

Traffic-related emissions are a complex mix of pollutants comprised of nitrogen oxides (including nitrogen dioxide), particulate matter, carbon monoxide, sulphur dioxide, volatile organic compounds, ozone, and many other chemicals such as trace toxics and greenhouse gases. This concentration of pollutants varies both spatially (by location) and temporally (by time).

Exposure to pollutants is elevated in urban areas with high traffic volumes and heavily travelled highway corridors (Peace et al. 2004; Zeka et al. 2005). High levels of vehicle-related emissions have been linked to high density traffic sites (Campbell et al. 1995). Street canyons (streets lined with tall buildings that impede the dispersion of air pollutants) and areas very close to busy roads typically have a high concentration of emissions (Hoek et al. 2002; Kaur et al. 2006; Longley et al. 2004). These areas may also contain a high concentration of people, including pedestrians and cyclists, or people within buildings alongside the road. Individual drivers or passengers of cars are also exposed to vehicle-related emissions. Individuals at all stages of their life are at risk from traffic pollution, however, the severity of the hazard varies with age and underlying medical conditions.

Factors That Affect Exposure to Traffic Pollutants

The extent to which people are exposed to air pollutants depends on a variety of factors, such as being inside a vehicle, working or living close to traffic, physical activity level, duration of exposure, stage of life and health status.

Individuals at all stages of life are at risk from traffic pollution; however the severity of the hazard varies with age and underlying medical conditions

Driving a Vehicle

Several studies have investigated the air pollution health effects associated with driving a vehicle. The majority of these consider professional drivers like taxi and truck drivers. Others look at non-professional drivers, like commuters on public transport or individuals driving their own vehicles. Lung cancer is one of the most commonly studied effects. A study in Denmark of 28,744 men with lung cancer found an increased risk among taxi drivers and truck drivers when compared with other employees, after adjustment for socioeconomic factors (Hansen et al. 1998). Other studies have found similar effects for lung cancer in taxi, truck, and bus drivers (Borgia et al. 1994; Guberan et al. 1992; Jakobsson et al. 1997; Steenland et al. 1990). It has been suggested that diesel exhaust may be the primary cause for this association as well as the effects of carcinogens like benzene.

Increased levels of respiratory conditions have also been associated with professional driving. A study in Shanghai compared respiratory symptoms and chronic respiratory diseases in 745 professional drivers, including bus and taxi, with unexposed controls (Zhou et al. 2001). Higher rates of throat pain, phlegm, chronic rhinitis, and chronic pharyngitis were seen in the exposed group. A recent study in Hong Kong evaluated the lung function and respiratory symptoms in drivers of air-conditioned and non-air-conditioned bus and tram drivers (Jones et al. 2006). Lung function was reduced in drivers of non-air-conditioned buses compared with air-conditioned buses. This difference was attributed to the increased exposure to vehicle-emissions of drivers of non-air-conditioned buses where direct air flow through open windows results in heightened exposure.

Commuters are also a population of interest for these effects and include populations of in-vehicle commuters on passenger cars, public buses, and school buses, as well as bicycle commuters. A study in Manchester, UK monitored exposure of bus commuters to $PM_{4.0}$ using personal sampling pumps (Gee and Raper. 1999). Levels inside the buses were much higher than background levels measured at national monitoring stations (Gee and Raper, 1999). A study that measured the level of CO in commuters in Los Angeles found nearly three times higher exposures in-vehicle than compared with exposure at home or work (Ziskind et al. 1997). Levels of $PM_{2.5}$ were reported to be twice as high in on-road vehicles during commutes in London, UK, when compared with background urban monitor levels (Adams et al. 2001).

Pollution levels inside vehicles during commutes tend to be higher than background levels at urban monitors

While the evidence supports an association between driving or being a passenger in a vehicle and adverse health outcomes, there are several factors that influence the degree and magnitude of this association. For example, different ages of vehicles contribute differently to individual levels of exposure. Older and more poorly maintained vehicles are typically associated with higher levels of emissions (White et al. 2006). Time of day of travel also has an influencing effect on exposure to vehicle emissions. There is evidence to suggest that exposure levels to CO and ultrafine

particle counts are highest during the morning and at lower levels later in the day, increasing again in the early evening (Kaur et al. 2005b). However, it has been suggested that this is due to the greater traffic density at this time of day, during typical commute rush-hours resulting in a greater number of vehicles, possibly travelling at a lower speed and emitting a higher concentration of pollutants. Longer trip times have been associated with higher levels of exposure (Peace et al. 2004).

Work-related Exposure to Vehicle Emissions

Aside from exposures while travelling inside a vehicle, a significant proportion of the population are exposed through occupations that lead to extended periods of time on or near roads and highways or close to traffic like asphalt workers (Randem et al. 2004), traffic officers (de Paula et al. 2005; Dragonieri et al. 2006; Tamura et al. 2003; Tomao et al. 2002; Tomei et al. 2001), street cleaners (Raachou-Nielsen et al. 1995), street vendors, and tollbooth workers. Health impacts are greater for these groups who work close to traffic than for those that are not occupationally exposed.

The same studies show increased cardiovascular and respiratory in these groups. A study in Copenhagen found that street cleaners had a greater risk for chronic bronchitis and asthma when compared with cemetery workers (Raaschou-Nielsen et al. 1995). It has been reported that traffic policemen present with airway inflammation and chronic respiratory symptoms at higher rates than in non-exposed groups (Dragonieri et al. 2006; Tamura et al. 2003). Asphalt workers have also been reported to have an increased risk of respiratory symptoms including lung function decline, and chronic obstructive pulmonary disease (COPD) as compared with other construction workers (Randem et al. 2004). The risk of cardiovascular diseases has been investigated in traffic controllers in Sao Paulo, Brazil. Exposure to both CO and SO_2 resulted to increased blood pressure and SO_2 also resulted in decreased heart rate variability, associated with an imbalance of the autonomic system (de Paula et al. 2005).

People who work close to traffic emissions experience higher rates of cancer and respiratory and cardiac illnesses compared to less exposed workers

Increased concentrations of vehicle exhaust carcinogens that have been associated with cancer risk like PAHs and VOCs (e.g. benzene and 1, 3-butadiene) have been reported in street vendors (Ruchirawat et al. 2005) and tollbooth workers (Sapkota et al. 2005) as measured by personal samplers. Interestingly, tollbooths have been found to offer a significant protective effect to tollbooth workers, where concentrations of 1, 3-butadiene and benzene inside the booth were found at less than half the concentration directly outside of the booth (Sapkota et al. 2005).

A higher rate of cancer incidence has been reported in a group of 19,000 Nordic service station workers who were followed for 20 years (Lynge et al. 1997) for kidney, pharyngeal, laryngeal, lung, and nasal cancer.

The risk of exposure to PAH and other carcinogens has been assessed using biomarker measurements in a Danish study of bus drivers and mail carriers. Bus drivers were more exposed than mail carriers working in indoor offices, and higher pollutant levels were reported in bus drivers than in outdoor mail carriers (Hansen et al. 2004). Higher levels of benzene exposure have also been found in traffic wardens in Rome (Tomei et al. 2001).

Pedestrians are also exposed to vehicle-emissions, although they are a less studied group. Pedestrians who walk on the side of the pavement further away from the road have been found to experience up to 10% lower exposure to traffic-related emissions than those who walk on the side of the pavement closest to the road (Kaur et al. 2005a). This has implications for urban planning and design.

Proximity to Roadways

Individuals living close to major roads are at increased risk of exposure to traffic-related pollution and related health effects. In fact, residential proximity to a major road has been associated with a mortality rate advancement period of 2.5 years (Finkelstein et al. 2004). Of particular concern are communities close to border crossings, where traffic levels are high and include a large proportion of transport trucks. For example, individuals living close to the Peace Bridge, one of the busiest US-Canada crossing points, show a clustering of increased respiratory symptoms, particularly asthma (Lwebuga-Mukasa et al. 2005; Oyana et al. 2004; Oyana et al. 2005). Similar associations have been reported for respiratory hospital admissions in Windsor, Ontario, another geographic area with high air pollution levels associated with border crossings (Luginaah et al. 2005).

People living close to busy roads experience increased respiratory symptoms

There are fewer studies of non-residential exposures, however, this is important to consider given the significant amount of time spent at work or in school for much of the population. Higher concentrations of traffic-related pollutants have been reported in schools in close proximity to busy roads, high traffic density, and the percentage of time a school is located downwind (Janssen et al. 2001). Furthermore, it has been suggested that public schools and day care facilities that are closest to busy roads also typically have a disproportionate number of economically disadvantaged children than those that are located at a further distance away (Green et al. 2004; Houston et al. 2006). This supports other findings that people living in more deprived neighbourhoods have greater exposure to air and traffic pollution than those in other neighbourhoods (Finkelstein et al. 2005). This raises an important issue of the complex factors that collectively contribute to individual exposure to vehicle-related emissions.

Level of Physical Activity

Exercising individuals may be at a higher risk of the adverse health effects because even at low intensities, a significant increase in pulmonary ventilation occurs. This results in an increase in inhaled particles that are deposited into the lungs during any outdoor exercise (Sharman et al. 2004), and has been demonstrated frequently in studies of cyclists (O'Donoghue et al. 2007; van Wijnen et al. 1995). There is temporal variability in the concentration of pollutants during the day, with particularly high levels during morning rush-hour in urban environments. Given this and the heightened exposure during exercise, it has been suggested that vigorous outdoor physical activity should be taken when air pollution levels tend to be lowest, particularly very early in the morning, before rush hour, and in low-traffic areas (Campbell et al. 2005).

As physical activity level increases, more air pollutants are deposited in the lungs

Duration of Exposure

Exposure to traffic-related pollutants is both constant and chronic, particularly for individuals who reside near busy roads for many years, and acute and short-term as a result of daily changes in pollutant levels over short periods of time. Chronic obstructive pulmonary disease (COPD) provides an example of a health effect that can result from both of these kinds of exposure. Short-term exposure to low levels of air pollution, particularly particulate matter, have repeatedly been associated with exacerbations of COPD (MacNee et al. 2000; Pope and Dockery. 2006; Yang et al. 2005). More recently, the risk of developing COPD has also been linked with long-term exposure to air pollution in a study of individuals living close to busy roads for at least five years (Schikowski et al. 2005).

Vulnerable Populations

There are some populations which are particularly susceptible to the effects of traffic-related pollution. These include fetuses and children, the elderly, and those with pre-existing breathing and heart problems. However, healthy individuals are also at risk of these effects from both short-term exposures as well as chronic exposure over several years or a lifetime.

The human fetus is particularly susceptible to the effects of traffic-related pollution given physiological immaturity. A study of the genotoxic effects of exposure to PAHs in pregnant mothers in Manhattan, Poland, and China used personal air monitors to assess exposure to air pollution. This study reported that in utero exposure increases DNA damage and carcinogenic risk to the fetus (Perera et al. 2005). Prenatal exposure to high levels of PAHs has been associated with decreased subsequent cognitive development at 3 years of age (Perera et al. 2006). Fetal growth impairment has also been linked to in utero exposure to airborne PAHs, even at relatively low levels of exposure (Choi et al. 2006).

Children are particularly vulnerable to the health impacts of traffic, as are seniors and people of all ages with underlying medical problems

Children are particularly vulnerable to the health impacts of traffic given their immature physiology and immune system which are still under development. Furthermore, children breathe more per unit body weight than adults. In addition, children tend to spend more time outdoors, engaged in strenuous play or physical activity, resulting in greater exposure to air pollution than adults.

Several studies suggest that the effect size from exposure to traffic-related pollution is greater among the elderly than other age groups (Goldberg et al. 2001; Pope 2000; Zeka et al. 2005). These individuals are also likely to have pre-existing illness and have been subject to a lifetime of exposure.

Individuals with pre-existing illness are particularly vulnerable to the effects of traffic-related pollution, especially those with illnesses with systemic effects like diabetes and cancer. It has been reported that increased levels of CO exacerbate heart problems in individuals with both cardiac and other diseases (Burnett et al. 1998b). Several studies support the suggestion that individuals with diabetes are particularly at risk of suffering from heart disease during periods when air pollution is high

(Goldberg et al. 2006; O'Neill et al. 2005; O'Neill et al. 2007). This has been attributed to the effects of fine particles and elemental carbon as well as other components of the air pollution mixture.

A slightly higher risk of mortality associated with vehicle-related pollutants has been associated with low socioeconomic status (SES), a variable that is known to be correlated with health status. This effect may result from the fact that individuals of low SES may live in lower value dwellings that are in close proximity to major roads and therefore at a higher risk of exposure (Smargiassi et al. 2006). Furthermore, vehicles may be newer and create less pollution in high SES neighbourhoods, with homes with better ventilation and insulation to offer protection against these effects (Ponce et al. 2005).

Poverty is linked with increased health risk from traffic

Environmental Influences

Ambient temperature and local meteorology influences the concentration and location of vehicle-emitted pollutants. For example, elevated sulphur dioxide levels are typically reported in the winter, and elevated ground-ozone levels in the summer (Goldberg et al. 2001; Rainham et al. 2005). Cold weather can result in higher levels of pollutants in ambient air due to reduced atmospheric dispersion and degradation reactions.

The genotoxic effects of $PM_{2.5}$ and PM_{10} have also been found to be greater in the winter months (Abou Chakra et al. 2007). Dispersion of pollutants is also affected by other meteorological factors like humidity, wind speed and direction and general atmospheric turbulence.

Adverse Health Effects of Traffic Pollution

Exposure to vehicle-related pollutants is associated with excess overall mortality as well as with diverse health effects. These detrimental outcomes occur over multiple pathways with varying end points.

Overall Mortality

There is little doubt that exposure to traffic-related emissions results in increased risks of mortality, particularly from respiratory and cardiopulmonary causes. A meta-analysis of 109 studies found that PM_{10}, CO, NO_2, O_3, and SO_2 were all positively and significantly associated with all-cause mortality (Stieb et al. 2002). A large study of mortality in Los Angeles for the period 1982-2000 found a strong increase in all-cause mortality with increased exposure to $PM_{2.5}$ (Jerrett et al. 2005). Two large Canadian studies investigated the association between several pollutants associated with traffic and mortality (Burnett et al. 1998a; Burnett et al. 2000). Daily variations in NO_2, SO_2, O_3, and CO were associated with daily variations in mortality in 11 Canadian cities from 1980 to 1991 (Burnett et al. 1998a). Of these, NO_2 was the strongest predictor of the 4 gaseous pollutants investigated. When fine particulate matter was included in the next study (Burnett et al. 2000), NO_2 was again a strong predictor of mortality. This effect was evident again during a later time series analysis of 12 Canadian cities between 1981-1999 where a positive and statistically significant association was again observed between daily variations in NO_2 concentration and fluctuation in daily mortality rates (Burnett et al. 2004). This is interesting given the ongoing debate in the current literature about whether the effect of NO_2 on health is independent, or if it is actually an indicator of other pollutants in vehicle emissions that are not necessarily directly observable.

Traffic pollution is strongly linked with premature mortality

Respiratory Effects

Perhaps the most commonly studied and most frequently reported health effect associated with traffic-related pollution are those associated with respiratory morbidity. Numerous studies have found an association with vehicle emissions and a diversity of respiratory symptoms and diseases. These adverse outcomes range from acute symptoms like coughing and wheezing to more chronic conditions such as asthma and chronic obstructive pulmonary disease (COPD), which includes chronic bronchitis and emphysema. Exposure to fine PM and ozone have been associated with these conditions. Studies have produced varying results on the relationship between NO_2 exposure and respiratory health. NO_2 is most clearly associated with cough (Sunyer et al. 2006), however, it is uncertain as to whether it acts as an indicator of traffic related pollution, rather than having a direct adverse health effect (Pattenden et al. 2006).

Many studies on the effect of vehicle emissions and respiratory health consider short-term changes in exposure and daily symptoms in the study population, particularly in exacerbating symptoms in asthmatics as well as inducing asthma in otherwise healthy individuals (Sarnat and Holguin. 2007). The Children's Health Study in southern California found that asthma and wheeze were strongly associated with residential

proximity to a major road (McConnell et al. 2006), a finding that is consistent with many other studies of children (Oyana and Rivers. 2005). Interestingly, similar effects have been found in populations of infants and very young children (Ryan et al. 2005), as well as adolescents (Gauderman et al. 2007).

A recent study used modelled exposures to traffic related air pollutants and found significant associations with sneezing/runny/stuffed noses and absorbance of $PM_{2.5}$, as well as an association between cough and NO_2 exposure in the first year of life (Morgenstern et al. 2007). A similar relationship has been demonstrated in adult populations in the SAPALDIA (Swiss Cohort Study on Air Pollution and Lung Disease in Adults) studies. These have demonstrated that living near busy streets not only induces or exacerbates asthma and wheeze but also is associated with bronchitis symptoms including regular cough and phlegm production (Bayer-Oglesby et al. 2006). A recent study in Paris investigated the relationship between daily levels of $PM_{2.5}$, PM_{10}, and NO_2 and the number of doctors' house calls for asthma, upper and lower respiratory diseases in adults (Chardon et al. 2007). A significant association was found for $PM_{2.5}$ and PM_{10} for upper and lower respiratory disease, but no association with NO_2. Other studies of respiratory hospital admissions (Chen et al. 2007; Luginaah et al. 2005; Oyana et al. 2004; Smargiassi et al. 2006) and modelled pollutant exposure (Buckeridge et al. 2002) support these findings.

Living near traffic is associated with increased asthma symptoms, wheeze and chronic bronchitis, and with reduced lung function

Another respiratory effect that has been associated with exposure to vehicle emissions is reduced lung function. While the magnitude of the effect reported is often small, there is consistency in these findings. Most studies investigate the effects in children, however, of particular interest is a study of exposure to NO_2 in healthy university students in Korea (Hong et al. 2005). Exposure levels were found to be significantly associated with proximity of residence to main roads, and this exposure was associated with a reduction in lung function.

Finally, there is an increasing body of literature that examines the chronic respiratory effects resulting from exposure to vehicle emissions. A study in Germany of 4757 women concluded that chronic exposure to PM_{10}, NO_2 and living near a major road for at least 5 years was associated with decreased pulmonary function and COPD (Schikowski et al. 2005). Chronic bronchitis has also been associated with close proximity to busy roads (and NO_2), particularly in women (Sunyer et al. 2006).

Cardiovascular Effects

There is substantial evidence that supports an association between vehicle emissions and cardiovascular disease, particularly mortality from cardiovascular causes (Gehring et al. 2006; Pope et al. 2004a; Miller et al. 2007). Cardiovascular and stroke mortality rates have been associated with both ambient pollution at place of residence as well as residential proximity to traffic (Finkelstein et al. 2005). Several recent studies also consider nonfatal cardiovascular outcomes like acute myocardial infarction (AMI) and have found an association with exposure to vehicle emissions, particularly as a result of long-term exposure to $PM_{2.5}$ and/or close residential proximity to busy roads (Hoffmann et al. 2006; Jerrett et al. 2005; Rosenlund et al. 2006; Tonne et al. 2007; Peters et al. 2004).

Short-term exposures have also been shown to be associated with ischemic effects (Lanki et al. 2006a). A case-crossover study of 772 individuals in Boston found that elevated concentrations of $PM_{2.5}$ were associated with an increased risk of AMI within a few hours and one day following exposure (Peters et al. 2001). Another study of 12,865 individuals in Utah found a similar effect for both AMI and unstable angina, and that this effect was worse for patients with underlying coronary artery diseases (Pope et al. 2006). The specific toxicants most commonly associated with these effects are PMs, although there is also evidence of an adverse influence of CO (Lanki et al. 2006b) and SO_2 (Fung et al. 2005).

Increased levels of CO and NO_2 have also been implicated in increased incidence of emergency department visits for stroke (Villeneuve et al. 2006). It has been suggested that it is the strong association between air pollution and ischemic heart disease that drives the cardiopulmonary association with air pollution (Jerrett et al. 2005). Many plausible pathophysiological pathways linking PM exposure and cardiovascular disease have been suggested and include systemic inflammation, accelerated atherosclerosis, and altered cardiac autonomic function reflected by changes in heart rate variability and increases in blood pressure (Brook et al. 2002; Brook et al. 2003; Luttmann-Gibson et al. 2006; Pope et al. 2004a; Pope et al. 2004b; Schwartz et al. 2005; Urch et al. 2005).

Living near heavy traffic is associated with increased cardiac problems, including heart attacks

Cancer

There is an increasing body of literature that suggests that vehicle emissions are also associated with the development of cancer, particularly lung cancer, although other types have been implicated. A large recently published study in Europe of 4000 individuals studied the relationship between lung cancer and vehicle-related pollution (Vineis et al. 2006). Exposure to air pollution was measured as proximity of residence to heavy traffic roads. Additionally, exposure to NO_2, PM_{10}, and SO_2 was assessed from monitoring stations. The findings from this study indicate that residence in close proximity to heavy-traffic roads, or exposure to NO_2 increases the risk of lung cancer. This is consistent with studies conducted in Oslo (Nafstad et al. 2003) and Stockholm (Nyberg et al.2000) that found a similar relationship between increased risk of lung cancer and levels of traffic-related NO_2. This effect has also been demonstrated in studies of fine PM and SO_2 (Pope et al. 2002) and exposure to diesel exhaust (Parent et al. 2007).

The effect of vehicle emissions on childhood cancers, particularly leukemia, is also of concern. While the research is this area is somewhat limited, there is some indication that vehicle emissions are associated with an increased risk of childhood cancer as indicated by residential proximity to busy streets (Pearson et al. 2000; Savitz and Feingold. 1989). An Italian study which modeled benzene concentrations (based on traffic density) found a nearly four-fold increase in the risk of childhood leukemia in the highest exposure group (Crosignani et al. 2004). An ecological study in Sweden (Nordlinger and Jarvholm. 1997) and a UK study of children residing close to main roads and petrol stations (Harrison et al. 1999) provide further support for this association.

Chronic elevated exposure to vehicle emissions is linked with increased rates of lung cancer in adults and leukemia in children

Information on the relationship between vehicle-emissions and other types of cancers are sparse. However, one recent study suggests that early life exposure to traffic

emissions (which include PAHs) may be associated with breast cancer in women (Nie et al. 2007). Specifically, higher exposure to traffic-related emissions at menarche was associated with pre-menopausal breast cancer, while emissions exposure at the time of a woman's first childbirth was associated with postmenopausal breast cancer (Nie et al. 2007). Lastly, a study in Finland of individuals exposed to diesel and gasoline exhaust occupationally found an association between ovarian cancer and diesel exhaust (Guo et al. 2004).

Hormonal and Reproductive Effects

There is evidence that suggests that exposure to traffic pollutants affects fertility in men. An Italian study evaluated sperm quality in men employed at highway tollgates (De Rosa et al. 2003). Total motility, forward progression, functional tests, and sperm kinetics were significantly lower in tollgate employees versus controls. In particular, nitrogen oxide and lead were implicated as toxins with adverse effects (De Rosa et al. 2003).

There is emerging evidence that vehicle-related emissions are associated with an increased risk of adverse pregnancy outcomes. Several studies have reported an association with low birth weight in infants and maternal exposure to emissions during pregnancy (Bell et al. 2007; Liu et al. 2003; Salam et al. 2005; Sram et al. 2005; Wilhelm and Ritz. 2005). It has also been suggested that there is an association with preterm births and intrauterine growth retardation, but these studies are less consistent (Ponce et al. 2005; Sram et al. 2005). Finally, there have been a few suggestions of an increased risk in these infants of sudden infant death syndrome and birth defects like congenital heart defects but further research is needed to confirm these findings (Dales et al. 2004; Ritz et al. 2002; Sram et al. 2005).

Chronic exposure to heavy traffic pollution is associated with reduced fertility in men and low birth weight

As has been discussed, prenatal and early exposure to traffic-related pollution has a significant impact on the health of the fetus and infant, but it can also predispose them to a range of other illnesses. Adverse birth outcomes like low birth weight have been linked to the development of chronic illnesses later in life like cardiovascular disease, type 2 diabetes, hypertension, lower cognitive function, and increased cancer risk (Perera et al. 2005; Perera et al. 2006).

Intervention Studies Related to Reducing Traffic

Despite the diversity and seriousness of health effects linked with vehicle emissions, there are many actions that can be undertaken to improve the current situation. Intervention studies, while not common, provide a unique opportunity to demonstrate the health benefits of taking specific policy or regulatory actions to improve air quality. A few vehicle-related intervention studies are highlighted here.

During the 1996 Summer Olympic Games in Atlanta, Georgia, a strategy for minimizing road traffic congestion was implemented. An ecological study comparing the 17 days of the Olympic Games to a baseline period of the 4 weeks prior to and following the Olympic Games was conducted (Friedman et al. 2001). Morbidity outcomes were measured and compared between these time periods and included the

number of hospitalizations, emergency department visits, and urgent care centre visits for asthma. In addition, data were collected for meteorological and air quality conditions and traffic and public transportation information. The results demonstrate a significant decrease in the number of asthma acute care events (by 42%) in children between the ages of 1 and 16 during this time. Air quality improved with a decrease in peak daily ozone and carbon monoxide by 28% and 19% respectively. There was a significant correlation between the decrease in weekday traffic counts and peak daily ozone. These results suggest that decreased traffic density have a direct effect of the risk of asthma exacerbations in children.

In 1990, a fuel composition restriction was implemented in Hong Kong where all road vehicles were required to use fuel with a sulphur-related content of not more than 0.5% by weight. This resulted in an average reduction in SO_2 concentrations by 45% over five years (Hedley et al. 2002), which was sustained between 35% and 53% over the next five years. One study of the health effects of this intervention reported a reduction in bronchial hyper-responsiveness in young children 2 years after the intervention (Wong et al. 1998). A more recent study of this same intervention assessed its relationship with mortality over the 5 years and found a decline in average annual trend in deaths from all causes (2.1%), respiratory (3.9%) and cardiovascular (2.0%) (Hedley et al. 2002).

Studying the effects of relocating individuals from more to less polluted areas also presents a unique opportunity to demonstrate the associated health benefits. Over the duration of a 10-year prospective study of respiratory health and air pollution in children in Southern California, 110 participants moved to a new place of residence. This provided an opportunity to study the effect of relocation to communities with higher or lower levels of air pollution on their lung function performance (Avol et al. 2001). Subjects who had moved to communities of lower PM_{10} showed increased lung function while those who moved to areas of higher PM_{10} showed decreased lung function (Avol et al. 2001).

Intervention studies also provide evidence of decreased emissions resulting from strategies to reduce traffic. During the 2004 Democratic National Convention in Boston, Massachusetts, numerous road closures were implemented as a security measure. To investigate the effects these closures had on air quality NO_2 monitoring badges were placed at various sites around metropolitan Boston and levels were compared before, during, and after the convention. The study demonstrated lowered NO_2 concentrations in the air with traffic reductions (Levy et al. 2006).

In 2003 the London Congestion Charging Scheme (CCS) was implemented in an effort to reduce traffic density in London, UK. A recent review of the impact of this scheme analysed traffic data and emissions modelling (Beevers and Carslaw. 2005). There was a 12% reduction in both NO_2 and PM_{10} emissions at the time of the study, and even greater reductions are likely with expansion of the program. Emission reductions were attributable to the reduction in number of vehicles, and to the higher speed vehicles could travel as a result of less congestion, and therefore fewer emissions per distance travelled.

These intervention studies provide evidence that reduction in vehicle-related emissions can have a significant impact on reducing associated morbidity and mortality. This has tremendous implications for individuals, but also for public health on a population level. A public health impact assessment in Europe reported that air pollution is responsible for 6% of total mortality, at least half of which can be attributed to be vehicle-related (Kunzli et al. 2000). An analysis of the impact of air pollution on quality-adjusted life expectancy in Canada reports that a reduction of 1 $\mu g/m^3$ in sulphate air pollution would yield a mean annual increase in quality-adjusted life years of 20,960, a very substantial positive impact (Coyle et al. 2003). It is clear that reducing vehicle emissions will have a significant impact on improved health outcomes. There is an urgent need to implement plans and policies that will work towards mitigating these adverse effects.

Intervention studies provide compelling evidence that reducing vehicle emissions improves health outcomes

Air Pollution and Traffic Trends in Toronto

Air pollutants generated by motor vehicle traffic are comprised of criteria pollutants, air toxics (toxic chemicals in the air) and greenhouse gases (GHG).

Criteria Pollutants

The combustion of fossil fuels (such as gasoline, diesel, propane, natural gas, oil, coal, and wood) generates common smog pollutants

In Toronto, as in most major urban centres in North America, vehicles are a significant source of 'criteria' (common) air pollutants of health concern. Criteria pollutants are commonly emitted from the combustion of fossil fuels, whether gasoline, diesel, propane, natural gas, oil, coal or wood. Toronto sources of these pollutants include vehicle, space heating of buildings, commercial and industrial operations. These common pollutants include nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO) and particles of various sizes. Particles are measured as total suspended particles (TSP), inhalable particles of 10 micron diameter or less (PM_{10}), and respirable particles of 2.5 micron diameter or less ($PM_{2.5}$). Vehicles also emit pollutants such as nitrogen oxides (NOx) and volatile organic compounds (VOCs) that enable ozone to form in the presence of sunlight.

Table 1 summarizes the sources of common air pollutants emitted as a result of activities by Toronto, based on 2004 data. Emission sources are categorized as follows:

- Mobile – cars, trucks, buses (but not trains);
- Area – residential and small scale commercial/industrial emissions;
- Point – industrial emissions (from 'smokestacks' reportable to NPRI);
- Natural gas combustion – all buildings (such as for space heating).

Table 1. Annual Emissions of Criteria Pollutants by Toronto (2004)

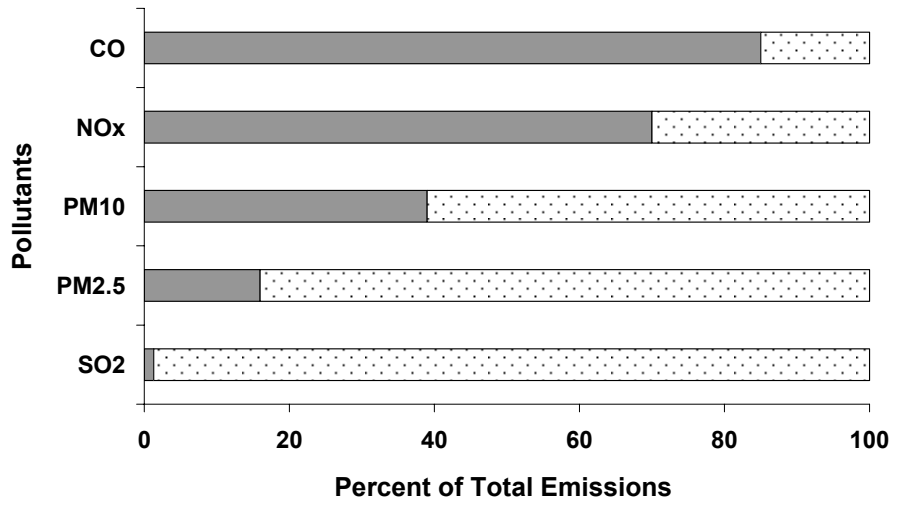
Pollutant	Emissions by Source (Tonnes/Year)				
	Mobile (Vehicles)	Area	Point	Natural Gas Combustion	Total
CO	306,174	47,573	435	4,154	358,336
NOx	27,434	3,740	1,749	6,684	39,607
PM_{10}	7,432	10,848	470	525	19,275
$PM_{2.5}$	1,576	7,305	408	525	9,814
SO_2	117	8,531	304	41	8,993

Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions*. Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

Figure 1 illustrates the proportion of the total emissions from Toronto activities that come from vehicles. These same emissions can be compared by source in Table 1. Vehicles are the largest source of CO (85%) and NOx (69%) emissions within Toronto. They also are a significant source of PM_{10} (39%) and $PM_{2.5}$ (16%). While

vehicles (or other combustion sources) do not emit ozone directly from the tailpipe, vehicles emit precursor chemicals (such as NOx) which give rise to large amounts of ozone that form in the air (usually downwind) and are of substantial health concern.

Figure 1. Vehicle Emissions as Proportion of Total Emissions from Toronto



Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions.* Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

The amount of pollutants in Toronto's air results from sources within the city, as well as emission sources upwind of Toronto, such as coal-fired power plants in Ontario and the U.S. Weather plays a large part in the fluctuation of ambient pollutant levels in the city. Wind, temperature and precipitation factors all strongly affect daily and seasonal air quality.

Figure 2 shows the trend in annual average concentrations of common air pollutants in Toronto over a 26 year span (1980 to 2006), based on data from the Ontario Ministry of the Environment. Some pollutants, such as CO and SO_2 are showing a decline in recent years, while other pollutants, such as TSP are not. Although NO_2 levels show a decline in the last decade, current levels are similar to levels in the 1980s, prior to the upward trend during the 1990s. Of greatest concern is ozone, which is showing a steady increase in the last decade.

Figure 2. Trends in Average Annual Pollutant Concentrations in Toronto

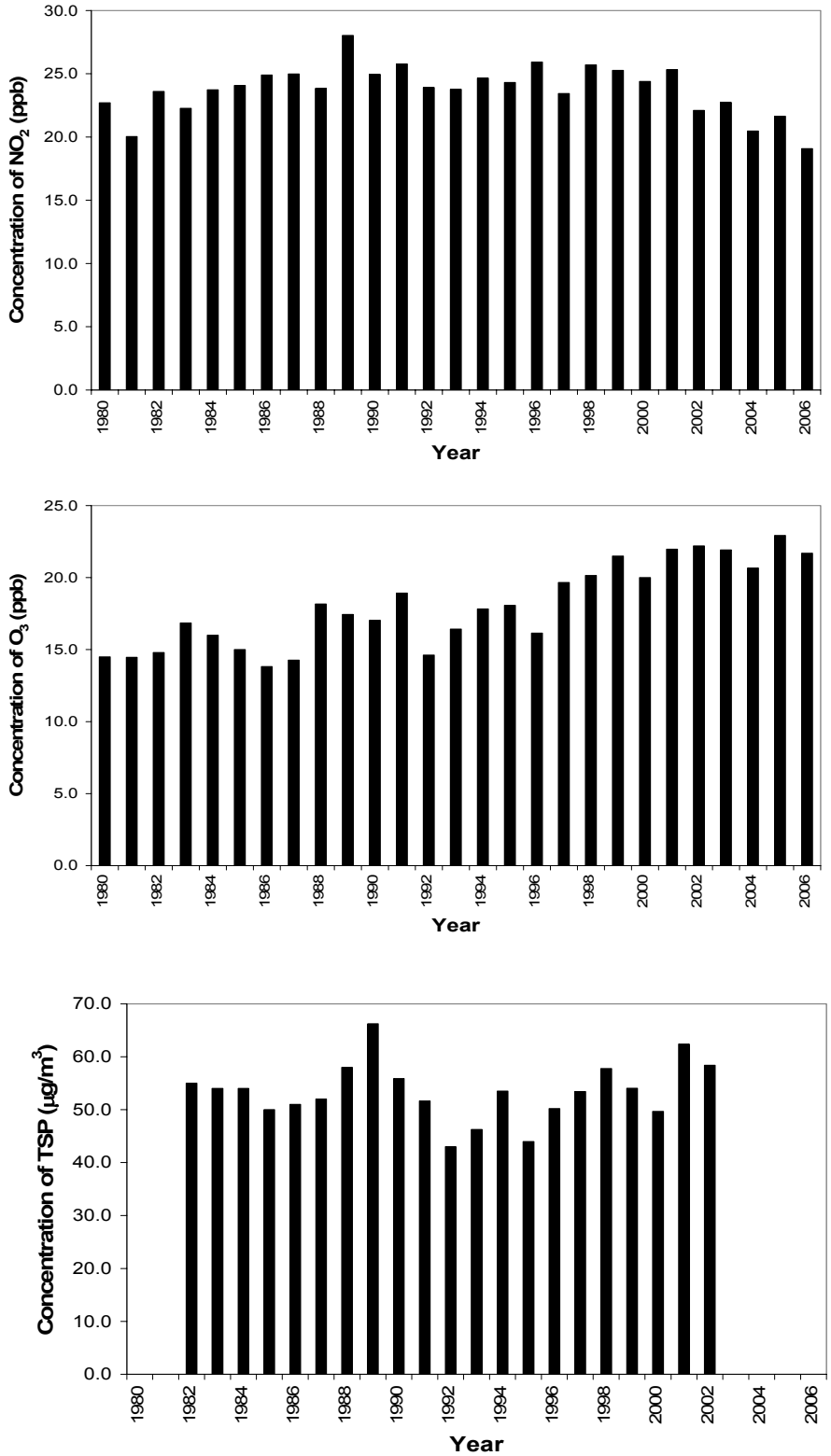
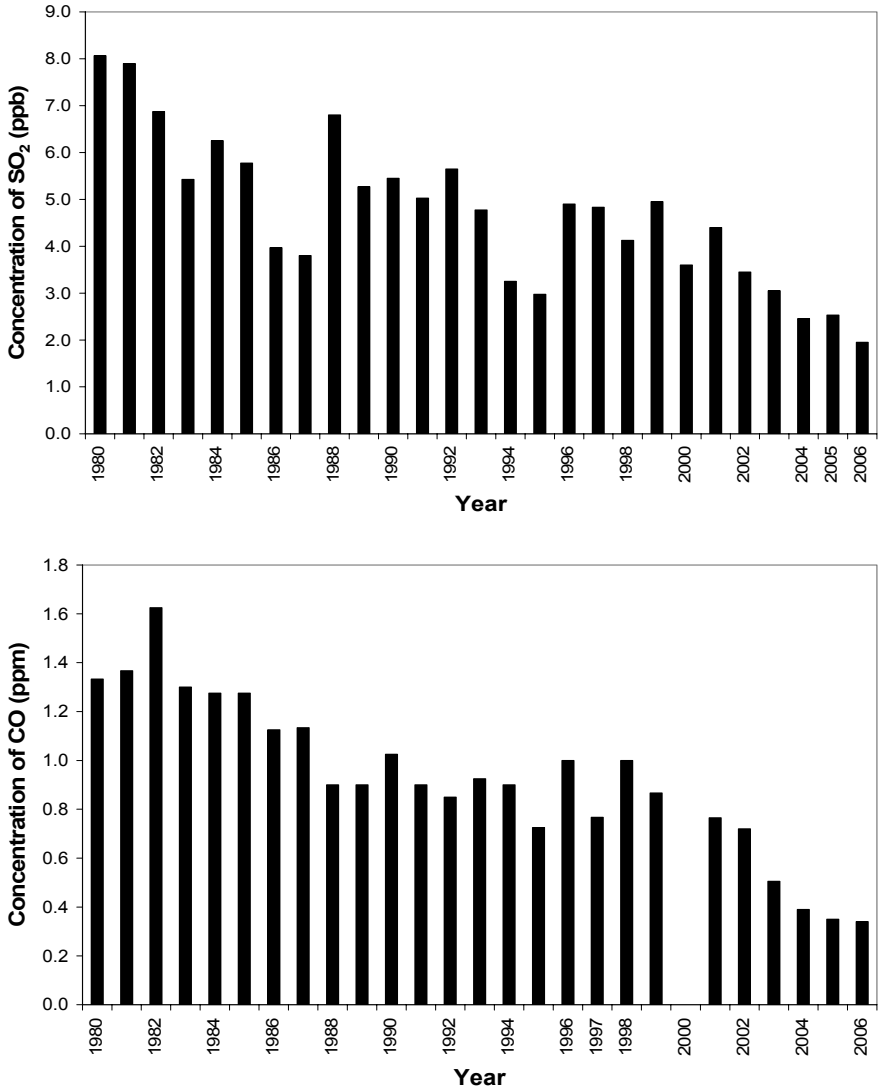


Figure 2 (continued). Trends in Average Annual Pollutant Concentrations in Toronto



Trend data suggest that progress is slow in improving air quality in Toronto. Gains in cleaner vehicles are being offset by increases in traffic volumes

It is of concern that pollution trends in Toronto for some key pollutants of health concern reveal little improvement in air quality over the last two decades. The trend data suggest that despite many important initiatives by all levels of government to improve air quality, progress is slow. It may be that gains in the transportation sector, such as the introduction of less polluting vehicles and improvements in fuel quality, are being off-set by the increased volume and frequency of vehicle use.

Air Toxics

Vehicles are a significant source of 'air toxics' (toxic chemicals in the air). Air toxics are substances that occur in the air in much smaller amounts than 'criteria' pollutants, but which are much more potent in terms of adverse impacts. In general, air toxics are of particular concern with chronic (long term) exposure, and are associated with serious health outcomes such as cancer and reproductive effects.

At present, no air toxics emissions inventory exists in Toronto, unlike for criteria pollutants or greenhouse gases. Such an inventory may be a possibility in the future if a community right to know bylaw is put in place. Such an inventory would enable the relative amounts of air toxics by source to be calculated. We can then determine air toxics of priority health concern in Toronto by comparing Environment Canada surveillance data with health benchmarks.

Table 2 indicates relative health risk of priority air toxics, based on exposure ratios relative to health benchmarks, and using average and maximum pollutant levels measured in Toronto's air during 2003, 2004 and 2005. The greater the exposure ratio number, the greater the health risk. Exposure ratios greater than 1 indicate health concern because they exceed health benchmarks for cancer or non-cancer effects. For non-carcinogens, the health benchmark is the level without observable adverse impacts. For carcinogens, the health benchmark corresponds to a 1-in-million excess cancer risk.

Vehicle-related pollutants such as benzene, PAHs, and 1,3-butadiene are of concern because they routinely occur in Toronto air at levels above health benchmarks

Table 2 provides a list of air toxics associated with vehicle emissions, and that occur in Toronto's air at levels of health concern. For many of these pollutants, industrial and commercial facilities also contribute to ambient levels observed in Toronto Of particular concern are vehicle-related exposures to chromium, benzene, polycyclic aromatic hydrocarbons (PAHs), 1,3-butadiene, formaldehyde, acrolein and acetaldehyde because these pollutants routinely occur at levels above health benchmarks.

Table 2. Priority Air Toxics in Toronto Associated with Vehicle Emissions

Air Toxic	Relative Health Risk (Exposure Ratio)	
	Based on Maximum Pollutant Concentration	Based on Average Pollutant Concentration
Chromium	1150	225
Benzene	176	30
PAHs	302	20
1,3-butadiene	102	26
Formaldehyde	67	27
Acrolein	20	2
Acetaldehyde	15	6
Nickel	4	0.8
Manganese	2	0.08

Source: Toronto Public Health. 2007. *Process to Identify Priority Substances of Health Concern for Enhanced Environmental Reporting*. Environmental Protection Office, Toronto Public Health, Toronto.

Greenhouse Gases

Vehicles are a very large source of greenhouse gases (GHGs) in Toronto. Table 3 summarizes total GHG emissions generated by Toronto activities in 2004, as expressed by carbon dioxide equivalents (eCO_2). By expressing GHGs in terms of eCO_2, it is possible to use a common measure to sum the global warming potential (GWP) of a variety of GHGs. The three primary GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Table 3. Annual Emissions of Greenhouse Gases for Toronto (2004)

Source of Emissions	GHG Emissions (eCO_2 tonnes/year)
Residential	5,997,042
Commercial & small industry	6,884,767
Large commercial & industry	2,002,172
Transportation	8,558,966
Waste transport to Michigan	35,507
Streetlights & traffic signals	29,203
Waste (methane from landfills)	942,550
Total	24,450,207

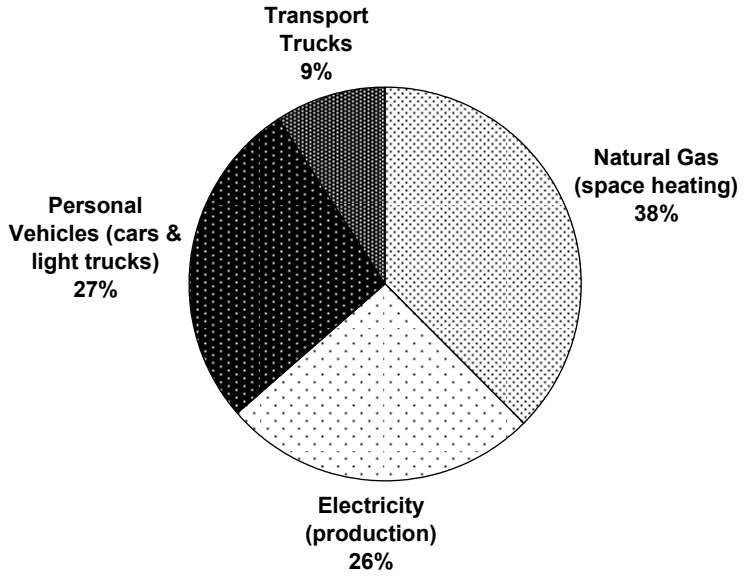
Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions.* Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

The transportation sector contributes about 35% of the total GHGs emitted as a result of activities in Toronto. Figure 3 shows the distribution in energy-related (fuel and electricity) GHG emissions by Toronto. Of the GHG emissions produced by vehicles, about 25% are attributable to transport trucks and 75% are generated by personal vehicles (cars and light trucks).

The transportation sector contributes about 35% of total greenhouse gases emitted as a result of activities in Toronto

Greenhouse gas emissions have continued to rise in the City during the period between 1990 and 2004. Over this period, greenhouse gas emissions have risen from 22.0 million tonnes to 24.4 million tonnes annually, with transportation emissions from the use of gas and diesel-powered vehicles continuing to be a major contributor.

Figure 3. Distribution in Energy-Related Greenhouse Gases Emissions (2004)



Source: *Greenhouse Gases and Air Pollutants in the City of Toronto: Towards a Harmonized Strategy for Reducing Emissions.* Prepared by ICF International in collaboration with Toronto Atmospheric Fund and Toronto Environment Office. Toronto June 2007

Unlike criteria pollutants and air toxics which have direct adverse impacts on health, GHGs are of health concern because of secondary effects such as global warming and climate disruption. Based on recent research, Toronto Public Health has determined that on average (over the 46 year study period), about 120 people die prematurely from heat-related causes in Toronto. Furthermore, it is projected that global warming could result in a doubling of heat-related deaths by 2050, and a tripling by 2080 (Toronto Public Health, 2005).

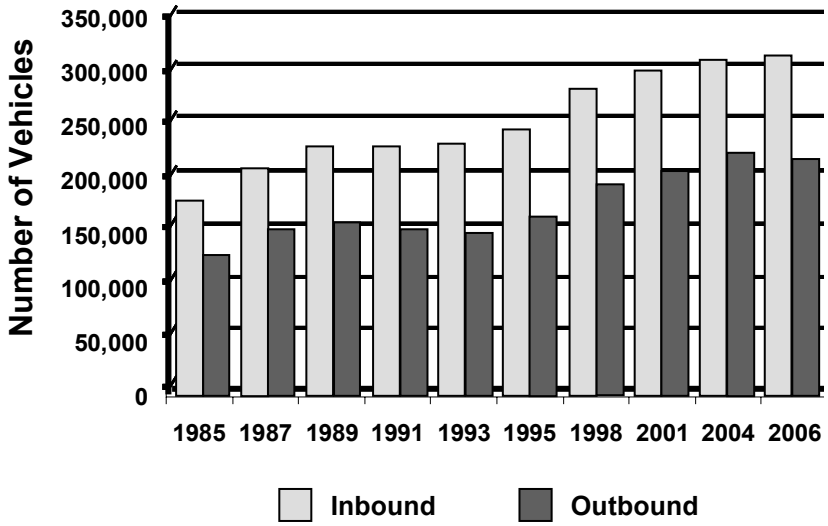
Traffic Trends

Data showing traffic trends in Toronto demonstrate that the number of vehicles travelling into Toronto each morning has increased each year from 1985 to 2006. Figure 4 illustrates that between 1985 and 2006, the number of inbound vehicles increased from 179,300 vehicles to 313,900 vehicles, an increase of 75% (City of Toronto, 2007).

The number of vehicles travelling out of the city each morning has fluctuated since 1985 and reached its peak level in 2004 (224,200 vehicles). Between 1985 and 2006, vehicles leaving the city each morning increased from 122,400 to 219,100 vehicles, showing an increase of 79%, as shown in Figure 4 (City of Toronto, 2007). This increase is attributed in part to employment growth in the region around Toronto and beyond.

In the last two decades, the number of vehicles entering the city each weekday morning has increased by 75%

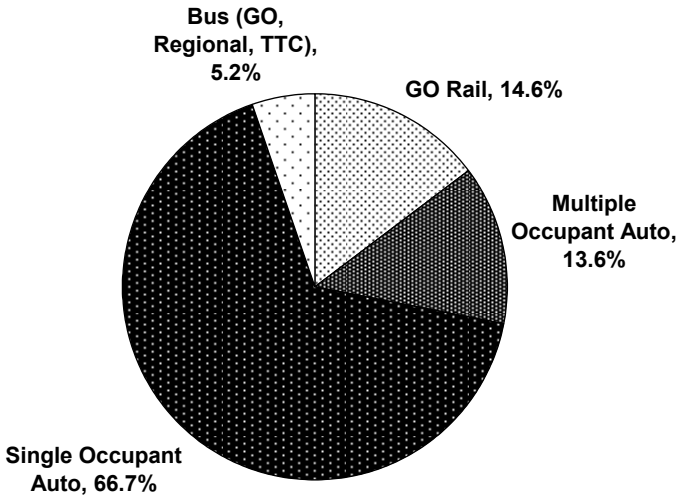
Figure 4. Trend in Mean Daily Number of Vehicles Entering and Exiting Toronto (6:30 a.m. – 9:30 a.m.)



Source: *2006 City of Toronto Cordon Count Program Information Bulletin*. Prepared by City Planning Division - Transportation Planning. Toronto June 2007

Figure 5 shows that 67% of trips entering Toronto in 2006 were made in single occupant vehicles. Only one in every five trips into Toronto during the morning peak travel period is made using GO train, GO bus, TTC and buses from other municipalities (City of Toronto, 2007).

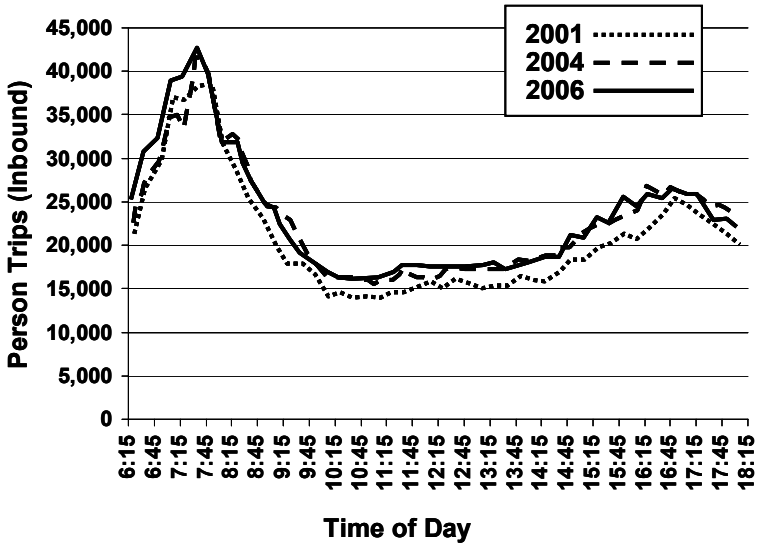
Figure 5: Mode of Travel – Inbound Person Trips (6:30 a.m. – 9:30 a.m.) 2006



Two thirds of the vehicle trips into the city in 2006 were made by single occupancy vehicles

Source: *2006 City of Toronto Cordon Count Program Information Bulletin*. Prepared by City Planning Division - Transportation Planning. Toronto June 2007

Figure 6. All-Day Inbound Travel (Person Trips – 6:30 a.m. – 6:30 p.m.)



Source: *2006 City of Toronto Cordon Count Program Information Bulletin*. Prepared by City Planning Division - Transportation Planning. Toronto June 2007

Figure 6 shows the steady growth in the volume of vehicles travelling into Toronto from 2001 to 2006. Of note is the pronounced peak in vehicle traffic during morning rush hour (6:30 to 9:30 a.m.). Continued population growth in the City combined with strong increases in both population and employment in the region surrounding Toronto has also led to increased off-peak travel, which is reflected in the growth of all-day traffic volumes crossing the City boundaries (City of Toronto, 2007).

Assessment of Air-Related Burden of Illness from Traffic

Methodology

Pollutant Concentration Data

To estimate the health impact of traffic pollution, the traffic component of ambient air pollution must be isolated

In order to calculate an estimate of the health and economic impacts of traffic-related pollution, the traffic component of ambient pollutant levels must be isolated. Toronto Public Health collaborated with air modelling specialists at the Toronto Environment Office (TEO) to determine the specific contribution of traffic-related pollutants to overall pollution levels. Using 2004 data, TEO modelled emissions from vehicles in Toronto and provided Toronto Public Health the average concentrations for four key pollutants of significant health concern: carbon monoxide (CO), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and fine particles (particles of 2.5 micron diameter or less) ($PM_{2.5}$) that could be attributed to traffic. The air quality model used was not able to provide modelled ozone (O_3) concentrations, so the ozone contribution from traffic was estimated based on monitoring data from the Ministry of Environment.

The City of Toronto's Air Quality Model

Air quality models can be used to predict the concentration of pollutants that people are exposed to that arise from various sources including those specifically from traffic. Unlike measurements taken directly from monitoring stations, these models are mathematical descriptions of air pollution. They take into account the relationship between emissions and air quality, including the dispersion, transport, and transformation of compounds emitted into the air.

The TEO uses an air quality dispersion model called CALPUFF (Atmospheric Sciences Group, TRC Solutions). CALPUFF is a sophisticated computer modelling system that models the dispersion and diffusion of emissions. The model has been adopted by the U.S. Environmental Protection Agency (U.S. EPA) in its *Guideline on Air Quality Models* as the preferred model for assessing long range transport of pollutants and on a case-by-case basis for certain applications involving complex terrain and meteorological conditions as occurs in Toronto given Toronto's proximity to Lake Ontario. The modelling system consists of three main components: CALMET (a diagnostic 3-dimensional meteorological model), CALPUFF (an air quality dispersion model), and CALPOST (a post-processing package). In addition to these components, there are numerous other processors that are used to prepare geophysical and meteorological data.

Traffic emissions were modelled from traffic flow count data provided by Transportation Services (TS). Effectively, the model utilizes hourly traffic count and flow data for every highway, major arterial, minor arterial and collector road in Toronto. Transportation Services also estimates and provides traffic volumes to typify the smaller local roads and lanes. The traffic flow and count data was then multiplied by Provincial vehicle classification volumes for Toronto and multiplied by Environment Canada emission factors to provide tailpipe emission inputs into the

TEO CALPUFF model. Using these data, the model provided an estimate of the concentrations of air pollutants in the air that could be attributed to traffic.

Actual traffic flow and count data were linked to vehicle classifications and emission factors, and input into a model to determine pollutant concentrations

Since the model was not able to provide accurate data for the contribution of vehicles to ozone found in the air, this contribution was estimated using air quality monitoring data for 2004 in Toronto, and assuming that the proportion of ozone from traffic would be the same as the proportion of nitrogen dioxide.

Air Quality Benefits Assessment Tool (AQBAT)

The modelled pollutant concentrations provided by TEO were then applied to the Air Quality Benefits Assessment Tool (AQBAT) to calculate estimates of health and economic impacts. AQBAT is a computer-based tool developed by Health Canada to enable local health units to estimate air-related burden of illness. AQBAT contains population data, pollutant concentrations, and health endpoint values so that the user can define specific scenario reduction models to determine associated benefits and see the effects of changing the levels of pollutants. The current study used this tool to determine the number of deaths and adverse health outcomes that could be prevented if air pollution from traffic in Toronto was reduced.

Pollutant concentrations attributable to traffic were used in AQBAT to model burden of illness and economic impacts

Health Outcomes

AQBAT calculates the health and economic impacts for 13 health endpoints. These health outcomes are described in Table 4.

Table 4. Description of Health Outcomes Assessed by AQBAT

Health Outcome[a]	Description
Acute exposure mortality	Premature deaths from short-term exposures; generally restricted to deaths from non-traumatic causes (i.e. excludes suicide and deaths from injuries)
Chronic exposure mortality	Number of people who die prematurely from chronic exposures; generally restricted to deaths from non-traumatic causes (i.e. excludes suicide and deaths from injuries)
Elderly cardiac hospital admissions	Number of cases involving seniors admitted to hospital for heart failure (over the age of 65 years)
Cardiac hospital admissions	Number of admissions to hospital for heart problems (e.g. angina/myocardial infarction, heart failure, dysrhythmia/conduction disturbance)
Respiratory hospital admissions	Number of admissions to hospital for breathing problems (e.g. asthma, COPD (emphysema and chronic bronchitis), and respiratory infection (croup, acute bronchitis and bronchiolitis, pneumonia)
Cardiac emergency room visits	Number of visits to emergency department for heart problems that do not result in hospital admissions
Respiratory emergency room visits	Number of visits to emergency department for breathing problems that do not result in hospital admissions
Adult chronic bronchitis cases	Number of incident (new) cases of adult chronic bronchitis attributable to traffic pollution in adults (age 25 and over)
Child acute bronchitis episodes	Number of episodes of acute bronchitis involving children
Asthma symptom days	Total number of days that people with asthma experience symptoms or an asthma attack.
Acute respiratory symptom days	Total number of days when any of the following respiratory symptoms or related conditions are reported: chest discomfort, coughing with or without phlegm, wheezing, sore throat, head cold, chest cold, sinus trouble, croup, hay fever, headache, eye irritation, fever, doctor-diagnosed ear infection, flu, pneumonia, bronchitis, bronchiolitis
Minor restricted activity days	Restricted Activity Days less days spent in bed
Restricted activity days	Total number of days spent in bed or days when people cut down on usual activities.

[a] Pollutants linked to each outcome in the analysis are shown in Appendix 1.

Source: Judek et al. *Air Quality Benefits Assessment Tool (AQBAT)* Release 1.0. Ottawa: Health Canada, 2006.

Economic Valuations

To calculate the economic impact of air pollution, AQBAT uses health endpoint valuations which assign a monetary value to a health outcome. Mortality valuation ("value of a statistical life") is based on an individual's willingness to pay to reduce mortality risks or willingness to accept compensation to experience increased mortality risks (i.e. wage premiums for riskier jobs). The morbidity outcomes are valued using a variety of approaches which evaluate costs of treatment (e.g. medical costs), lost productivity, pain and suffering and averting expenditures.

Concentration Response Functions

In AQBAT, concentration response functions (CRFs) are used to determine the percent excess occurrence of a health outcome associated with an increase in pollutant concentration. These are based on risk coefficients from epidemiology studies in the scientific literature.

This analysis likely underestimates the true burden of illness given the limited number of morbidity (illness) outcomes currently captured in AQBAT

Appendix 1 provides an overview of the CRFs available in AQBAT. It is clear that a limited number of mortality and illness outcomes are captured relative to all those potentially attributable to the mix of air pollution. This likely results in an underestimate of the true burden of illness resulting from exposure to the combined mix of pollutants.

Air-Related Morbidity and Mortality from Traffic

Table 5 summarizes of the morbidity and mortality estimates that result from application of AQBAT to the traffic-related pollution data modelled by the Toronto Environment Office. The results show the number of Toronto residents who experience premature death, hospitalizations, chronic bronchitis, asthma symptoms and more minor health impacts that are attributable to year-long exposure to air pollutants from traffic (vehicles). Mean values are presented given that they are the most reasonable estimate of health impact and most likely to reflect the true burden of illness without over- or underestimation. Confidence intervals are also presented to illustrate the upper and lower bounds of each estimate. These confidence intervals reflect the amount of uncertainty on the concentration response functions as reported in the literature, with wide confidence intervals representing greater uncertainty than narrow ones.

Table 5. Traffic-Related Morbidity and Mortality Estimates (Toronto 2004)

Health Outcome	Mean (number of occurrences per year)	95% Confidence Interval (CI)
Acute exposure mortality	257	161 - 352
Chronic exposure mortality	183	104 - 262
Elderly cardiac hospital admissions	1,595	149 - 3,032
Cardiac hospital admissions	14	7 - 20
Respiratory hospital admissions	60	20 – 100
Cardiac emergency room visits	5	0 - 15
Respiratory emergency room visits	244	60 - 449
Adult chronic bronchitis cases	190	0 - 377
Child acute bronchitis episodes	1,234	0 - 2,651
Asthma symptom days	67,912	24,918 – 110,374
Acute respiratory symptom days	66,830	60,782 – 1,355,571
Minor restricted activity days	99,182	0 - 423,332
Restricted activity days	211,674	124,654 – 298,447

Researchers have long recognized that air pollution results in a 'pyramid' of health effects, with the least common but most serious health outcomes (such as premature death) appearing at the peak of the pyramid, and the less serious but more numerous health outcomes (such as chronic bronchitis and asthma symptom days) appearing in progressive levels below that peak).

Figure 7 illustrates the pyramid of health effects from traffic-related air pollution, as determined through this study. This pyramid is used to illustrate some of the data

shown in Table 5, according to severity of illness. It shows that traffic pollution gives rise to about 440 premature deaths per year. These deaths would not have occurred when they did without exposure to traffic-related air pollution.

Also of concern is that traffic pollution gives rise to about 1,700 respiratory and cardiovascular hospitalizations. The current study suggests that the majority of these hospitalizations (96%) occur in the elderly.

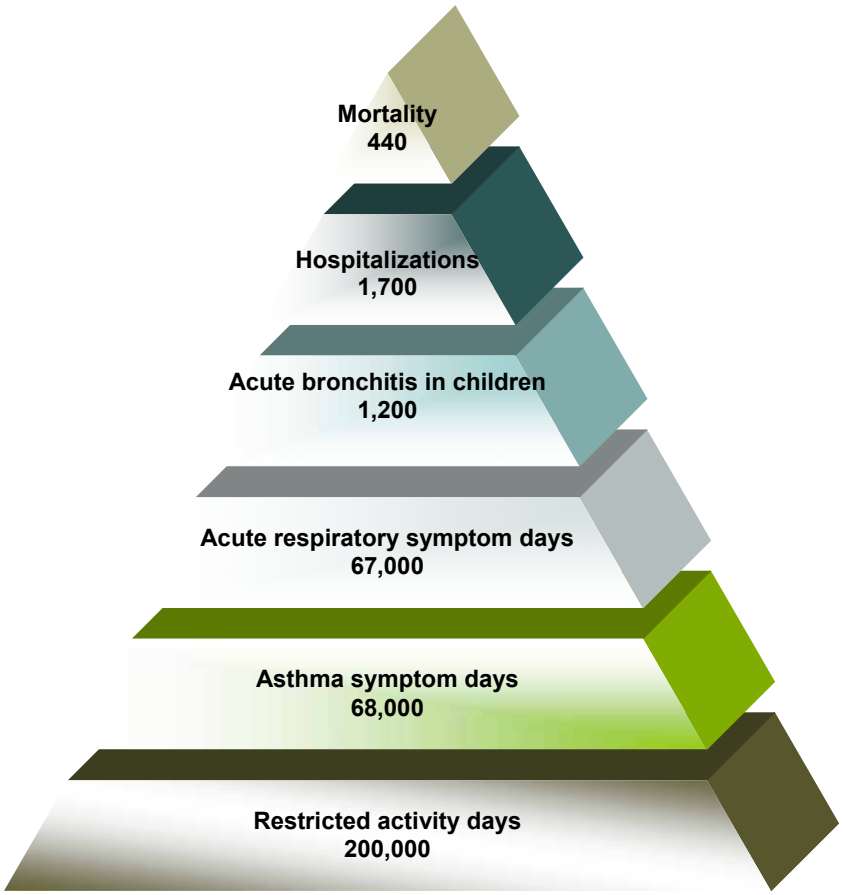
Children are also adversely impacted by traffic-related air pollution, including nearly 1300 episodes of acute bronchitis. Children are also likely to experience the majority of asthma symptom days (about 68,000), given that asthma prevalence and asthma hospitalization rates are about twice as high in children as adults (Toronto Public Health, 2004).

In addition to asthma symptom days, traffic pollution gives rise to about 67,000 acute respiratory symptom days. As shown in Table 4, these are the total number of days when respiratory symptoms or related conditions are reported. Symptoms include chest discomfort, coughing, wheezing, sore throat, headache and eye irritation.

Traffic pollution affects a very large number of people in Toronto. Children and seniors are particularly at risk

The current study shows that traffic-related pollution affects a very large number of people. Impacts such as the 200,000 restricted activity days per year due to days spent in bed or days when people cut back on usual activities are disruptive, affect quality of life and pose preventable health risk.

Figure 7. Pyramid of Health Effects from Traffic-Related Air Pollution[a]: Annual Illness outcomes for Toronto in 2004



(a) Numbers are rounded

Economic Costs Associated with Traffic Pollution

Assessments of the health benefits of interventions to improve air quality are intended to provide information to policy makers which permits them to directly weigh the cost of implementing a program with the benefits to society resulting from the program. While this is not the only consideration in policy decision making, it ensures that decisions are not determined strictly by costs without due consideration to benefits. While benefits described here are estimated for a single year, it must also be borne in mind that current capital investments in some programs will result in a stream of benefits continuing into future years.

There is considerable variation among researchers regarding the methods used to estimate the economic costs associated with air pollution. While economic impact assessments differ among air-related studies, the studies are consistent in showing that financial costs associated with air pollution are substantial. For example, the health-related economic impacts of transport emissions (not including paved road dust) in Canada for the year 2000 were recently estimated at $3.7 billion (in 2000 dollars), of which of $1.6 billion was estimated to occur in Ontario (Transport Canada, 2007).

Based on the application of the AQBAT model, this study estimates that the mortality-related economic impact of traffic pollution in Toronto is about $2 billion (in 2004 dollars) annually (Table 6).

The mortality-related economic impact of traffic pollution in Toronto is about 2 billion dollars

Table 6. Annual Economic Costs Associated with Traffic-Related Air Pollution (a)

Health Outcome	Economic Cost (billion dollars)	95% Confidence Interval (CI) (billion dollars)
Mortality	2.2	1.1 – 4.1

(a) Based on dollar value in 2004

Modelled Health and Economic Benefits from Emission Reductions

While most studies to date have focussed on the adverse impacts of air pollution, a growing number of studies are evaluating the health benefits of policy and regulatory measures that have reduced exposure to pollution (see previous section 'Health Benefits of Reducing Traffic Emissions' for a summary of research findings).

In this study, we have used AQBAT to project the number of premature deaths that could be avoided in Toronto as a result of reductions in traffic-related air pollution. Table 7 shows the results of this analysis, based on emission reduction scenarios of 10, 20 and 30%. Also shown are the cost savings related to deaths avoided. A 30% reduction in vehicle emissions is projected to save 189 lives and result in 900 million dollars of health benefits annually.

A 30% reduction in vehicle emissions is projected to save about 190 lives and result in 900 million dollars in health benefits each year in Toronto

Table 7. Annual Premature Deaths and Costs Avoided With Traffic Emission Reductions

Emission Scenario (% reduction in pollutant emissions)	Deaths Avoided (number)	Value of Health Benefits (Million $)
10	63	300
20	126	600
30	189	900

The emission reduction scenarios modelled in this study appear to be realistic and achievable. Table 8 summarizes policy options identified by the Victoria Transport Policy Institute. The table shows the capacity of each option to reduce vehicle use, based on observations from other cities. Some options (such as planning reforms and fuel tax shifting) affect everyone who travels by car, whereas other options (such as school trip management and car-sharing) affect only a portion of people who drive. The Institute estimates that if these various policies and programs are implemented in a comprehensive and integrated approach, when taken together they are expected to reduce total vehicle travel by 30 to 50%, when compared with current planning and pricing practices in place in most communities.

Table 8. Capacity of Policy Options to Reduce Vehicle Use

Policy Option	Description	Reduction in Vehicle Use (%)	
		Targeted [a]	Total [b]
Transportation Planning	Adoption of options that consider all direct and indirect costs and benefits	10 – 20	10 - 20
Mobility Management Programs	Local Transportation Demand Management (TDM) programs that support and encourage use of alternative modes	10 – 20	4 – 8
Commute Trip Reduction	Programs by employers to promote alternative commuting options	5 – 15	1 – 3
Commuter Financial Incentives	Offers commuters financial incentives for using alternative modes.	10 – 30	1 – 6
Fuel Taxes – Tax Shifting	Increases fuel taxes and other vehicle taxes	5 – 15	5 - 15
Pay-as-You Drive Pricing	Converts fixed vehicle charges into distance-based fees.	10 – 15	7 -13
Road Pricing	Charges users directly for road use, with rates that reflect true costs.	10 – 20	1 – 3
Parking Management	More efficient use of parking facilities.	5 – 10	2 – 8
Parking Pricing	Direct charges for using for parking facilities, with rates that may vary by location	10 – 20	3 - 10
Transit and Rideshare Improvements	Enhances public transit and car-sharing services.	10 – 20	2 - 12
HOV Priority	Improves transit and rideshare speed and convenience based on high-occupancy vehicle lanes.	10 – 20	1 – 2
Walking and Cycling Improvements	Improves walking and cycling conditions.	10 - 20	1 – 4
Smart Growth Policies	More accessible, multi-modal land use development patterns.	10 – 30	3 - 15
Location Efficient Housing & Mortgages	Encourages businesses and households to choose more accessible locations.	10 - 30	1 – 6
Mobility Management Marketing	Improved information and encouragement for transport options.	5 - 10	2 – 5
Freight Transport Management	Encourages businesses to use more efficient transportation options.	5 - 15	0.3 – 2
School & Campus Trip Management	Encourage parents and students to use alternative modes for school commutes.	5 - 15	0.3 – 1.5
Regulatory Reforms	Reduces barriers to transportation and land use innovations.	5 – 10	0.1 - 1
Car sharing	Vehicle rental services that substitute for private car ownership.	20 - 30	0.2 – 0.6
Traffic Calming & Traffic Management	Roadway designs that reduce vehicle traffic volumes and speeds.	3 - 6	0.1 – 0.4

(a) 'Targeted Reduction' refers to typical reductions in area affected by the specific policy.
(b) 'Total Reduction' refers to reduction as a % of total vehicle travel in the community.

Source: Todd Litman. *Win-Win Transportation Solutions*. Victoria Transport Policy Institute. September 2007.

Sustainable Transportation Approach

A sustainable transportation system incorporates environmental, social and economic best practices. Sustainable transportation:

- allows the movement needs of individuals and societies to be met safely and in a manner consistent with human and ecosystem health, and with equity within and between generations;
- is affordable, operates efficiently, offers choice of transport mode, and supports a vibrant economy; and
- limits emissions and waste, minimizes consumption of non-renewable resources, re-uses and recycles its components, and minimizes the use of land and the production of noise (Centre for Sustainable Transportation, 2005).

Implementation of a sustainable transportation system typically focuses on enhancements to transit services, urban form, and behaviour shifts towards becoming more physically active and driving less

Efforts to implement a sustainable transportation system typically focus on improvements to transit services, urban form, and efforts to modify human behaviour towards becoming more physically active and driving less.

Sustainable Transportation Hierarchy

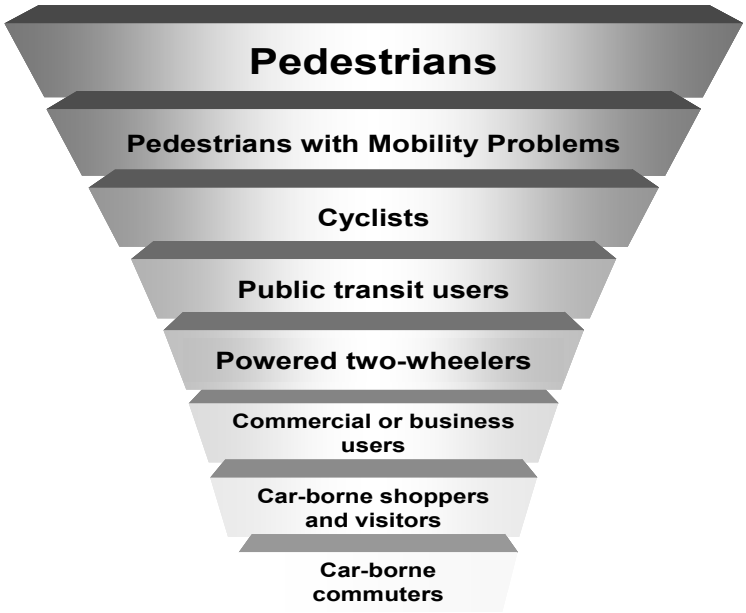
Modes of transportation that are alternatives to motor vehicles provide benefits to both individuals and the community. 'Active transportation' refers to modes of travel that rely on using one's own energy to get from one place to another. Examples include walking, cycling, roller-blading and self-propelled scooters. Active transportation is a core component of a sustainable transportation system. Among its many benefits are:

- Reduced greenhouse gas emissions, smog pollutants, and air toxics;
- Reduced congestion on roads, and
- Increased physical activity, good health and well-being.

The City of York in England has developed an integrated transportation network that focuses on active transportation alternatives to vehicles in order to meet local air quality objectives. Walking, addressing needs of individuals with mobility problems, cycling, and public transit are emphasized. York was one of the first local authorities to adopt a hierarchy of transportation users when making decisions related to land use and transportation (World Health Organization, 2006).

Figure 8 illustrates the hierarchy of transportation users implemented by the City of York. In this hierarchy, cities are designed around people, not cars. A sustainable transportation network focuses on active transportation modes first, followed by modes that are vehicle dependent. It is also important to note the emphasis placed on the needs of individuals with mobility problems. These individuals require special attention to enable them to enjoy active modes of transport. Toronto is considering adopting this transportation hierarchy as part of its Walking Strategy, which is currently being developed. In order to be most effective, this priority setting approach needs to be applied to all land use and transport decisions.

Figure 8. Hierarchy of Transportation Users (In Descending Order of Priority)



Source: World Health Organization. 2006. *Promoting Physical Activity and Active Living in Urban Environments.*

Addressing transportation needs by fostering excellent public transit, walking and cycling infrastructure helps to stimulate an effective mobility network. Enabling individuals to connect seamlessly within these nodes increases the convenience of transportation options, encourages daily physical activity, and reduces adverse impacts on air quality and associated health impacts.

Furthermore, active transportation contributes to sustainability from an economic perspective. Active transportation is relatively inexpensive to the user and to the community in terms of dollars required to sustain infrastructure. The International Association of Public Transport (IAPT) has demonstrated that higher density cities spend the least on providing mobility infrastructure for their residents when trips are being made using predominantly public transport, walking and cycling. The proportion of community income used on transportation rises from less than 6% in densely populated cities where most trips are made by walking, cycling and public transit, to 12% in cities where the car is relied upon almost exclusively for transportation (IAPT, 2005).

Health Benefits of Active Transportation

Active transportation is relatively inexpensive to the user and the community in terms of infrastructure costs

The World Health Organization is among many international and national agencies that highlighted the importance of moderate activity for health, encouraging at least 30 minutes of physical activity daily. The 30 minutes can be built up over a day, with even two to three episodes of 10 to 15 minutes each to provide important health benefits (WHO, 2002a). A study from the Centers for Disease Control and Prevention in Atlanta indicates that each additional kilometre walked per day is associated with a 4.8% reduction in obesity (Frank et al. 2000). These examples illustrate the health benefits that may be realized just by incorporating walking or cycling into daily routines, such as getting to public transit, walking from the transit stop to work, or walking or cycling to the store. These short, but important additions of physical activity are lacking when individuals rely exclusively upon a vehicle for mobility.

Toronto's rate of physical activity is well below what is needed for good health.

Toronto's rate of physical activity is well below what is needed for good health (Toronto Public Health, 2003). Recent studies have indicated that the Canadian population and children in particular are not as physically active as recommended by health professionals (Ontario Ministry of Health and Long-term Care, 2004). Over 2.6% of all health care costs in Canada are spent dealing with the ill health effects of physical inactivity (Katzmarzyk & Janssen, 2004).

Studies provide evidence of the importance of regular physical activity for children (WHO, 2006). Regular physical activity is necessary for the healthy growth and development of children and youth. Physical activity also provides social, behavioural and mental benefits to young people (TPH, 2003). Including the perspectives of young people and their care givers in mobility- related decision-making is important to the overall success of any sustainable transportation endeavour (WHO, 2006).

Evidence also shows that even modest increases in physical activity among older people can make a major difference in their well-being and in their ability to remain independent and actively contribute to civic life. Enabling and encouraging increased physical activity among this population may be one of the most effective means of preventing and lowering the high costs associated with health and social services (WHO, 2006).

Individuals with disabilities are generally less physically active than those without a disability. Yet, physical activity is critical for people with disabilities to prevent disease as well as to reduce the number of secondary conditions that can result from an initial disability (WHO, 2006). Sidewalks and curb ramps at intersections and rough surfaces on trails and paths make maintaining balance and mobility extremely difficult for those with disabilities and the elderly. Knowing that these issues are addressed may encourage vulnerable individuals to become more physically active.

A report by the Ontario College of Family Physicians (OCFP) notes that car-dependent neighbourhoods contribute significantly to air pollution and traffic fatalities (Bray et al. 2005). Further, the OCFP concluded that people who live in spread-out, car-dependant neighbourhoods walk less, weigh more and suffer from obesity and high blood pressure and consequent diabetes, cardiovascular and other diseases, as compared to people who live in higher density, "walkable" communities. The low-walkability of sprawling neighbourhoods and the resulting increase in car use contributes to the growing obesity epidemic, especially in children (Bray et al. 2005).

People who live in spread-out, car-dependent neighbourhoods walk less, weigh more, and suffer from more high blood pressure, diabetes and heart problems than people who live in high density, walkable communities

Increased cycling and walking are good forms of moderate-intensity physical activity to improve public health. Incorporating just thirty minutes per day of moderate activity such as swift walking or cycling helps to maintain or improve muscular strength, flexibility and healthy bones, and contributes towards healthy weights. Other benefits of being physically active include improving concentration and boosting self-confidence (Toronto Public Health, 2003). When active transport is easily integrated into regular routines such as getting to and from work and school, social activities, running errands, it becomes part of a healthy lifestyle. (Agence de la sante et des services sociaux de Montreal, 2006).

Increased levels of participation in physical activity can contribute to social cohesion, neighbourhood vitalization and a greater sense of community identity (Social Exclusion Unit, 2006). Green spaces, skateboarding parks, trails, and sports facilities provide a social focus and enhance people's perception of their neighbourhood (WHO, 2006). Providing equitable and safe opportunities for active living may also encourage the expansion of social networks, which is especially important for members of minority ethnic, racial and religious groups and for older residents (WHO, 2006).

Investments that support active transportation result in important social benefits, including better social cohesion, neighbourhood vitalization, and sense of community

Some research findings suggest that where safe opportunities exist to walk and cycle, low-income Canadians are more likely to make use of cycling and walking infrastructure (Agence de la sante et des services sociaux de Montreal, 2006). Therefore, investments that support active transportation result in important social benefits.

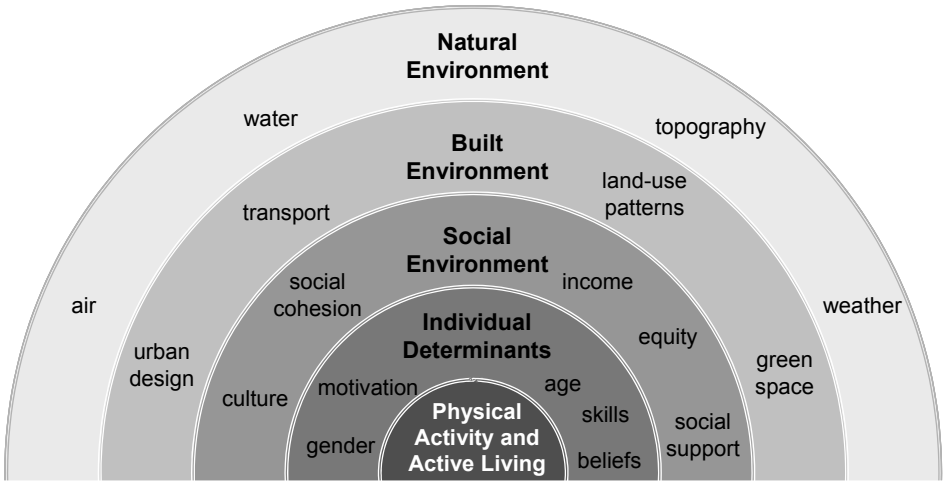
Factors that Enable Active Transportation

Researchers are beginning to quantify neighbourhood elements that encourage or discourage active transportation (Butler et al., 2007). Figure 9 illustrates the many factors that influence an individual's activity level. Design elements in the built environment, such as street layout, land use, public transit, and the location of recreational facilities, green space and public buildings, are all components of a community that can either encourage or discourage active living. It is important to understand how urban planning decisions impact on citizens' decisions to walk or cycle as a form of transportation and to make planning decisions accordingly (Agence de la sante et des services sociaux de Montreal, 2006).

Density, variety, and type of destinations available in a neighbourhood affect a resident's choice in leisure walking and travelling to work and to do errands. For example, the availability of preferred destinations for walking and cycling, such as

errands and leisure activities, friends and family, schools, and workplaces, is critical to one's decision to engage in active transportation (Agence de la sante et des services sociaux de Montreal, 2006). Overall, an integrated approach to transportation planning is essential in order to reduce the burden of illness associated with vehicle traffic. Increasing and promoting public and active transportation that enables people to get to important destinations such as work and school is an important way of achieving this.

Figure 9. Factors Influencing Physical Activity in Communities



Source: World Health Organization. 2006. *Promoting physical activity and active living in urban environments.*

As urban density increases, walking, cycling, and use of transit increases while car travel declines

Residents of more densely populated zones tend to engage more extensively in walking than residents of less densely populated areas because density affects the distances between destinations and the proportion of destinations that are within convenient walking or cycling distance (Agence de la sante et des services sociaux de Montreal, 2006).

Access to public transit also promotes physical activity, since many trips involve walking or cycling links. As density increases, the number of hours and kilometres of car travel tend to decline while walking, cycling and use of public transit increase. The degree to which the street network provides direct and safe routes for pedestrians and cyclists also influences citizens' decisions to engage in active transportation (WHO, 2006).

Several individual determinants influence participation in physical activity including gender, age, skill level, ability and disability, beliefs, attitudes and motivation (WHO, 2006). A key barrier to engaging in physical activity involves concerns about safety and security. For example, residents will not use a cycle lane or path if they believe it is dangerous (WHO, 2006).

Shared road use by motor vehicles, pedestrians and cyclists increases the risk of a traffic injury among walkers and cyclists (WHO, 2006). This is especially true for older adults. Research suggests that people often identify safety concerns as a barrier to engaging in walking or cycling. A survey shows that 82% of Canadians have expressed an interest in walking more regularly, and 66% of Canadians have indicated a desire to cycle more, however, safety concerns prevent them from becoming more active (Agence de la sante et des services sociaux de Montreal, 2006).

Safety concerns are a significant barrier to engaging in walking or cycling

Traffic injuries and fatalities from vehicles travelling at high speeds, heavy traffic flow and a lack of separate lanes and paths are key reasons why citizens do not walk or cycle in cities. Seniors and children are particularly affected by these safety factors. Short traffic signals and wide streets with inadequate lane marking on roadways have also been shown to compromise the safety of older pedestrians. High vehicle speed, the number of kilometres of major arterial streets in a neighbourhood, poorly located bus stops and crosswalks, inadequately maintained sidewalks and poor lighting are also associated with greater risks to the safety of pedestrians of all ages (WHO, 2002a). Sidewalks and protected areas for walking and cycling can help reduce collisions between vehicles and pedestrians and cyclists (WHO, 2002a). Also at issue is enabling safer year-round cycling through snow removal on bike routes and lanes.

Efforts that increase physical safety are important to increase people's uptake of active transportation. For cyclists in Toronto, this means completing the 1,000 km bikeway network of bicycle lanes, routes and trails recommended by the Toronto Bike Plan, as quickly as possible. Other important cycling improvements include more and higher security bicycle parking at work places and other destinations and better integration with public transit for longer trips. For pedestrians, this means implementing measures that encourage Toronto residents to make more walking trips, including wider and more continuous sidewalks and walkways, enhancements to pedestrian crossings and traffic signal timing, narrowing pavements where feasible, and promoting a culture of walking.

A key barrier to engaging in physical activity involves concerns about safety and security. People will not cycle if they believe it is dangerous. Shared road use by vehicles, pedestrians and cyclists increases the risk of a traffic injury among walkers and cyclists. This is especially true for children and seniors. Also of concern is the speed of vehicle traffic along bicycle routes. A survey shows that 66% of Canadians have a desire to cycle (or cycle more) but that safety concerns prevent them from being more active.

Many current cyclists, and people who would like to cycle, are also concerned about breathing vehicle emissions on roads with heavy traffic. The closer one is to the tailpipe of vehicles, the greater the exposure to pollutants, and the greater the health risk.

Given the finite amount of space for all traffic modes, more roadway space needs to be allocated towards expanded infrastructure for walking, cycling, and public transit, and less to vehicle use.

Given there is a finite amount of public space in the city for all modes of transportation, there is a need to reassess how road space can be used more effectively to enable the shift to more sustainable transportation modes. More road space needs to be allocated towards development of expanded infrastructure for walking, cycling and on-road public transit (such as dedicated bus and streetcar

lanes) so as to accelerate the modal shift from motor vehicles to sustainable transportation modes that give more priority to pedestrians, cyclists and transit users.

Expanding and improving the infrastructure for sustainable transportation modes will enable more people to make the switch from vehicle dependency to other travel modes. This will also benefit motorists as it would reduce traffic congestion, commuting times and stress for those for whom driving is a necessity. Creating expanded infrastructure for sustainable transportation modes through reductions in road capacity for single occupancy vehicle use will require a new way of thinking about travelling within Toronto and beyond. To be successful, it will require increased public awareness and acceptance of sharing the road in more healthy and sustainable ways, as well implementation of progressive policies and programs by City Council.

Health Promotion Initiatives Underway

Municipalities make decisions concerning planning, transportation, health, housing, recreation and economic development that affect opportunities for active living. Neighbourhood design, the location of schools and businesses and the priority assigned to cars, cyclists and pedestrians all affect citizen's ability to engage in physical activity and active living. Local strategies and plans should aim towards promoting physical activity among people of all ages, in all social circumstances and living in all parts of cities, with special attention afforded to equity and vulnerable populations (WHO, 2006).

In 2002, Toronto City Council approved the Toronto Pedestrian Charter, a set of six principles that recognizes the importance of pedestrian movement in the city. The Charter reflects the principle that a city's walkability is one of the most important measures of the quality of its public realm, and of its health and vitality. This is the first pedestrian charter in North America, and the first approved by a municipality anywhere.

In approving the development of the Charter in 2000, The City intended:

- to outline what pedestrians have a right to expect from the City in terms of meeting their travel needs;
- to establish principles to guide the development of all policies and practices that affect pedestrians; and
- to identify the features of an urban environment and infrastructure that will encourage and support walking.

Transportation Services is preparing the Toronto Walking Strategy, in partnership with several City divisions and agencies. The Walking Strategy will build on the existing policies of the Official Plan to set out the policies, programs and projects required to promote a culture of walking in Toronto. The main theme of the strategy is "putting pedestrians first" in future city building. The Walking Strategy will call for a change in mindset from a transportation system designed principally for automobiles to one that places pedestrians at the top of the transportation hierarchy.

Putting pedestrians first is a critical component of efforts to create a sustainable transportation infrastructure in Toronto. As discussed in *Sustainable Transportation*

Initiatives: Short Term Proposals, a report prepared by Transportation Services and City Planning (September 2007), the City is considering numerous options for encouraging safe walking in the City. For example, placing a greater focus on planning pedestrian zones and streets, enhancements at intersections to make it easier for pedestrians to cross, and trail corridors that are separated from traffic are important considerations for fostering sustainable transportation.

The City of Toronto has also identified priority initiatives to encourage more individuals to cycle. These include enhancing bike storage and parking, assessing the development of bike share programs, establishing dedicated bicycle paths and trail corridors throughout the City, with particular attention to the downtown core.

The City of Toronto is engaged in other projects as well that promote active transportation, such as:

a) ***Get Your Move On***: a program that works with individuals, community groups, agencies, institutions, businesses and all levels of government to achieve increased physical activity among all residents. Partners in the program promote healthy active living for all Toronto residents and develop and promote a civic culture where active living is part of everyday life;

b***) Toronto Bike Plan***: the vision for cycling in Toronto. To shift towards a more bicycle friendly city, the Plan sets out integrated principles, objectives and recommendations regarding safety, education and promotional programs as well as cycling related infrastructure, including a comprehensive bikeway network.

c) ***Walking School Bus***: The City of Toronto is a participant through the Active and Safe Routes to School program. A Walking (or Cycling) School Bus is two or more families, traveling to school together for safety.

d) ***20/20 The Way to Clean Air***: This program provides individuals with a Planner to help reach a 20 per cent energy reduction goal. This practical guide identifies some easy-to-do activities as well as longer-term, greater cost savings actions. It also connects individuals with programs and services in the Greater Toronto Area that will help reduce energy use at home and on the road. Reducing vehicle use is one of the primary goals of 20/20 and active transportation is emphasized as an alternative to driving.

e) ***Air Quality Health Index*** (AQHI): a new national health-based index to help individuals protect their health. The AQHI helps individuals find out the health risk from air pollution on an hourly basis. The AQHI forecast allows people to plan and enjoy outdoor activities for times when health risks are low, and to reduce their exposure to pollutants when the health risks are moderate or high. An important way to minimize exposure is to reduce the intensity of strenuous physical activity outdoors during peak pollution periods.

Toronto's Commitment to Improving Air Quality

In July 2007, Toronto City Council adopted the *Climate Change, Clean Air and Sustainable Energy Action Plan.* This comprehensive and ambitious plan targets the following air quality improvements:

- Reduction in greenhouse (GHG) emissions from 1990 levels of 6% by 2012, 30% by 2020 and 80% by 2080; and

- Reduction in locally-generated smog-causing pollutants from 2004 levels of 20% by 2012.

The plan consists of a broad range of actions involving community, business and government participants. Components include: engaging neighbourhoods; greening the economy (institutions, commercial and industrial sectors); fostering creation and use of renewable energy; making more sustainable transportation choices; greening City operations; increasing the tree canopy; preparing for climate change; enhancing public awareness; and monitoring and evaluating progress.

A key component of the plan is to develop and implement a more sustainable transportation system. Advancing sustainable transportation in Toronto consists of many planned initiatives, some of which are highlighted here:

- Implement environmental, engineering and financial planning studies to support the Transit City Plan;
- Expand the network of bike lanes and trails from 300 to 1,000 km by end of 2012;
- Prepare a Sustainable Transportation Implementation Strategy, drawing from and integrating existing policies and plans (e.g. Official Plan, Bike Plan, Transit City Plan, TTC Ridership Growth Strategy, Walking Strategy);
- Create an initiative to 'green' commercial fleets in the city;
- Develop a program to shift taxis and limousines to low emission or hybrid technologies by 2015 or earlier;
- Encourage provincial and federal governments to provide policy, program and funding support to Toronto to achieve a sustainable transportation system. Aspects of key concern include:
  (i) improved vehicle engine and fuel standards
  (ii) financial incentives for using public transit;
  (iii) stable funding for transit operation and expansion;
  (iv) management of urban growth to reduce car dependency;
- Work with province, GTA Transportation Authority and GTA municipalities to investigate a road pricing regime that reduces vehicle use and helps finance transit improvements.

In October 2007, City Council endorsed the staff report *Sustainable Transportation Initiatives: Short Term Proposals.* The report identified a number of helpful initiatives, including those affecting pedestrians and cyclists, that could be implemented fairly quickly and in most cases at relatively little expense.

Toronto Public Health's current study demonstrates the significant burden of illness and health-related costs associated with current levels of smog-generating pollutants, greenhouse gases and air toxics that are emitted by vehicles in Toronto. The study also highlights the health and economic benefits of preventing traffic-related air pollution. As such, this study provides an important rationale for investing in Council's plan to combat smog and climate change, and for renewing the vigour with which sustainable transportation is pursued.

Conclusion

Burden of illness studies provide a reliable and cost-effective mechanism by which local health authorities can estimate the magnitude of adverse health impacts from air pollution. In 2004, Toronto Public Health (TPH) estimated that air pollution (from all sources) is responsible for about 1,700 premature deaths and 6,000 hospitalizations each year in Toronto.

Since that time, Health Canada has developed a new computer-based tool, called the *Air Quality Benefits Tool (AQBAT)* which can be used to calculate estimates of burden of illness and economic impacts. TPH used this tool in the current study to determine the burden of illness from traffic-related air pollution. TPH collaborated with air modelling specialists at the Toronto Environment Office to determine the specific contribution of traffic-related pollutants to overall pollution levels. Data on traffic counts and flow, vehicle classification and vehicle emission factors were analysed by Toronto Environment Office and Transportation Services for input into a sophisticated air quality model. The air model takes into account the dispersion, transport and transformation of compounds emitted from motor vehicles. Other major sources of air pollution in Toronto are space heating, commercial and industrial sources, power generation and transboundary pollution.

The current study determined that traffic gives rise to about 440 premature deaths and 1,700 hospitalizations per year in Toronto. While the majority of hospitalizations involve the elderly, traffic-related pollution also has significant adverse effects on children. Whereas adults experience 190 cases of chronic bronchitis, children experience more than 1,200 acute bronchitis episodes per year. Children are also likely to experience the majority of asthma symptom days (about 68,000), given that asthma prevalence and asthma hospitalization rates are about twice as high in children as adults.

This study shows that traffic-related pollution affects a very large number of people. Even minor impacts, such as the more than 200,000 restricted activity days, are disruptive, affect quality of life and present preventable health risk to Toronto residents.

This study estimates that mortality-related costs associated with traffic pollution in Toronto are greater than $2 billion per year. A 30% reduction in vehicle emissions is projected to save 189 lives and results in 900 million dollars in health benefits annually.

Given there is a finite amount of public space in the city for all modes of transportation, there is a need to reassess how road space can be used more effectively to enable the shift to more sustainable transportation modes. There is a need to allocate more road space towards development of expanded infrastructure for walking, cycling and on-road public transit (such as dedicated bus and streetcar lanes) so as to accelerate the modal shift from motor vehicles to sustainable transportation modes that give more priority to pedestrians, cyclists and transit users.

Expanding and improving the infrastructure for sustainable transportation modes will enable more people to make the switch from vehicle dependency to other travel modes. This will also benefit motorists as it would reduce traffic congestion, commuting times and stress for those for whom driving is a necessity. Creating expanded infrastructure for sustainable transportation modes through reductions in road capacity for single occupancy vehicle use will require a new way of thinking about travelling within Toronto and beyond. To be successful, it will require increased public awareness and acceptance of sharing the road in more egalitarian ways, as well implementation of progressive policies and programs by City Council.

Enabling greater development and use of public transit and active modes of transportation such as walking and cycling is of significant benefit to the public's health and safety. This study provides a compelling rationale for investing in City Council's plan to combat smog and climate change, and for vigorously pursuing implementation of a comprehensive sustainable transportation strategy in Toronto.

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Appendix 1. Concentration Response Functions Currently Available in AQBAT

Health Endpoint	Pollutant					
	CO	NO_2	O_3	O_3 (May-Sept)	$PM_{2.5}$ (dichot)	SO_2
Acute exposure mortality	✓ (24 hr.)	✓ (24 hr.)	✓ (1 hr. max.)			✓ (24 hr.)
Acute respiratory symptom days				✓ (1 hr. max.)	✓ (24 hr.)	
Asthma symptom days				✓ (1 hr. max.)	✓ (24 hr.)	
Cardiac emergency room visits					✓ (24 hr.)	
Cardiac hospital admissions					✓ (24 hr.)	
Child acute bronchitis episodes					✓ (24 hr.)	
Chronic exposure mortality					✓ (24 hr.)	
Elderly cardiac hospital admissions	✓ (1 hr. max.)					
Minor restricted activity days				✓ (1 hr. max.)		
Respiratory emergency room visits				✓ (1 hr. max.)	✓ (24 hr.)	
Respiratory hospital admissions				✓ (1 hr. max.)	✓ (24 hr.)	
Restricted activity days					✓ (24 hr.)	

Source: Judek S, Stieb D, Jovic B. Air Quality Benefits Assessment Tool (AQBAT) release 1.0. Ottawa: Health Canada, 2006.