APPENDIX N
AIR QUALITY REPORT

Air Quality Impact Assessment for New Highway 7

(Guelph to Kitchener Section)

Report

Prepared by

Toros Topaloglu, Ph.D., P.Eng.
Provincial and Environmental Planning Office
Ministry of Transportation of Ontario

March 2002

Table of Contents

Air Quality Impact Predictions for Highway 7

1. Introduction

The Ministry of Transportation of Ontario (MTO) is planning to expand the capacity of Highway 7 from Guelph to Kitchener. The existing highway may be considered in four sections:

- Victoria Street in Kitchener - five lane urban arterial roadway
- Between the CN Rail crossing and Hopewell Creek - four lane rural arterial highway
- Between Hopewell Creek and City of Guelph - two lane arterial highway
- Within Guelph (Woodlawn Avenue) - four lane urban arterial roadway

The following expansion alternatives have been considered by MTO during the 1992 – 2002 period.

Existing Highway Alternatives

These alternatives involve upgrading the existing rural portion of Highway 7 in the central section of the study area to either:

- A four lane divided highway with right-in / right-out access only; or
- Controlled access with continuous service roads on both sides of the highway; or
- Controlled access with discontinuous service roads.

New Route Alternatives

- Three new alignment alternatives in the western (Kitchener) portion of the study area; and
- Two new alignment alternatives in the eastern (Guelph) portion of the study area.
- Additional new alignment alternatives in the central rural portion of the study area (2001).

The route recommended by MTO's Southwestern Region is described in the Appendix of this report. It runs from the intersection of Highway 6 and Woodlawn Road in Guelph to the Kitchener-Waterloo Expressway, following a path parallel to and just to the north of the existing Highway 7.

MTO's Provincial and Environmental Planning Office prepared this report for the Environmental Unit of MTO's Southwestern Region. The report's principal purpose is to help assess the air quality implications of the proposed undertaking for its vicinity. It deals directly with but is not limited to the recommended route described in the Appendix. It includes a brief review of the background information used in the assessment (Section 2), followed by the methodology (Section 3), analysis and results (Section 4), and conclusions (Section 5).

2. Background

Transportation, and road transportation in particular, is a significant contributor to air pollution. It is, however, not the only contributor. Industrial, commercial, residential, agricultural and other activities contribute also to air pollution. Hence, it is not easy to discern, with a high degree of accuracy, the local air quality impact of a specific highway in the presence of all other contributing sources of pollution. This task is further complicated by the variability of meteorological and traffic conditions, which have a strong influence on local air quality impacts.

The primary pollutants from road vehicles (automobiles, trucks, etc.) are carbon monoxide (CO), oxides of nitrogen (NO_x), and volatile organic compounds (VOC). NO_x has two principal constituents, NO and NO_2. Vehicles emit mainly NO, which oxidizes in the atmosphere relatively quickly to NO_2. These two compounds are collectively designated NO_x. VOC has a large number of constituents, most of which are not particularly toxic. The principal exceptions are benzene, 1,3-butadiene, formaldehyde and acetaldehyde. The concentrations of these four specific pollutants in the immediate vicinity of well-travelled roads can be related to emissions from vehicles.

A second group of transportation related pollutants, secondary pollutants, are not directly emitted by vehicles and affect regional as well local air quality. The principal members of this group are ozone (O_3) and particulate matter (PM). Ozone is one of the products of photochemical atmospheric reactions in which NO_x and VOC play key roles. These reactions occur over large regions and take considerable time for completion. Hence, local ambient concentrations of ozone are not directly related to emission rates of NO_x and VOC of specific sources, such as local road traffic. Similarly, but to a lesser extent, particulate matter are regional pollutants. They emanate from a large number of sources, including road vehicles, and is also formed in secondary reactions in the atmosphere from gas phase pollutants such as NO_x and SO_x (oxides of sulphur)[1]. For regulatory purposes, they are classified by size. Particulate matter smaller than 10 micron (PM_{10})[2] and, especially, smaller than 2.5 micron in diameter ($PM_{2.5}$)[3] are of concern, since they may travel deeper in the human pulmonary system and cause harm. Size is however not the only factor affecting health impacts, chemical composition is also a factor. Particulate matter emanating from vehicle

---

[1] Typically, 50% or more of the fine particulate matter in the lower atmosphere originates from gas phase pollutants.

[2] Inhalable particulate matter

[3] Respirable particulate matter

exhaust may have more serious health effects than ordinary road dust (crustaceous materials).

Road transportation's share of these pollutants varies widely with location and time. Typically, this share is larger in urban centres and during rush hours. Table 1 below provides average values for the province of Ontario over the full year of 1997. Ozone is not included in this table, since it is not a primary pollutant and cannot be readily associated with specific emission sources.

Table 1: Road Transportation's Share in Pollutant Emissions (1997)

Pollutant	Road Transportation Share (%)
Carbon Monoxide (CO)	50
Oxides of Nitrogen (NO_x)	38
Volatile Organic Compounds (VOC)	21
Particulate Matter (PM_{10})	11

Source: Ministry of the Environment of Ontario (MOE)

Pollutants can affect human health and the environment adversely. The federal government regulates emissions from new motor vehicles[4]. This practice dates back to 1966, when the state of California first started to set limits on emission rates for automobiles and light trucks, in grams of pollutant emitted per mile (g/mile) on a prescribed urban driving cycle. Recent emission standards, listed in Table 2, represent a better than 90% reduction of emission rates since the pre-control era.

Table 2: Progress of New Automobile Emission Standards

Period	Emission Levels/Standards (g/mile)		
	CO	NO_x	VOC
Typical pre-control levels	77	4.4	10
1981-1995	3.4	1.0	0.41
1995-2001 (Tier 1)	3.4	0.4	0.25
2001 - (NLEV)	3.4	0.2	0.075
2004/07 - (Tier 2)	3.4	0.07	0.075

Note: Table 2 contains some simplifications to allow a more compact presentation. For instance, in the US, Tier 2 standards will be phased in over 2004 to 2007 and will allow averaging, banking and trading in emission credits to encourage early reduction of sulphur in gasoline. Canada intends to harmonize its standards with those of the US EPA.

The NLEV and Tier 2 standards listed in Table 2 demonstrate the emphasis on reducing the precursors of ozone (NO_x and VOC) from mostly gasoline powered light-duty vehicles. Lately, emissions of particulate matter (PM) have been

---

[4] Federal vehicle standards prescribe maximum emission rates for production vehicles. Emission rates of in-use vehicles are subject to provincial guidelines, which are enforced primarily through the Drive Clean program in Ontario.

attracting greater attention. Diesel powered vehicles are major contributors of PM as well as NO_x. Hence, US regulatory efforts have focused on reducing PM and NO_x emissions from heavy-duty diesel powered vehicles (heavy trucks and buses)[5]. Most recent and future heavy-duty diesel engine emission standards are provided in Table 3[6].

Table 3: Progress of Heavy-Duty Diesel Engine Emission Standards[7]

Period	Emissions (grams of pollutant / horsepower-hour)			
	CO	NO_x	VOC	PM_{10}
1990	15.5	6.0	1.3	0.60
1991-93	15.5	5.0	1.3	0.25
1994-97	15.5	5.0	1.3	0.10
1998-2003	15.5	4.0	1.3	0.10
2004-2007	15.5	2.3	0.2	0.10
2007 +(proposed)	15.5	0.20	0.14	0.01

Notes: 1/ The emission units express amount of pollutant emitted per unit amount of work done.
2/ VOC corresponds to hydrocarbons (HC) for 1990-2003 and non-methane hydrocarbons for 2004+.

It is important to note that the US EPA proposed standards for the period commencing in 2007 would see heavy-duty engine emissions of NO_x, VOC and PM drop to 10% of their levels in 2003. This will mean a large reduction in heavy-duty truck emissions. At the time of writing this report (February 2002) the US and Canadian federal governments have not formally adopted the propsed 2007+ standards, yet. Hence, in the analysis and results of this study (Section 4), the benefits of the 2007+ standards were not taken into account.

Despite the unprecedented regulatory and technical progress of the last three decades, it has become evident that vehicle emission standards alone cannot ensure good air quality. While new vehicles are cleaner, their numbers and use have increased steadily. Furthermore, in-use vehicles emit significantly more than suggested by new vehicle emission standards, in part due to real-life driving conditions and deterioration of emission control equipment with usage. Ontario introduced its mandatory vehicle emissions inspection and maintenance (Drive Clean) program to address this latter issue in an effective manner.

Until recently, meeting emission standards has been almost the sole responsibility of vehicle and engine manufacturers. This is now changing. Under stricter emission standards, vehicle manufacturers have been calling for "cleaner"

---

[5] Currently, gasoline powered automobiles and light trucks are not subject to PM emission standards, but diesel powered ones are.

[6] Heavy-duty vehicle emissions are regulated via engine emission standards rather than vehicle emission standards.

[7] Strictly speaking these are US standards; however, they apply equally to Canada under various Memoranda of Understanding. This regulatory framework is a practical outcome of the fact that almost all heavy-duty highway vehicle engines used in Canada are imported from the U.S.A.

fuels to help them reduce emissions. Fuel composition, for instance the sulphur, benzene, and aromatic contents of gasoline, influence emission rates of PM, NO_x, benzene and other toxic substances. Furthermore, fuel composition affects the vehicle manufacturers' ability to employ better emission control technologies.

The vehicle manufacturers' calls have already succeeded in bringing fuel quality under regulation. For instance, the sulphur in diesel fuel and gasoline is being reduced dramatically. This development alone is expected to produce major air quality benefits, especially lower PM emissions.

In conclusion, stricter standards for vehicles and fuels along with provincial inspection and maintenance programs help protect air quality, particularly in the vicinity of heavily travelled roads. Provincial and federal Ambient Air Quality Criteria (AAQC) represent another set of safeguards against air pollution. Among these, Ontario's short-term exposure criteria for transportation related pollutants are most pertinent for the worst-case scenario analysis of this study and are listed in Table 4. This table lists the most relevant current criteria and those expected to be in effect in 2010 (future criteria). It also includes typical background concentration levels for each pollutant.

Table 4: Ontario Ambient Air Quality Criteria (AAQC)

Pollutant	Current AAQC	Future AAQC	Background Conc.
CO	30 ppm (1 hour)	N/A	0.27 ppm
NO_2	0.2 ppm (1 hour)	N/A	0.014 ppm
Ozone	0.080 ppm (1 hour)	0.065 ppm (8 hour)	0.025 ppm
PM_{10}	50 $\mu g/m^3$ (24 hour)	N/A	22 $\mu g/m^3$
$PM_{2.5}$	N/A	30 $\mu g/m^3$ (24 hour)	13 $\mu g/m^3$
Benzene	N/A	N/A	1-7 $\mu g/m^3$
1,3-Butadiene	N/A	N/A	0.1-1.5 $\mu g/m^3$
Formaldehyde	65 $\mu g/m^3$ (24 hour)	N/A	2-4 $\mu g/m^3$
Acetaldehyde	500 $\mu g/m^3$ (24 hour)	N/A	2-3 $\mu g/m^3$

Source: Ministry of the Environment of Ontario and the U.S. Environmental Protection Agency
Notes: ppm stands for "parts per million by volume" and $\mu g/m^3$ for "microgram per cubic metre". N/A stands for "not applicable".

Over the last decade, greenhouse gas (GHG) emissions of transportation and other anthropogenic sources of pollution have also become a matter of concern, since evidence for their effects on the global climate has been mounting. The principal anthropogenic greenhouse gases are carbon dioxide, nitrous oxide and methane. These compounds have no known deleterious effects on human health at ambient concentration levels and are not listed as criteria air contaminants. Therefore, they are normally not taken into account in project-specific air quality impact assessments. Rather, they constitute a global environmental problem; their impacts are not localized and may extend across the globe. Hence, efforts to limit GHG emissions need to be addressed through international agreements, such as the Kyoto Protocol, and are best handled through broader transportation measures.

3. Methodology

The methodology employed in this study draws upon MTO's first-hand experience with highway air quality impact assessment and the numerous contributions made by other agencies and individuals to this complex subject.

The potential long-term air quality impacts of a highway are assessed in terms of expected changes in the atmospheric concentration of road traffic related pollutants in the vicinity of the highway. These concentration changes will, in turn, depend on projected changes in traffic volume and associated factors. Hence, air quality impact assessment is necessarily based on predictions. The following paragraphs summarize the basic scientific knowledge and methods used in these predictions.

There is strong and well-documented empirical evidence that the concentrations of CO and NO_x in the immediate vicinity of a highway are proportional to their rates of emission on the highway[8]. So, everything else being equal, doubling emission rates will result in doubling of ambient concentrations at a given site[9]. CO in particular, being stable and not prone to deposition, is an excellent "marker" of road traffic and is most often used in modelling highway air quality impacts. NO_x, taken as the aggregate of all oxides of nitrogen, is also a good marker even though the concentrations of its constituents (primarily NO and NO_2) change over time and distance.

VOC, on the other hand, consisting of over 100 chemicals - some highly reactive, many emitted by numerous other sources - are much more difficult to treat in the same manner. Ozone is a secondary pollutant the concentration of which does not directly depend on highway traffic. Thus, local CO, NO_x, and PM concentration changes are the more direct consequences of highway traffic and can be more easily related to their respective emission rates.

The ambient concentration of a pollutant, such as CO, is however not only a function of its emission rate but a large number of other variables as well[10]. Hence, knowledge of emission rates (a major task in itself) is not sufficient to predict corresponding ambient concentrations. The influence of other variables has to be taken also into account. Most of these are meteorological variables such as wind speed, direction and variability (atmospheric stability), and mixing

---

[8] Horowitz, J.L. Air Quality Analysis for Urban Transportation Planning. Cambridge, Massachusetts: The MIT Press. 1982.

[9] This relation is encapsulated in the Gaussian dispersion models commonly used to relate ambient concentrations and emission rates of pollutants.

[10] Pasquill, F. and Smith, F. B. Atmospheric Diffusion. West Sussex, England: Ellis Harwood Ltd. 1983.

height. But, they also include distance from the highway, the topography of the site, and the presence and size of objects on the ground (surface roughness).

For a given emission rate, ambient concentrations drop with increased distance from the highway, increased wind speed and variability and greater mixing height. As far as wind direction is concerned, the maximum concentrations prevail typically with the wind blowing at an angle of approximately 5 degrees off the highway axis (almost parallel to the highway). Wind in this direction causes an accumulation of pollutants, giving rise to higher ambient concentrations.

Above observations suggest that air quality is a strong function of environmental factors, traffic conditions, and distance from the highway. Since it would be very time consuming to model all possible conditions, the practical approach adopted in air quality impact assessment is one of predicting the consequences of a credible worst-case scenario only. This scenario entails the coincidence of the worst credible traffic and meteorological conditions. It is understood that if all provincial ambient air quality criteria are met under the worst-case scenario with a sizeable margin of "safety", air quality will be significantly better than required by provincial guidelines under ordinary conditions.

The worst credible set of conditions for the site in question is selected as follows:

- Peak hour traffic volumes (during morning or afternoon rush hours) and associated emission rates
- Lowest credible wind speed of 1 metre per second
- Wind direction at 5 degrees to the principal axis of the highway
- High degree of atmospheric stability (stability class F)[11] - although unlikely during morning or afternoon rush hours
- Ambient ozone concentration of 0.050 ppm (this rather high level of ozone ensures that NO is promptly converted to NO_2)[12]

Distance of the receptor from the highway is not set; instead, predictions are made for distances of 20, 40, 100, and 200 metres from the edge of the highway. These distances should span the relative location of current and future residents along the highway. As indicated in Section 4 of the report, concentrations of highway related pollutants decline rapidly with distance from the highway.

All above conditions specifying the worst-case scenario are unambiguous, simple specifications, except for emission rates. Emission rates cannot be specified. They are complex functions of composition of the vehicle fleet, traffic conditions, and environmental factors. Traditionally, predictions of the US EPA vehicle

---

[11] A higher degree of atmospheric stability contributes to accumulation of pollutants in the atmosphere close to the ground. Stability class F represents very stable conditions, occur

[12] The 0.050 ppm level is not an absolute maximum for Southern Ontario, but it is approximately double the mean ozone concentration in the region.

emissions model, MOBILE 5 and PART 5[13], are used to fulfil this need. This is, however, not entirely satisfactory, since the model is based on emission rates measured under laboratory conditions and over a specific test cycle not entirely representative of highway driving. Hence, the current study uses emission rates that are derived, in part, from MTO's 1994 Highway 404 air quality impact study.

The next section of the report is devoted to a brief description of the 1994 Highway 404 study and its principal conclusions to inform the reader about the knowledge and experience that is carried through to the current study.

3.1 Input from MTO's 1994 Highway 404 Study

In 1994, MTO conducted an extensive air quality impact assessment of the planned Highway 404 widening between Highways 401 and 407[14]. In this field study, traffic flows, meteorological conditions, and the ambient concentrations of 88 air contaminants were measured simultaneously during Spring and Summer 1994, over a 4-month period, at three monitoring stations adjacent to the highway, one on each side at 30-50 m from the edge of the highway, the third at 330 m.

These measurements helped assess the prevailing air quality in the immediate vicinity of Highway 404 and, by extension, the expected air quality in the vicinity of a heavily travelled 8-lane highway (peak hourly volume of 14,800). Some of the measurement results are provided in Table 5, in the form of average and maximum concentration levels.

It is worth noting that the measurements did not exceed the AAQC, except those for ozone and particulate matter. These two, particularly ozone, are regional pollutants, whose concentrations exceed AAQC in most parts of the province, on a number of days in a given year. Hence, the highway cannot be held responsible for their high concentrations.

In addition to providing a direct assessment of the prevailing air quality in 1994, the measurements, along with dispersion modelling, helped develop and verify the air quality prediction methodology. An important element of this methodology was the correlation of pollutant emission rates with ambient concentrations. This was achieved by comparing measured and calculated contributions of the highway to the ambient CO and NO_x concentrations.

---

[13] MOBILE 5 predicts gas phase pollutant emission rates and PART 5 particulate matter emission rates. There are "Canadianized" versions of these models, Mobile 5C and PART 5C, which MTO has used for predicting future vehicle fleet composition. They account for the unique composition of Ontario's as well as GTA's light-duty and heavy-duty vehicle fleets and corresponding emission rates.

[14] Ministry of Transportation of Ontario. Air Quality Impact Assessment of Highway 404 Widening. 1998.

Table 5: Highway 404 Study Measurement Results (1994)[15]

Pollutant	Average Level	Maximum Level	AAQC
CO, ppm	0.64	3.0	30 (1 h)
NO_2, ppm	0.025	0.143	0.2 (1 h)
VOC, ppm	2.20	5.8	N/A
O_3, ppm	0.0228	0.0885	0.080 (1 h)
PM_{10}, $\mu g/m^3$	29.7	78.3	50 (24 h)
Benzene, $\mu g/m^3$	3.95	9.61	N/A
1,3-Butadiene, $\mu g/m^3$	1.38	10.42	N/A
Formaldehyde, $\mu g/m^3$	2.21	3.60	65 (24 h)
Acetaldehyde, $\mu g/m^3$	1.88	3.80	500 (24 h)

Note: CO, NO_2, VOC and O_3 results represent one-hour averages, PM_{10} results are 24-hour averages, and those for the four toxics 8-hour averages. The "average levels", in the second column, represent averages for the entire measurement period.

Measured contributions were based on differences of pollutant concentrations upwind and downwind of the highway. Calculated contributions were based on extensive modelling with the dispersion model of the California State Department of Transportation (CALINE4)[16]. The model inputs included measured traffic volumes on Highway 404 proper as well as on all ramps and major roads in the vicinity. This extensive effort provided confirmation of the methodology employed and produced more accurate emission rates, representative of the traffic conditions and the total vehicle fleet on Ontario's major highways. On average, approximately 8% of the vehicle fleet at this site consisted of heavy-duty trucks and buses. These vehicles are powered mainly by diesel engines and typically emit more NO_X and PM, per unit of distance travelled, than light-duty vehicles.

3.2 Derivation of Emission Factors

Strictly speaking, the emission rates deduced in the Highway 404 study apply to the 1994 environment on Highway 404. However, they can be extrapolated to future years and other highways, using the "Canadianized" versions of the US EPA MOBILE and PART models as tools to predict changes (i.e., ratios and not absolute values) of emission rates in response to fleet turnover and regulatory developments.

The US EPA revises periodically its emission prediction models to reflect, among other things, changes in regulations, fleet composition, and modelling techniques. In fact, EPA issued the latest version of MOBILE (MOBILE 6) during

---

[15] The data in this table are provided as background information only. They are not used in any calculation of this study.

[16] California State Department of Transportation. CALINE4 – A Dispersion Model for Predicting Air Pollutant Concentrations. 1984.

January 2002. This model is expected to improve the accuracy with which future emission rates of CO, NO_x and VOC can be assessed. It will become the preferred tool for use by MTO and other Canadian transportation agencies once it is "Canadianized" to reflect the composition of Canadian vehicle fleets. This modification is necessary, since, over the years, variations in purchasing habits have created significant differences in fleet composition between the US and Canada and between provinces.

A further and perhaps more pressing need exists for revising PART 5 to reflect the future impacts of heavy-duty diesel engine and fuel regulations. The US EPA has recognized this need and is acting on it, but it will take at least one year to issue a revised model that can predict future PM emissions more accurately.

In the absence of revised and "Canadianized" models to predict future emission rates more accurately, Environment Canada engaged consultants to produce future emission rates by making some modifications to MOBILE 5C and PART 5C. These modifications account for the consequences of new regulations for vehicles, engines, and fuels that will have a direct impact on emission rates, but do not attempt to improve the model. Such improvements are built into MOBILE 6. The results of this work are in a recent report[17], which was used to derive the emission factors in Table 6. These emission factors apply to Ontario's road vehicle population.

Table 6: Emission Factors Based on Model Predictions
(Grams of Pollutant Emitted per Mile Travelled by Average Light-Duty (LDV) and Heavy-Duty Vehicles (HDV))

Year	Vehicle Type	Emission Factor (gram/mile)				
		CO	NO_x	VOC	$PM_{2.5}$	PM_{10}
1995	LDV	30.0	2.7	3.05	0.03	0.04
	HDV	6.8	10.4	1.10	0.56	0.63
2000	LDV	17.5	1.9	1.75	0.03	0.04
	HDV	9.2	14.5	1.15	0.54	0.61
2010	LDV	5.6	0.5	0.55	0.01	0.03
	HDV	5.1	5.7	0.47	0.21	0.26
2016	LDV	4.2	0.14	0.35	0.01	0.03
	HDV	3.2	3.9	0.40	0.20	0.24

Table 6 includes fleet-average emission factors for CO, NO_x, VOC, $PM_{2.5}$ and PM_{10}, specific to light- and heavy-duty vehicles. The PM emission factors in this table account for emissions of exhaust and tire and break wear products, but not re-entrained road dust.

---

[17] Report to Environment Canada by SENES Consultants Limited and Air Improvement Resources, Inc., "Updated Estimate of Canadian On-road Vehicle Emissions for the years 1995-2020" (July 2001)

Re-entrained road dust emissions are commonly calculated by using the US EPA recommendations in AP-42[18]. This document provides the following empirical model (equation) to estimate re-entrained dust emissions from paved roads, as a function of the amount of silt (particles less than 75 μm in diameter) per unit are (in g/m^2) and the average weight of all vehicles in the traffic (in US ton):

$$\text{Emission Factor} = k \times (\text{Silt Loading} / 2)^{0.65} \times (\text{Average Vehicle Weight} / 3)^{1.5}$$

The value of the parameter k depends on the units chosen for the emission factor and the size range of PM (for emissions in g/mile, k=1.8 for $PM_{2.5}$, 7.3 for PM_{10}, and 38 for PM_{30} or TSP). The model applies to the total fleet, with the average vehicle weight representing the total fleet, and cannot be used to predict emissions from individual vehicles or groups of vehicles.

In recent years, a number of studies have concluded that the AP-42 model overstates PM emissions, particularly $PM_{2.5}$ emissions[19]. In an effort to address some of these concerns, the US EPA recently proposed the inclusion of an additional factor in the above equation to account for the natural mitigation effect of precipitation. It also acknowledged that previously recommended silt-loading values have been biased high for "normal" situations and recommended the default value of 0.015 g/m^2 for limited access highways. It is understood that, under special circumstances such as subsequent to heavy road salting, higher silt loads may prevail. With the 0.015 g/m^2 silt loading level and an average vehicle weight of 3 short tons (2724 kg), the AP-42 model predicts the emission factors listed in Table 7. In this calculation, the correction factor for precipitation, which would reduce emission factors by approximately 20%, is omitted, since the principal objective of this study is credible worst-case analysis.

---

[18] AP-42 is US EPA's official source of emission factors. Section 13.2-1 in this source document deals with road dust emissions and is currently being revised (last revision was published in September 2001).

[19] **Review papers:**
John G. Watson and Judith C. Chow. Reconciling Urban Fugitive Dust Emissions Inventory and Ambient Source Contribution Estimates: Summary of Current Knowledge and Needed Research. 2000.
Senes Consultants Limited. Particulate Matter Arising from Paved Roads. Report to the Canadian Council of Ministers of the Environment. March 2000.
Akula Venkatram. A Critique of Empirical Emission Factor Models: A Case Study of the AP-42 Model for Estimating PM-10 Emissions from Paved Roads. Atmospheric Environment, 34, 1-11. 2000.
Jay R. Turner. Mobile Source Particulate Issues. Transportation Planning and Air Quality III – Emerging Strategies and Working Solutions, Lake Tahoe, California. 1997.

Table 7: AP- 42 Emission Factors for Re-entrained Road Material (Emission Factors for "Average" Vehicle in the Fleet)

PM Size Class	Emission Factor, g/mile
$PM_{2.5}$	0.075
PM_{10}	0.30
TSP	1.58

The appropriateness of the emission factors in Table 7 for the current study was addressed by reviewing the literature not explicitly used in the derivation of the AP-42 model. This effort uncovered four relatively recent papers[20] that contain relevant PM emission factors based on original field measurements. Their results, as summarized in Table 8, suggest composite emission factors (sum of exhaust, tire/break wear products, and re-entrained road dust emissions) of $PM_{2.5}$ and PM_{10} in the range of 0.03 – 0.13 g/mile. Hence, the re-entrained dust emission factors in Table 7 are significantly larger than those suggested in the reviewed papers. This would imply that the adoption of the factors in Table 7 would constitute a conservative approach.

Table 8: Summary of Emission Factors for Paved Roads from Literature

Study	Composite Emission Factor (gram/vehicle-mile)		
	Gasoline Powered Light-duty Vehicles	Diesel Powered Heavy-duty Vehicles	Total Fleet (8% Heavy- + 92 % Light-Duty)
Lamoree and Turner (99); $PM_{2.5}$ and PM_{10}			0.03 – 0.04
Balogh et al. (93); $PM_{2.5}$	0.032	1.28	0.13
Wittorff et al. (94); PM_{10}	0.015+/-0.060	0.67+/-0.13	0.067
Venkatram et al. (99); PM_{10}			0.1

Notes: The heavy-duty fleet in Balogh et al.'s measurements are exclusively on heavy-duty diesel buses, some of them with bottom exhaust, operating on an urban driving cycle. The PM emissions of these city buses are expected to be higher than those of heavy-duty trucks under highway driving conditions. The rest of the references deal with typical light- and heavy-duty vehicles under highway driving conditions.

---

[20] **Papers which provide field measurement based PM emission factos:**
M. Balogh et al. Analysis of Fine Particulate Matter near Urban Highways. Transportation Research Record 1416: 25-32. 1993.
D.N. Whittorf et al. The Impact of Diesel Particulate Emissions on Ambient Particulate Loadings. Paper 94-WP91.01, presented at the 87th Annual Meeting & Exhibition of the Air & Waste Management Association, Cincinnati, Ohio, June 19-24. 1994.
W.R. Pierson and W.W. Brachaczek. Particulate Matter Associated with Vehicles on the Road. Aerosol Science and Technology 2: 1-40. 1983.
D.P. Lamoree and J.R. Turner. PM Emissions Emanating from Limited Access Highways. J. Air and Waste Management Association 49: PM-85-9. 1999.

The next stage in the derivation of emission factors involves addition of the re-entrained dust component of $PM_{2.5}$ and PM_{10} to the data in Table 6. This step requires definition of the vehicle fleet composition, since re-entrained dust emission factors, as predicted by the AP-42 model, apply to the entire vehicle fleet rather than to only light- or only heavy-duty vehicles. The fleet most appropriate for this study would consist of 8% heavy- and 92% light-duty vehicles. With this stipulation, Table 6 results are revised to produce the composite emission factors in Table 9.

Table 9: Composite Emission Factors Based on Model Predictions
(Grams of Pollutant Emitted per Mile Travelled by the "Average" Highway Vehicle)

Period	Emission Factor (gram/mile)				
	CO	NO_x	VOC	$PM_{2.5}$	PM_{10}
1995	28.1	3.3	2.9	0.15	0.39
2000	16.8	3.0	2.8	0.15	0.39
2010	5.6	0.9	0.5	0.10	0.35
2016	4.1	0.4	0.4	0.10	0.34

Table 9 suggests that the year-to-year improvements in $PM_{2.5}$ and, particularly, PM_{10} emission factors will be smaller those for the other pollutants. This outcome has two principal contributors. First, composite PM emission factors are dominated by their re-entrained dust component, which stays constant from year to year. Second, the PM reduction benefits of the proposed 2007+ heavy-duty engine and diesel fuel standards are not taken into account.

The last stage in the derivation of the emission factors used in this study involves combination of the Table 9 modelling results with the "measurements" of MTO's Highway 404 study. This is achieved by "scaling" the "measured" emission factors (EF) with appropriate ratios of "modelled" emission factors. The approach is illustrated by the following equation that generates the 2020 emission factor for CO ($EF_{CO,\,2020}$).

$$EF_{CO,\,2020} = EF_{CO,\,1994}\text{ (measured)} \times \{EF_{CO,\,2020}\text{ (predicted)} / EF_{CO,\,1994}\text{ (predicted)}\}$$

This equation applies also to NO_x but not VOC and PM, since these latter pollutants could not be measured continuously and accurately in the MTO Highway 404 study. In the case of VOC and PM, the emission rates are directly obtained from model predictions. The resulting fleet emission factors are provided in Table 10.

Table 10: Emission Factors Based on Hwy 404 Study and Model Predictions – Used in the Analyses of this Study

(Grams of Pollutant Emitted per Mile Travelled by the "Average" Highway Vehicle)

Period	Emission Factor (gram/mile)				
	CO	NO_x	VOC	$PM_{2.5}$	PM_{10}
1995	15.7	4.2	2.9	0.15	0.39
2000	9.4	3.8	2.8	0.15	0.39
2010	3.2	1.1	0.5	0.10	0.35
2016	2.7	0.45	0.36	0.10	0.34

Comparison of Table 9 and Table 10 suggests that the principal effects of using the Highway 404 measurement results are on CO and NO_x emission factors. The CO factor is reduced while to NO_x factor is slightly increased. This outcome is consistent with expected differences of highway and urban driving cycles. Under typical highway driving conditions CO, VOC and PM emission rates are lower than those under urban driving conditions. On the other hand, NO_x emission rates tend to be higher under highway driving conditions.

The emission rates of the more toxic components of VOC are commonly derived from detailed chemical analysis of the exhaust of typical in-use vehicles. The information used here is obtained from the US EPA and is listed below. It should be noted that this information represents conservative estimates, since it is based on emissions from older vehicles running on regular gasoline. In the near future and certainly by 2020, the percentages in table 11 are expected to be significantly lower than suggested here.

Table 11: Percentage of Air Toxics in Gasoline Vehicle Exhaust (2000)

Pollutant	Percentage of the VOC
Benzene	1.6 %
1,3-Butadiene	0.7 %
Formaldehyde	1.4 %
Acetaldehyde	0.5 %

Source: US EPA

3.3 Summary of the Methodology

Before providing results, it may be advisable to recap the methodology outlined above and to discuss its pros and cons.

The concentrations of highway traffic related pollutants can be estimated for the worst-case credible scenario applicable to the site. This process uses the following inputs: predicted peak hour traffic volume on the new or expanded highway, vehicle emission rates predicted from MTO's detailed 1994 Highway 404 Study and US EPA models, and measured local ambient pollutant concentrations (background concentrations). The calculations exploit the empirically and theoretically established fact that the ambient air concentration of a stable compound (CO and NO_x, in particular) is linearly dependent on its emission rate from the highway, expressed as grams of pollutant emitted per unit distance and per unit time (e.g., g/km-h). This rate, in turn, is directly proportional to the expected vehicular traffic volume, provided that the ratio of heavy-duty to light-duty vehicles is not drastically different from the one experienced on the section of Highway 404 between Highway 401 and Steeles Avenue in Toronto.

The traffic volume projections for the site, as provided by the Southwestern Region, do not differentiate between the proposed expansion options under consideration. Judged from the preliminary site plans, any traffic volume and resulting air quality difference will be very minor, and certainly much smaller than the worst-case predictions provided here (see Section 4). There can be, however, small differences in the air quality experienced by specific residents, depending on distance from the edge of the highway for the three different options. Such differences can be derived from the concentration-distance profiles provided in Section 4.

It is important to note, however, that consideration of the worst-case scenario makes the distinction between the alternatives irrelevant. The worst-case scenario is the worst-case for all the alternatives considered. A detailed analysis of each alternative would be warranted only if the worst-case scenario suggested potential violations of the provincial ambient air quality criteria.

The advantages of the methodology adopted here are better accuracy (since it minimizes the number of assumptions and employs as much empirical evidence as possible), simplicity, and transparency than attainable with dispersion modelling alone. Its principal disadvantage is that it produces worst-case predictions that are indeed worse than what would be experienced under most conditions. This disadvantage may be overcome by appreciating the fact that the worst-case scenario represents a very rare event.

4. Analysis and Results

4.1 Traffic Volumes

MTO's Southwestern Region provided the crucial traffic data needed in this study: Average Annual Daily Traffic (AADT) volumes on each major section of the proposed highway as well as on adjacent roads. These are projections for the near term, for 2011 and for 2016. The AADT information is summarized in Table 12 and may best be reviewed in conjunction with the site map in the Appendix. The percentage of trucks on the new Highway 7 is expected to be less than 8%.

In a credible-worst-case analysis, the traffic volume of greatest interest is the peak hour traffic volume; i.e., the number of vehicles traversing the highway during the one hour of the day when traffic volume is at its peak. This peak hour traffic volume is commonly estimated at 10% of the AADT, an assumption based on a wealth of empirical evidence. The projections in Table 12 suggest that the peak hour traffic on the new Highway 7 would not exceed 5000 vehicles during 2002 to 2016.

Table 12: Traffic Volume Projections for Proposed New Highway 7 and Existing Highway 7 with New Facility

Location	Traffic Volume (AADT)		
	Near Term	2011	2016
New Highway 7:			
KW Expressway to Regional Road 17	34,400	49,300	49,800
Regional Road 17 to Regional Road 30	22,000	34,700	43,700
Regional 30 to Hanlon Expressway	26,100	35,500	42,750
Existing Highway 7 (with New Facility):			
KW Expressway to Regional Road 17	21,172	20,342	30,650
Regional Road 17 to Regional Road 30	9,011	14,214	17,900
Regional 30 to Hanlon Expressway	18,804	25,577	30,800
Adjacent Roads:			
KW Expressway: North of Wellington Street			123,350
KW Expressway: South of Wellington Street			146,150
Regional Road 17: North of Existing Hwy. 7			19,800
Regional Road 17: South of Existing Hwy. 7			29,350
Woolwich Road 66			2,550
Woolwich Road 72			2,550
Regional Road 30: North of Existing Hwy. 7			6,250
Regional Road 30: South of Existing Hwy. 7			9,600
Townline Road			2,100
Guelph Road 3			2,550
Country Road 86			12,800
Silvercreek Parkway: North of Ramp Terminal			6,350
Silvercreek Parkway: South of Ramp Terminal			6,350

Notes: 1/ The traffic volume figures for the new and existing Highway 7 represent maximum levels

2/ All traffic data were provided by MTO's Southwestern Region, except for the "near term" and 2011 figures for the existing Highway 7. These figures were derived from the 2016 figures.

4.2 Location of Receptors

In devising a more efficient air quality impact assessment, one needs to focus on receptors most affected by the presence of the new highway. This selection takes the following factors into account: spatial distribution of receptors with respect to proposed highway alignment, criticality[21] of the receptors, influence of other emission sources on the receptors, and direction of prevailing winds.

The new Hwy 7 will run through a rural community, essentially parallel to the existing Hwy 7. There are no critical receptors in the vicinity. There are, however, a number of scattered rural residences along Bridge Street, existing Hwy 7, Regional Road 17, Regional Road 30, Township Road 72, County Road 86 and the Silver Creek Parkway. Traffic on the Kitchener Waterloo Expressway is the principal source of air pollution in the immediate vicinity.

Wind direction is the next subject to consider. For any road, winds blowing along the road have a greater impact on the air quality of the immediate vicinity. In the specific case of the recommended new highway alignment, winds blowing from the southwest to the northeast (south-westerly winds) will have the greatest local impact. Homes on the Silvercreek Parkway, where the recommended alignment curves to join the Hanlon Expressway, are expected to be the most affected receptors. These homes are approximately 100 m away from the edge of the planned road. Homes along Bridge Street would be also affected by emissions from traffic on the new highway. They are over 1 km away from the Kitchener Waterloo Expressway and are not significantly affected by this larger source of pollution.

4.3 Air Quality Impacts

The next step in the analysis is to estimate worst-case ambient pollutant concentration impacts of traffic on the Highway 7 system (the new Highway 7 and the existing Highway 7). More precisely, the object is to predict the expected increases in the concentrations of key pollutants at the proposed site as one moves from a condition of no pollution at all to a situation that includes a new four-lane highway and an existing two-lane highway operating under the credible-worst-case traffic and meteorological conditions. The estimated impact of Hwy 7 is calculated by scaling the worst-case scenario predictions for the Hwy 404 according to the relation below:

Future Impact of Hwy 7 = Impact of Hwy 404 in 1994 x TR2 / TR1 x EF2 / EF1,

where TR2 = Peak-hour traffic volume for Hwy 7 (new and existing) in future years
TR1 = Peak-hour traffic volume for Hwy 404 in 1994

---

[21] Criticality is a function of population density and vulnerability. Hospitals, old-age homes and schools are considered critical receptors.

EF2 = Emission factors for future years
EF1 = Emission factors for 1994

This approach, namely scaling the Hwy 404 predictions with respect to traffic volume and emission rates rather than independent modelling of Hwy 7 impacts, helps integrate the extensive measurement and modelling results of the Hwy 404 study in a consistent manner. Such measurements and detailed modelling would be prohibitively expensive to repeat.

The predictions of this study employ the emission factors in Table 10 of Section 3.2 and peak hour traffic volumes which correspond to 10% of the sum[22] of the AADT figures for the proposed new Hwy 7 and the existing Hwy 7. Only these two roads are sufficiently close to the key receptors to warrant inclusion in the analysis. The specific peak-hour traffic volumes adopted are 4490, 6108, and 7355 for the near term, for 2011, and for 2016, respectively.

The results of this analysis are predicted ambient pollutant concentration increases of CO, NO_x, VOC, $PM_{2.5}$ and PM_{10} at 100, 200, and 500 m from the edge of the highway. These predictions are summarized in Table 13. Among VOCs, the four "toxic" substances, benzene, 1,3-butadiene, formaldehyde and acetaldehyde, are singled out for quantitative assessment.

The concentration increases predicted by this approach represent peak-hour (one-hour) values. They can be added to ambient background concentrations and compared with the provincial ambient air quality criteria (AAQC), except for PM concentrations. The AAQC for PM are written as 24-hour, rather than one-hour, criteria. Hence, one-hour concentration increases have to be converted to 24-hour increases. This conversion can be based on the MTO Highway 404 study measurement results. Specifically, during the Highway 404 study the maximum hourly PM_{10} and the 24-hour average PM_{10} readings were compared and a ratio of one-third[23] was deduced. This ratio was used in deriving the PM_{10} and $PM_{2.5}$ concentration increases in Table 13.

---

[22] Addition of traffic volumes exaggerates the environmental impact of the roadway under southerly wind conditions and produces conservative results. The experience of the Hwy 404 study suggests that the pollution caused by traffic on roads perpendicular to the wind direction (and, also to the main road) veins rapidly with distance and is "insignificant" beyond 1 km.

[23] This ratio is derived from PM_{10} data only; $PM_{2.5}$ measurements were not available. Empirical evidence with gas-phase pollutants (persistence factor results) supports this ratio.

Table 13: CO, NO_x, VOC, $PM_{2.5}$, and PM_{10} Concentration Impacts (Increases in Ambient Pollutant Concentrations due to Highway 7 Traffic)

Pollutant	Period	Concentration (ppm for CO and NO_2, $\mu g/m^3$ for others)		
		100 m from Hwy	200 m from Hwy	500 m from Hwy
CO	2002	0.472	0.345	0.145
	2011	0.219	0.160	0.067
	2016	0.222	0.162	0.068
NO_2	2002	0.022	0.019	0.016
	2011	0.009	0.008	0.006
	2016	0.004	0.004	0.003
Benzene	2002	2.57	1.88	0.79
	2011	0.63	0.46	0.19
	2016	0.54	0.40	0.17
1,3 - Butadiene	2002	1.13	0.82	0.35
	2011	0.27	0.20	0.08
	2016	0.24	0.17	0.07
Formaldehyde	2002	2.25	1.65	0.69
	2011	0.55	0.40	0.17
	2016	0.47	0.35	0.15
Acetaldehyde	2002	0.80	0.59	0.25
	2011	0.20	0.14	0.06
	2016	0.17	0.12	0.05
$PM_{2.5}$	2002	2.87	2.10	0.88
	2011	2.60	1.90	0.80
	2016	3.14	2.29	0.97
PM_{10}	2002	7.46	5.46	2.30
	2011	9.11	6.66	2.80
	2016	10.66	7.79	3.28

Notes: The Year 2000 estimates are to provide a hypothetical baseline.
The number of digits displayed in this table should not be interpreted as an indication of degree of accuracy but a means to show trends.

The results suggest that the highway's influence on air quality drops strongly with distance. At 500 m from the highway, the expected pollutant concentration increases are less than one-third of those at 100 m. The results also suggest that PM, especially PM_{10}, pollution will be higher in 2020 than in 2000. This effect which is the result of higher traffic volumes and essentially constant emission factors would not come to pass with the adoption of post-2007 heavy-duty diesel emission standards.

In order to help pass judgement on the acceptability of this influence, the current ambient concentrations (background concentrations) of the pertinent pollutants need to be added to the predicted concentration impacts in Table 9. These background concentrations are available from the ambient air quality monitoring stations of the Ministry of Environment (MOE) of Ontario.

The station closest to the proposed highway is Station 26060 in Kitchener (West Avenue and Homewood). This station provided the background concentration levels (90 percentile values)[24] for CO, NO_2, $PM_{2.5}$, benzene, and 1,3-butadiene. For other pollutants data from other MOE stations in the province had to be employed, since the Kitchener Station does not monitor them. The background concentration level of PM_{10} was obtained from MOE's Hamilton Mountain monitoring station (Station 29114). The formaldehyde and acetaldehyde background levels were obtained from the Egbert (near Barrie) and Windsor monitoring stations.

The background concentration values thus acquired are listed in Table 14.

Table 14: Background Concentrations

Pollutant	Background Concentration
CO	1 ppm
NO_2	0.028 ppm
$PM_{2.5}$	26 $\mu g/m^3$
PM_{10}	41 $\mu g/m^3$
Benzene	1.43 $\mu g/m^3$
1,3 – Butadiene	0.18 $\mu g/m^3$
Formaldehyde	3.78 $\mu g/m^3$
Acetaldehyde	2.36 $\mu g/m^3$

These values are added to the expected concentration impacts in Table 13 to arrive at predicted worst-case ambient concentration levels, which are presented in Table 15. Note that the background concentration values are higher, in most cases much higher, than the Hwy 7 impacts presented in Table 13. At 500 m from the highway, the expected contribution of background pollution to ambient PM 2,5 and PM10 concentrations is 97% and 93%, respectively. This point is illustrated in Figures 1 and 2.

---

[24] A ninety percentile value designates a concentration level which is higher than 90% of all measured values.

Figure 1: The Sources of $PM_{2.5}$ at 500 m from Highway 7

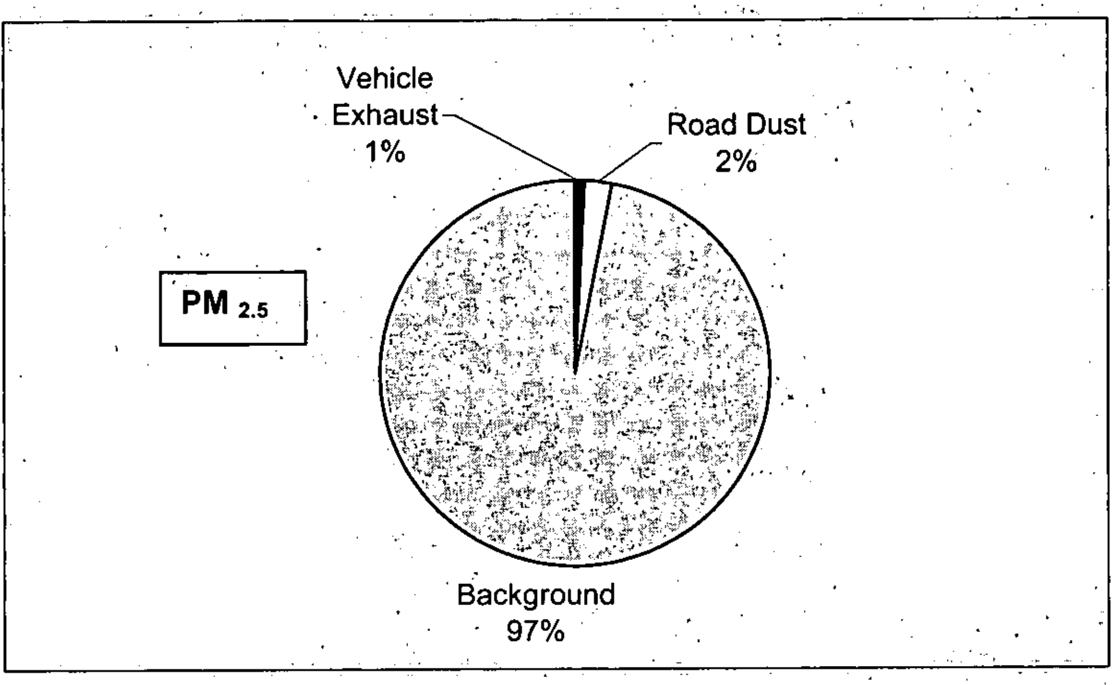


Figure 2: The Sources of PM_{10} at 500 m from Highway 7

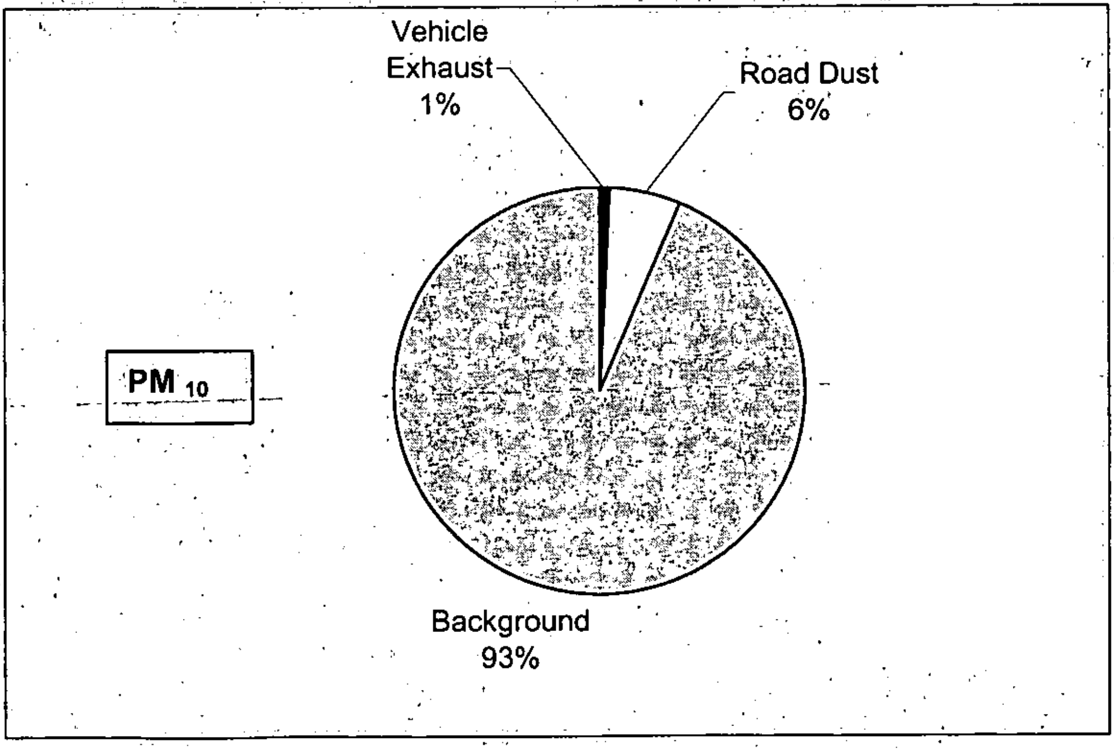


Table 15: Worst-Case Ambient Concentrations of CO, NO_2 and VOC
(Inclusive of Highway 6 Impacts and Background Concentrations)

Pollutant	Period	Concentration (ppm for CO and NO_2, µg/m^3 for others)		
		100 m from Hwy	200 m from Hwy	500 m from Hwy
CO	2000	1.47	1.35	1.45
	2010	1.22	1.16	0.67
	2016	1.22	1.16	0.68
NO_2	2000	0.05	0.05	0.04
	2010	0.04	0.04	0.03
	2016	0.03	0.03	0.03
Benzene	2000	4.00	6.69	5.96
	2010	5.78	6.68	5.54
	2016	5.81	6.71	5.55
1,3 - Butadiene	2000	1.16	3.31	2.22
	2010	2.05	1.89	1.62
	2016	1.97	1.83	1.60
Formaldehyde	2000	6.03	5.42	4.47
	2011	4.33	4.18	3.95
	2016	4.25	4.13	3.93
Acetaldehyde	2000	3.16	2.95	2.61
	2011	2.56	2.50	2.42
	2016	2.53	2.48	2.41
$PM_{2.5}$	2000	28.87	28.10	26.88
	2010	28.60	27.90	26.80
	2016	29.14	28.29	26.96
PM_{10}	2000	48.46	46.45	43.30
	2010	50.11	47.66	43.80
	2016	51.66	48.79	44.28

Notes: The Year 2000 estimates are to provide a hypothetical baseline.
The number of digits displayed in this table should not be interpreted as an indication of degree of accuracy but a means to show trends.

Comparison of predicted local ambient pollutant concentrations with the ambient air quality criteria in Table 4, suggests that the impact of the highway will not bring the ambient air quality in violation with the provincial criteria under worst-case conditions at 500 m from the highway. In fact, as far as CO and NO_2 is concerned, there is a very large safety margin. This point is illustrated further in Figures 3 and 4. In the case of $PM_{2.5}$ and PM_{10} (Figure 5) the apparent safety margin is small. This is, however, largely due to the contribution of background pollution and road dust rather than vehicle exhaust. With the adoption of the strict 2007+ heavy-duty diesel emission standards, the vehicle exhaust component of PM will become even smaller.

The concentration of ozone is not directly related to the presence of the highway. In fact, NO emissions of highway vehicles scavenge ozone according to the reaction,

$$NO + O_3 \rightarrow NO_2,$$

causing a reduction of ambient ozone concentrations in the immediate vicinity of the highway. During 1999, the background ozone concentration at the site was 0.048 ppm (90th percentile value for 1999 at MOE's monitoring station #26060) with a maximum 1-hour reading of 0.116 ppm. Higher ozone concentrations are of concern. The provincial anti-smog plan (ASP) is aimed at addressing this concern.

Figure 3: Worst-Case CO Concentrations

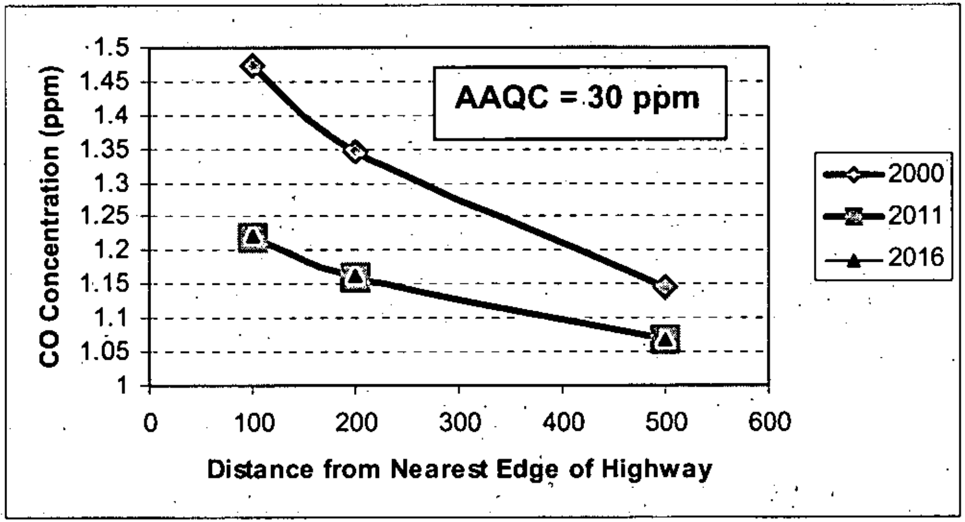


Figure 4: Worst-Case NO_2 Concentration

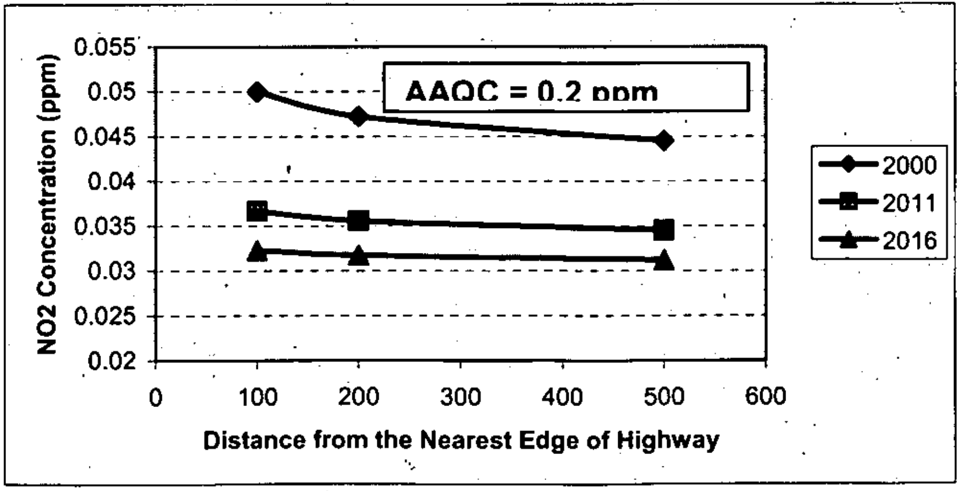
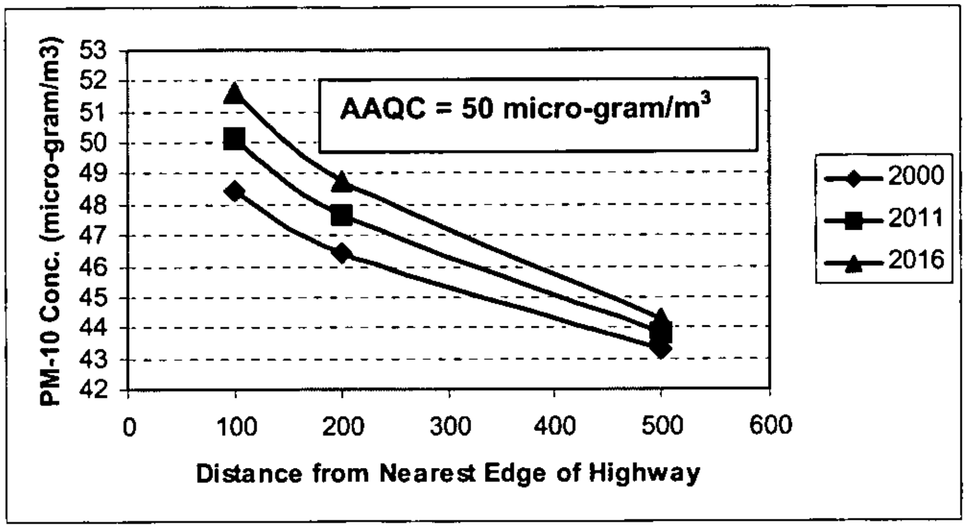


Figure 5: Worst-Case PM_{10} Concentration



5. Conclusions

The potential local air quality impacts of the proposed new Highway 7 along with the existing Highway 7 are assessed for a credible worst-case scenario in 2011 and 2016. This scenario assumes the coincidence of peak traffic volumes with poor meteorological conditions (low wind speeds in a direction almost parallel to the highway, and a high degree of atmospheric stability). The analysis methodology builds on MTO's extensive measurement and modelling study for Highway 404 in Toronto and US EPA and Environment Canada emission factor models.

The scope of the analysis encompasses potential increases in the ambient concentrations of CO, NO_2, VOC and PM in the vicinity of the planned four-lane highway. This vicinity is largely rural, with a significant number of residences located at approximately 100 m and farther from the edge of the planned highway.

The results of the analysis indicate that, even under the credible worst-case scenario and conservative assumptions, the ambient concentrations of CO, NO_2 and toxic VOCs in the vicinity of the highway will not exceed provincial ambient air quality criteria. In fact, they will remain much below these criteria. The concentrations of fine particulate matter, on the other hand, may approach or even exceed the provincial / federal criteria for PM_{10} and $PM_{2.5}$ under credible worst-case conditions.

The primary cause for this effect is the background level for PM_{10} and $PM_{2.5}$ at the site and across the province. Highway traffic, through re-entrained dust, vehicle exhaust, and brake and tire wear, is only a small contributor.

Appendix:

Recommended Route for New Highway 7