MINISTRY OF TRANSPORTATION

Environmental Guide for Assessing and Mitigating the Air Quality Impacts and Greenhouse Gas Emissions of Provincial Transportation Projects

January 2012

Environmental Guide: Recommended Approach for Assessing and Mitigating the Air Quality Impacts and Greenhouse Gas Emissions of Provincial Transportation Projects

Citation

Environmental Guide for Assessing and Mitigating the Air Quality Impacts and Greenhouse Gas Emissions of Provincial Transportation Projects (October 2011, Ontario Ministry of Transportation).

Acknowledgements

This Guide was developed in response to increased demand from provincial and federal regulatory agencies, and the public, to improve the assessment and mitigation of air quality and greenhouse gas emissions associated with provincial transportation projects. It outlines a standardized assessment approach and methodology for both individual and Class EA projects.

It was developed in consultation with technical and environmental assessment representatives from both levels of government, including Environment Canada, Health Canada, Transport Canada, the Canadian Environmental Assessment Agency (Ontario Region) and the Ontario ministries of Environment and Health. The time and effort expended by these individuals, to thoroughly review and provide comment on the document, throughout its development, is greatly appreciated. We hope that their interest and input regarding suggested improvements to the document will continue following implementation of the assessment approach and methodology.

This Guide is intended to be a living document that will be reviewed and revised as necessary.

Comments and Suggestions

The Ministry of Transportation welcomes comments and suggestions on ways to improve the document with the objective of providing a practical and pragmatic approach to environmental management in the Province of Ontario. MTO anticipates that changes will be warranted to clarify, improve and incorporate new information.

The format of the document is designed to accommodate such changes. Such revisions and amendments will be incorporated in later editions of this document. MTO will not formally respond to unsolicited comments submitted in response to the document.

Ce document hautement spécialisé n'est disponible qu'en anglais en vertue du règlement 411/97, qui en exempte l'application de la Loi sur les services en français. Pour obtenir de l'aide en français, veuillez communiquer avec le ministère des Transports, Bureau des services en français au: 905-704-2045 ou 905-704-2046.

VERSION HISTORY

VERSION #	DATE	DESCRIPTION OF MAJOR CHANGE

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1   INTRODUCTION

The Ontario and the Canadian Environmental Assessment Acts call for due consideration of the potential impacts of transportation projects on the social and physical environments.

The operation of large transportation facilities, highway construction and highway traffic in particular, can have significant local, regional and, cumulatively, global impacts on the atmosphere and the climate system. Specifically, pollutants in vehicle exhaust and evaporative emissions and in re-entrained road surface contaminants affect air quality adversely. They also contribute to the gradual accumulation of greenhouse gases. These potential air quality (AQ) impacts and greenhouse gas (GHG) emissions[1] of road transportation are explained in Appendix 1 of this document.

1.1   Current Approach

MTO, as a proponent of provincial transportation initiatives, is responsible for addressing the air quality and climate change/greenhouse gas (CC/GHG) emission impacts of proposed transportation projects. The methodology for this task is, however, not well established, and as a result, it is handled on a project-by-project basis by MTO, with input from the Ministry of the Environment (MOE) and, where the *Canadian Environmental Assessment Act* is triggered, from Environment Canada and Health Canada. This project specific approach pursued to date is subject to inefficiencies.

1.2   Recommended Approach

Purpose

The purpose of this document is to recommend a systematic and generic approach to assess the potential air quality impacts and greenhouse gas emissions of provincial transportation undertakings for which MTO is directly responsible. It is also to address mitigation of impacts, where such mitigation is necessary and practical. It does not limit, however, the ability of project teams and regulatory agencies to address any project specific issue in the manner that they deem to be appropriate.

Corporate and Regulatory Support

The recommended approach has been presented to MOE, the Canadian Environmental Assessment Agency (CEA Agency), Environment Canada and Health Canada; as well as other interested federal agencies including Transport Canada.

With the endorsement of the regulatory agencies and MTO senior management, the approach will allow MTO staff and consultants to follow a defined analysis and mitigation methodology.

The defined analysis and mitigation methodologies will become available for use by MTO staff and consultants after the Guide has been endorsed.

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[1]   Transportation's primary climate change (CC) impact is through its greenhouse gas (GHG) emissions. The scope of the proposed approach for CC impacts includes assessment and mitigation of these emissions. It does not include any attempt to assess how transportation might influence the climate or conversely be influenced by the climate.

An "endorsed" Guide, also:

- validates the extraordinary amount of time and effort put forward by all parties to develop the standardized approach;

- removes uncertainty, for both MTO and EA reviewers, resulting in more predictable timelines and budgets for all parties;

- results in more credibility with review agents, resulting in increased efficiencies in the EA process;

- increases public confidence and support for MTO's approach to assessing air quality impacts and greenhouse gas emissions;

- demonstrates intergovernmental collaboration; and

- promotes interest and potential adoption by other transportation service providers within Ontario (e.g., municipalities) and across Canada.

Scope

The approach in this Guide **will not** apply to ongoing, current MTO projects where:

1. MOE has been consulted on and accepted the air quality assessment methodology in accordance with MOE's existing air quality assessment requirements, **and**

2. MTO has:

   - initiated an AQ/GHG assessment already and selected a preferred alternative; or
   - issued a Notice of Completion of its Transportation Environmental Study Report (TESR); or,
   - submitted to MOE an Individual Environmental Assessment (EA) Report for approval (Terms of Reference excluded); or
   - completed all *Environmental Assessment Act* (EAA) requirements (MOE approved Individual EA or Process Completion Statement [PCS] issued by MTO for Class EA Group A or B projects).

Administration

The Environmental Guide will be revisited in five-year intervals and, if necessary, revised to account for major advances in science, technology or regulation.

Updated documents will contain the most recent criteria air contaminant (CAC) and greenhouse gas (GHG) emission inventories by using authoritative sources, including the following links:

- Environment Canada's Greenhouse Gas Sources and Sinks in Canada 1990-2007 (http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/4771.php); and

- Environment Canada's 2007 Provincial Air Pollutant Emission Summaries http://ec.gc.ca/pdb/websol/emissions/ap/ap_query_e.cfm.

2   POLICY FRAMEWORK

2.1   Classification of Projects

The majority of MTO's transportation planning and design projects are subject to the Ontario and Canadian Environmental Assessment Acts. They involve new facilities or improvements to existing facilities.

Under the Ontario *Environmental Assessment Act*, projects that involve the planning of new large facilities such as provincial freeways are subject to an Individual EA. Other projects, which are relatively small in scale, routinely performed, or have predictable and mitigable environmental effects, are subject to MTO's Class EA process.

Projects subject to the Class EA are divided into four groups - A, B, C, and D. Group 'A' projects involve new facilities, Group 'B' are major improvements to existing facilities, Group 'C' entail minor improvements to existing facilities, and Group 'D' include operation, maintenance, administration and other work on existing facilities.

2.2   Air Quality Impact and Greenhouse Gas Emissions

The air quality and climate change/greenhouse gas (AQ and CC/GHG) implications of projects subject to an Individual EA can be significant[2]. The same is also true for some Group 'A' and 'B' projects completed through the Class EA process. Group C and D projects, on the other hand, are not likely to have significant AQ and CC/GHG impacts or offer opportunities to influence these impacts substantially. Hence, the detailed assessment and mitigation approach proposed in this document is intended for Individual EA and select Group 'A' and 'B' projects.

Under the EAA, MTO is required to assess the environmental consequences of an undertaking, including the effect on air quality. However, MOE may not require an air quality and greenhouse gas assessment for certain Group 'A' and 'B' MTO Class EA projects under the circumstances described below.

MTO provides MOE with supporting documentation so as to satisfy MOE that there is:

1. a relatively small increase in the number of emission sources (i.e., vehicles and/ or traffic capacity); and

2. sufficient distance from the edge of the highway right-of-way to sensitive receptors (e.g., residential dwellings and institutional buildings).

While there is no legal obligation for MTO to meet any specific air quality standard or GHG emission target, MTO will endeavour to meet all relevant standards and do better by minimizing the air quality and GHG emission impacts of all of its projects whenever and wherever this is technically feasible and economically viable.

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[2]The word 'significant' is used in this document in its dictionary meaning – not in any specific meaning assigned to it in a legal document.

2.3   Federal-Provincial EA Coordination

Projects that warrant detailed AQ and CC/GHG assessment will be studied with the technical methodology defined in this document. This methodology will meet the needs of both provincial and federal regulatory agencies, in the spirit of the Canada-Ontario Agreement on EA Cooperation.

3 AIR QUALITY AND CC/GHG IMPACT ASSESSMENT AND MITIGATION

3.1 General Methodology

The proposed methodology to air quality impact assessment relies on pollutant emission and dispersion modelling to predict the contribution of the project to ambient pollutant concentrations over a 20-year period. This contribution, added to background concentration levels, allows prediction of the combined effects of the proposed project and all other contributors to air pollution. The resulting concentration levels are compared with the provincial and federal ambient air quality criteria and standards to assist in the assessment and evaluation of transportation alternatives and to judge the need for any mitigation.

The methodology for potential CC/GHG impacts relies on emission modelling to predict the net amount of greenhouse gases attributable to the project over a 20-year period. A decrease in net emissions will help Ontario meet its GHG emission targets for 2014, 2020 and 2050 (Ontario's Action Plan on Climate Change – August 2007). Similarly, it will help Canada contribute to the international effort to reduce GHG emissions.

It should be noted that the MOE, where appropriate, may require pre-construction and post construction ambient air monitoring in such a manner as would adequately assess potential impacts to local air quality.

The general methodology is described by the outline of individual tasks in Section 3.5 and in Appendices 2 – 5 of this document.

3.2 Limitations

The above-sketched general approach to AQ and CC/GHG impact assessment is limited to prediction of emissions and ambient pollutant concentration levels. It does not extend to an explicit prediction of health and welfare effects. However, the likelihood of health and welfare effects of air pollution can be inferred by comparing predicted pollutant concentrations with the Provincial Ambient Air Quality Criteria, the National Canada-Wide Standards, and the National Ambient Air Quality Objectives. The same cannot be done with greenhouse gases. Hence, climate change impacts will be assessed indirectly and on a relative scale by comparing the net GHG emission consequences of a proposed initiative with relevant benchmarks, such as Ontario's transportation and total GHG emissions.

3.3 Objectives

The AQ and CC/GHG impact assessment will serve the following specific objectives:

1) Provide comparative pollutant emission estimates that can be used in the selection of the "preferred" transportation and route alternative(s). This information can become part of the set of traditional project planning and design criteria and enhance the societal value of the selection process.

2) For the preferred alternative and the planning timeframe (typically, 20 years):

- Assess <u>local</u>[3] air quality impacts and, specifically, the likelihood, extent and duration of exceeding provincial ambient air quality criteria and national air quality standards. The results of this assessment are of direct interest to the agencies and to local residents, institutions and businesses.

- Assess <u>regional</u>[4] air quality impacts. The results of this analysis are of particular interest to local, provincial and federal governments and can assist in the project approval process. The impacts can be either positive or negative relative to a do-nothing scenario.

- Assess the incremental increase or decrease in expected greenhouse gas emissions. This information is of particular interest to the provincial government with respect to the Climate Change Action Plan and the federal agencies responsible for Canada's international efforts on Climate Change (CC).

3) Assess the need for and practicality of mitigation measures and predict their utility. This information can be useful to MTO, regulatory agencies, stakeholders, and the public.

4) Inform MTO's long-term transportation policy and planning decisions through the collective experience gained from diverse projects over the course of several years. This last objective falls beyond the scope of the Environmental Guide but will be pursued by MTO's Air Quality and Climate Change Team on an ongoing basis.

3.4 Tasks

A comprehensive AQ and CC/GHG study can pursue the above objectives by performing the six tasks listed below.

1. Assessment of transportation planning alternatives
2. Assessment of route alternatives
3. Detailed assessment of the preferred alternative (selected transportation planning and route option)
4. Assessment of need for mitigation
5. Evaluation of mitigation options
6. Reporting

Note: Tasks 1 – 6 apply to Individual and Group 'A' projects. Tasks 3 – 6 apply to Group 'B' projects.

The balance of this document is devoted to a brief description of each task. The details of the scientific methodology recommended for each task are provided in individual appendices (Appendix 2 – 5).

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[3] The word 'local' refers to the immediate vicinity of the transportation system where the concentration of transportation-related air pollutants may exceed the ambient air quality criteria for one or more hours in a typical year. For major roads, the collective experience of the scientific community suggests that the affected immediate vicinity is limited to the area within approximately 500 m of the road.

[4] The word 'regional' refers to a geographic area in which the planned transportation system is likely to have a significant contribution to the cumulative air pollution and greenhouse gas emissions load. The definition of an air quality region is not unique and will depend on the specifics of the transportation system and the natural and social geography around it.

Task 1:   Assessment of Transportation Planning Alternatives

The principal function of a transportation system is to provide access to people and/or goods at a certain capacity and level of service (performance). This capacity and level of service can be achieved, in theory, by a number of equivalent alternative transportation systems (e.g., road, rail, marine, transit) or a combination of these and/or transportation demand management, traffic control and road improvement.

The transportation demand management measures include transitways and HOV lanes. Under favourable conditions, these can be effective in reducing the total vehicle kilometres (VKTs) travelled and, hence, total vehicle emissions. Access management and Intelligent Transportation Systems (ITS) are part of the traffic control toolkit.   They may improve traffic flow (reduce vehicle stops per distance and time spent at idle) and traffic related total emissions. Road improvements with respect to geometric and structural design may contribute to lower vehicle fuel consumption and emissions.

The EA process affords the opportunity to compare these and other alternatives systematically with respect to a set of evaluation criteria. AQ and CC/GHG impacts are part of this set of criteria.

Some transportation alternatives may have significant air quality consequences for the local community and even for the region (air shed) at large. They may also contribute incrementally to the growing greenhouse gas content of the global atmosphere and the extent of anthropogenic climate change. Most of these consequences are proportional to the amount of pollutants (criteria air contaminants) and greenhouse gases emitted by the transportation alternative studied. Hence, a comparative assessment of equivalent transportation alternatives with respect to AQ and CC/GHG can be conducted by estimating the total amount of pollutant and greenhouse gas emissions, in tonnes per year, for each transportation alternative studied. This approach is often referred to as burden analysis.

Burden analysis is most appropriate for road transportation initiatives with one or more credible alternatives and with significant emission burdens. The proposed approach posits that any transportation initiative that increases the total provincial emissions of a critical air pollutant or those of greenhouse gases (weighted sum of CO_2, CH_4 and N_2O emissions) by more than 0.1% (one-thousandth)[5] of their respective values in an appropriate reference year is a significant pollution burden. [Note: To accommodate potential special requirements of regulatory agencies, MTO may use a stricter criterion than the 0.1% level recommended.] The critical air pollutants are NO_x and $PM_{2.5}$. These are arguably the most important transportation related contributors to smog.

Burden analysis can be carried out during that phase of an environmental assessment study where transportation planning alternatives are being assessed and evaluated. The principal steps of this analysis are described below.   The details of the recommended scientific methodology for the burden analysis are provided in Appendix 2.

<u>**Burden Analysis: Key Steps**</u>

- Define credible transportation alternatives with equivalent passenger and/or goods movement capacity and level of service in one or more appropriate reference years. Alternatives may include a new highway, expansion of an existing highway, one or more transit routes, rail, etc.

- For each alternative, predict the annual vehicle kilometres travelled (VKT) by each major vehicle type (e.g., VKT for cars and light trucks, heavy trucks, buses, and freight trains) for the reference years.

- For each vehicle type, estimate emission factors in gram/VKT of principal pollutants (CO, NO_x, VOCs, $PM_{2.5}$, and PM_{10}) and greenhouse gases (CO_2, N_2O and CH_4). The VOCs will include, specifically, the following "air toxics": formaldehyde, acetaldehyde, benzene, 1, 3-butadiene, and acrolein.

- Integrate the VKT and emission factor data to estimate the total pollutant and greenhouse gas emissions for each credible transportation alternative in each reference year.

- Compare alternatives with respect to emissions in the context of relevant emission inventories (e.g., total emissions and/or transportation emissions in Ontario and in Canada). This information is available from Environment Canada.

Task 2: Assessment of Route Alternatives

An AQ and CC/GHG impact assessment will be needed at the route planning phase of the EA process, if the preferred transportation alternative (highway or other mode) involves potentially one or more <u>new</u> route alternatives.

Route location can have local and regional AQ and provincial/national CC policy implications (Ontario's GHG targets and Canada's international obligations). The route of a highway and/or alternative transportation mode is of greatest significance to the <u>local</u> community. During planning, the project team may have the opportunity to keep the distance of the highway or other major transportation facilities from sensitive receptors (residences) and critical receptors (hospitals, retirement homes, childcare centres, etc.), at approximately 100 m or greater. This would help, in most cases, to avoid the need for air quality impact mitigation.

The project team will always assess the local AQ implications of each route alternative for the critical and sensitive receptors affected by the pollution generated on each route and associated infrastructure. Commercial and industrial buildings are not included in this assessment, unless specifically called for by the Ministry of the Environment.

The regional and national AQ & CC/GHG implications, on the other hand, warrant detailed analysis only if there is a significant difference in the expected emissions from

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[5] The significance of the 0.1% figure may be explained in the following context: Road traffic on a typical 16 km (10 mile) portion of a four-lane highway produces more than, but not much more than, 0.1% of Ontario's NO_x and $PM_{2.5}$ emissions. Hence, a 0.1% "screen" will capture any transportation alternative with emissions exceeding those of a 16 km (10 mile), four-lane highway.

the alternative routes, which can be estimated by comparing route lengths. A difference of 10% in route length corresponds to approximately 10% difference in most pollutant emissions and is deemed to be significant enough to warrant a burden analysis, as described under Task 1 of this Guide. A burden analysis is not warranted if the route lengths of the shortest and longest alternatives are less than 10% apart. At an absolute level, a route length difference of less than 1 km is deemed to be clearly insignificant. Hence, a route length difference of more than 10% or 1 km, whichever is larger, is the recommended trigger for the burden analysis.

The proposed analysis is most appropriate for the "alternative methods" phase of the EA process. Its principal steps are described as follows:

- Define the credible alternative routes with equivalent passenger and goods movement capacity and performance in the reference years.

- Establish the need for a burden analysis, and if warranted, conduct this analysis according to the method outlined under Task 1. The burden analysis is to help assess, for each route alternative, the potential for regional air quality and national climate change (GHG emissions) issues.

  The route with the "least" pollutant burden will affect the regional air quality less than its alternatives. It will also have the least climate change impact (GHG emissions). However, it may not necessarily be the one with the least local air quality impacts. This issue is addressed by dispersion modelling, as outlined in the points below.

- In order to assess local air quality impacts, produce a site and project-specific pollutant concentration profile with distance from the edge of the planned infrastructure for a credible worst-case[6] scenario. This profile will explain to the public the air quality implications of living at various distances from the highway.

  NO_x and $PM_{2.5}$ are the two key pollutants to be considered in this analysis. These are the principal transportation related air pollutants of concern in Ontario. NO_x is most directly related to the volume and type of traffic (vehicle mix, driving cycle, etc.) while $PM_{2.5}$ reflects the influence of both traffic and road conditions (primarily silt loading of roads). The credible worst-case incorporates 90th percentile figures for background concentrations.

- Describe and compare the "credible worst-case" air quality (atmospheric concentration of pollutants) implications for living within approximately 500 m of each route alternative - with appropriate references to affected critical (e.g., institutional buildings) and sensitive receptors (e.g., residences).

Task 3:   Detailed Assessment of the Preferred Alternative

The preferred alternative, combining the preferred transportation and route alternatives, has a high potential for implementation. Hence, the proposed approach for this alternative includes a methodology for more comprehensive local as well as regional AQ and CC/GHG emissions impact assessment.

The operation of a typical transportation system, particularly a new highway, can have significant long-term local and regional impacts. The local impacts involve primarily air quality. The regional impacts, on the other hand, can involve both air quality and climate change - although climate change is largely a global phenomenon.

The local AQ impacts of the transportation system (e.g., highway and other major local vehicle traffic) can be assessed by emissions and dispersion modelling at the EA for Route Location and Concept Design or a later stage in the EA process. The scientific methodology recommended for this analysis is presented in Appendix 3. Its principal steps are described below.

- For the preferred alternative, encompassing the preferred transportation alternative and the preferred route, identify those critical receptors (hospital, retirement facility, etc.) and residences (sensitive receptors) that are in part or wholly within 500 m of the edge of the travelled transportation infrastructure.

- For each community, select the infrastructure elements that will have a significant air quality impact. This selection will include the appropriate portion of the mainline highway with its associated road infrastructure and/or other transportation facility (e.g., commuter rail line, freight rail line, etc).

- For each community and the relevant infrastructure elements, conduct a credible worst-case air quality impact assessment. This assessment will produce site-specific concentration distance profiles for CO, NO_2, VOCs, $PM_{2.5}$, and PM_{10}.

If any of the credible worst-case analyses indicates that a critical receptor (hospital, retirement facility, etc.) or a significant number of sensitive receptors may be subject to air quality that does not meet the provincial/national ambient air quality criteria/standards, then a more detailed analysis will be carried out for that specific community or receptor. Otherwise, no further local air quality impact assessment is needed. The detailed air quality impact assessment will be the combined effects analysis, as defined in Appendix 3. In this analysis, the combined simultaneous influences of meteorology, traffic volumes, and background pollution on local air quality are assessed for the reference year(s).

- Explain the implications of the combined effects analysis results in the context of provincial air quality and other relevant reference data, comparing also build and no-build alternatives.

The regional AQ and CC/GHG impacts of transportation systems are more difficult to predict quantitatively. The methodology recommended below is based on quantitative and detailed prediction of emission inventories and qualitative assessment of their regional air quality and GHG emission implications.

Estimate the regional air quality implications of the preferred alternative. This entails prediction of the incremental change (increase or decrease) in the pollution burden of the region for each reference year (i.e., difference between the build and no-build options). The recommended methodology for this step is presented in Appendix 4.

- Explain regional impacts in their appropriate context.

- Estimate the total GHG emissions of the preferred alternative for the reference

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[6] The credible worst-case scenario is a hypothetical condition in which near-worst states for background pollution, meteorology and traffic volume coincide – a highly conservative scenario.

years and assess their implications for Ontario's GHG emission targets and Canada's international obligations (Appendix 4). This information is primarily to meet the needs of provincial and federal agencies.

Task 4: Assessment of Need for Mitigation

The local air quality impacts of the preferred alternative may warrant mitigation, if these impacts are predicted to result in the exceedances of the provincial/federal ambient air quality criteria, objectives, and standards for one or more criteria air contaminants over a significant period of time per year and at a significant number of receptors.

Any mitigation decision on regional impacts ought to consider transportation's role (share) in the air quality issue of concern. This decision should also be informed by the relative cost of reducing emissions from transportation and other major provincial sources of air pollution and by a broad consideration of macro-economic implications.

The necessity to mitigate local and regional air quality impacts is a function of the likelihood and severity of exposure to air quality that does not meet provincial/federal ambient air quality criteria, objectives, and standards. This document stipulates that exposure of only existing institutional buildings and residences, and those explicitly planned for in official municipal plans at the time the assessment is carried out will be taken into account in assessing this necessity.

The detailed analyses proposed under Task 3 are designed to deliver the transportation related data necessary to assist in local and regional mitigation decisions. These data are however not sufficient to make all decisions, since transportation is only one variable to affect air quality. Future regional and local air quality will depend in large part on how emissions from other Ontario sources and trans-boundary pollution will change over time.

Most long-term air quality trends are at present pointing in the right direction, thanks to continuing efforts in Canada and the U.S. to curtail emissions from transportation and other sources of air pollution. It is more than likely that background pollutant concentrations will decrease in the foreseeable future. The magnitude of this decline is however very difficult to predict. Hence, the air quality modelling methodology recommended in this paper will assume that the background pollutant concentrations will persist at their most recent values over the entire study period (a conservative assumption).

Task 5: Mitigation Options and their Evaluation

MTO has jurisdiction over a very limited set of mitigation options. This set is often insufficient to influence regional and local air quality and CC/GHG emission impacts to a significant degree. There is however greater scope for mitigation within the combined jurisdictions of the local, provincial and federal governments.

The mitigation options for regional impacts include transportation demand management, fiscal and financial measures to reduce demand for travel by single occupancy vehicles, encouragement for the production and use of cleaner vehicles and fuels, and adoption of stricter new and in-use vehicle and fuel standards. These broader regional measures and their utility in reducing AQ and CC/GHG impacts are discussed in Appendix 5.

Although many of them fall beyond MTO jurisdiction and cannot be delivered by MTO, a judicious assessment of their utility in the AQ and CC/GHG emissions report can be useful to all three levels of government and provide the public with a broader perspective on mitigation initiatives that they can participate in.

The mitigation options for local impacts include traffic control measures to reduce and improve traffic flow, better geometric design, better landscaping, and dust control on the highway. The design and efficacy of these potential measures are discussed in Appendix 5.

Task 6:   Reporting

The AQ and GHG emissions assessment and mitigation work will be documented in a stand-alone report, which provides the full context of the project and a detailed presentation and interpretation of the results. This project specific report will not need to justify the methodology employed. This will be accomplished by referencing the appropriate sections of the Environmental Guide in hand.

Figure 1: Methodology Flowchart: Selection of Preferred Alternative

Figure 1
Methodology Flowchart:

SELECTION OF
PREFERRED ALTERNATIVE

Figure 2: Methodology Flowchart: Assessment of Preferred Alternative
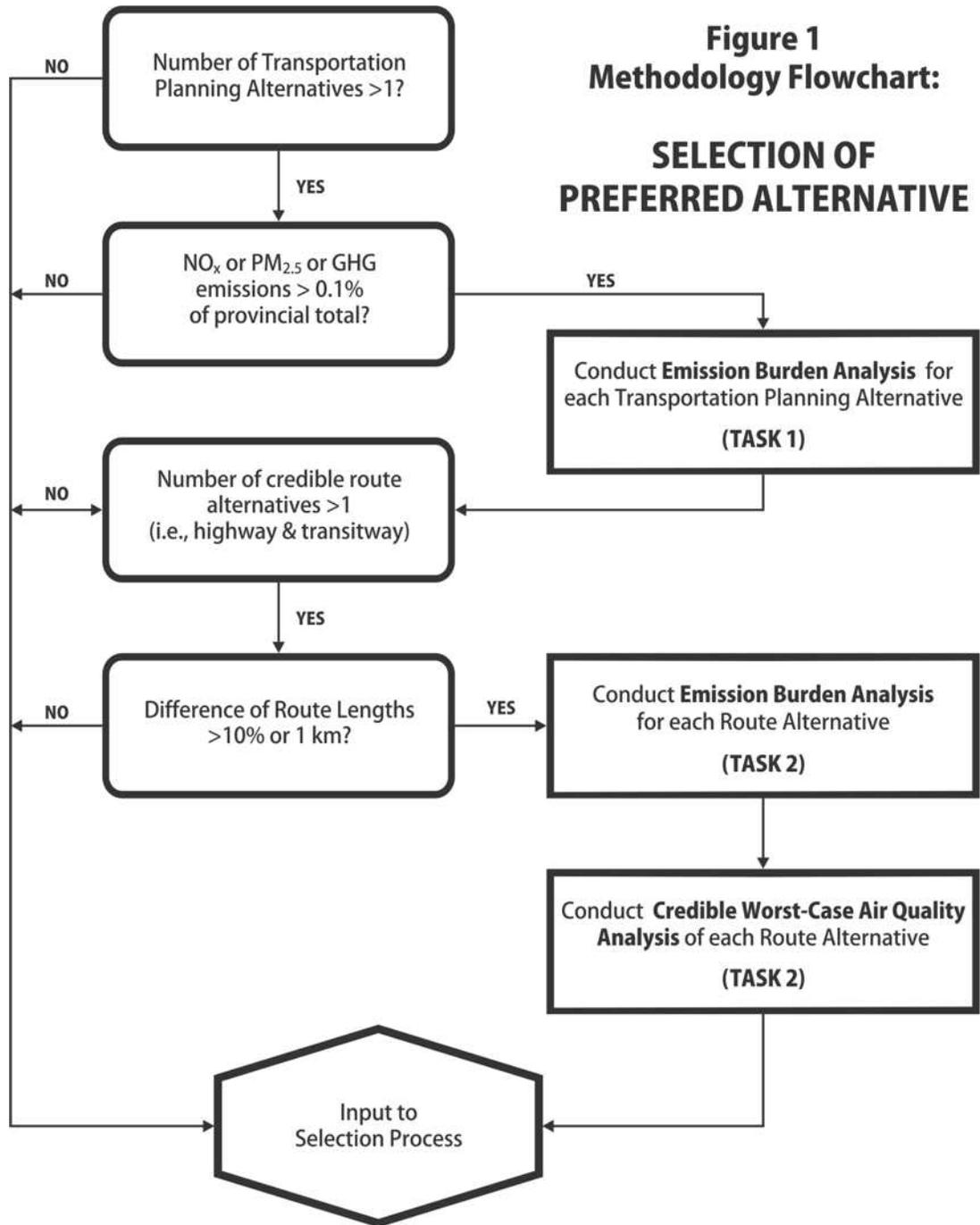
Figure 2
Methodology Flowchart:

ASSESSMENT OF
PREFERRED ALTERNATIVE
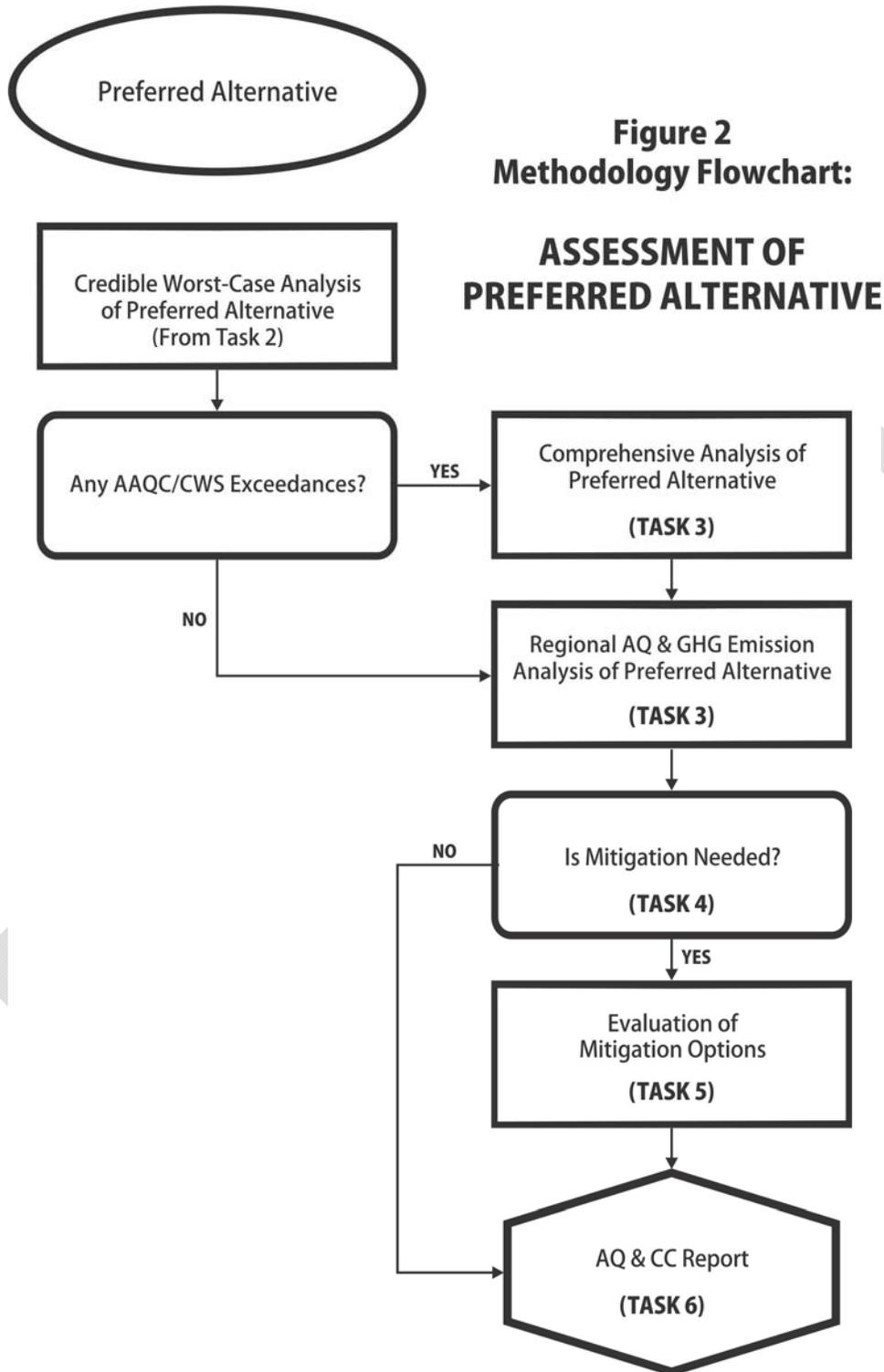
APPENDICES

Appendix 1:   Air Quality and GHG Emissions – A Transportation Perspective

Appendix 2:   Prediction of Criteria Air Contaminant and Greenhouse Gas Emissions of Road Transportation Vehicles

Appendix 3:   Assessment of Local Air Quality Impacts

Appendix 4:   Assessment of Regional Air Quality and Greenhouse Gas Emission Impacts

Appendix 5:   Mitigation Options for Local Air Quality, Regional Air Quality and Greenhouse Gas Emission Impacts

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APPENDIX 1:   Air Quality and GHG Emissions – A Transportation Perspective

1.   AIR QUALITY

1.1   Measurement and Planning

The Ontario Ministry of the Environment (MOE) measures ambient air quality in terms of the concentration of six specific common pollutants in outdoor air. These pollutants are ozone, particulate matter, carbon monoxide, nitrogen dioxide, sulphur dioxide, and total reduced sulphur compounds. Their concentrations are measured hourly by a network of air quality monitoring stations spread across the Province.

MOE converts measured pollutant concentrations into air quality indices (AQIs) with numeric values of 0 to 100+. Values of 0-15 indicate "very good", 16-31 "good", 32-49 "moderate", 50-99 "poor", and 100+ "very poor" air quality. Indices are calculated for each of the six pollutants on a regional basis. The highest calculated value is reported as the air quality index for that region. MOE uses the AQI to issue air quality advisories to individual communities across the Province. These advisories may turn into "smog alerts" on days with persistently poor air quality.

The relation between the index and pollutant concentrations reflects the "best available" science in human health effects of air pollution. MOE currently employs the relations presented in Table 1.

Table 1: Relation between the Air Quality Index and Pollutant Concentrations

AQI Category	CO (ppm)	Ozone (ppb)	TRS (ppb)	$PM_{2.5}$ ($\mu g/m^3$)	SO_2 (ppb)	NO_2 (ppb)
Very Good	0-12	0-23	0-5	0-11	0-164	0-104
Good	13-22	24-50	6-10	12-22	165-250	105-204
Moderate	23-30	51-80	11-27	23-45	251-340	205-254
Poor	31-49	81-149	28-999	46-90	341-1999	255-524
Very Poor	>49	>149	>999	>90	>1999	>524

Note: The concentration units in this table are those reported by MOE in their website and documents.
      The unit ppm stands for parts per million, ppb for parts per billion, and $\mu g/m^3$ for micro-gram per cubic-metre.

In July 2007, Canadian federal, provincial and municipal governments commenced a collaborative program to test/pilot a new index – the Air Quality Health Index (AQHI). This initiative is now providing relevant information on the "healthiness" of the ambient air by accounting for the combined effects of ozone, NO_2 and $PM_{2.5}/PM_{10}$.

The AQHI is a useful tool to convey general air quality conditions to the public. For a more detailed and source-specific assessment of air quality, the ambient concentration

of each relevant pollutant is compared directly with its ambient air quality criterion or standard. This more detailed approach is adopted in transportation air quality impact assessments.

1.2   Transportation Related Air Pollutants

Most transportation vehicles run on hydrocarbons and emit essentially the same pollutants. These directly emitted pollutants are called "primary pollutants" and include carbon monoxide (CO), oxides of nitrogen (NO_x) and volatile organic compounds (VOCs). Oxides of nitrogen include nitric oxide (NO), nitrogen dioxide (NO_2) and nitrous oxide (N_2O). The volatile organic compounds constitute a large group of compounds that contain carbon and hydrogen. Some of the VOCs emitted by transportation vehicles are deemed to have significant health impacts and are designated as "air toxics". These are benzene, 1, 3-butadiene, formaldehyde, acetaldehyde, and acrolein.

There are also secondary pollutants, which are formed in the atmosphere through the chemical and physical transformation of the primary pollutants, some significant distance downstream of their point of emission. These include ozone and particulate matter, the two principal constituents of smog and, currently, the focus of attention of public health officials.

Ozone is formed through a complex photochemical reaction of oxides of nitrogen with volatile organic compounds. The rate of this reaction is a function of the composition of the atmosphere and weather conditions. Under ordinary conditions, the rate is relatively slow. Hence, ozone is typically formed many kilometres downwind of the source of its precursors, such as highway traffic. In fact, ozone concentrations are usually depressed around highways, since the nitric oxide (NO) emitted by vehicles reacts relatively rapidly to convert ozone into oxygen ($NO+O_3 \rightarrow NO_2+O_2$). This phenomenon is commonly referred to as the "scavenging of ozone".

Particulate matter consists mainly of liquid droplets and solid particles with absorbed or adsorbed gaseous substances and has many sources. Some of the transportation related sources are: road dust; vehicle brake and tire wear products; incomplete combustion products emitted through vehicle exhaust; sulphates formed from the sulphur dioxide emitted by vehicles; and nitrates formed from the oxides of nitrogen emitted by vehicles. The first three of these are deemed to be primary while the last three secondary pollutants. Sulphates and nitrates are formed over time and cannot be traced to a single source or group of sources. Many stationary sources such as smelters, refineries, power plants and all kinds of fossil fuel combustors contribute to these pollutants.

Particulate matter of greatest relevance to transportation air quality impacts is commonly classified into two size fractions: those smaller than 10 micron in diameter (PM_{10}, inhalable particulate matter) and those smaller than 2.5 micron ($PM_{2.5}$, respirable particulate matter). PM_{10} includes $PM_{2.5}$ and is commonly split into two fractions: the fine fraction ($PM_{2.5}$) and the course fraction (PM_{10} - $PM_{2.5}$). Currently, health professionals are paying greater attention to the fine fraction, since it appears to be more directly related to respiratory and cardiovascular health effects attributable to particulate matter. The principal transportation source of $PM_{2.5}$ is vehicle exhaust.

The pollutants of greatest relevance to transportation air quality impact assessments are the ones that are subject to provincial or federal air quality guidelines. These include carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), particulate matter ($PM_{2.5}$ and PM_{10}), benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein. The first four pollutants are included in the MOE air quality index program. The remaining five are volatile organic compounds designated as "air toxics". Most of these pollutants, but not all, are subject to the provincial ambient air quality criteria (AAQC) and Canada-wide standards (CWS). These criteria and standards are listed in Table 2 in the concentration units of $\mu g/m^3$ (micro-gram per cubic metre) and ppm (parts per million) or ppb (parts per billion).

Table 2: Provincial Ambient Air Quality Criteria (AAQC) and Canada-Wide Standards (CWS)

POLLUTANT	AAQC (μg/m³ / ppm / ppb)[1]	CWS (μg/m³ / ppb)
CO	30 ppm (1hour) 36,200 μg/m³ (1hour)	
CO	13 ppm (8 hour) 15,700 μg/m³ (8 hour)	
NO$_2$	200 ppb (1 hour) 400 μg/m³ (1 hour)	
NO$_2$	100 ppb (24-hour) 200 μg/m³ (24 hour)	
PM$_{10}$[2]	50 μg/m³ (24 hour)	
PM$_{2.5}$[3]		30 μg/m³ (24 hour)
Ozone[4]	80 ppb (1 hour) 165 μg/m³ (1 hour)	65 ppb (8 hour) 127 μg/m³ (8 hour)
Benzene[5]	10 μg/m³ (24 hour)	
1,3-Butadiene[5]	2.3 μg/m³ (24 hour)	
Formaldehyde	65 μg/m³ (24 hour)	
Acetaldehyde	500 μg/m³ (24 hour)	
Acrolein[6]	0.04 μg/m³ (24 hour)	
Acrolein[6]	4.5 μg/m³ (1hour)	

Source: Ontario Ministry of the Environment and the U.S. Environmental Protection Agency

Notes:
1) μg/m³ stands for "microgram per cubic metre"; ppm for "parts per million"; and ppb for "parts per billion".
2) The 50 μg/m³ 24-hour PM$_{10}$ level represents an interim AAQC adopted in 1997.
3) The 30 μg/m³ 24-hour PM$_{2.5}$ level represents the 98th percentile annual ambient measurement averaged over three consecutive years.
4) The 65 ppb 8-hour O$_3$ level represents the fourth highest annual ambient measurement averaged over three consecutive years.

Air quality studies subject to this Environmental Guide will address the potential direct impacts of proposed projects on the ambient air concentrations of the pollutants listed in Table 2. MTO will consult with MOE before studies are conducted to determine whether a stricter criterion or additional emission factors are required.

1.3 Local and Regional Air Quality

Large transportation projects can have a significant air quality impact on their immediate vicinity. This constitutes their local air quality impact and is usually of greater interest to the local community. Hence, project level air quality impact assessments are largely devoted to this topic. Air pollution knows, however, no boundaries and can affect a larger geographical area – a region. The definition of a region is specific to a project and its location. Its boundaries may be defined by various considerations such as jurisdictional borders, geographic features (e.g., mountain chains or large watersheds) or simply by the distance from the source over which pollutant concentrations drop to "background" levels.

Regional air quality is typically not a strong function of a single source of pollution. It is rather a function of all sources within the region and transboundary pollution. Specifically, air quality in Ontario is influenced by emissions in Ontario as well as in the U.S. In fact, in many regions of Ontario a large fraction of the regional pollution can be attributed to U.S. sources. This is the principal cause for many regions in Ontario to exceed the particulate matter and ozone ambient air quality criteria on some days of the year. Hence, local air quality can exceed the criteria without the contribution of a nearby source such as highway traffic.

In short, transboundary pollution complicates Ontario's efforts to improve air quality. However, over the last decade, progress has been made in controlling emissions through a number of bilateral agreements: the 1980 Memorandum of Understanding on Air Quality; the 1991 Canada – U.S. Air Quality Agreement; the 2000 Ozone Annex, and the 2003 Border Air Quality Strategy. This subject is discussed further in Appendix 4.

1.4 Indoor versus Outdoor Air Quality

Most individuals spend a majority of their time indoors – in homes, workplaces, and other buildings. According to surveys, North American city dwellers appear to spend approximately 90% of their time indoors. Hence, indoor air quality is of greater relevance to public health than outdoor air quality.

Indoor and outdoor air quality is however related. This relation depends, among other things, on the identity of the pollutant and the permeability of the building envelope. One would expect that with particulates and to a lesser extent with gases, indoor concentrations are significantly lower than outdoor concentrations, since the building envelope would serve as a filter and prevent penetration. This is often the case, and the ability of particles and gases to penetrate a building is characterized by a penetration factor, P.

However, sometimes, indoor concentrations of pollutants are greater than outdoor concentrations – often due to generation or re-suspension of pollutants within the building. The rate at which a pollutant is generated depends, in part, on the type and

intensity of various activities such as cooking and may be expressed by a pollutant-specific variable (say, G). The concentration of this pollutant would continually rise in a perfectly sealed building for as long as the activity continues. However, there is an air exchange between the building and the outside, which dilutes the concentration of indoor generated pollutants and is often characterized by an air exchange rate, α. The product of this rate with the volume of the building, V, expresses the volumetric flow rate of air in and out of the building.

With these definitions, the relation between time-average indoor concentrations, C_{in}, and outdoor concentrations, C_{out}, of gases and fine particles may be expressed by the following simple approximation[7]:

$$C_{in} \approx P \times C_{out} + G / (\alpha \times V)$$

In principle, a relation of this nature could be used to better assess long-term exposure to air pollution, accounting for both outdoor and indoor exposure. However; this approach remains impractical, since P, G and α are not universal constants but variables that are highly dependent on building location, design and operation, activities of inhabitants, meteorological conditions, and many other factors. To date, scientific attempts to correlate indoor and outdoor pollutant concentrations have not produced results that can be generalized. As a result, transportation air quality impacts are usually assessed in terms of the concentration of pollutants in the outdoor ambient air. In general, this is a conservative approach, since the indoor concentration of transportation related pollutants is almost always lower than their outdoor concentrations.

1.5 Transportations Contribution to Air Pollutants

Ontario is part of a large North American airshed burdened by pollution from various sources on both sides of the Canada-U.S. border. Transportation is one of these sources.

MOE produces an annual inventory of the pollutants emitted in Ontario by each major sector. For some sectors (mainly industry), the inventory is based on self-reported emissions; for others (including transportation), it is based on MOE estimates. This information is rolled up by Environment Canada into the National Pollution Release Inventory (NPRI).

Transportation emissions are broken down as road and other transportation emissions. Table 3 presents the transportation component of the Ontario inventory for four important air pollutants: carbon monoxide (CO), oxides of nitrogen (NO$_x$), volatile organic compounds (VOCs), and particulate matter (PM). These are important pollutants, since they are the principal constituents of smog: ozone and PM.

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[7] Dockery, D.W. and Spengler J.D., 1981. Indoor and Outdoor Relationships of Respirable Sulfates and Particles. Atmospheric Environment 15, 335-343; and
C.M. Ni Riain et al, 2003. Averaging Periods for Indoor-Outdoor Ratios of Pollution in Naturally Ventilated Non-Domestic Buildings Near A Busy Road. Atmospheric Environment 37, 4121-4132.

Table 3: Transportation's Share of Air Pollutant Emissions from Ontario Sources

POLLUTANT	ROAD TRANSPORTATION (%)	OTHER TRANSPORTATION (%)	TOTAL TRANSPORTATION (%)
Carbon Monoxide	45	1	46
Oxides of Nitrogen	27	16	43
Volatile Organic Compounds	13	1	14
Particulate Matter ($PM_{2.5}$)	2	5	7

Source: Environment Canada, NPRI for 2007

Notes:
1)   Total Ontario emissions do not include emissions from open sources.
2)   Transportation emissions do not include emissions from off-road mobile sources.

The percentages in Table 3 are indicative of transportation's role in the Ontario generated portion of the regional air pollution during 2007 (the most recent complete data set).

Transportation emissions, unlike most industrial emissions, occur often in highly populated locations and in the immediate vicinity of where people live and work. Hence, transportation's role in local air quality can be significant. Specifically, the concentrations of some pollutants can be substantially above their respective regional levels within approximately 100 m of major local roads and 500 m of major highways. The extent of this elevation depends on many factors, particularly traffic volume and meteorological conditions.

Transportation's regional and local air quality impacts are both important. Most Ontarians live far enough from major transportation facilities. They experience essentially the regional air quality, which is in part shaped by transportation emissions. A minority of Ontarians live near transportation facilities and are subject to essentially the sum of regional pollution and the impact of the nearby transportation facility.

2.   GREENHOUSE GAS EMISSIONS (CLIMATE CHANGE)

It is widely accepted today that anthropogenic greenhouse gases (GHGs) have started to influence the global climate. This new man-made phenomenon, which is superimposed on natural climatic variations, is commonly referred to as "Climate Change" or "Global Warming".

Climate Change is a global phenomenon with global causes and global consequences. Most climatologists concur that while the exact timing and magnitude of climate change impacts are difficult to predict, they are likely to be serious and irreversible. Hence, most leaders of the developed world have pledged to stabilize and then reduce global GHG emissions.

Transportation produces almost one-third of Ontario's total anthropogenic GHG emissions – over 60 Mt in 2004 and growing by at least 1.2% per annum[9]. Approximately three-quarters of this amount is attributable to road transportation.

The principal transportation related GHG is carbon dioxide (CO_2). Other important GHGs include methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is a direct product of hydrocarbon fuel combustion. Methane is a by-product of hydrocarbon combustion, but it can also be emitted as unburnt fuel from natural gas powered equipment. Nitrous oxide is formed in small quantities as a byproduct of combustion.

The relative impacts of various greenhouse gases are often expressed in terms of their global warming potential (GWP) relative to carbon dioxide. The two primary determinants of GWP are the ability to absorb infrared radiation and residence time in the atmosphere. On a 100-year time scale, the GWP of CH_4 and N_2O are 25 and 298, respectively[10]. Currently, CO_2 accounts for over 98% of transportation's global warming impact, by virtue of the large amount of CO_2 produced. Each litre of gasoline results in 2.3 kg of CO_2 emissions and each litre of diesel 2.6 kg.

Transportation's GHG emissions are almost directly proportional to its fuel consumption, since almost all transportation runs on petroleum products (mainly, gasoline, diesel fuel, jet fuel, and bunker oil). Hence, in the short term, transportation related GHG emissions can be reduced substantially only by reducing vehicle kilometres travelled and by improving vehicle fuel efficiency. In the long run, alternative forms of energy such as electricity, hydrogen, and biofuels can make substantial contributions towards reducing transportation GHG emissions.

This Environmental Guide addresses GHG emissions (principal suspected contributor to the Climate Change phenomenon) by providing the methodology to assess GHG emissions attributable to transportation projects (Appendix 2) and proposing mitigation measures such as transportation demand management and fuel efficiency improvements (Appendix 5).

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[9] Natural Resources Canada, "Canada's Energy Outlook: The Reference Case", 2006.
[10] http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_CH02.pdf

APPENDIX 2: Prediction of Criteria Air Contaminant and Greenhouse Gas Emissions of Road Transportation Vehicles

1. PREDICTION OF CRITERIA AIR CONTAMINANT EMISSIONS

1.1 Preamble

The central task in transportation air quality impact assessment is the prediction of the long-term air quality effects of transportation projects. These effects arise mainly from future vehicle emissions attributable to the project. Hence, prediction of vehicle emissions is a crucial element of air quality impact assessment. It is also a broad and complex technical subject covering four major transportation modes and numerous factors that shape emissions. The mode of greatest relevance to MTO is road transportation, which happens to be also the predominant source of transportation related air pollution and greenhouse gases in Ontario. Hence, this Appendix is devoted to emissions from road transportation.

The term "vehicle emissions" commonly refers to the amount of criteria air contaminants[11] released into the atmosphere by one or more transportation vehicles over a specific time period or travelled distance. For road vehicles, most of this amount is generated by fuel combustion (vehicle exhaust emissions), fuel evaporation from parked and driven vehicles, re-entrainment of road dust, and tire and brake wear.

It is very difficult to predict quantitatively vehicle emissions from first principles. Hence, emission predictions are usually based on vehicle emission test results. The U.S. Environmental Protection Agency (EPA) is the principal source of these results. It tests annually a cross-section of vehicle models under controlled laboratory conditions. These emission test laboratories employ sophisticated chassis dynamometers, which allow repeated simulation of representative driving conditions. Exhaust and evaporative emissions are continuously sampled and averaged over entire driving cycles. The test data thus generated on individual vehicles are used in the U.S. EPA emission model MOBILE[12] to predict fleet-average emissions.

The methodology sketched above applies to cars, light trucks and motorcycles. A similar methodology is employed for heavy trucks and buses. With these larger road

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[11] Environment Canada and the Ontario Ministry of the Environment designate the following substances as criteria air contaminants (CAC): carbon monoxide, nitrogen oxides, volatile organic compounds, particulate matter, ozone, sulphur oxides and ammonia. The presence and interaction of these substances give rise to air issues such as smog and acid rain.

[12] MOBILE is a series of models, the most recent being MOBILE 6.2. At present, the US EPA is developing the next generation of vehicle emission predictors – MOVES.

vehicles, only engines and associated equipment, rather than the entire vehicle, is emission tested.

The results of the engine tests are used to deduce vehicle emissions over representative driving cycles.

The methodology for the rail, air and marine modes is less developed. However, the emissions of these modes are, in principle, easier to predict. This is due to the smaller variety within each of these modes with respect to powertrain characteristics and operating conditions.

1.2   Criteria Air Contaminants

The criteria air contaminants most relevant to transportation are carbon monoxide (CO), nitrogen oxides (NO_x), volatile organic compounds (VOCs), particulate matter PM, and ozone (O_3). Among the volatile organic compounds, five specific ones are classified as "air toxics". These are formaldehyde, acetaldehyde, benzene, 1,3-butadiene, and acrolein.

With the exception of ozone, all above contaminants are primary air pollutants (i.e., they are directly emitted into the atmosphere). Ozone, on the other hand, is a secondary pollutant. It is not a direct emission; it is formed in the atmosphere through complex photochemical reactions of NO_x and VOCs. Particulate matter (PM) is emitted by vehicles and hence is a primary pollutant; however, it is also formed in the atmosphere through chemical and physical transformations of gas phase precursors such as nitrogen and sulphur oxides. Therefore, PM is both a primary and a secondary pollutant. VOCs consist of a large group of chemicals with very diverse natural and man-made sources. Transportation vehicles are one of the many sources of some VOCs, the air toxics being the most relevant VOCs to human health.

The emission prediction approach proposed here deals with all primary criteria air contaminants listed above.

1.3   Prediction of Emissions – General Methodology

The air quality impact assessment approach in this document addresses local and regional impacts. Both assessments rely on the use of individual emission factors for each primary criteria air contaminant listed above. Emission factors are intrinsic parameters that characterize the emission rate of a specific contaminant over one kilometre of travel by a specific fleet over a specific driving cycle. In typical MTO projects, there is more than one relevant fleet and driving cycle. In these projects, one will need to apply the emission model with more than one set of input parameters to predict emission factors representative of each relevant vehicle fleet and driving cycle.

These emission factors multiplied with corresponding vehicle fleet size and kilometres of distance travelled will help produce the requisite total emissions.

In North America, the most commonly used model to predict fleet-average emission factors is U.S. EPA's mobile source emission factor model MOBILE 6.2 (2004 version). This is a complex computer model, which has been under development since 1978 (starting with MOBILE 1). It estimates emission factors for past, current, and future models of cars, light trucks, heavy trucks, buses, and motorcycles. It is based on emission testing of tens of thousands of vehicles over many years. It accounts for a large range of factors such as emission standards, fuel quality (composition) standards, vehicle technology, vehicle population, vehicle activity, emission inspection and maintenance, fuel properties, and environmental conditions.

MOBILE 6.2 predicts explicitly vehicle exhaust and evaporative emission rates of carbon monoxide, oxides of nitrogen, total volatile organic compounds, and six specific air toxics relevant to Canada (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein). It also predicts emission rates of particulate matter generated by vehicle exhaust, tire wear and brake wear in two size groups: $PM_{2.5}$ and PM_{10}. It does not model, however, particulate matter generated through the re-entrainment of road dust by vehicle travel. This latter component of particulate matter is addressed off-line through a specific U.S. EPA recommended method described later in this Appendix.

MOBILE 6.2 can model emission factors of almost all highway vehicles for the calendar years 1952 – 2050. These vehicles are placed into 16 major vehicle classes, which are described in Table 1. The accuracy of model predictions depends, in part, how accurately the relevant vehicle fleet is described in terms of this classification for all relevant years. For instance, if emission factors are being sought for the calendar year of 2007, MOBILE 6.2 requires specification of the vehicle fleet composition, according to the vehicle classification in Table 1, for 1983-2007 inclusive (vehicles 25 years old or older are lumped together into a single group; in this case, the 1983 group).

Recognizing the strong dependence of emission rates on vehicle driving conditions, MOBILE 6.2 provides predictions for four roadway types: freeway, arterial/collector, local roadway, and freeway ramp. The model represents each roadway type by a typical driving cycle representative for driving on that specific roadway type. Furthermore, for the freeway and arterial/collector road types, it allows user specification of the average travel speed. This latter option provides the opportunity to produce more site-specific emission factors.

Environment Canada has slightly modified the U.S. EPA Mobile 6.2 mainly to reflect Canadian vehicle population records and forecasts. This slightly modified program can be used to better account for Canadian vehicle population make-up, emission

standards, and environmental conditions. This version of MOBILE 6.2 is recommended for use in MTO studies.

Table 1:   Major Vehicle Classes of MOBILE 6.2

NUMBER	CLASS ABBREVIATION	CLASS DESCRIPTION
1	LDV	Light –Duty Vehicles: Cars
2	LDT1	Light-Duty Trucks 1: GVWR 0 - 6,000 lb and LVW 0 - 3750 lb
3	LDT2	Light-Duty Trucks 2: GVWR 0 - 6,000 lb and LVW 3751- 5750 lb
4	LDT3	Light-Duty Trucks 3: GVWR 6,001 - 8,500 lb and ALVW 0 - 5,750 lb
5	LDT4	Light-Duty Trucks 4: GVWR 6,001 - 8,500 lb and ALVW >5,750 lb
6	HDV2B	Class 2B Heavy-Duty Vehicles: GVWR 8,50 - 10,000 lb
7	HDV3	Class 3 Heavy-Duty Vehicles: GVWR 10,001- 14,000 lb
8	HDV4	Class 4 Heavy-Duty Vehicles: GVWR 14,00 - 16,000 lb
9	HDV5	Class 5 Heavy-Duty Vehicles: GVWR 16,001- 19,500 lb
10	HDV6	Class 6 Heavy-Duty Vehicles: GVWR 19,501- 26,000 lb
11	HDV7	Class 7 Heavy-Duty Vehicles: GVWR 26,00 - 33,000 lb
12	HDV8A	Class 8A Heavy-Duty Vehicles: GVWR 33,001 - 60,000 lb
13	HDVB	Class 8B Heavy-Duty Vehicles: GVWR >60,000 lb
14	HDBS	School Buses
15	HDBT	Transit and other Urban Buses
16	MC	Motorcycles

Notes:
1) GVWR stands for Gross Vehicle Weight Rating, which is specified by the vehicle manufacturer and includes the curb weight of the vehicle as well as the weight of the driver and the maximum recommended payload.
2) LVW stands for Loaded Vehicle Weight, which includes the weight of the vehicle and, 300 lbs to represent the weight of the driver and any incidental payload.
3) ALVW stands for Adjusted Loaded Vehicle Weight and represents the numerical average of the curb weight and GVWR.
4) The complete classification system includes 28 classes, which have been combined here into 16 for ease of presentation.

The U.S. EPA provides a set of comprehensive references to assist MOBILE 6.2 users. (See the U.S. EPA website: www.epa.gov/otaq.) The following two references are particularly useful:

- User's Guide to MOBILE 6.1 and 6.2, EPA420-R-03-010, August 2003
- Technical Guidance on the Use of MOBILE 6.2 for Emission Inventory Preparation, EPA420-R-04-013, August 2004.

1.4   Prediction of Emissions: Practices for MTO MOBILE 6.2 Applications

MOBILE 6.2 was originally devised for use in developing region-wide emission inventories, as required by the U.S. Clean Air Act for developing and then proving conformity with State Implementation Plans (SIPs). These inventories are estimates of total emissions generated by the entire road vehicle activity in a region. Hence, the model is very elaborate and requires a large amount of input data.

Since the early 1980s, U.S. and Canadian agencies (including MTO) and consultants have used the model to generate project-specific emission factors. The adequacy of

the model in this application has since been tested with roadside and tunnel air pollutant concentration monitoring. MTO conducted the first Canadian test of an earlier version of the model[13] (MOBILE 5.1C) in 1994, by monitoring extensively upwind and downwind roadside pollutant concentrations along with traffic volumes and meteorological conditions. These efforts have established that, with sufficiently detailed and accurate input data, MOBILE 6.2 is capable of producing valid project-level emission factors.

Representative emission factors for MTO's local and regional air quality impact assessments of roadway projects can be achieved by using a mix of project specific and regional input data along with some of the default variables in MOBILE 6.2. The following is a list of practices MTO and its consultants will follow, unless there is a compelling technical reason to diverge. These relate to the specification of input variables of greater consequence for the results.

- *Selection of the Month of Evaluation*: MOBILE 6.2 prescribes January and July as the two default months for the year of evaluation. Selection of one of them facilitates the application of the program. For MTO studies, July is the preferred month, provided that July traffic data are available. In July, Ontario usually experiences higher traffic volumes and poorer air quality than in January. In those instances where both January and July data are available, results can be generated for both months.

- *Temperature of the Evaluation Day*: MOBILE 6.2 provides the option of specifying the minimum and maximum temperatures of the day of evaluation. With these two extremes, MOBILE 6.2 generates an hour-by-hour temperature profile for the day. For MTO studies, typical or average July and January daily maximum and minimum temperatures should be used. These averages can be obtained from the daily temperature records for the region of interest.

- *Humidity of the Evaluation Day*: This parameter has no major influence on results. Hence, adoption of the default value is acceptable. Alternatively, a typical or average historic value for the absolute humidity (mass of water vapour per unit mass of dry air) can be adopted.

  Vehicle Characteristics: These characteristics include the age distribution, annual mileage accumulation rates, and diesel fractions for the 16 vehicle classes (see Table 1) of the relevant vehicle fleet over 25 years (vehicles 25 years and older are grouped together). These parameters can have a strong influence on emission factors. However, they are difficult to estimate at the project level. Hence, the default input data built into the MOBILE 6.2C (Canadian version) will be used for age distributions and annual mileage. This approach implies that vehicles travelling on the specific infrastructure are no different from the rest of the Ontario fleet with respect to their age distribution, annual mileage, and diesel fractions.

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[13] Topaloglu, T. and Elliott, D., Air Quality Impact Assessment of Highway 404 Widening", MTO Report, 1996.

- *Vehicle Miles Travel Fraction by Vehicle Class*: This is an important parameter that permits, indirectly, the customization of MOBILE predictions to individual projects. Specifically, with detailed traffic volume data, one can represent the miles travelled fraction by the corresponding traffic volume fraction, thus simulating the "right" traffic composition. For instance, if the heavy heavy-duty vehicles represent 10% of the traffic volume, making the vehicle miles travelled for this class of vehicles 10%, accomplishes indirectly the "correct" representation of the fleet mix with respect to this class of vehicles. Unfortunately, traffic volume data and projections hardly ever provide the detailed classification needed in MOBILE 6.2. Hence, approximations are needed.

  Typical vehicle counts and projections distinguish between cars/light trucks, medium trucks and heavy trucks/buses. These data can be combined with knowledge of Ontario-wide fleet composition to split the three monitored major classes into the 16 classes required by MOBILE 6.2. This will result in an input file which replicates fleet composition accurately in terms of gasoline and diesel vehicles. Since the accuracy of the emission factors is critically affected by the diesel versus gasoline vehicle fraction, this level of detail in fleet composition is seen to be adequate to estimate project-level emission factors.

- *Emissions Inspection and Maintenance (I/M) Program*: Ontario's DriveClean Program qualifies as an I/M program and should be part of the input file. Its current and future descriptive parameters can be specified in consultation with Ontario Ministry of Environment.

- *Roadway Type and Average Speed:* These two parameters help predict emission factors which more closely represent project-level driving conditions. The four road type options (freeway, arterial/collector, local road and freeway ramp) along with observed and future expected average traffic speeds for freeways and arterials/collectors provides the input needed to generate project-specific emission factors. Vehicle speeds on local roads and freeway ramps are fixed in MOBILE 6.2.

- *Fuel Composition and Properties*: These parameters have a significant influence on results and need to be representative of Ontario. Specifically, for gasoline, the aromatic, olefin, benzene, sulphur and oxygenate (ethanol) contents along with volatility characteristics (E200, E300 and RVP) have to be specified. For diesel fuel, the only required input is the sulphur content. In the preparation of these inputs, the Ontario Ministry of the Energy can be consulted.

1.5   Prediction of Emissions: Re-Entrained Road Dust

The contribution of re-entrained road dust to PM emissions is not well quantified. It is generally accepted, however, that this component of PM emissions consists primarily of larger particles (see Table 2), which have a relatively short lifetime in suspended state

and hence do not travel too far from the road and do not play a major role in health effects[14].

<div align="center">

Table 2:   Size Distribution of Road Dust[13]

SIZE CLASS	ABUNDANCE (% BY WEIGHT)
<1.0 μm	4.5
<2.5 μm	10.7
<10 μm	52.3
>10 μm	47.7

</div>

The most widely used model to predict re-entrained road dust emissions for paved roads is provided in the U.S. EPA AP-42 document[15]. This is an empirical model that relates emission factors to the silt (crustal material of <75 μm geometric diameter) loading of the road in g/m^2 and the average weight of the vehicles on the road, in tons:

$$\textbf{Emission Factor = k x (Silt Loading / 2)}^{0.65} \textbf{ x (Average Vehicle Weight / 3)}^{1.5 - C}$$

The U.S. EPA recommended values for the parameters k and C, in g/km, are listed below in Table 3.

<div align="center">

Table 3:   Parameter Values for the Paved Road Equation[16]

PM SIZE RANGE	k (g/km)	C (g/km)
PM$_{2.5}$	0.66	0.1005
PM$_{10}$	4.60	0.1317

</div>

The success of the model depends on the accuracy of the silt loading and mean vehicle weight data. Both parameters should ideally be based on measurements. For existing roads, the mean vehicle weight may be estimated from traffic volume data. The same is not possible, however, with silt loading – particularly, on heavily travelled highways.

Furthermore, for most MTO projects, the impacts of future roads or future conditions are of relevance.

Hence, the U.S. EPA recommended silt loading factors are of great value. These factors, in g/m^2, are summarized in Table 4. They apply to dry paved roads (under wet conditions, silt loading decreases). Their magnitude depends strongly on the annual daily traffic volumes (ADTs) and on road type (limited access).

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[14] 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", May 2000.

[15] SENES Consultants Limited Report to the Canadian Council of Ministers of the Environment, Particulate Matter Arising from Paved Roads, March 2000.

[16] U.S. EPA, "Emission Factor Documentation for AP-42, Fifth Edition, Section 13.2.1 – Road Dust", 2006.

Table 4:   Recommended Silt Loading Factors[17]

ADT CATEGORY	<500	500-5,000	5,000-10,000	>10,000
Silt Loading Factor (g/m^2)	0.6	0.2	0.06	0.03 0.015 (limited access road)

The recommended value for limited access highways with ADT>10,000 is 0.015 g/m^2. This value should be applied in all projects that involve major highways.

According to the U.S. EPA, application of ordinary salt and other chemicals add little to silt loading. Hence, road salting will not affect the value of the silt loading. The application of sand, on the other hand, can significantly increase silt loading. Similarly, mud/dirt carryout from construction sites can have a major impact.

1.6   Prediction of Emissions: Truck Idle Emission Rates

At idle, heavy-duty diesel trucks produce exhaust emissions but no tire and brake wear material or re-entrained road dust; the diesel truck emissions of CO and HC at idle are relatively small. The emissions of NO$_x$ and PM can, however, be significant. MOBILE 6.2 provides idle emission factors, in g/h, for gas-phase pollutants as well as PM. These factors are based on g/km emission factors for vehicle travel at 4 km/h. This approach produces sufficiently accurate results for gas-phase pollutants but not for PM.

In order to address this issue, the U.S. EPA provided explicit recommendations for idle PM$_{2.5}$ and PM$_{10}$ emission rates for current and future truck fleets. These factors (listed in Table 5 below) should be used in MTO projects. The PM$_{2.5}$ and PM$_{10}$ emission factors have identical values, since almost all truck exhaust PM are in the PM$_{2.5}$ size range.

The data in Table 5 reflects the large drop in PM emissions expected in future decades for diesel PM emissions – at idle and other operating modes. This is simply the consequence of the tough U.S. EPA and Environment Canada heavy-duty diesel emission standards and the reduction of the sulphur content of diesel fuel from 500 ppm to 15 ppm over this timeframe.

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[17] U.S. EPA, "Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity", EPA420-B-04-001, 2004.

Table 5: U.S. EPA Recommended Heavy-Duty Diesel Truck Idle Emission Factors for $PM_{2.5}$ & PM_{10}[18]

CALENDAR YEAR	$PM_{2.5}$ / PM_{10} EMISSION FACTOR (g/h)
2006 and earlier	3.68
2007	3.43
2008	2.94
2009	2.52
2010	2.16
2011	1.88
2012	1.60
2013	1.38
2014	1.10
2015	0.89
2016	0.79
2017	0.71
2018	0.58
2019	0.54
2020	0.50
2021	0.47
2022	0.44
2023	0.41
2024	0.39
2025	0.38
2026	0.36
2027	0.35
2028	0.34
2029	0.33
2030	0.33

2.   PREDICTION OF GREENHOUSE GAS EMISSIONS

Road transportation vehicles emit significant quantities of three greenhouse gases: carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Carbon dioxide is by far the most prevalent GHG. It is emitted in large quantities by transportation vehicles while methane and nitrous oxide are emitted in smaller quantities.

MOBILE 6.2 produces CO_2 emission factors, given the very same inputs described for predicting emission factors for criteria air contaminants. It does not, however, provide estimates of CH_4 and N_2O emission factors. This is due to the paucity of emission data

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[18] U.S. EPA, "Guidance for Quantifying and Using Long Duration Truck Idling Emission Reductions in State Implementation Plans and Transportation Conformity", EPA420-B-04-001, 2004.

for these latter two greenhouse gases. Just as with other pollutants, the CH_4 and N_2O emission factors depend, among other things, on the types of fuel, vehicle, and emission control technology. This deficiency of MOBILE 6.2 can be overcome by resorting to information in the appendices of Environment Canada's annual GHG inventory reports.

In these reports, Environment Canada provides greenhouse gas emission factors, which are specific to classes of vehicles (not as detailed as MOBILE 6.2) and fuels, but not specific to driving cycles. While the absolute values of these factors may not be adequate for the purposes of this Appendix, their ratios are.   Specifically, the ratios of CH_4 and N_2O emission factors with CO_2 factors for a given class of vehicle and fuel "divide out" the effect of the driving cycle. Thus, these ratios multiplied with the more accurate and driving cycle specific CO_2 emission factors of MOBILE 6.2, produce CH_4 and N_2O emission factors that are sensitive to the driving cycle.   This is a practical, albeit not a highly accurate, method to derive CH_4 and N_2O emission factors. It is also deemed to be an adequate approach, given the smaller amounts of CH_4 and N_2O produced by road vehicles.

The latest Environment Canada GHG[19] report was used to derive the emission factor ratios in Table 6 below[20].   In this table, similar classes of vehicles were combined, recognizing that traffic data will represent only these broader vehicle classes.

The ratios in Table 6 may change over the years with the adoption of new fuels, powertrains, and emission control technologies. Hence, the latest Environment Canada GHG inventory report ought to be consulted to derive up-to-date emission factor ratios.

Table 6 Ratios of GHG Emission Factors[21]

VEHICLE CLASS	CH_4/ CO_2 RATIO	N_2O /CO_2 RATIO
LDV	0.00005085	0.0001102
LDT1-LDT4	0.00009322	0.0001737
HDV2B-HDV8B	0.00004396	0.00002930
MC	0.0005932	0.00001949

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[19] Environment Canada, "National Inventory Report, 1990-2005 – Greenhouse Gas Sources and Sinks in Canada", 2007

[20] The ratios were derived by dividing the g/L emission factors for CH_4 and N_2O with the corresponding factors for CO_2

[21] Environment Canada, "National Inventory Report, 1990-2005 – Greenhouse Gas Sources and Sinks in Canada", 2007

APPENDIX 3: ASSESSMENT OF LOCAL AIR QUALITY IMPACTS

1. INTRODUCTION

A new or expanded transportation facility may mean measurable changes in pollutant emissions and air quality to its immediate vicinity. Recognizing the potential for significant changes, MTO started in 1994 to include science based local air quality impact assessments in some of its environmental studies. These assessments have contributed to at least one of the following functions.

- Selection of preferred transportation option(s)
- Selection of preferred facility location (route location for a highway)
- Assessment of the overall preferred option with respect to air quality implications
- Assessment of the need for mitigation
- Assessment of the effectiveness of mitigation options

The methodology described in this Appendix is based on MTO's experience over 1994-2007. It is directly applicable to highway projects; however, with the few adaptations suggested in this Appendix, it can also be applied to other transportation projects.

The air quality impacts of transportation facilities are assessed primarily in terms of changes in pollutant concentrations that are directly attributable to the facility. The most relevant pollutants are CO, NO_2, $PM_{2.5}$, PM_{10}, and the five air toxics (benzene, 1, 3-butadiene, formaldehyde, acetaldehyde, and acrolein). Ozone is not considered here. It is not a primary pollutant. Its photochemical production from its precursors takes at least a few hours, which almost always ensures its transport out of the local environment. Furthermore, vehicle emissions of NO rapidly neutralize ozone. As a result, ozone concentrations are typically depressed near highways.

Experience to date suggests that MTO's publics are most interested in the following specific local air impacts.

- Near-term impacts of the new or expanded facility as quantified by expected increases/decreases of local air pollutant concentrations
- Long-term impacts of the new or expanded facility as measured by expected changes in local air pollutant concentrations
- Near and long-term changes in ambient pollutant concentrations in response to project alternatives and any mitigation measure that is deemed necessary

The calculation of the changes in the first two points necessitates assessment of "current" pollutant concentrations (base case) and prediction of future ones with and without the project – comparison of "current" conditions and the "build" and "no build" scenarios in the two timeframes. This approach recognizes that, in all likelihood, future

pollutant concentrations will be different from "current" concentrations in the "build" as well as the "no build" scenarios.

MTO and its publics are interested not only in air quality impacts, which are based on differences in pollution levels, but also in expected "absolute" pollutant concentrations in the local ambient air. The absolute concentrations signify the concentrations that local residents are expected to experience and include the collective contribution of all sources of pollution (not just local sources) to the local air pollution. They are calculated as the sum of the predicted changes in pollutant concentrations due to the project and the background pollutant concentrations as measured by the MOE and Environment Canada air quality monitoring stations nearest to the study site.

Comparison of predicted absolute pollution concentrations with the provincial ambient air quality criteria (AAQC), the national ambient air quality standards (NAQS), and the Canada Wide Standards (CWS) is the recommended approach to assess the need for mitigation.

2.   GENERAL APPROACH

A highway is a conduit for road vehicles with individually small but collectively large air pollutant emission rates. Each vehicle constitutes a distinct and variable pollution source. The emission rate of each vehicle is often different from that of any other vehicle, and it varies instant by instant as a function of driving conditions and driver behaviour.

The air quality impact of such a large number of diverse and variable sources of pollution cannot be easily accomplished without some simplifications. The principal simplifications inherent to the recommended method are summarized below:

- Highway traffic is viewed as a continuous "line source" of pollution.

- The highway or highway section of interest and its ramps are divided into a set of contiguous links, with each link small enough to present a uniform geometry and traffic conditions. Separate sets of links are devised for each direction of travel.

- Each link is assigned a single emission rate, in grams of pollutant emitted per unit time, based on the product of a composite emission factor (in grams per kilometre per vehicle) and a traffic volume (number of vehicles per unit of time) specific to the link and time period of interest. For a period of one hour (h):

   Emission Rate (g/h) = Emission Factor (g/vehicle/km) x Traffic Volume (vehicle/h)

   This approach assumes implicitly that pollutants are completely mixed over the highway, presenting a uniform and continuous source of pollution.

- The impact of the highway traffic at a given receptor location is assessed by adding the impacts of all links at that location (principle of superposition).

- Dispersion occurs only in the downwind direction, upwind receptors are not affected. This commonly made assumption is to neglect the very small rate of molecular diffusion of pollution in the upwind direction.

- All gas phase air pollutants are assumed to disperse at the same rate from the line source, subject to the Gaussian dispersion equation (defined below, in this Appendix).

- The unique dispersion characteristics of particulate matter are addressed through corrections for settling and deposition of particles.

- Chemical reactions among pollutants are omitted, except for the instantaneous conversion of NO to NO_2 through reaction with ambient ozone (O_3):

$$NO + O_3 \rightarrow NO_2 + O_2$$

It is assumed that the rate of conversion of NO to NO_2 is controlled by the availability of ozone only (i.e., ozone limiting method). Given sufficient amounts of O_3 in the atmosphere, all NO emitted by vehicles will immediately transform into NO_2 and disperse like any other stable gas phase compound.

The dispersion and dissipation of pollutants is a complex process, which is strongly influenced by meteorological conditions, the characteristics of the emission source and the local topography. A large number of computer models have been developed to model this process for various emission sources.

In 1972, The California Department of Transportation (Caltrans) issued one of the very first line source dispersion models, CALINE1. This led to a series of improved versions: CALINE2 in 1975, CALINE3 in 1979, and CALINE4 in 1984.

The CALINE models are highly specialized and well-developed line source dispersion models. They are ideally suited to modelling dispersion of emissions from highway traffic and rail traffic. They are, however, not suited to model emissions from point sources or area sources. Transportation facilities such as parking lots, construction sites, bus or train terminals, harbours and airports can be better represented as area and point sources. For these and similar applications, the U.S. EPA and Ontario's MOE recommend AERMOD, which is a sophisticated Gaussian dispersion model. MTO recommends AERMOD to predict dispersion from transportation facilities, equipment and activities that can be best represented as point or area sources. AERMOD is not tailored to the analysis of pollution from road traffic.

3. CAL3QHC/R DISPERSION MODELS: A BRIEF REVIEW

In 1980, after careful validation with field data, the U.S. EPA endorsed CALINE3 as the official model for estimating concentrations of nonreactive (stable) pollutants near highways. Since this date, it has developed CALINE3 further into CAL3QHC and CAL3QHCR, which are more versatile and user-friendly than the original model CALINE3.

CAL3QHC is most suited to predict concentrations for a single set of meteorological conditions. Hence, it is the preferred model for the credible worst-case analysis method covered in Section 4 of this Appendix. CAL3QHCR, on the other hand, can process one year's worth of metrological data in a single computer run. This makes it most suited for the full-year comprehensive analysis method recommended in Section 5 of this Appendix.

CAL3QHC and CAL3QHCR are equipped with a built-in routine to account for the initial mixing of pollutants over the roadway by the movement of vehicles and their hot exhaust. They can account for pollutant removal by dry deposition. They can model depressed and elevated roads as well as curved alignments. They are equipped with built in routines to simulate traffic behaviour at road intersections and parking lots. However, they are not capable of handling complex topography, chemical reactions and wet deposition. They are also weak in modelling extremely stable and unstable atmospheric conditions and dispersion beyond 10 km.

The judicious application of these models and the quality of the input data plays a large part in the accuracy of their results. Hence, a thorough understanding of their workings and their theoretical basis is crucial. The following paragraphs are intended to provide a brief introduction to this theory.

CALINE3QHC/R, as well as AERMOD, are both based on the Gaussian dispersion model, which has proven itself as one of the most practical mathematical descriptions of the dispersion of plumes (plumes arise from continuous emission of pollutants, such as from highway traffic). This model accounts for the effects of the wind and the atmospheric turbulence on the spread of plumes. The wind carries the plume away from the source and turbulence spreads it out.

For a ground level source-receptor pair and under homogeneous and steady-state meteorological conditions (reasonable assumptions for pollutant dispersion from busy highway traffic), the general and more complex Gaussian dispersion equation can be simplified to the following equation, which may serve to illustrate the dependence of pollutant concentration on the most relevant source and meteorological parameters.

$$C(x, y) = \frac{E}{\pi \sigma_y \sigma_z u} \times \exp\{-\frac{1}{2}(\frac{y}{\sigma_y})^2\}$$

This is a two-dimensional Gaussian dispersion equation, with x measured from the source along the direction of the wind and **y** axially perpendicular to it. **C** (**x,y**) represents the average concentration of a pollutant at point (**x,y**), downwind from the source. **E** represents the source strength (i.e., the rate at which the pollutant is emitted). The parameters σ_y and σ_z represent the extent of plume spread at distance **x** along the **y** and **z** axes (axial and vertical spread). They are usually referred to as dispersion coefficients or eddy diffusivities. The parameter **u** represents the average wind speed. The equation does not explicitly contain the distance from the source **x**; however; σ_y and σ_z are both functions of **x**[22].

Extensive field data has established the validity of this equation as a good approximation of the physics of dispersion, provided that long enough averaging times are used (say, one hour). As predicted by this equation, the concentration-distance profile of pollutants across the wind direction follows roughly the normal Gaussian curve; similarly, pollutant concentrations increase with source intensity and decrease with wind speed and level of turbulence.

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[22] For distances up to 500 m from the source, the functional relation is $\sigma = ax^b$ (a and b are empirically determined constants).

Turbulence or mixing plays a critical role in dispersion. It has two components: mechanical turbulence and thermal turbulence. Mechanical turbulence arises from the interaction of moving air with objects on the ground, such as trees and buildings. Higher wind speeds and taller objects generally lead to more turbulence. The latter arises from changes in atmospheric temperature with altitude. Declines in temperature with distance (usually, temperature drops by $1^{o}C$ per 100 metres of rise) lead to a more turbulent and less stable atmosphere. Increases in temperature with altitude lead to a less turbulent and more stable atmosphere. Unfavourable changes in the slope of temperature profiles lead to the phenomenon of "inversion", which limits the atmospheric height available to mixing and vertical dilution.

The relation of turbulence intensity to measurable parameters, such as wind speed and temperature profile is very complex. At present, the best relations in the literature are based on empirical data. These relations find their way into CAL3QHC/R and other dispersion models via the following key parameters: surface roughness length (affecting mechanical turbulence or mixing), atmospheric stability and mixing height (affecting thermal turbulence and mixing).

Surface roughness length is a function of the predominant land use feature of the area adjacent to the highway. Representative roughness lengths are provided in Table 1 below.

CAL3QHC/R employ internal routines to calculate the dispersion coefficients, σ_y and σ_z, based on the six atmospheric stability classes, as defined by Pasquill[23] in 1968 and reproduced in Table 2 below. The relation of stability classes to easily measurable meteorological parameters is provided in Table 3. This table helps predict daytime atmospheric stability as a function of wind speed and insolation, and night-time stability as a function of wind speed and cloud cover. The relation of insolation to solar altitude is provided in Table 4. The information in Tables 3 and 4 is extracted from Schnelle and Partha[24].

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[23] Pasquill, F. (1961): "The Estimation of the Dispersion of Windborne Material", Meteorology Magazine, vol. 90, pp.33-49.
[24] Pasquill, F. and F.B. Smith (1983): <u>Atmospheric Diffusion</u>, John Wiley and Sons, New York.

Table 1: Seasonal Values for Surface Roughness[25]

LAND COVER	SEASONAL SURFACE ROUGHNESS (M)				
	SEASON 1	SEASON 2	SEASON 3	SEASON 4	SEASON 5
Open water	0.001	0.001	0.001	0.001	0.001
Low intensity residential	0.54	0.54	0.50	0.50	0.52
High intensity residential	1	1	1	1	1
Commercial/industrial/transport (at airport)	0.1	0.1	0.1	0.1	0.1
Commercial/industrial/transport (not at airport)	0.8	0.8	0.8	0.8	0.8
Bare rock/sand/clay	0.05	0.05	0.05	0.05	0.05
Quarry/strip mine/gravel	0.3	0.3	0.3	0.3	0.3
Deciduous forest	1.3	1.3	0.6	0.5	1
Evergreen forest	1.3	1.3	1.3	1.3	1.3
Mixed forest	1.3	1.3	0.95	0.9	1.15
Shrubland (arid region)	0.15	0.15	0.15	NA	0.15
Shrubland (non-arid region)	0.3	0.3	0.3	0.15	0.3
Orchard/vineyard/other	0.3	0.3	0.1	0.05	0.2
Grassland/herbaceous	0.1	0.1	0.01	0.005	0.05
Pasture/hay	0.15	0.15	0.02	0.01	0.03
Row crops	0.2	0.2	0.02	0.01	0.03
Small grains	0.15	0.15	0.02	0.01	0.03
Fallow	0.05	0.05	0.02	0.01	0.02
Urban/recreational grass	0.02	0.015	0.01	0.005	0.015
Woody wetlands	0.7	0.7	0.6	0.5	0.7
Emergent herbaceous wetland	0.2	0.2	0.2	0.1	0.2

Notes:
Season 1: Midsummer with lush vegetation
Season 2: Autumn with unharvested cropland
Season 3: Late autumn after frost and harvest or winter with no snow
Season 4: Winter with continuous snow on the ground
Season 5: Transitional spring with partial green coverage or short annuals

Table 2: Pasquill Stability Classes

STABILITY CLASS	DESCRIPTION
A	Extremely Unstable
B	Moderately unstable
C	Slightly unstable
D	Neutral
E	Slightly stable
F	Moderately stable

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[25] U.S. Environmental Protection Agency (2008): AERSURFACE User's Guide, EPA-454B-08-001.

Table 3: Prediction of Pasquill Stability Classes

WIND SPEED (m/s)	DAY-TIME INSOLATION			NIGHT-TIME CLOUDINESS	
	Strong	Moderate	Slight	≥ 1/2	<3/8
<2	A	A-B	B	-	-
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
>6	C	D	D	D	D

Notes:
1) The degree of cloudiness is defined as that fraction of sky above the local apparent horizon that is covered by clouds.
2) Insolation is the rate of radiation from the sun received per unit of earth's surface.
3) Strong insolation corresponds to sunny mid-day in summer. Slight insolation corresponds to similar conditions in mid-winter.
4) Night-time refers to the period one hour before sunset to one hour after sunrise.

Table 4: Insolation as a Function of Solar Altitude

SOLAR ALTITUDE (A)	INSOLATION
A>60	Strong
60>A>35	Moderate
35>A>15	Slight
A<15	Weak

4. CREDIBLE WORST-CASE ANALYSIS: METHODOLOGY

The local air quality impacts of transportation systems vary over time, mainly due to variations in traffic conditions and local meteorology. This variability makes it difficult to judge the acceptability of impacts over the useful life of the project and the need for mitigation.

One of the common analytical responses to this issue is the credible worst-case analysis. It is based on the concept that a project is acceptable under all conditions if it is acceptable under a credible worst-case condition. The results of this analysis are a set of ambient pollutant concentrations predicted under a credible worst-case condition. The condition is deemed to span one hour for all gas phase pollutants and 24 hours for particulate matter, as dictated by the averaging periods for these pollutants in the AAQCs and CWSs. During the averaging periods, the entire study area is assumed to be subject to a constant traffic and meteorological condition, namely, the credible worst-case condition. This briefly outlined approach allows a relatively quick scientific assessment and obviates the need for further assessment if its results clearly indicate acceptability of the predicted ambient pollutant concentrations. It is, however, a severe test that is likely to reflect a much worse condition than expected under usual conditions.

The credible worst-case analysis is conducted with the computer models recommended in this document, viz., MOBILE 6.2 for the prediction of emissions and CALINE3QHC for the prediction of ambient pollutant concentrations. AERMOD is recommended for transportation facilities that are best represented as point or area sources.

The definition of a "credible worst case" and its application are subject to judgement. Hence, it is particularly important for MTO to specify how the credible worst case will be defined and applied in major transportation projects. This is presented below, in point form.

4.1   Local air quality impacts will be assessed for the "no-build" and "build" scenarios. The credible worst-case analysis is best suited to assess the "acceptability" of the preferred project options. However, it can also be used to compare options and scenarios.

4.2   The "no-build" scenario applies to projects that involve improvements to an existing transportation system or facility (Class B projects); not to projects that involve a new system. The no-build scenario will be assessed to four timeframes: i) current conditions (base case); ii) year of inauguration of the improved facility; iii) ten years from inauguration; and iv) twenty years from inauguration.

4.3   The "build scenario" will be assessed for three timeframes: i) year of inauguration of the complete facility; ii) ten years from inauguration; and iii) twenty years from inauguration. Certain changes expected over this 20-year timeframe can be predicted with some degree of accuracy. These include changes in traffic conditions and vehicle emission rates. Certain other potential changes, such as those in background pollution cannot be predicted with any degree of accuracy.

4.4   The local air quality impacts are assumed to be limited to a distance of approximately 500 m from the transportation facility, in each direction[26]. For highways, the 500 m will be measured from the edge of the mixing zone (travelled road plus 3 m on each side) to the appropriate lived-in property (point of property closest to the highway). The choice of a 500 m limit is based on empirical evidence for heavily travelled large highways, which clearly indicates that the concentrations of road-related pollutants drop to within 10% of their background pollution levels over this distance[27]. The same criterion may not apply to transportation facilities of a vastly different nature such as harbours and airports.

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[26] For a highway, this amounts to a 500-m band on each side of the highway, with appropriate adjustments for interchanges and ramps.
[27] Topaloglu, T. and Elliott, D., "Air Quality Impact Assessment of Highway 404 Widening", Ontario Ministry of Transportation Report, 1996.

4.5   Within the 500 m range (as defined under Point 4.4 above), pollutant concentrations will be assessed for critical and sensitive receptors. Using the same input data, the dispersion model will be run to generate site-specific isoconcentration contour maps that allow easy assessment of the variation of concentrations over the entire study area.

4.6   Commercial and industrial buildings will be deemed outside of the scope of this analysis. The air quality requirements of this sector are addressed by occupational health and safety rules.

4.7   Outdoor and indoor air pollutant concentrations will be assumed equal. This is a conservative assumption.

4.8   The assessment will include the proposed mainline highway, its on/off ramps, interchanges, bridges, service roads and any other travelled structures. It will also include any existing arterial roads within 500 m of the mainline highway that carry 10% or more of the expected traffic on the mainline highway. All other planned new arterial roads within 500 m of the highway will be included. This guideline presumes that the air quality impacts of existing roads are already included in the background pollution levels unless they carry a large traffic volume (more than 10% allocated to the highway).

4.9   In the CAL3QHC application, the mainline highway and its ancillary travelled elements will be split into links with substantially uniform geometry and traffic conditions. Separate links will be defined for each traffic direction. Signalized intersections will be modelled as individual links. No link will stretch over 10 km.

4.10   Uniformity in mainline highway geometry will be assessed in terms of road width, curvature and slope. Mainline highway links will be devised so as to present substantially constant width, curvature and slope.

4.11   Traffic conditions will be quantified in terms of three parameters:
* Traffic volume (vehicles per hour);
* Average traffic speed (km/h); and
* Percentage of the total traffic volume represented by all heavy-duty vehicles (GVWR > 8,500 lb).

        These traffic conditions will be assessed for the three analysis timeframes.

4.12   Traffic conditions will be derived with validated traffic demand forecasting models. The air quality modeller will assess the accuracy of the data and seek explanations where anomalies are detected.

4.13   Emission factors will be derived according to the methodology in Appendix 2 of this document.

4.14   In the one-hour credible worst-case analysis (applicable to all pollutants except particulate matter), the weekday morning or afternoon peak hour traffic conditions will be used.

4.15   In the 24-hour credible worst-case analysis (applicable to particulate matter), the weekday 24-hour traffic volume predicted by traffic modelling will be used. This 24-hour figure will be used to create a table of hour-by-hour traffic volumes by applying the best available traffic engineering input.

4.16   In the one-hour and 24-hour analyses, the following credible worst-case meteorological inputs will be used:

- The wind speed will be set at 1 m/s. This is the lowest wind speed that can be handled by CAL3QHC. It is a very rare condition to prevail for 24 hours.
- The wind direction will be set at 5° off the mainline highway axis, to the right or to the left off the axis so as to produce the highest CO concentration at the nearest receptor. This is a very rare condition to prevail over 24 hours.
- The stability class for urban regions will be set at D and that for rural and suburban regions at E, unless there is a compelling scientific reason to set it at a different level. A setting worse than class D cannot be deemed credible.
- The mixing height will be set at 500 m.

4.17   The worst traffic hour and the worst meteorological hour will be assumed to coincide. This is one of the assumptions leading to a worst-case scenario.

4.18   The surface roughness length will be set for the prevailing land use in the study area in accordance with Table 1 of this Appendix.

4.19   The settling and deposition velocities of the gas-phase compounds will be set at zero, indicating no measurable deposition under any condition.

4.20   The settling velocities for $PM_{2.5}$ and PM_{10} will be set at 0.02 and 0.3 cm/s, respectively.

4.21   The deposition velocities for $PM_{2.5}$ and PM_{10} will be set at 0.1 and 0.5 cm/s, respectively.

4.22   The concentrations predicted by the dispersion model represent the impact of the highway (i.e., the expected change in concentration). They are added to background pollutant concentration levels to predict final concentration levels.

4.23   The background pollutant concentration levels to be used in this analysis are the 90th percentile of the most recently measured and complete concentration data from the nearest MOE or Environment Canada air quality monitoring station. These concentration levels will be applied for all three analysis timeframes, implicitly assuming that background pollution levels will persist at their latest measured levels.

4.24   The potential pollutant concentration effects of existing and planned large sources of pollution in the immediate vicinity of the project site will be explicitly taken into account in a limited cumulative effects analysis.

The results of the credible worst-case analysis have several applications. They can be used to compare transportation and route alternatives. In this application, the following approach can be devised to arrive at an objective single score for each alternative:

- Select the pollutant that least conforms to the criteria/standards – say, pollutant A.
- Compare alternatives with respect to local community exposure to pollutant A. This may be achieved by creating the following sum:

$$Score = \sum (Weighting\ factor) \times (Concentration\ of\ A\ at\ receptor/AAQC\ or\ CWS\ for\ A) +$$
$$\sum (Average\ concentration\ of\ A\ for\ subdivision/AAQC\ or\ CWS) \times$$
$$(Number\ of\ residences\ in\ the\ subdivision)$$

- The above sum is calculated by accounting for all critical receptors and all residential subdivisions (or portions of subdivisions) within 500 m of the mainline highway or highway segment of interest.
- The average concentration for a subdivision may be assessed by averaging predicted concentrations at representative receptors within the subdivision or at the geometric centre of the subdivision, if this can be justified scientifically.
- Weighting factors will be devised for each critical receptor (e.g., hospital, old age home, daycare or school), based on the average number and condition (age/health status) of attendees. The weighting factor for the residences (sensitive receptors) is set at one. Commercial and industrial buildings are not considered in this score.
- The alternative with the lowest score would be the preferred alternative with respect to air quality.

The results of the credible worst-case analysis will also be used to assess the acceptability of the "preferred option". In this task, pollutant concentrations predicted by the credible worst-case analysis will be compared with the provincial AAQC for gas-

phase pollutants and the CWS for the particulate matter. In those instances when the criteria are met, no further analysis is deemed necessary. Exceedances of even a single criterion will be deemed sufficient grounds for a comprehensive analysis, according to the methodology described in Section 5 of this Appendix.

5.   Comprehensive Analysis: Methodology

The second common analytical approach to address the variability of traffic and meteorological conditions is the comprehensive analysis, which involves hour-by-hour prediction of ambient pollutant concentrations for a full year. In this approach, the air quality effects of the proposed alternatives and the preferred one can be assessed over the spectrum of meteorological conditions expected over a year. While somewhat more time- consuming, this makes for a more comprehensive and realistic assessment. It is the preferred approach for major projects.

The credible worst-case and comprehensive analyses have many common steps. The principal differences are in the specification of traffic and meteorological conditions and the interpretation of the analysis results. For ease of reference, the complete set of steps for the comprehensive analysis is provided below – including those steps that are common with the credible worst-case analysis.

5.1   Local air quality impacts will be assessed for the "no-build" and "build" scenarios. The comprehensive analysis is highly suited to compare scenarios and to assess the "acceptability" of the preferred alternative with respect to local air quality.

5.2   The "no-build" scenario applies to projects that involve improvements to an existing transportation system or facility (Class B projects); not to projects that involve a new system. The no-build scenario will be assessed to four timeframes: i) current conditions (base case); ii) year of inauguration of the improved facility; iii) ten years from inauguration; and iv) twenty years from inauguration.

5.3   The "build scenario" will be assessed for three timeframes: i) year of inauguration of the complete facility; ii) ten years from inauguration; and iii) twenty years from inauguration. Certain changes expected over this 20-year timeframe can be predicted with some degree of accuracy. These include changes in traffic conditions and vehicle emission rates. Certain other potential changes, such as those in background pollution cannot be predicted with any degree of accuracy.

5.4   The local air quality impacts are assumed to be limited to a distance of approximately 500 m from the transportation facility, in each direction[28]. For highways, the 500 m will be measured from the edge of the mixing zone (travelled road plus 3 m on each side) to the appropriate lived-in

building (point of the building closest to the highway). The choice of a 500 m limit is based on empirical evidence for heavily travelled large highways, which clearly indicates that the concentrations of road-related pollutants drop to within 101% of their background pollution levels over this distance. The same criterion may not apply to transportation facilities of a vastly different nature such as harbours and airports.

5.5   Within the 500 m range, pollutant concentrations will be assessed for all critical receptors and representative sensitive receptors (i.e., residences). Isoconcentration contour maps will be also produced to allow easy assessment of concentrations over the entire study area.

5.6   Commercial and industrial buildings will be deemed outside of the scope of this analysis. The air quality requirements of this sector are addressed by occupational health and safety rules.

5.7   Outdoor and indoor air pollutant concentrations will be assumed equal. This is a conservative assumption.

5.8   The assessment will include the proposed mainline highway, its on/off ramps, interchanges, bridges, service roads and any other travelled structures. It will also include any existing arterial roads within 500 m of the mainline highway that carry 10% or more of the expected traffic on the mainline highway. All other planned new arterial roads within 500 m of the highway will be included. This guideline presumes that the air quality impacts of existing roads are already included in the background pollution levels unless they carry a large traffic volume (more than 10% allocated to the highway).

5.9   In the CAL3QHC application, the mainline highway and its ancillary travelled elements will be split into links with substantially uniform geometry and traffic conditions. Separate links will be defined for each traffic direction. Signalized intersections will be modelled as individual links. No link will stretch over 10 km.

5.10   Uniformity in mainline highway geometry will be assessed in terms of road width, curvature and slope. Mainline highway links will be devised so as to present substantially constant width, curvature and slope.

5.11   Traffic conditions will be quantified in terms of three parameters: i) traffic volume (vehicles per hour); ii) average traffic speed (km/h); and iii) percentage of the total traffic volume represented by all heavy-duty vehicles (GVWR > 8,500 lb). These traffic conditions will be assessed for the three analysis timeframes.

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[28] For a highway, this amounts to a 500-m band on each side of the highway, with appropriate adjustments for interchanges and ramps.

5.12   Traffic conditions will be derived with validated traffic demand forecasting models. The air quality modeller will assess the accuracy of the data and seek explanations where anomalies are detected.

5.13   Emission factors will be derived according to the methodology in Appendix 2 of this document.

5.14   Two sets of traffic conditions will be needed. The first set will apply to weekdays and the second to weekends (no special provision is made for holidays). Each set will include, hour-by-hour, total traffic volume, average traffic speed and percentage of the traffic represented by heavy-duty vehicles. The weekday conditions will be applied to each weekday of the year. Similarly, the weekend conditions will apply to each Saturday and Sunday of the year.

5.15   The meteorological data requirements for the comprehensive analysis include surface wind direction and velocity, stability class, and mixing height.   These are obtainable from public and private meteorological stations that monitor the surface and the upper air.

5.16   The full-year meteorological data (surface and upper air data) needed for the data will be acquired from the nearest meteorological station(s) (usually, the nearest airport). The five-year average meteorology for the most recent five years constitutes the preferred data set. However, in case five years' worth of data is difficult to obtain, the meteorology of the most recent year will be deemed sufficient. The meteorological data will be processed with the U.S. EPA PCRAMMET data processor to generate the inputs for the dispersion model.

5.17   The meteorological data used in dispersion modelling will be documents in the study report as wind roses and frequency distributions.

5.18   The surface roughness length will be set for the prevailing land use in the study area in accordance with Table 1 of this Appendix.

5.19   The settling and deposition velocities of the gas-phase compounds will be set at zero, indicating no measurable deposition under any condition.

5.20   The settling velocities for $PM_{2.5}$ and PM_{10} will be set at 0.02 and 0.3 cm/s, respectively.

5.21   The deposition velocities for $PM_{2.5}$ and PM_{10} will be set at 0.1 and 0.5 cm/s, respectively.

5.22   The concentrations predicted by the dispersion model represent the impact of the highway (i.e. the expected change in concentration). They

are added to background pollutant concentration levels to predict final concentration levels.

5.23   The background pollutant concentration levels to be used in the comprehensive analysis are those concurrently measured with the meteorological data. In case these data are not available or difficult to process, the 70th percentile of the most recently measured and complete concentration data from the nearest MOE or Environment Canada air quality monitoring station will be accepted.

5.24   The potential pollutant concentration effects of existing and planned large sources of pollution in the immediate vicinity of the project site will be explicitly taken into account in a limited cumulative effects analysis.

5.25   The averaging period for all gas phase pollutants is one hour and that of particulate matter 24 hours.

5.26   For each pollutant studied, the predictions of the comprehensive analysis will be presented as cumulative frequency curves of concentration versus time at critical receptors and representative sensitive receptors (i.e., residences).   These curves will display, among other things, the percentage of time over a year the pollutant is expected to spend at, above or below any concentration level within the range of concentrations predicted.

5.27   In addition to the cumulative frequency charts the study report will include the maximum, mean and median concentrations predicted for each pollutant and a comparison of these with applicable provincial and national criteria and standards.

5.28   The cumulative frequency charts will be used to assess the period over which any pollutant may exceed the ambient pollution criteria or standards.

The results of the comprehensive analysis can be used to compare transportation and route alternatives. In this application, the following approach can be devised to arrive at an objective single score for each alternative:

• Select the pollutant that least conforms to the criteria/standards – say, pollutant A.
• Compare alternatives with respect to local community exposure to pollutant A. This may be achieved by creating the following sum with annual average pollutant concentrations:

Score = ∑ (Weighting factor) x (Concentration of A at receptor/AAQC or CWS for A) +
∑ (Average concentration of A for subdivision/AAQC or CWS) x
(Number of residences in the subdivision)

- The above sum is calculated by accounting for all critical receptors and all sensitive receptors in residential subdivisions (or portions of subdivisions) within 500 m of the highway segment of interest, as defined under Point 5.4 above.
- The average concentration for a subdivision may be assessed by averaging predicted concentrations at representative receptors within the subdivision or at the geometric centre of the subdivision, if this can be justified scientifically.
- Weighting factors will be devised for each critical receptor, based on the average number and condition (age/health status) of attendees. The weighting factor for the residences (sensitive receptors) is set at one. Commercial and industrial buildings are not considered in this score.
- The alternative with the lowest score would be the preferred alternative with respect to air quality.

The results of the comprehensive analysis provide superior means to assess the acceptability of the "preferred option". This assessment will include a rigorous discussion of the following considerations:

- Are the AAQC and CWS met at all critical receptors? If not, what are the extent, magnitude, and duration of the exceedances?
- Are the AAQC and CWS met at all sensitive receptors? If not what is the extent and duration of the exceedances?
- What are the causes of any exceedances? The causes will include the contributions of highway traffic related pollution and background pollution.
- What are the contributions of the principal traffic related pollution – (i.e., exhaust emissions, evaporative emissions, break/tire wear products and re-entrained road dust)?
- What are the trends over time? Is highway traffic related pollution expected to increase or decrease over time? What are the principal contributors to the predicted trends?
- What are the differences between the build and no-build scenarios, over the 20 year timeframe? What are the principal contributors to the predicted differences?

Thorough scientific discussion of above considerations is expected to lead to a rationale assessment of the air quality implications of the preferred option. If warranted, this discussion will be continued in Appendix 5 to address mitigation options.

APPENDIX 4:   Assessment of Regional Air Quality and CC/GHG Emission Impacts

1.   INTRODUCTION

Large provincial transportation projects have the potential of influencing transportation and other economic and social activities much beyond their confines. In this process, they may significantly alter the distribution and the rate of air emissions in the region and thereby affect, incrementally, regional air quality and contribute even to global climate change.   These effects are real but very difficult to quantify.

Specifically, the following challenges have to be addressed in devising a practical regional air quality and greenhouse gas emission impact assessment approach:

- Predicting the net effect of a proposed project on regional transportation activity over a 20-year timeframe.
- Adopting a scientific assessment approach that can be applied reliably and routinely with all major transportation projects at a "reasonable" cost.
- Devising a quantitative method that will always provide an unambiguous measure of an individual project's expected long-term air impacts and can be readily used to compare transportation alternatives.
- Choosing a technique that applies to both air quality and climate change (GHG emission) impacts.

This Appendix is intended to provide a reasoned recommendation that addresses the above-noted challenges.   It includes a short discussion of regional air quality and greenhouse gas emission impacts in Ontario, explores alternative assessment methods, and recommends a uniform practical approach to assess these two impacts.

1.1   Describing Regional Air Quality

Regional air quality is commonly described in terms of the concentrations of regionally important air pollutants. These concentrations vary with time and location. Hence, they have to be treated statistically. The two statistical parameters of special interest are the average and the peak (or near-peak) values of the concentrations. The averages take on a more precise meaning with the stipulation of the averaging period and the extent of the region.

The definition of the regionally important pollutants, the averaging periods of pollutant concentrations, and the spatial extent of the region are integral to the assessment methodology and are discussed in this section.

1.1.1 Regionally Important Pollutants

Current knowledge on health and environmental effects clearly identifies ground level ozone (O_3) and fine particulate matter ($PM_{2.5}$) as the two pollutants of greatest regional importance. They are the major constituents of smog and are produced by numerous physical and chemical processes that usually take place over extended periods of time and over large geographic areas. During air pollution episodes, their concentrations are elevated over large areas in parts of Canada. Hence, the Canadian Council of the Ministers of the Environment has seen fit to impose national O_3 and $PM_{2.5}$ standards (Table 2 in Appendix 1), which came into effect in 2010.

Ozone and most $PM_{2.5}$ are secondary pollutants. They are formed from primary pollutants or precursors, which include NOx, CO and VOCs. Regional air quality management encompasses measurement and control of these primary pollutants. They not only contribute to the formation of O_3 and $PM_{2.5}$ but also to smog, acid rain and other pollution phenomena and present direct human health hazards. Hence, they need to be included in both local and regional air quality impact assessments.

1.1.2 Averaging Periods for Pollutant Concentrations

In local air quality impact assessments, the averaging periods for air pollutants are dictated by the AAQC and CWS (Table 2 of Appendix 1). These same averaging periods, which vary from one hour to twenty-four hours depending on the pollutant, apply also for regional assessments. They are most appropriate for acute health effects. A one-year averaging period is deemed relevant to pollutants, such as O_3 and $PM_{2.5}$ that may pose chronic health risks.

From a regulatory perspective, the near-peak 8-hour average for O_3 (4th highest measurement annually, averaged over 3 consecutive years) and the near-peak 24-hour average for $PM_{2.5}$ (98th percentile ambient measurement annually, averaged over 3 consecutive years) are of particular interest. They establish whether the Canada Wide Standards (CWS) are met. The highest concentrations of these regionally important pollutants occur during air pollution episodes, which are often caused by unfavourable large-scale meteorological conditions.

1.1.3 Spatial Extent of the Region

From an air pollution meteorology perspective, the maximum spatial extent relevant to regional air pollution is the air shed, which for Ontario includes the province as well as twenty-two neighbouring mid-western and eastern U.S. states[29]. Emissions in the air-

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[29] Ontario Ministry of the Environment, "Air Quality in Ontario – 2006 Report", Queen's Printer for Ontario, 2007.

shed shape Ontario's air quality. The contribution of the neighbouring jurisdictions varies with meteorological conditions. Higher levels of O_3 and $PM_{2.5}$ are generally associated with slow moving high-pressure systems south of the Great Lakes.

From a jurisdictional perspective, the spatial extent of the region may be defined as the Windsor-Ottawa corridor or Southern Ontario[30]. This is the most populated region and arguably most polluted portion of Ontario.

From a practical project-level air quality impact assessment perspective, the region may be confined to the total geographic area serviced by the transportation project and its immediate transportation network. This operational definition encompasses the sources of pollution the project may have an influence on and omits all other sources in the airshed.

1.2   Regional Air Quality In Ontario

1.2.1   Recent Trends

The most recent MOE report[31] on Ontario's air quality indicates that the Province is currently enjoying relatively good air quality, which in many respects is improving. However, it also indicates that O_3 and $PM_{2.5}$ concentrations continue to exceed the AAQC and CWS. There were 6 smog advisories covering 17 days between May and August 2006. Ozone exceeded the eight-hour-average 65 ppb CWS at 19 of the 20 monitoring sites. It exceeded the one-hour-average 80 ppb provincial AAQC at 35 of the 38 sites. The maximum 1-hour average for the province was 115 ppb (MOE Station 31190, 301 Front Street W., Toronto). $PM_{2.5}$ exceeded the 24-hour-average 30 µg/m3 CWS at 5 of the 18 sites. The maximum 24-hour average for the province was 49 µg/m3 (MOE Station 44008, Hwy 2/ North Shore Blvd. E., Burlington).

On the other hand, the NO_2 and CO concentrations, which are more directly related to local transportation activity, did not exceed the AAQC at any one of the MOE monitoring sites during 2006. In fact, they have been steadily declining since 1971. According to MOE[32], Ontario's O_3 and $PM_{2.5}$ problems are largely attributable to air emissions in the U.S. Midwest and Ohio Valley. Hence, reducing emissions across the entire airshed appears to be necessary for reducing Ontario's O_3 and $PM_{2.5}$ levels significantly.

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[30] The U.S. Clean Air Act divides the U.S. into air quality control regions and holds each region and its state government responsible to meet national ambient air quality standards. There is no parallel arrangement in Canada.

[31] Ontario Ministry of the Environment, "Air Quality in Ontario – 2006 Report", Queen's Printer for Ontario, 2007.

[32] Ontario Ministry of the Environment, "Transboundary Air Pollution in Ontario", 2005.

1.2.2   Attribution of Pollution to Local and Distant Sources

On days when Ontario exceeds the 65 ppb 8-hour average for O_3, stopping Ontario emissions of O_3 precursors would reduce ambient O_3 concentrations in Windsor by 1%, in the GTA by 9%, in Oshawa by 16%, and in Kingston by 7%. On days when the 24-h average for $PM_{2.5}$ exceeds 30 μg/m^3, the contribution of Ontario sources appears to be 20% in Windsor, 50% in the GTA, and 40% in Ottawa.

Ontario is not just a recipient of regional air pollution; it is also a contributor to it. According to MOE, it contributes approximately 16% of the $PM_{2.5}$ in Quebec, 20% in upper state New York, and 7% in Vermont and New Hampshire. Its contribution to the O_3 concentrations in these jurisdictions is estimated at approximately 3%.

1.3   Climate Change and GHG Emissions

Climate Change is attributed to anthropogenic emissions of greenhouse gases (GHGs), wherever they occur. According to Natural Resources Canada (NRCan)[33], Ontario's total GHG emissions were 204.9 mega-tonnes (Mt) in 2004 and transportation contributed 62.8 Mt or 30.6 % of the total. NRCan expects transportation's contribution to increase steadily to 79.6 Mt or 34.3% of the total provincial GHG emissions by 2020. While these figures may decline as Canada and Ontario undertake GHG mitigation measures, transportation is likely to remain the largest sectoral contributor to Ontario's GHG emissions in the foreseeable future.

In view of above considerations, the only effective transportation policy to reduce transportation's role in regional air quality and Climate Change is the reduction of all contributing emissions.

2.   ASSESSMENT OF REGIONAL AIR QUALITY IMPACTS

2.1   Rationale For Assessment

Individual transportation projects are not likely to lead to large changes in Ontario's air pollutant emission inventory. A major project causing a 5% or 2.3 billion km/year[34] change in the total annual vehicle kilometres travelled on Ontario's provincial highway system would change Ontario's emission inventory by no more than 1.25%, as indicated in Table 1.

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[33] Natural Resources Canada, "Canada's Energy Outlook: The Reference Case", 2006.

[34] At present, approximately 46 billion kilometres of travel occur on the entire provincial highway system in Ontario by all types of vehicles.

According to MOE[35], this would impact regional concentrations of O_3 and $PM_{2.5}$ by much less than 1.25%. On the other hand, the local impacts of such a project would invariably be much more significant. Hence, while recognizing the importance of regional air quality, MTO and other Canadian transportation agencies are more concerned with local impacts of planned transportation projects. Federal and provincial agencies responsible for the environment and human health have the additional concern of protecting regional air quality. They have expressed their interest in the regional air impacts of individual transportation projects.

There is a North American example for regional air quality impact assessment. U.S. states conduct such assessments as part of their state implementation plans (SIPs) to demonstrate attainment of national ambient air quality standards[36], particularly with respect to O_3 and $PM_{2.5}$. These two pollutants can be assessed only at the regional level, not at the local level. It is important to note however that the scope of SIPs is regional emissions from all sources – not individual project emissions. The U.S. EPA provides the methodology and the scientific tools[37] for this effort. It prescribes an assessment methodology that is tailored to the region's air quality status. Under the U.S. EPA rules, Ontario, with its relatively favourable air quality record would not be prescribed the rigorous airshed modelling approach reserved to areas with serious air quality issues[38].

Ontario can, however, benefit from air quality impact assessments, if these include the broader area-wide network effects of individual transportation projects and thus provide the opportunity for a more comprehensive assessment of project options.

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[35] Ontario Ministry of the Environment, "Transboundary Air Pollution in Ontario", 2005.

[36] The U.S. EPA expects states with non-attainment areas to demonstrate the conformity of their transportation plans with SIPs and thus attain NAAQS. In Ontario, regional transportation planning is not subject to the environmental assessment process. Hence, regional air quality implications of transportation are not addressed in the provincial transportation planning process.

[37] U.S. Federal Register, Environmental Protection Agency, 40 CFR, Pt. 51. App W – Guideline on Air Quality Models (2003) and Revision to the Guideline on Air Quality Models: Adoption of Preferred General Purpose Dispersion Model and Other Revisions; Final Rule (2005).

[38] The U.S. Clean Air Act Amendments of 1990 classifies U.S. air quality regions that do not meet the NAAQS as "extreme", "severe", "serious", "moderate" and "marginal non-attainment areas".

Table 1: Emission Contribution of a Hypothetical New Highway

POLLUTANT	EMISSION FACTOR (g/km)	ABSOLUTE PROJECT IMPACT (tonne/year)	PROVINCIAL EMISSION INVENTORY (tonne/year)	RELATIVE PROJECT IMPACT (%)
CO	18.8	27,025	2,398,256	1.12
NOx	4.5	6,469	459,777	1.41
VOCs	1.35	1,940	436,121	0.44
$PM_{2.5}$	0.075	108	70,418	0.15
PM_{10}	0.090	138	92,401	0.15

Note: The provincial emission inventory (4th column in Table 1) was obtained from the 2007 NPRI and includes man-made emission sources only (i.e., it does not include open and natural sources of pollution).

2.2   Potential Assessment Approaches

2.2.1 Airshed Simulation with Atmospheric Chemical Transport Models[39]

The regional air quality impacts of planned transportation projects can be simulated, in principle, with atmospheric chemical transport models. These are detailed mathematical representations of known physical and chemical processes that pollutants undergo in the airshed[40]. They attempt to account for the space and time dependent rates of production, physical and chemical transformation, transport, and removal of pollutants such as O_3 and $PM_{2.5}$ in the airshed. The modelled processes are highly nonlinear and interactive, which means that all relevant biogenic and anthropogenic processes across the airshed have to be simulated simultaneously – not just those associated with the project at hand. This is especially true for predicting ozone concentrations.

To date, a number of sophisticated models have been demonstrated to predict regional pollutant concentrations within approximately 20%. The U.S. EPA's MM3 (Model 3 Air Quality Modelling System) and Environment Canada's AURAM are two such models[41]. The U.S. EPA requires the use of MM3 or a similar model in the air quality management process of regions with serious air quality issues, as defined by the U.S. Clean Air Act. Environment Canada does not have such a requirement – possibly because no region in Canada is subject to the serious air quality issues faced by U.S. regions.

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[39] Seinfeld, J.H. and Pandis, S.N. (1998) Atmospheric Chemistry and Physics: From Air Pollution to Climate Change. John Wiley & Sons, Inc., Toronto / U.S. National Research Council (1991) Rethinking the Ozone Problem in Urban and Regional Air Pollution. National Academy Press, Washington, D.C.

[40] There are two major types of airshed simulation models: Lagrangian and Eulerian. Lagrangian models simulate changes in the pollutant content of a package of air as it moves from point to point over the region (airshed). Eulerian models simulate changes in the concentration of pollutants at a set of fixed points (a grid of points) over the entire region. Hence, the can, in principle, predict the temporal and spatial variation of pollutant concentrations.

[41] MM3 is actually a modelling system that allows assessment of air quality at more than one geographic scale.

In theory, MM3 or AURAM could be used to predict the extent to which a transportation project might alter future air quality in Ontario. However, in practice, the regional air quality impact of a single transportation project is likely to be too small to discern with these models and the readily available input data. Furthermore, the current state of Ontario's air quality does not appear to warrant this very resource intensive approach.

2.2.2 Empirical Source-Receptor Modelling

Above difficulties mean that regional airshed modelling remains impractical in Ontario at the individual transportation project level. Hence, at this time, it cannot be recommended for routine application in environmental assessment projects.

A less ambitious approach involves empirical modelling, which is built on the premise that there is a quasi-permanent, long-term emission-concentration relation for each pollutant in a given region. Environment Canada and RWDI AIR Inc. have developed such an empirical model, the Reduced Form Source-Receptor Tool (SRT).[42] RWDI have applied this spreadsheet model in a number of studies for the federal government, the Ministry of Transportation of British Columbia, and the British Columbia Lung Association.

The basic relation in this model postulates a linear relationship between relative changes in concentration and emissions of primary pollutants[43]:

$$\Delta C_i = (C_i - C_{i,b}) \times \frac{\Delta E_i}{E_i}$$

In this equation, C_i represents the regional concentration of a pollutant (pollutant i), $C_{i,b}$ the portion of this concentration that is due to transboundary pollution. ΔC_i represents the predicted change in the concentration of the pollutant in response to a change in its regional emissions, ΔE_i, relative to its baseline regional emission inventory of, E_i.

The relations for $PM_{2.5}$ and O_3 are somewhat more complicated. The primary component of $PM_{2.5}$ is handled by the basic source-receptor equation above. The secondary components of $PM_{2.5}$ (i.e., the sulphate, nitrate and ammonium components), are handled individually by modifying the basic equation to reflect the concentration relationship between each secondary pollutant and its precursor(s). In the case of O_3, SRT assumes that the O_3 the concentration response depends on the emission rate of the limiting precursor only, (i.e., VOCs or NO_x).[44] It also assumes that this is a simple nonlinear relation with 0.5 power dependence.[45]

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[42] RWDI AIR Inc., "User Manual for Reduced Form Source-Receptor Tool for Air Quality Policy Impact Analysis, v.1.1", Internal Document (May 2005).

[43] The basic equation can be improved with weighting factors that account for differences in types of emission sources. For instance, tall stacks can be recognized for having a smaller impact than ground-level sources.

This model can be readily used to estimate changes in annual regional concentrations of pollutants in response to predicted emission rate changes. In other words, it can estimate ensemble average concentration changes, but does not provide temporal and spatial resolution. Hence, it cannot be used to simulate air pollution episodes or predict regional pollution hot spots.

There are also questions about its accuracy. The accuracy of an empirical model such as the SRT depends largely on the robustness of its relations and the quality of the baseline regional emission inventory and pollutant concentration data it is built on. These attributes can be ascertained by applying the model over longer time intervals (say 10 years) to verify its ability to cope with changes in the emission inventory. Some of the changes of particular interest are those in the regional VOC composition, VOC/NO_x ratio, the share of transboundary pollution, and the distribution of emissions among major sources. Such changes are not likely to occur over a short period of time. Until this assessment is carried out, the accuracy of empirical modelling to predict impacts on the important secondary pollutants, O_3 and $PM_{2.5}$, will remain uncertain.

Above issues suggest that empirical modelling, and specifically SRT, is not ready for routine application. This tentative conclusion may be revisited when Environment Canada or MOE provide SRT or an equivalent with an appropriate assessment of its accuracy and utility for transportation projects. In Ontario, only these two regulatory agencies have the jurisdictional and technical ability to assemble such a model.

2.2.3 Regional Air Pollution Burden Analysis

A number of conclusions can be drawn from the above discussion and the material in the preceding appendices. The linkages between regional pollutant concentrations and emissions are inherently complex. Current models, even in the hands of experts, do not have the resolution to accurately predict changes in regional pollutant concentrations due to individual projects. Air quality in Ontario is heavily influenced by emissions in the U.S., but remains relatively good. Transportation emissions of CACs are on a declining trend thanks to stringent emission standards. Hence, project level regional air quality impact assessment with mathematical or empirical airshed models is neither advisable nor necessary.

It is important however to minimize the pollution burden of individual transportation projects by deploying the best available planning and technological means. In order to ensure that this general principle is upheld, project related emissions should be

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[44] The question of whether NO_x or VOCs are the limiting precursor is an important and difficult issue, which affects not only modelling but also the pollution abatement strategy for the region.

[45] The net production rate of O_3 is subject to scores of chemical and physical transformations, which are strongly influenced by meteorological conditions and the composition atmosphere.

quantified in the most comprehensive and accurate manner. This approach is often called "burden analysis". It is equally applicable to primary air pollutants and greenhouse gases.

Burden analysis entails quantitative assessment of the net increase or decrease in pollutant emissions attributable to the project. Its scope includes the project as well as its effects on the existing transportation network. Thus, it involves a more regional and comprehensive approach, which should help identify the best transportation and route options with respect to regional air quality impacts at the project planning and design stage.

Burden analysis is a practical, systematic approach to recognize and compare the project's and its alternatives' regional contributions to air pollution. At this time, mathematical or empirical airshed modelling, are not as practical and useful in guiding project planning and design. They are more suited to assess the regional air quality implications of a whole sector or of broad measures such as the adoption of new emission standards.

Above considerations lead to the conclusion that "burden analysis" is the preferred approach to assess the regional air quality implications of individual projects. Hence, the recommended methodology in Section 2.2.4 will deal solely with this approach.

2.2.4 Recommended Methodology for Regional Air Quality Burden Analysis

In the broadest sense, the regional pollution burden of a project entails the net effect of the project on regional emissions of relevant primary pollutants. It includes the emissions incurred/avoided by the transportation project (e.g., a new highway or transitway) and the associated transportation network over a 20-year timeframe. The methodology to calculate the emission rates of the relevant pollutants is similar to that recommended for the assessment of local air quality impacts in Appendix 2 and 3. The assessment of net effects adds, however, an important task; namely, the assessment of the network effects of the project.

The prediction of the project's network effects over a 20-year timeframe is a major transportation demand modelling task. The methodology for this task is beyond the scope of this document and is well known to MTO and the transportation engineering community. The outline below provides the principal tasks involved in burden analysis. It has been written with large highway projects in mind, but can be generalized to other transportation projects.

1. Estimate total transportation demand associated with the transportation project proper for three time frames: immediately following completion of project, 10 years from project completion and 20 years from project

completion. These estimates will be generated by integrated land use and transportation demand modelling and will encompass passenger and freight transportation. Demand will be expressed in vehicle kilometres travelled per year by facility and vehicle type.

2. Estimate emission factors specific to each pollutant (designated by the subscript *i*), facility type, and vehicle type. The pollutants of regional significance are CO, VOC, NO_x and $PM_{2.5}$. The emission factors will account for exhaust and evaporative emissions as well as tire and brake wear; however, they will not include re-entrained road dust, since this component of the regional $PM_{2.5}$ is small, has lesser health implications, and is difficult to predict accurately. Most road dust falls into the coarse fraction of PM_{10}, which will not be included in regional air quality impact assessment due its short range and lesser significance in regional air pollution. The facility types are dictated by the nature of the transportation project. For highways, the principal types include mainline highway, service roads, and ramps. Two vehicle classes will be considered: light- and heavy-duty vehicles. At present, the vast majority of light-duty vehicles run on gasoline and heavy-duty vehicles on diesel fuel. Emission factors will be derived with the US EPA's MOBILE 6.2 computer model or an equivalent model. The recommendations of this Environmental Guide regarding the application of MOBILE 6.2 are included in Appendix 2.

3. Estimate total annual vehicle emissions for the project proper by carrying out the following nested summation for each individual pollutant:

$$Total\ Annual\ Emissions\ of\ Pollutant\ i =$$
$$\sum_{Facility} \sum_{Vehicle} EF_i(Facility, Vehicle) \times VKT(Facility, Vehicle)$$

In this equation, EF_i stands for the emission factor specific to a pollutant (designated by the subscript i), facility type, and vehicle class; *VKT* stands for the corresponding annual vehicle kilometres travelled. Summation of the product of emission factors and vehicle kilometres travelled first over all vehicle classes and then facility types will produce the grand total of expected annual emissions on all facilities making up the project.

4. Estimate the transportation network effects. This involves the passenger and freight transportation demand impact of the project on all significantly affected regional transportation facilities, in VKT per year by facility and vehicle type, for three time frames: immediately following completion of project, 10 years from project completion and 20 years from project completion. The decision on which facilities are significantly affected will be made by the responsible MTO transportation/traffic engineer and will include assessment of foreseeable traffic conditions as well as expected demographic, employment, land use and other relevant developments.

The overall net demand change on affected facilities may be negative (a reduction) as the new facility (the project) attracts demand from existing and presumably less "efficient" facilities.

5.   Based on the passenger and freight transportation demand (VKT) estimates of Step 4, predict total annual vehicle emissions of CO, VOCs, NO_x and $PM_{2.5}$ generated on all affected regional transportation facilities (the network effect) by applying the methodology described under Steps 2 and 3 above. Emissions will be segregated by year, facility type and vehicle type.

6.   Calculate the net emission impacts of the project proper and its associated transportation network by combining the results of Steps 3 and 5 above. Net emission impacts will be estimated for the three time frames specified in Step 1 and will be segregated by year, facility type and vehicle type.

7.   Assess regional significance of the projected net emission impacts by comparison with appropriate statistics, such as those provided in Table 2, and published regional airshed modelling studies for Ontario and other jurisdictions.

8.   Perform the analyses in Steps 1–7 for each relevant transportation and route alternative, including the no-build alternative, to provide the opportunity for a comprehensive assessment of all relevant options from a regional air quality impact perspective. The most desirable air quality consequence of a transportation project is a net reduction in the regional emission of criteria air contaminants by transportation. In other words, the build scenario results in less emission than the no-build scenario. Some transportation projects such as mass transit projects often deliver this positive outcome immediately. With road projects such a positive result may be achieved over time.

Table 2: Air Pollutant Emissions in Ontario

(Environment Canada, National Pollution Release Inventory, Reviewed Data Release, May 2009)

PROVINCIAL POLLUTION SOURCE	ANNUAL EMISSION RATE (tonne/year)			
	CO	VOC	NO$_x$	PM$_{2.5}$
All Provincial Sources	2,583,980	4,421,998	479,395	255,265
All Transportation Sources	2,066,933	160,625	310,812	16,464
Road Transportation - Passenger	1,052,988	53,323	59,438	749
Road Transportation – Freight	26,257	3,249	64,434	1,517
Rail Transportation	5,336	964	35,751	1,213
Marine Transportation	1,213	478	14,252	1,183
Air Transportation	18,105	3,782	24,673	303
Off-road Transportation	963,032	98,835	112,263	11,497

Note: The May 2009 NPRI report, which is the source of the above table, is based on 2007 emissions (the latest complete data set available).

3. ASSESSMENT OF REGIONAL GHG EMISSION IMPACTS

With Climate Change, the most appropriate and practical metric to assess the impact of the project is the annual emission of greenhouse gases (GHGs). The global atmospheric concentrations of these gases have been gradually rising since the industrial revolution, mainly due to the rising consumption of hydrocarbons but also many other anthropogenic (man-made) influences. This is a truly global phenomenon with global causes and consequences. It is very difficult to associate concentrations of GHGs in the atmosphere with specific regions or activities. However, it is relatively easy to associate emissions of GHGs with specific regions and activities and to make comparisons with national and provincial targets such as those announced in Ontario's 2007 Action Plan on Climate Change. This Plan includes sectoral GHG reduction targets for 2014 and 2020, which are listed in Table 3.

Table 3: Ontario's GHG Emission Reduction Targets
(Action Plan on Climate Change – 2007)

Year	Actual/Projected Provincial GHG Emissions (Mt CO_{2eq})	Provincial Emission Target (Mt CO_{2eq})	Provincial Reduction Target (Mt CO_{2eq})	Reduction Target for Passenger Transportation (Mt CO_{2eq})	Reduction Target for Freight and Diesel (Mt CO_{2eq})
1990	177				
2004	203				
2014	227	166	61	3.05	3.05
2020	249	150	99	12.87	5.94

Notes:
1. The 2004 GHG figure in this table is slightly lower than the NRCan figure (204.9 Mt) quoted in Section 1.3 of this Appendix.
2. NRCan estimates Ontario's 2004 GHG emissions at 62.8 Mt.

The most prevalent transportation GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).   Carbon dioxide, along with water vapour, is the main combustion product of common transportation fuels. It is the most abundant anthropogenic GHG. Methane and nitrous oxide are by-products of the combustion of common transportation fuels.   Their atmospheric concentrations are smaller than that of CO_2. However, they are more potent greenhouse gases than CO_2. This potency is expressed as a relative global warming potential, whose commonly assessed values for a 100-year time horizon are provided in Table 4.

Table 4: Global Warming Potentials for 100-Year Time Horizon
(IPCC Fourth Assessment Report - 2007)

Greenhouse Gas	Lifetime (Year)	Global Warming Potential
CO_2	5 – 200	1
CH_4	12	21
N_2O	114	310

The global warming potential of each gas is taken into account to express GHG emissions from a source in terms of a single parameter – namely, CO_2 equivalent (CO_2-eq) emissions. Specifically, for transportation vehicles, the global warming potentials are used to calculate the weighted sum of the emission rates of CO_2, CH_4, and N_2O, which yields the CO_2-eq mass emitted per unit of distance (with the usual units of "grams of CO_2-eq per kilometre"). This convention is adopted here.

In transportation, the term "GHG emissions" usually refers to tailpipe emissions of GHGs - consistent with the emissions of CACs. This definition omits the GHGs emitted

and/or absorbed in the production and distribution of the fuel. Hence, it does not account for all the GHGs associated with the fuel. Furthermore, it does not recognize the amount of CO_2 absorbed in the production of biofuels. With full accounting for all the GHGs created and absorbed in the life cycle of the fuel, one can, in principle, associate a fuel-cycle emission factor with each type of fuel.

The calculation of fuel-cycle GHG emission factors is, however, complicated by the fact that there is no unique life cycle for any fuel. Fuels are produced with different raw materials and processes, distributed through different means, and used in different ways – implying a spectrum of GHG emission factors for the same fuel. Hence, one can at best speak of a representative GHG emission factor for a fuel, representing the dominant life cycle(s) of that fuel for a given country or region. This approach has been adopted in a number of computer models that essentially integrate the empirical data available for various transportation fuels and their respective dominant life cycles.

University of California (Mark Delucci) developed the first publicly available fuel cycle GHG emission model: The LEM. With U.S. Department of Energy sponsorship, Argonne National Laboratory (Michael Q. Wang) developed a second model: GREET. Natural Resources Canada sponsored Connor and Levelton Associates to "Canadianize" the LEM, producing GHGenius. These models build primarily on empirical data that reflect current and past industry practices in various parts of the world. They need periodic updates to maintain relevance. However, even then, their use to predict future fuel cycles and corresponding emission factors is problematic.

Given above issues with fuel-cycle GHG emission factors and the inconsistency with how CAC emissions are treated (tailpipe only), the utility of fuel-cycle emission factors in this Environmental Guide is debatable. The regional GHG emission implications of transportation projects can be assessed, consistent with the approach proposed for CACs, by comparing the build and no-build scenario emissions and assessing their significance relative to benchmarks such as provincial transportation GHG emissions. These comparative analyses can be carried out, without loss of accuracy or relevance, with tailpipe emissions, unless the use of alternative fuels or electricity is central to the project, in which case project relevant fuel-cycle emission factors can be developed and used. This general approach is described in the recommended methodology below.

3.1 Recommended Methodology to Predict Regional GHG Emission Impacts

The methodology in Section 2.2.4 for CAC emissions (burden analysis) is directly applicable to GHG emissions and will not be repeated here. In fact, once the transportation demand projections are available, the CAC (pollutant) and GHG emission implications of the project can be calculated readily with appropriate emission factors.

Most of these factors, but not all, are predictable with MOBILE 6.2C, as described in Appendix 2.

MOBILE 6.2C estimates regional fleet-average emission factors for target years. This level of aggregation is tailor-made for emission impact assessments at the regional scale. However, MOBILE 6.2C is designed to estimate only vehicle emissions, not fuel-cycle emissions. Furthermore, it addresses CO_2 emissions only, not CH_4 and N_2O emissions. The latter deficiency will be alleviated by U.S. EPA's new emission model: MOVES. It will include emission factors for all three GHGs and will replace MOBILE 6.2 by the end of 2009.

Until MOVES is officially adopted, the following steps are recommended to derive GHG emission factors for regional GHG emission impact assessment:

- In projects that do not include a transportation option dedicated to an alternative fuel or source of energy, only tailpipe emissions will be accounted for by employing tailpipe emission factors of CO_2, CH_4 and N_2O.

- Tailpipe CO_2 emission factors will be derived with the MOBILE 6.2C model, until MOVES becomes US EPA's official emission factor predictor. Tailpipe CH_4 and N_2O emission factors will be derived with the most recent Environment Canada published data as described in Section 2 of Appendix 2 of this document.

- In those projects that include one ore more transportation options dedicated to vehicles powered by alternative fuels or electricity, fuel-cycle emission factor will be employed to compare options with each other and with the no-build option. However, tailpipe emissions will be used to compare project emissions with targets or benchmarks such as Ontario's total GHG emissions and emission targets in Table 4.

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APPENDIX 5: Mitigation Options for Local Air Quality, Regional Air Quality and GHG Emission Impacts

1. INTRODUCTION

Mechanized transportation is almost invariably associated with some air pollutant and greenhouse gas emissions. Highway traffic, in particular, can elevate local pollutant concentrations and add to the pollutant and greenhouse gas burden of the region and beyond.

At the planning and design stage of a new transportation project, there is the opportunity to avoid or minimize these impacts by making appropriate planning and design choices – as noted under Task 1 and Task 2 in the body of this Guide. It is important to note that avoiding air quality and GHG emission impacts by judicial project planning and design is often much more effective than mitigation. However, in those instances where impacts remain unacceptably high, MTO will consider mitigation options and mitigate adverse impacts using those tools within its control.

There is a spectrum of mitigation options - direct or indirect measures to alleviate the negative impacts of the project. Local impacts are best mitigated by reducing local emissions and/or exposure. Regional and global impacts can only be influenced through net reductions in pollutant and CC/GHG emissions across the region. These net reductions are primarily derived from broader air quality programs (discussed under Broad Regional Air Quality Programs, below). In some cases they may be achieved through the project's influence on regional transportation activity or through unrelated measures such as the adoption of stringent vehicle emission and fuel consumption standards.

The need for project-specific mitigation is determined on a case-by-case basis. This process involves a degree of subjectivity due to the absence of clear regulatory requirements with the air quality and GHG emission impacts of mobile sources. The document at hand stipulates a need to consider mitigation of local impacts, especially where the local air quality impact assessment predicts exceedances of the provincial AAQC or the national CWS for criteria air contaminants over a significant period of time per year at a significant number of receptors. The need to mitigate regional impacts may arise if the regional air quality and GHG emission impact assessments predict a significant net addition to the regional air pollution and GHG burden.

Broad Regional Air Quality Programs - Background

To date, the most effective mechanism to reduce transportation air quality impacts has been through regulation of new vehicle emissions with gradually tightening federal

emission standards. This process was established in 1967 and since then achieved over 90% reduction in key smog causing pollutant emissions. In 1997, Canada has also started to regulate fuel quality. Specifically, the sulphur content of gasoline and diesel fuel are now subject to strict standards, which have contributed directly to a reduction in particulate matter emissions and, indirectly, to reductions in gaseous pollutants. Fuel quality standards are very effective since they immediately affect emissions of all vehicles in the region.

Ontario's Drive Clean program, which came into effect in 1999, is an important element of Ontario's effort to control emissions from in-use vehicles by mandatory inspection and maintenance. A 2005 review of the program estimates its VOCs, NO_x and CO reductions for 2005 at 7502, 7371, and 174662 tonne, respectively. The review's projections for 2010 and 2015 are slightly smaller but still very respectable. Car Heaven is another Ontario program to reduce regional pollutant emissions. Its objective is to accelerate scrappage of older and more polluting vehicles.

There are also a number of effective federal and provincial actions to reduce vehicle GHG emissions. Canada's 2005 Memorandum of Understanding (MOU) with the auto industry will reduce the GHG emissions of the new light-duty vehicle fleet by 5.3 Mt by 2010. An ambitious vehicle fuel consumption regulation was adopted to reduce GHG emissions of new light-duty vehicles over 2012-16. The objective of this regulation is to reduce average new vehicle fuel consumption from approximately 8.6 L/100km to 6.7 L/100km by 2020. This corresponds to a GHG emission reduction of approximately 22% from new vehicles.

Ontario has a number of ambitious direct and indirect transportation GHG reduction initiatives of its own. These include the Places to Grow Initiative, which is intended, among other things, to steer the province towards sustainable development and sustainable transportation. Public transit, enabled by better land use and transportation planning and better funding, is one of the cornerstones of the government's sustainable transportation effort. Thanks, in part, to new transit investments, transit ridership has increased by approximately 13% since 2002. The goal is to increase municipal transit and GO transit ridership by 3% per annum over the foreseeable future. This has significant beneficial GHG emission implications.

The Province is active in promoting more energy efficient vehicles and practices through fiscal and financial incentives, eco plates, fleet challenges, and mandates. Ride sharing is being encouraged through the introduction of HOV lanes on the provincial highway system, improvements to GO transit parking lots, and other TDM measures. A new regulation mandates the adoption of truck speed limiters, which limit truck speeds to 105 km/h. A high-speed rail system for Ontario and Quebec is currently under study.

The GHG implications of these measures may not be easily measurable. They are, however, likely to be rather significant.

Ontario is also trying to reduce GHG emissions by influencing vehicle fuel composition. To this end, a 5% ethanol mandate was introduced in 2007. There is also serious consideration being given to a fuel standard that would reduce the carbon content of all road transportation fuel sold in Ontario by 10% by 2020. The ultimate impact of this standard would be a 10% reduction in the GHG emissions of all (new and old) road vehicles.

The above government programs represent a concerted effort to curtail emissions of pollutants (criteria air contaminants) and greenhouse gases. They are clearly intended to mitigate the negative impacts of transportation on air quality and climate change. They clearly constitute mitigation of regional and global impacts.

In addition to the planned, deliberate government actions to mitigate transportation's negative impacts on air quality and the climate, there are a number of favourable market developments. These include growing public/corporate involvement in air issues, high-density residential developments, and supply of a broader range of more efficient cars and light trucks. Rising fuel prices may have contributed to some of these developments and can, potentially, cause greater reductions in fuel consumption and emissions in the long term.

2. LOCAL AIR QUALITY IMPACTS

2.1 MTO Experience with Local Air Quality Impacts:

Experience with MTO air quality impact assessments over more than a decade suggests that the principal local air quality issue regarding major highways is with particulate matter concentrations. Specifically, $PM_{2.5}$ concentrations may exceed the 24-hour CWS of 30 g/m^3 on a number of days in a typical year when highly unfavourable meteorological conditions persist. Exceedances are, however, limited to $PM_{2.5}$ and PM_{10} and to locations within 100 m from the edge of highways. None of the other criteria air pollutants have been observed or predicted to exceed the AAQC for a significant period of time over a typical year.

The role of highway traffic on local air quality, and specifically PM concentrations, is a strong function of distance from the highway. At very short range (30 m or less), large highway traffic volumes (over 100,000 vehicles per day) can contribute typically 80% of the ambient $PM_{2.5}$ concentrations. This fraction drops to approximately 50% at 100 m from the edge of the highway. With PM_{10}, concentrations drop even faster due to faster loss to deposition. The principal source of $PM_{2.5}$ from highway traffic is vehicle exhaust,

particularly diesel vehicle exhaust. The primary source of the course fraction of PM_{10} (portion of PM_{10} beyond $PM_{2.5}$) around highways is re-entrained road dust.

2.2 Local Mitigation Opportunities and Considerations:

Mitigation is best planned based on the scientific findings of the air quality impact assessment and the specifics of the project and its social and natural environments. MTO experience suggests that the need for mitigation with major highways will depend, in part, on whether any critical receptors or a large number of sensitive receptors are located very close (less than approximately 30 m) to the highway. It also suggests that mitigation should be aimed at minimizing emissions of PM and exposure to PM.

Recognizing the health hazards and primary sources of PM2.5, the federal government imposed in 2006/07 stringent diesel fuel quality and diesel engine emission standards. These standards are designed to reduce the PM2.5 from diesel-powered vehicles by 90%. The benefit of the fuel standard is immediate, while that of the engine emission standard will take 5 - 10 years to take full effect. These standards are perhaps the most effective mitigation measure possible against PM from highway traffic.

It is quite possible that in 5 - 10 years, mitigation against PM around highways may not be necessary. In the meantime, however, the following mitigation options are available for consideration around transportation, particularly highway transportation projects. The potential benefits of these options should be assessed, where feasible, by dispersion modelling prior to implementation.

Some examples of how the AQ impacts can be minimized, by either limiting or rectifying the effect, include: dust control, limiting vehicle speed, and vegetative groundcover.

2.2.1 Dust Control

Re-entrained road dust, which is the primary source of traffic related PM_{10}, can be controlled where problematic by reducing the amount of dust precursors on the road. This may be achieved by minimizing tracking of mud and other debris onto the highways and by sweeping and washing any issue areas more frequently and thoroughly.

2.2.2 Limiting Vehicle Speed

The rate at which dust is re-entrained is a function of vehicle size and vehicle speed. Larger vehicles travelling at higher speeds contribute more to dust re-entrainment and to the PM_{10} level in the atmosphere near highways. Hence, where PM_{10} levels are expected to exceed the ambient air quality criteria for significant periods of time and

affect a significant number of sensitive and/or critical receptors, the project team may consider the potential effects of speed limits.

This option is however not available for freeways (controlled access highways) and is practical only on new roads.

2.2.3   Vegetative Groundcover

Vegetative groundcover, such as grasses, shrubs and trees, along highways can enhance gravitational deposition of particles through agglomeration, impaction and interception. In particular, planted windbreaks (shrubs or rows of trees) can reduce particulate matter concentrations by several distinct mechanisms. The particle-laden air as it flows through the windbreak (bleed flow) is filtered. This process contributes significantly to a decrease in airborne particulate matter; especially, those of larger diameter.

There is a considerable volume of scientific literature on particle deposition to help design effective windbreaks or other means to enhance particle deposition. This literature suggests that there is an optimum windbreak density for a given particle size to achieve maximal deposition. Some field experiments may, however, be needed to develop more specific guidance on the best means for typical highway settings in Ontario.

3.   MITIGATION OF REGIONAL AIR QUALITY AND GHG EMISSION IMPACTS

3.2   Regional Mitigation Opportunities and Considerations

The scope for project level mitigation of regional air quality and GHG emission impacts is limited and consists mainly of the measures suggested in Section 2. Most of these measures help reduce or trap emissions and will provide both local and regional benefits.

Broader measures that target emissions from entire transportation sectors such as emission and fuel consumption standards can have a profound effect on emissions. Many such measures are already being implemented or close to being implemented by the three tiers of government, the private sector and the public at large. They are described in the introduction to this Appendix and will not be repeated here, unless they can be part of an individual project.

The remainder of this section is devoted to potential measures with a regional reach that can be considered within the context of an individual project. Most of these options (alternative transportation modes, HOV lanes, road pricing and geometric design) are

applicable to MTO's Individual and Group 'A' projects during the early stages of the planning process.

3.2.1   Provision of Transportation Modes with Low Emission Rates

Certain transportation modes, such as commuter and freight rail, can incur potentially less emissions per passenger-kilometre and per freight tonne-kilometre travelled, respectively. Preference can be given to these modes over highways, where they can adequately serve transportation needs and are economically viable. The pollutant and greenhouse gas emission benefits of these rail-based modes are in part due to their inherent energy efficiency advantage, which is particularly relevant to GHG emissions. They have further advantages. For instance, they typically enjoy higher load factors and thus lower emissions per unit of transportation service. This is particularly true in the comparison of a single occupant vehicle (car occupied by only the driver) with commuter rail. They can also run on electricity obtained from low-emission or renewable sources, producing next to no pollutants and GHGs.

3.2.2   Provision of HOV Lanes

On new highways, continuous and extensive HOV lanes can contribute significantly to the reduction of total vehicle kilometres travelled and emissions generated in the region. This potential is a function of the level of service on the highway. Under free-flow conditions, the full potential of HOV lanes cannot be realized. Conversely, under severely congested conditions, HOV lanes may not succeed.   The full potential of HOV lanes is realized with marginally congested highways, where the use of HOV lanes by ridesharing provides significant time savings.

3.2.3   Road Pricing

Road pricing through electronic tolling or other means may result in a net reduction of total vehicle kilometres travelled and emissions generated in the region. The potential of this measure will, in part, depend on the availability of alternatives to the corridor and can be estimated with transportation demand models.

Note: This measure is only applicable to new highways.

3.2.4   Highway Geometric Design

Highways that provide the most direct and shortest route between prevalent origins and destinations will help reduce vehicle kilometres travelled and emissions.   Other geometric measures that minimize the need for acceleration and braking will also help reduce emission.