Appendix 8D

Air Quality & Health Impacts

December 2010

METROLINX
An agency of the Government of Ontario

METROLINX
An agency of the Government of Ontario

APPENDIX 8D

Air Quality & Health Impacts

December 2010

Prepared for:

METROLINX
An agency of the Government of Ontario

20 Bay Street, Suite 901
Toronto ON M5J 2N8

Prepared by:

Delcan Arup JV

In Association with:

steer davies gleave
LURA
CANAC A Savage Company
LGL Limited environmental research associates
RWDI Consulting Engineers & Scientists
LTK Engineering Services
Economic Development Research Group
DPRA

METROLINX
An agency of the Government of Ontario

APPENDIX 8D
AIR QUALITY & HEALTH IMPACTS
TABLE OF CONTENTS

FIGURES

TABLES

Table 11 – Summary of threshold distances for odour ... 40

DOCUMENT DEFINITIONS AND GLOSSARY OF TERMS

Term	Definition
90^{th} Percentile	The 90^{th} percentile of a dataset is the value below which 90% of all data points in that set fall.
Airport Rail Link (ARL)	Express rail shuttle service between Union Station and Toronto Pearson International Airport.
Background Level	Contaminant concentrations in outside air excluding contributions from GO and/or ARL.
Baseline occurrence rate	The overall occurrence rate per million people of health-related type of event, such as mortality, hospitalization, emergency room visit, etc.
Benzo[a]pyrene (B[a]p)	Carcinogenic polycyclic aromatic hydrocarbon formed during incomplete combustion of fossil fuels such as gas, coal and diesel.
Central valuation estimate	The mean estimated value in dollars of a health-related event, such as a mortality, hospitalization, emergency room visit, etc.
Chemical of Concern (COC)	Contaminant identified for inclusion in the health assessment.
Carbon Monoxide (CO)	Colorless, odourless and tasteless gas which is slightly lighter than air. It is toxic to humans and animals in high quantities.
Concentration Response Factor	The percentage increase in baseline occurrence rate of a health-related event, due to a unit increase in average concentration.
Diesel Emissions	Contaminants emitted to the atmosphere in the exhaust stream of diesel combustion engines. This does not refer to emissions of diesel fuel itself, but rather the by-products associated with its combustion.

Term	**Definition**
Diesel Particulate Matter (DPM)	Particulate matter in the exhaust stream of modern diesel combustion engines. A portion of these particles are in the ultrafine size fraction.
Geographic Information System (GIS)	Computer tool that captures, stores, analyzes, manages and presents data that are linked to physical locations. For example the mapping of population data.
Greenhouse Gas (GHG)	Gases in the atmosphere that contribute to global warming and climate change. GHGs include carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4).
GTHA	Greater Toronto and Hamilton Area.
Hydrocarbon (HC)	Organic compound consisting entirely of hydrogen and carbon. Considered to be similar to volatile organic compounds (VOC) and total organic carbon (TOC) for the purposes of regional emissions assessment.
Network Options	An alternative to the Reference Case network, involving the use of a short listed rolling stock technology on one or more GO lines.
Ontario Ministry of the Environment (MOE)	Provincial body mandated with developing, implementing and enforcing regulations and other programs and initiatives aimed at addressing environmental issues that have local, regional and/or global effects.
Oxides of Nitrogen (NO_x)	Nitric oxide (NO) and nitrogen dioxide (NO_2), which are produced from the reaction of nitrogen and oxygen gases in the air during combustion.
Ozone Limiting Method (OLM)	Method used to estimate the conversion of nitric oxide (NO) emissions to nitrogen dioxide (NO_2) based on the availability of ozone for oxidation.

Term	Definition
Particulate Matter (PM)	Considered here to be pollution in the form of small particles and liquid droplets with aerodynamic diameters less than 44µm. Also referred to as Total Suspended Particulate (TSP).
PM_{10}	Particulate matter less than 10µm in aerodynamic diameter. Referred to as the inhalable size fraction of PM since it may pass through the nose and throat and enter the lungs.
$PM_{2.5}$	Particulate matter less than 2.5µm in aerodynamic diameter. Referred to as the respirable size fraction of PM since they may penetrate into the gas exchange region of the lungs.
Reference Case	The base case against which future technology and network options are compared. This base case incorporates existing attributes and approved/planned enhancements of GO's rolling stock, rail infrastructure and service levels.
Sulphur Dioxide (SO_2)	Non-flammable, colourless gas, produced during the combustion of fossil fuels (e.g., coal, diesel). May lead to acid rain and the formation of secondary particulate matter.
Tier 4	Emissions standard established by the U.S. EPA that applies to locomotives manufactured in 2015 or later.
Total Suspended Particulates (TSP)	Considered here to be pollution in the form of small particles and liquid droplets with aerodynamic diameters less than 44µm. Also referred to as Particulate Matter (PM).
Ultrafine Particulate (UFP)	Particulate matter less 0.1µm in diameter which may be inhaled deep into the lung with the potential to penetrate tissue. Diesel Particulate Matter (DPM) is typically in this size range.

Term	**Definition**
Ultra-low Sulphur Diesel (ULSD)	Diesel fuel with 15 ppm maximum sulphur content. The sulphur content of Regular Sulphur Diesel (RSD) ranges from 500 to 5000 ppm. ULSD is currently in use by GO locomotives.
United States Environmental Protection Agency (U.S. EPA)	An agency of the federal government of the United States charged with protecting human health and the environment, by writing and enforcing regulations based on laws passed by Congress.
World Health Organization (WHO)	A specialized agency of the United Nations (UN) that acts as a coordinating authority on issues of international public health with the objective of attainment of the highest possible level of health by all people.
Zone of Influence (ZOI)	Zone defined by the distance from the centre of the rail corridor within which air emissions from GO & ARL operations result in a measurable change in air quality relative to existing ambient levels.

NOTE: Use hereafter of the terms “we”, “our” or similar means “Delcan/Arup Joint Venture team”.

1. INTRODUCTION

1.1. Context

Metrolinx operates a comprehensive transportation system of bus and commuter rail lines in the Greater Toronto and Hamilton Area (GTHA). The system includes the GO rail network, which is an essential part of Metrolinx's service to the area commuters. GO Transit currently provides commuter rail service on seven corridors in the GTHA, using conventional diesel-electric locomotives and non-powered, bi-level coaches in push-pull configuration.

In late 2008, Metrolinx published a Regional Transportation Plan – The Big Move – a multimodal vision for regional transportation to strengthen the economic, social and environmental sustainability of the Greater Toronto and Hamilton Area. The Big Move sets out a fast, frequent and expanded regional rapid transit network as a key element of the plan. The plan includes establishing Express Rail and Regional Rail services at speeds and frequencies that could be enhanced by system electrification.

1.2. Metrolinx Electrification Study

Metrolinx has initiated a study of the electrification of the entire GO Transit rail system as a future alternative to diesel trains now in service. The Electrification Study examined how the future GO rail services will be powered – using electricity, enhanced diesel technology or other means – when improved services are implemented in the future. The Study assessed the benefits and costs of a full range of technology options, including enhanced diesel, electric and alternative technologies. The Study considered the existing GO Transit network, the proposed network expansions to St. Catharines, Kitchener/Waterloo, Allandale, Bloomington, Bowmanville, as well as the future Pearson Air Rail Link. The Study provides Metrolinx's Board of Directors with the information needed to decide how GO trains will be powered in the future.

As per the Appendix 1, *High Level Decision Making Framework*, the comparative analysis of network options considered 6 broad evaluation categories:

- Environmental & Health;
- User Benefits/Quality of Life;
- Social-Community;
- Economic;
- Financial; and
- Deliverability.

The final stage of the Study (Stage 5) involved conducting a detailed assessment of corridor/technology scenarios in terms of the above evaluation categories. However, for the purposes of the detailed assessment, the 6 broad evaluation categories listed above were each broken into sub-categories. The sub-categories are geared towards specific realms of knowledge and technical specialization in order to promote a comprehensive analysis.

1.3. Air Quality & Health White Paper

The evaluation category that is relevant to this White Paper is Environmental & Health. This category is broken into the following 6 sub-categories:

- Emissions Reductions;
- Noise and Vibration;
- Health;
- Terrestrial Ecosystem;
- Aquatic Ecosystem; and
- Effects on Parks / Public Open Space.

This White Paper describes the approach and results for the emissions reductions (i.e., air quality) and health assessment conducted under the overarching Environmental & Health category. Included in this paper are sections providing:

- An overview of the considerations associated with the air quality and health discipline;
- The objectives addressed by the air quality and health discipline;
- Assumptions for the air quality and health discipline;
- Criteria, indicators and data sources for the air quality and health assessment;
- Assessment of Options;
- Conclusions; and
- References.

2. OVERVIEW OF AIR QUALITY CONSIDERATIONS

This air quality and health assessment considers the question of relative air quality benefits of various options for electrification of GO Transit's rail system. A short-list of six electrification options was considered, representing electrification of different parts of the network as well as electrification of the complete network. These options were compared to the Reference Case – a hypothetical future operating scenario based on the operation of Tier 4 diesel technology throughout the rail network.

In comparing the electrification options, four types of air quality benefits were considered:

1. Benefits related to Greenhouse Gas (GHG) emission reduction and climate change;
2. Benefits to the regional airshed;
3. Benefits to local air quality in the vicinity of the corridors; and
4. Benefits related to nuisance effects (dust, visibility and odour).

2.1. Greenhouse Gases And Climate Change

The averaging temperature of the earth has increased significantly over the past century resulting in a variety of related effects, such as changes in global precipitation patterns, decline of Arctic and Antarctic ice packs, decline of glaciers, rising sea level, etc. The trend of global warming is expected to continue and human activities are implicated. Combustion of fossil fuels, for example, releases carbon dioxide (CO_2) and other greenhouse gases to the atmosphere, which influence the Earth's radiation balance and cause warming. At the same time, global deforestation depletes the Earth's population of trees, reducing their role in removing CO_2 from the atmosphere for photosynthesis.

Like all combustion equipment, diesel-powered locomotives emit greenhouse gases (GHG's). Electric locomotives may also generate GHG emissions depending on how the electricity used to power them is generated. Compared to the automobile, however, both diesel- and electric-powered passenger rail services offer an efficient way of transporting people, with a net reduction in GHG emissions. The Electrification Study has considered the difference in the amount of GGH emissions between the Reference case and each of the options.

2.2. Regional Air Quality And Health

It has been recognized for centuries that air quality can affect human health. Considerable research has been undertaken in the past 50-60 years to better understand these effects. Governmental health and environment agencies have identified chemical compounds within air pollution that have linkages to human health and have implemented policies and regulations aimed at reducing them.

In Canada, the concentrations of many air pollutants have been dramatically reduced over the past several decades as a result of various regulatory programs aimed at vehicle emissions, industrial emissions and other miscellaneous emission sources. Nevertheless, many members of the population still experience a variety of undesirable effects of air pollution. This is especially true in connection with periodic smog events, which can be quite widespread, so that the size of population exposed to the pollutants is large. Also, some air pollutants have linkages with various types of cancer when the exposure occurs over long periods of time. As a result, the desire remains at all levels of government for continued reduction of air pollution.

Collectively, motor vehicles are a major emitter of air pollutants. Passenger trains fall into this category, although their emissions are a relatively small component of all motor vehicle emissions. Furthermore, the emissions from diesel-powered locomotives are gradually declining as older engine and exhaust treatment technology is replaced with newer, cleaner technology mandated by North American regulations. In the present study, replacement of diesel power with electric power is being considered as a means to reduce locomotive emissions further still. The role of these emissions reductions in terms of *regional* air quality is the key consideration here.

2.3. Local Air Quality And Health In The Vicinity Of The Corridors

The benefit of electrification for *local* air quality in the vicinity of the corridors depends on the current state of the air quality in those areas, and also on how large GO Transit's emissions are relative to emissions from other sources in the surrounding area. If the current pollutant levels are already well below desired thresholds and GO Transit's contribution is relatively small, then the benefit of electrification would be small. If, on the other hand, pollutant levels currently exceed one or more desired thresholds and GO transit's contribution is relatively large, then the benefit would be large.

The benefit of electrification also depends on where one is situated. Diesel locomotive emissions are most concentrated within or immediately adjacent to the rail corridor and are less concentrated farther away. Therefore, it is of interest to know how many people live within a certain distance of the corridors, where the benefit is greatest.

2.4. Nuisance Effects Related to Air Quality

Pollutants within diesel combustion exhaust can contribute to nuisances that are related to air quality. The potential effects are threefold: (1) impairment of visibility; (2) soiling of property (e.g., siding of houses), and (3) adverse odours associated with the exhaust fumes.

In the context of soiling and visibility issues, airborne particulate matter of all types is often referred to as dust. Dust is a widely acknowledged potential nuisance resulting from both human and naturally occurring sources. The human sources include industrial and non-industrial operations such as vehicle traffic (especially on unpaved areas), domestic and commercial heating, wood stoves, campfires, pollen, burning of wastes, forest/grass fires, and various other sources. There are two potential sources of dust associated with locomotive operations: particulate matter in the diesel exhaust, and turbulent disturbance of dust settled on the ground near the right of way. The effects of increased service levels under the Reference Case on dust emissions should be assessed, and any benefits associated with the electrification options should be accounted for.

The odours of exhaust gases vary widely; however, diesel engine exhaust fumes have a characteristic odour that could cause a nuisance effect. Therefore, it is of interest to know how the increased service levels as defined in the Reference Case might affect worst-case odour levels and also how the various electrification options might mitigate those effects.

3. OBJECTIVES ADDRESSED BY DISCIPLINE

Appendix 1, *High Level Decision Making Framework*, identified several 'Environment and Health' objectives, which are summarized in Table 1. These 'Environment and Health' objectives were also presented at a March 31, 2010 Stakeholder workshop for public comment.

Findings from the air quality and health assessment will be integrated with the findings from other disciplines to ensure that the overall environment and health objectives listed in the table are addressed. Specific elements of the overall objectives that have been addressed by the air quality and health assessment are also summarized in Table 1.

Table 1 – Objectives of the Air Quality & Health Assessment in Relation to the Study's overall Environment and Health Objectives

Overall Environment and Health Objective	Elements of Objective Addressed by Air Quality & Health Assessment
1. The selected options should result in a net improvement to human health in adjacent communities	Human health effects related to changes in air quality in adjacent communities have been assessed and compared for the short-listed network options.
2. The selected technology should contribute to improved air quality	Local and regional air quality effects have been assessed and compared for the short-listed network options.
3. The implementation of the selected technology should make a significant contribution to the achievement of the transportation related GHG reduction targets of GO Green: Ontario's Action Plan for Climate Change	GHG emissions resulting from GO locomotive and ARL shuttle operations have been assessed and compared for the short-listed network options.
4. The selected technology should be implemented in a manner that will minimize negative impacts on agricultural and natural systems	It is expected that this objective will be addressed by one of the other disciplines.
5. The selected technology should decrease the use of non-renewable resources	It is expected that this objective will be addressed by one of the other disciplines.
6. The selected technology should encourage environmentally sustainable operations (e.g., through the use of green technologies)	It is expected that this objective will be addressed by one of the other disciplines.

4. ASSUMPTIONS FOR THE AIR QUALITY & HEALTH ASSESSMENT

The following is a list of assumptions relating to the purpose of this assessment:

- The air quality and health assessment contributes to Stage 5 of the Electrification Study, which is the detailed assessment stage and involves the comparison of six network options.
- The assessment is designed to evaluate electrification options relative to the Tier 4 reference case with the intention of generating information helpful for decision making by Metrolinx.
- This assessment is not intended to replace the detailed air quality and health assessments that would be required as part of future environmental assessments for any sections of the network subject to changes in infrastructure or changes from currently approved service levels.

The following is a list of assumptions relating to the scenarios considered in the assessment:

- The ‘benchmark’ or ‘base case’ used as the point of comparison for the six short-listed electrification options is the Reference Case.
- The Reference Case is a hypothetical operating scenario with defined service levels and schedules for each of the seven GO Transit rail corridors plus the ARL shuttle service.
- The Reference Case is based on operation of Tier 4 diesel locomotives by GO Transit and diesel locomotive units (DMU’s) for the Airport Rail Link (ARL).
- The six short-listed electrifications options under evaluation are as summarized in Table 2.
- The evaluation period is for the years 2020 – 2049.

Table 2 – Summary of the Network Electrification Options Considered

Green indicates "Electrified"							
Blue indicates "Tier 4 Diesel"							
Corridor	**Reference Case**	**Option 1**	**Option 2**	**Option 3**	**Option 11**	**Option 15**	**Option 18**
Lakeshore West	[blue]	[blue]	[green]	[green]	[green]	[green]	[green]
Milton	[blue]	[blue]	[blue]	[blue]	[green]	[green]	[green]
Georgetown	[blue]	[green]	[blue]	[green]	[green]	[green]	[green]
ARL	[blue]	[green]	[blue]	[green]	[green]	[green]	[green]
Barrie	[blue]	[blue]	[blue]	[blue]	[blue]	[green]	[green]
Richmond Hill	[blue]	[blue]	[blue]	[blue]	[blue]	[blue]	[green]
Stouffville	[blue]	[blue]	[blue]	[blue]	[blue]	[blue]	[green]
Lakeshore East	[blue]	[blue]	[green]	[green]	[green]	[green]	[green]

Note: Refer to Figures 1 and 2 for layouts of the GO rail network's corridors.

The following is a list of assumptions relating to the technical approach used in the assessment:

- The diesel technologies used by GO locomotives meet U.S. EPA Tier 4 emission limits for all applicable pollutants.
- Auxiliary power engines on the GO locomotives and DMU's on the ARL trains were assigned Tier 4 emissions based on the locomotive standards when, in reality they will be subject to more stringent Tier 4 limits for non-road diesel equipment.
- Locomotive travel speed is assumed to increase linearly with horsepower, and a speed of 130 kph corresponds to full horsepower.
- Emissions are estimated based on mean travel speed, with no accounting for minor increases in emissions associated with acceleration or deceleration.
- Idling at stations, layovers and maintenance yards was not considered since these emissions are generally localized, brief and small in relation to emissions from travelling locomotives.
- Deadhead train movements were not considered, as they are relatively few in number and short in distance.
- Some minor simplifications of the geometry of the GO Transit network were made (e.g., track orientation relative to north), the effects of which were verified to be small via sensitivity tests.

- Additional power plant emissions associated with electrification options are based on the anticipated mix of sources of power in Southern Ontario at the horizon time of study (~2020). The combustion portion of power production consisting primarily of natural gas (coal-fired power plants no longer operating).
- Passengers who use GO Transit on a daily basis were estimated to experience similar maximum concentrations of locomotive emissions as a person who resides immediately adjacent to the busiest section of the network.

5. CRITERIA, INDICATORS AND DATA SOURCES

Table 3 summarizes the criteria, indicators and data sources used in the air quality assessment.

Table 3 – Air Quality & Health Detailed Assessment Criteria, Indicators and Data Sources

Criteria	Rationale	Indicators	Data Sources
1. Potential to affect climate change	Clean diesel and electric options have differing GHG emissions. GHG emissions are linked to global climate change. Favourable options will have incremental emissions that are small compared to region-wide GHG emissions.	Inventory of GO Transit/ARL network-wide annual emissions of greenhouse gases, compared to regional emissions from all sources.	See Table 4
2. Potential to affect regional air quality	Both diesel and electric options will contribute to regional emissions which, together with pollutants from upwind regions, result in periodic region-wide smog events. Smog events are linked to increased hospital admissions, emergency room visits, and premature mortalities. Favourable options will have incremental emissions that are small compared to region-wide emissions.	Inventory of GO Transit/ARL network-wide annual emissions of criteria contaminants (NO_x, CO, SO_2, PM, HC), compared to regional emissions from all sources.	See Table 4
3. Potential to affect local air quality and health	Fuel combustion emits substances into the outside air that can contribute to undesirable health effects in the local community. GO Transits plans to increase future rail traffic, and offset the potential increase in emissions by either clean diesel (Tier 4) or electrification. Favourable options will have an air pollution increment that is small relative to health-based thresholds and existing air pollutant levels.	Population on either side of corridor that may experience a measurable pollutant increment from GO Transit/ARL relative to background levels. Magnitude of the GO Transit/ARL increment relative to health-based thresholds and background air pollutant levels.	See Table 4
4. Potential to affect soiling, visibility, and odour	Pollutants within diesel combustion exhaust can contribute to nuisance effects such as soiling, visibility and adverse odour. Particulate matter emissions (referred to as dust in the context of nuisance assessments) directly affect soiling and visibility. Diesel exhaust can be odourous in high enough concentrations despite significantly reduced sulphur contents in the ultra-low sulphur diesel used by the GO Transit and ARL fleets.	Population on either side of corridor that may experience a measurable increase in dust or odour effects from GO Transit/ARL operations. Magnitude of the GO Transit/ARL increment, relative to background dust levels and the detectable threshold for odours.	See Table 4

Table 4 lists the various data that served as inputs to the assessment. The table also identifies the sources of those data. Table 5 summarizes the daily train traffic volumes used in the assessment and Figures 1 and 2 provide a visual representation of the rail corridors considered in this assessment.

Table 4 – Data Sources and Notes

Data	Data Source & Notes
Railway Operations	
• Daily and hourly GO traffic volumes	Reference Case – Final Workbook (Delcan Arup Joint Venture, 2010).
• Daily and hourly ARL traffic volumes	Georgetown South Service Expansion and Union-Pearson Rail Link Environmental Project Report (Metrolinx, 2009).
• GO train speeds	Provided for existing conditions by Delcan Arup Joint Venture.
• ARL speeds	Assumed to be the same as GO train speeds.
• Railway network layout/geometry	Provided for proposed expanded rail network by Delcan Arup Joint Venture.
• Passenger ridership data	Projections for the year 2021 provided by Steer Davies Gleave.
GO & ARL Emission Factors	
• CO, NO_x, HC, PM	U.S. EPA Tier 4 Locomotive Emission Standards (U.S. EPA, 2008)
• Inhalable Particulate ($PM_{2.5}$)	Scaled PM emission factor by 0.97 based on U.S. EPA Technical Highlights on Emission Factors for Locomotives report (U.S. EPA, 2009).
• Sulphur Dioxide (SO_2)	Locomotive Emissions Monitoring Program report (Railway Association of Canada, 2007).
• Chromium	Speciation of PM emissions from diesel bus exhaust: U.S. EPA's SPECIATE 4.2 Profile #4743, 2-Stroke Diesel Bus Exhaust, 20°C for Ottawa year 2000.
• 1,3-Butadiene	
• Benzene	
• Acrolein	Pechan compilation of diesel emissions speciation data (Pechan, 2007).
• Formaldehyde	
• Acetaldehyde	
• Benzo[a]Pyrene	U.S. EPA documentation for the national emissions inventory (U.S. EPA, 2005).
• Greenhouse Gases (CO_2e)	Locomotive Emissions Monitoring Program report (Railway Association of Canada, 2007).

Data	Data Source & Notes
Power Plant Emission Factors	
• NO_x, CO, SO_2, HC, PM and CO_2e	U.S. EPA AP-42 Compilation of Air Pollutant Emission Factors for Stationary Gas Turbines (U.S. EPA, 2000). Assumed the listed TOC emissions equal HC.
Dispersion Modelling	
• Selected model	U.S. EPA's CAL3QHCR line source model (U.S. EPA, 1995).
• Meteorological data	• Upper air and surface data obtained from the meteorological resource website for Ontario Regulation 419/05 (Ontario Ministry of the Environment, 2007). • Upper air data for Buffalo station for the year 2007. • Surface data for Toronto Pearson International Airport for the year 2007. • Files were processed using PCRAMMET for use with CAL3QHCR.
• Land use category (rural or urban)	• Air Dispersion Modelling Guideline for Ontario (Ontario Ministry of the Environment, 2009). • Google Earth imagery.
• Surface roughness length	
• Impact locations (receptors)	Linear receptor grids extending 1000 metres perpendicular to the right of way, in 5 metre increments.
Historical Air Quality Data	
• Regional emissions data	Pollutant data came from Environment Canada's National Pollutant Release Inventory Online Data Search (Environment Canada, 2010). Year 2007 data for Ontario. Assumed the listed VOC emissions equal HC. GHG emissions came from Canada's Greenhouse Gas Inventory (Environment Canada, 2008).
• Regional population data used to scale Provincial emissions to the GTHA	Ontario Ministry of Finance (www.fin.gov.on.ca/en/economy/demographics/projections/table6.html)
• Historical monitoring data	Online historical data (Ontario Ministry of the Environment, 2010a), (Environment Canada, 2010).
Future Power Generation	

Data	Data Source & Notes
• 2020 Electricity supply mix	Supply Mix Advice from the Ontario Power Authority to the Ontario Minister of Energy (OPA, 2005). Projected electricity production is 10% non-renewable thermal, 42% renewable, 48% nuclear. The latter two were assumed to have no relevant airborne emissions.
Air Quality Thresholds	
• CO, PM_{10}, Acrolein, Formaldehyde, Acetaldehyde	Ontario Ambient Air Quality Criteria (Ontario Ministry of the Environment, 2008)
• NO_x (as NO_2), $PM_{2.5}$, SO_2	World Health Organization Air Quality Guideline (World Health Organization, 2005)
• Benzene, Chromium, 1,3-butadiene, B[a]p	Proposed Ontario Ambient Air Quality Criteria (Ontario Ministry of the Environment, 2010b).
Air Quality Valuation Analysis	
• Baseline occurrence rates of health effects	Default National averages within the Air Quality Benefits Analysis Tool, AQBAT (Health Canada, 2008). Mortality and hospitalization rates based on Ontario averages (Region of Peel, 2008).
• Concentration response factors	AQBAT defaults (Health Canada, 2008).
• Transboundary contribution to pollution in Ontario	Study published by the MOE (Ontario Ministry of the Environment, 2005).
• Valuation estimates	AQBAT defaults (Health Canada, 2008).

Table 5 – Summary of Railway Operational Inputs

Rail Line	Segment Description	Label	Daily Train Volume
Union East	Union E1 - Union to Don River	UE1	239
	Union E2 - Don River to Scarborough Jctn	UE2	181
Union West	Union W1 - Union to Bathurst St	UW1	306 (140)
	Union W2 - Bathurst St to Lansdowne Av	UW2	192 (140)
	Union W3 - Lansdowne Av to Dupont St	UW3	134 (140)
Lakeshore East	Union E2 to Pickering	LE1	114
	Pickering to Oshawa 2	LE2	114
	Oshawa 2 to Bowmanville	LE3	15
Lakeshore West	Union W1 to Oakville	LW1	114
	Oakville to Hamilton-James	LW2	114
	Hamilton Jctn to Hamilton TH+B	LW3	114
	Hamilton-James to St Catherine's	LW4	8
Milton	Union W3 to Meadowvale	MT1	67
	Meadowvale to Milton	MT2	58
Georgetown	Union W3 to Brampton	GT1	67 (140)
	Brampton to Georgetown	GT2	67
	Georgetown to Kitchener	GT3	21
Barrie	Union W2 To Bradford	BA1	58
	Bradford to Allandale	BA2	15
Richmond Hill	Union E1 to Richmond Hill	RH1	58
	Richmond Hill to Bloomington	RH2	15
Stouffville	Union E2 to Mt Joy	ST1	67
	Mt Joy to Lincolnville	ST2	21

ARL = Airport Rail Link, train volumes shown in brackets.

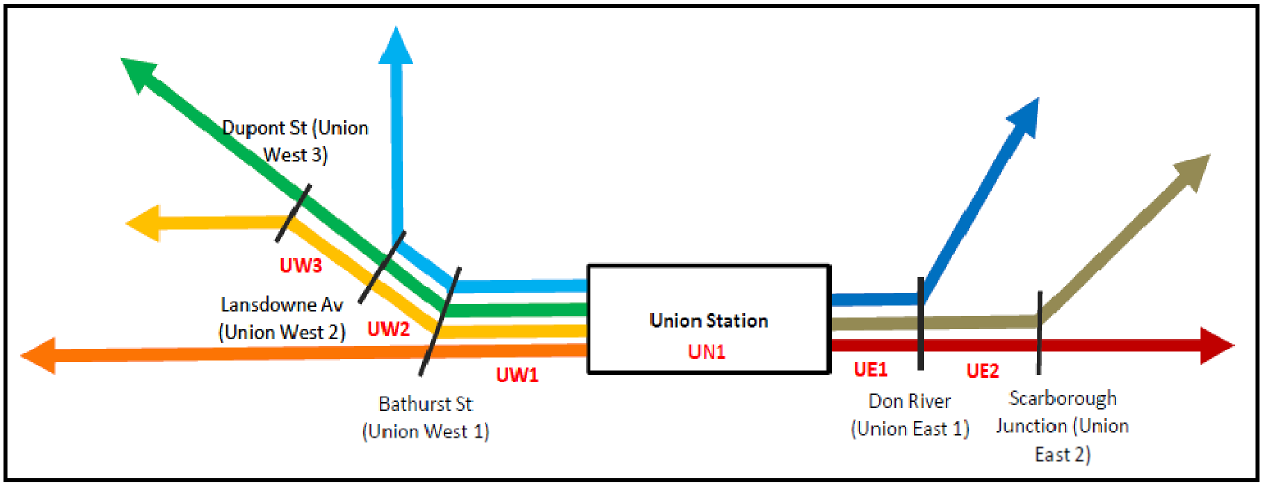

Figure 1 – GO Transit Rail Corridors near Union Station

Figure 2 – Overview of GO Transit Rail Network

6. ASSESSMENT OF OPTIONS

6.1. Greenhouse Gases

The potential to affect greenhouse gas emissions was assessed for each of the electrification options. This issue was examined by completing an inventory of GO Transit's direct GHG emissions in the Reference Case and comparing it to the residual emissions for the various electrification options. Annual emissions were calculated based on fuel consumption data, the reference numbers of daily train trips for each corridor of the network, and the distances travelled.

The results, as summarized in Table 6a, show that the six electrification options lead to progressively lower GHG emissions (represented by CO_2e in the table) in comparison to the Reference Case. However, to put the results into perspective, they have also been compared to GTHA total GHG emissions (Table 6b) and GTHA GHG emissions from all transportation sources (Table 6c). Note that the regional totals for the GTHA were estimated from provincial totals, based on relative population. From these summaries, it is seen that all options, including the Reference Case, have a network-wide GHG emission inventory that is a fraction of 1% of the GTHA's overall regional emission inventory from all sources. This is illustrated in Figure 3. Thus, none of the electrification options will significantly reduce regional GHG emissions that contribute to global warming and, as such, none will provide an appreciable benefit.

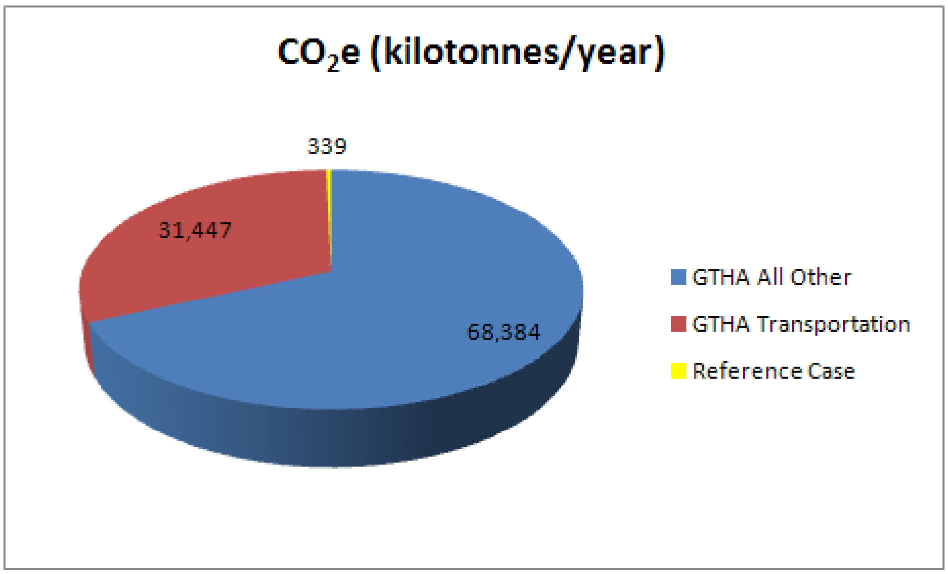

Figure 3 - GHG Emissions: Tier 4 Reference Case

6.2. Regional Air Quality and Health

The potential to affect regional air quality was assessed for each of the electrification options. The significance of GO Transit rail fleet and ARL emissions to regional smog events was estimated by computing an annual emissions inventory for the relevant pollutants, similar to that for GHG emissions mentioned in the preceding section. The most relevant pollutants with respect to regional smog are oxides of nitrogen (NO_X), sulphur dioxide (SO_2), fine particulate matter ($PM_{2.5}$) and hydrocarbons (considered to be similar to volatile organic compounds (VOC's)).

Annual inventories were calculated for the Reference Case and each of the six short-listed electrification options. The emission reduction associated with each electrification option was then compared against GTHA total emissions from all sources.

The results of this analysis are presented in Table 6a through c alongside the GHG results as described above. From these results it is seen that all options, including the Reference Case have a network-wide emission inventory that is a fraction of 1% of the GTHA's overall regional emission inventory from all sources. Thus, none of the electrification options will significantly reduce regional emissions that contribute to large scale smog events and, as such, none will provide an appreciable benefit.

A preliminary, screening-level analysis was performed to estimate the regional air quality benefit of full electrification, in terms of the reduction in undesirable health effects to the population, and in terms of the economic value of the reduction. This is described further in Section 6.5.

Table 6a – Summary of GO & ARL Annual Emissions (tonnes/year)

Pollutant	Reference Case	Option 1	Option 2	Option 3	Option 11	Option 15	Option 18
Nitrogen Oxides (NO_x)	515	433	323	241	199	133	55
Carbon Monoxide (CO)	594	492	352	249	196	113	14
Sulphur Dioxide (SO_2)	2.9	2.5	1.9	1.5	1.3	1.0	0.58
Total Hydrocarbons (HC)	55	46	33	24	19	11	1.9
Particulate Matter (PM)	12	10	7.4	5.5	4.5	3.0	1.1
Carbon Dioxide Equivalent (CO_2e)	338,333	286,786	202,347	150,801	120,912	74,491	19,041

Table 6b - Comparison to Existing Regional Emissions

Pollutant	GTHA Total Emissions (tonnes/year)	Reference Case	Option 1	Option 2	Option 3	Option 11	Option 15	Option 18
		(% of GTHA Total)						
NO_x	239,291	0.22%	0.18%	0.13%	0.10%	0.083%	0.056%	0.023%
CO	1,289,797	0.046%	0.038%	0.027%	0.019%	0.015%	0.0088%	0.0011%
SO_2	218,154	0.0013%	0.0011%	0.00087 %	0.00070 %	0.00060%	0.00045%	0.00027%
HC	2,207,246	0.003%	0.002%	0.001%	0.001%	0.0008%	0.0005%	0.00009%
PM	1,855,235	0.00064%	0.00054 %	0.00040 %	0.00030 %	0.00024%	0.00016%	0.00006%
CO_2e	99,830,245	0.34%	0.29%	0.20%	0.151%	0.121%	0.075%	0.019%

Table 6c - Comparison to Existing Regional Transportation Emissions

Pollutant	GTHA Transportation Emissions (tonnes/year)	Reference Case	Option 1	Option 2	Option 3	Option 11	Option 15	Option 18
		(% of GTHA Transportation)						
NO_x	155,142	0.33%	0.28%	0.21%	0.16%	0.13%	0.086%	0.035%
CO	1,031,712	0.058%	0.048%	0.034%	0.024%	0.019%	0.011%	0.0014%
SO_2	8,910	0.032%	0.028%	0.021%	0.017%	0.015%	0.011%	0.0065%
HC	80,176	0.069%	0.057%	0.041%	0.029%	0.023%	0.014%	0.0024%
PM	9,286	0.13%	0.11%	0.080%	0.059%	0.048%	0.032%	0.012%
CO_2e	31,446,527	1.1%	0.91%	0.64%	0.48%	0.38%	0.24%	0.061%

6.3. Local Air Quality and Health

Background Air Quality

This study examined data on current air quality conditions throughout the GTHA, made predictions of GO Transit and ARL air pollutant contributions in the Tier 4 diesel Reference Case, and considered the size of population located close enough to the rail corridors to experience a measurable change in air quality due to the electrification options.

For chemical compounds that have linkages to human health, government health and environmental agencies have established threshold levels. The Ontario Ministry of the Environment (MOE) has developed Ambient Air Quality Criteria (AAQC's), which are effects-based levels in air, based on health, odour, vegetation, soiling, visibility, corrosion or other effects, depending on the pollutant. They are used in environmental assessments, special studies using monitoring data and the assessments of general air quality in a community, to assess the potential for causing an adverse effect (MOE, 2008).

In addition to the MOE, the World Health Organization is a widely-consulted authority that has developed air quality guidelines for selected contaminants of key concern. The guidelines are intended for world-wide use, to support the achievement of air quality that protects public health in various contexts (WHO, 2005). They are based on an extensive body of scientific evidence for air pollution and its health effects.

In general, it can be said that if the concentration of an airborne pollutant can be maintained below its threshold, then either no health effect is observed or the effect is small enough that it presents an acceptably low risk to the population. The historical data for key air pollutants in the GTHA were compared to the applicable thresholds in order to characterize the current air quality.

Table 7 lists the key chemical compounds of concern (COC's) associated with internal combustion engines, and shows information on present-day outdoor concentrations of the COCs in the Greater Toronto and Hamilton Area (GTHA). These are referred to as background concentrations. Background concentrations vary widely from day-to-day, depending on weather conditions, and also vary from place to place. The table shows representative high-end values. These values are annual 90^{th} percentile concentrations, averaged over five years of data and multiple monitoring sites throughout the GTHA as shown in Figure 4. The table also shows health-based thresholds. Some of the COC's have multiple thresholds corresponding to various averaging times.

It can be seen that the representative high-end background concentrations are generally well within the health-based thresholds. Other COC's, such as $PM_{2.5}$, SO_2 and benzene, have representative high-end values that approach the threshold and, in fact, outdoor levels of these contaminants may exceed their thresholds in some parts of the GTHA from time to time. In addition, NO_2 has annual average levels that may exceed the WHO's annual guideline at some locations within the GTHA.

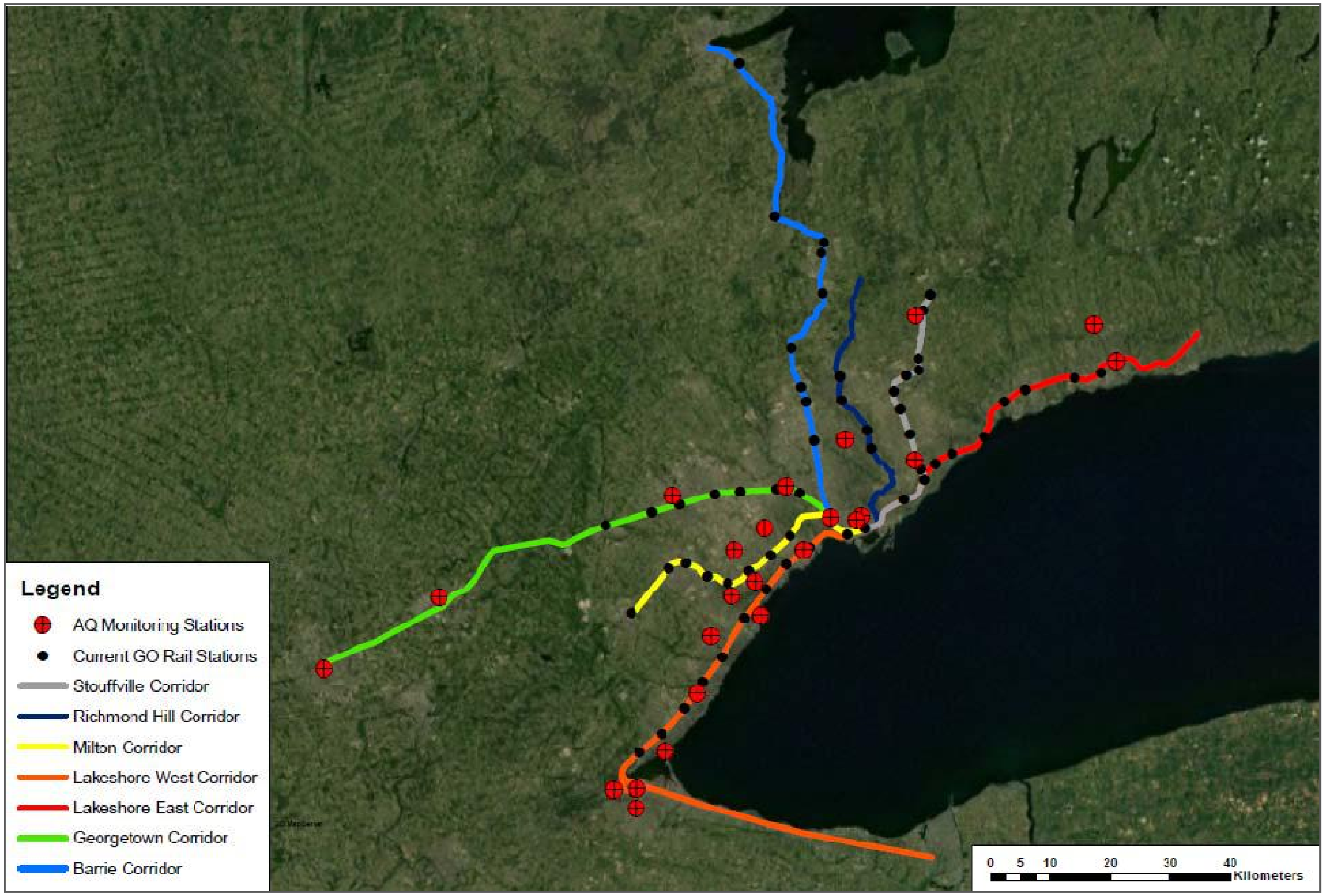

Figure 4 – NAPS and MOE Air Quality Monitoring Stations

Table 7 – Key Contaminants of Concern (COC's) in Combustion Exhaust Gases

Contaminant	Representative High-End Concentration in the GTHA (µg/m³)	WHO Guideline (µg/m³)	MOE AAQC	Averaging Time	Critical Effect
CO	655		15,700	8-hour	Reduced blood oxygen
NO_2	61	200 40	400 --	1-hour Annual	Respiratory effects
PM_{10}	32	50 20	50 --	24-hour Annual	Cardiovascular effects
$PM_{2.5}$	18	25 10	--	24-hour Annual	Increased cancer mortality rate
SO_2	15	500 20	690 275	10-min/1hr 24-hour	Increased mortality rate
Chromium	0.0054	--	1.50	24-hour	Respiratory effects
1,3 Butadiene	0.1740	--	--	24-hour	Carcinogen
Benzene	2.2	--	--	24-hour	Carcinogen
Acrolein	0.20	--	0.4	24-hour	Respiratory effects
Formaldehyde	4.5	--	65	24-hour	Carcinogen, odour
Acetaldehyde	2.6	--	500	24-hour	Respiratory effects
B[a]p	0.00034	--	0.0011 0.0003	24-hour Annual	Carcinogen

Contaminants of Greatest Concern

ARL and GO Transit contributions to local air pollutant levels were predicted using computer dispersion modelling techniques. A key input to the dispersion modelling is the estimated rates at which pollutants are emitted from the GO Transit and ARL diesel engines. The contaminants of greatest concern are those having the highest emission rate relative to their background concentrations, and relative to their health-based thresholds. Table 8 shows emission rates beside the present-day outdoor concentrations and health-based thresholds. The ranking in the last column shows that oxides of nitrogen (NO_X) has the highest emission rate relative to its background concentration and threshold, followed by acrolein and 1,3-butadiene.

Table 8 – Ranking of COC's Relative to Background Levels and Thresholds

Contaminant	Tier 4 Emission Factor (g/bhp-hr)	Representative High-End Concentration in the GTHA (µg/m³)	Relevant Health-Based Threshold (µg/m³)	Rank
CO	1.5	655.2	15,700	10
NO_x	1.3	60.93	200	1
PM_{10}	0.03	32.33	50	8
$PM_{2.5}$	0.03	18.1	25	6
SO_2	0.0046	14.7	20	11
Chromium	1.35E-06	0.005417	0.50	12
1,3 Butadiene	0.01	0.1740	10	3
Benzene	0.011	2.200	2.3	4
Acrolein	0.0035	0.2028	0.4	1
Formaldehyde	0.027	4.492	65	5
Acetaldehyde	0.015	2.589	500	8
B[a]p	1.28E-07	0.0003400	0.00005	7

The findings above were compared to previous work related to GO Transit locomotives. An Environmental Assessment for the Georgetown South Service Expansion and Union Pearson Rail Link was completed in 2009. The Human Health Assessment of Air Quality Impacts under that environmental assessment concluded that most of the air pollutants studied would remain within their applicable health-based thresholds. In other words, most of the pollutants would remain at levels where no effect is observed or the effect is small enough that it presents an acceptably low risk to the population. The possible exceptions were nitrogen dioxide, acrolein and 1,3-butadiene, under worst-case meteorological conditions.

The Ontario Ministry of the Environment (MOE) recently completed new reviews of the potential health effects of acrolein and 1,3-butadiene and proposed new health-based thresholds for these compounds. In comparison to these thresholds, both acrolein and 1,3-butadiene are now expected to remain within their applicable thresholds, leaving only nitrogen dioxide as the possible exception.

In October of 2009, the MOE issued its notice of approval of the environmental assessment, and that approval included a requirement for further analysis of some of the air pollutants. In written guidance on this "enhanced" analysis, the MOE identified three pollutants that should be studied further: NO_2, particulate matter smaller than 2.5μm in diameter ($PM_{2.5}$) and sulphur dioxide (SO_2). The MOE had various reasons for wanting to include $PM_{2.5}$ and SO_2 in addition to NO_2. Since that time, however, it came to light that GO Transit has already implemented the use of ultra-low sulphur diesel fuel in its fleet, and the 2009 human health assessment, which was based on the use of higher sulphur fuel, significantly over-estimated GO Transit's contribution to SO_2. Therefore, SO_2 has ceased to be of concern, leaving only $PM_{2.5}$ and NO_2.

Taking into consideration the MOE's guidance on the Environmental Assessment for Georgetown South, $PM_{2.5}$ was carried forward in the dispersion modelling analysis in addition to NO_2, 1,3-butadiene and acrolein. This is fitting, since $PM_{2.5}$ is currently of significant concern to the healthcare community due to its correlation to various cardiovascular effects and increased mortality rate in urbanized areas. In the historical research, fine particulate matter has been measured in the form of $PM_{2.5}$ and PM_{10} (particles smaller than 2.5μm and 10μm). Weight measurements of $PM_{2.5}$ and PM_{10} have been correlated to health outcomes. Our studies look at these measures. However, an issue in recent literature is that health outcomes may be more related to the ultra-fine portion of $PM_{2.5}$, i.e., particles smaller than 0.1μm. At this time, the state of science is in the preliminary stages in terms of determining causality relationships between exposure to ultra-fine particulate and health outcomes (Stanek, Sacks, Dutton, Ross, 2010). Therefore, air quality thresholds have not been established by the World Health Organization or other regulatory bodies and UFPM has not been assessed in this study.

ARL and GO Transit Contributions

As per the dispersion modelling results, the predicted contribution of GO Transit and ARL diesel engines to local concentrations of these four COC's was plotted as a function of distance from the corridor. The plotted concentrations were then compared to background levels. GO Transit's contribution was considered measurable wherever it was greater than 10% of the background. Otherwise, it is considered to be too small to be reliably distinguished. By comparing the plotted concentrations to background levels, a distance from the corridor was determined within which GO Transit's contribution is measurable. The area within the specified distance was referred to as the zone of influence (ZOI). The zones of influence were determined for all the various corridors within GO Transit's system, for the Tier 4 diesel Reference Case as well as each of the electrification options.

Figure 6 through Figure 9 show examples of concentration as a function of distance from the centreline of the UW1 corridor for the COC's of greatest concern (NO_2, $PM_{2.5}$, 1,3-butadiene and acrolein). Note that the UW1 corridor is from Union to the Lakeshore West Junction – Refer to Figure 5 as a key map for the sample charts presented in this section. The figures show GO Transit/ARL contribution for the Reference Case and each of the six short-listed electrification options relative to background concentration and the applicable health-based threshold.

The background concentrations shown here represent general background conditions away from the influence of the rail corridors. Areas adjacent to the rail corridors may experience somewhat increased background levels (apart from GO Transit contributions), due to contributions from other rail corridor users (VIA, CN and CP). These other contributions were not considered when determining whether or not the GO Transit/ARL contribution was measurable in relation to background. This approach tends to overstate the relative contribution of the GO Transit/ARL emissions slightly, with a corresponding slight overestimate of the zones of influence. This effect, however, is small in relation to other uncertainties in the analysis, as will be discussed.

Contributions to air pollutant concentrations from GO Transit/ARL engines would vary widely from day to day, depending on weather conditions. Figures 6 through 9 show the predicted maximum concentrations under worst-case weather conditions, based on a 1 year simulation for the UW1 corridor. This section has the highest Reference Case volume of GO Transit/ARL trains (280 GO + 140 ARL trains/day) of any section of the network and, as a result, has the largest emission contribution from GO Transit/ARL locomotives relative to background concentrations and thresholds. The background concentrations shown in these plots were derived from multiple years of data for monitoring stations located in the downtown area of Toronto (at Bay and Wellesley, and on College Street).

Figures 10 through 13 show additional examples for NO_2 and $PM_{2.5}$, for two other sections of the network: (i) the Georgetown corridor, between Weston Road and Highway 427, and (ii) the Lakeshore West corridor, between Jamieson Avenue and Park Lawn. In these areas, the GO Transit/ARL contribution is smaller than in the previous examples, due to a smaller daily number of trains.

Before making comparisons between Figures 6 through 13, the reader should note the differences in scale along the x-axis between the figures.

In summary, these figures show that the GO Transit/ARL contributions may be large relative to background levels in some cases, but are always small relative to the health-based thresholds. They have little effect on whether or not the concentrations of COC's in the surrounding area will remain within their thresholds. For contaminants such as $PM_{2.5}$, that occasionally experience background levels above the threshold, the GO Transit/ARL contribution is so small that it does not significantly alter the potential for these events to occur. As such, the significance of the GO Transit/ARL contribution can be considered to be small.

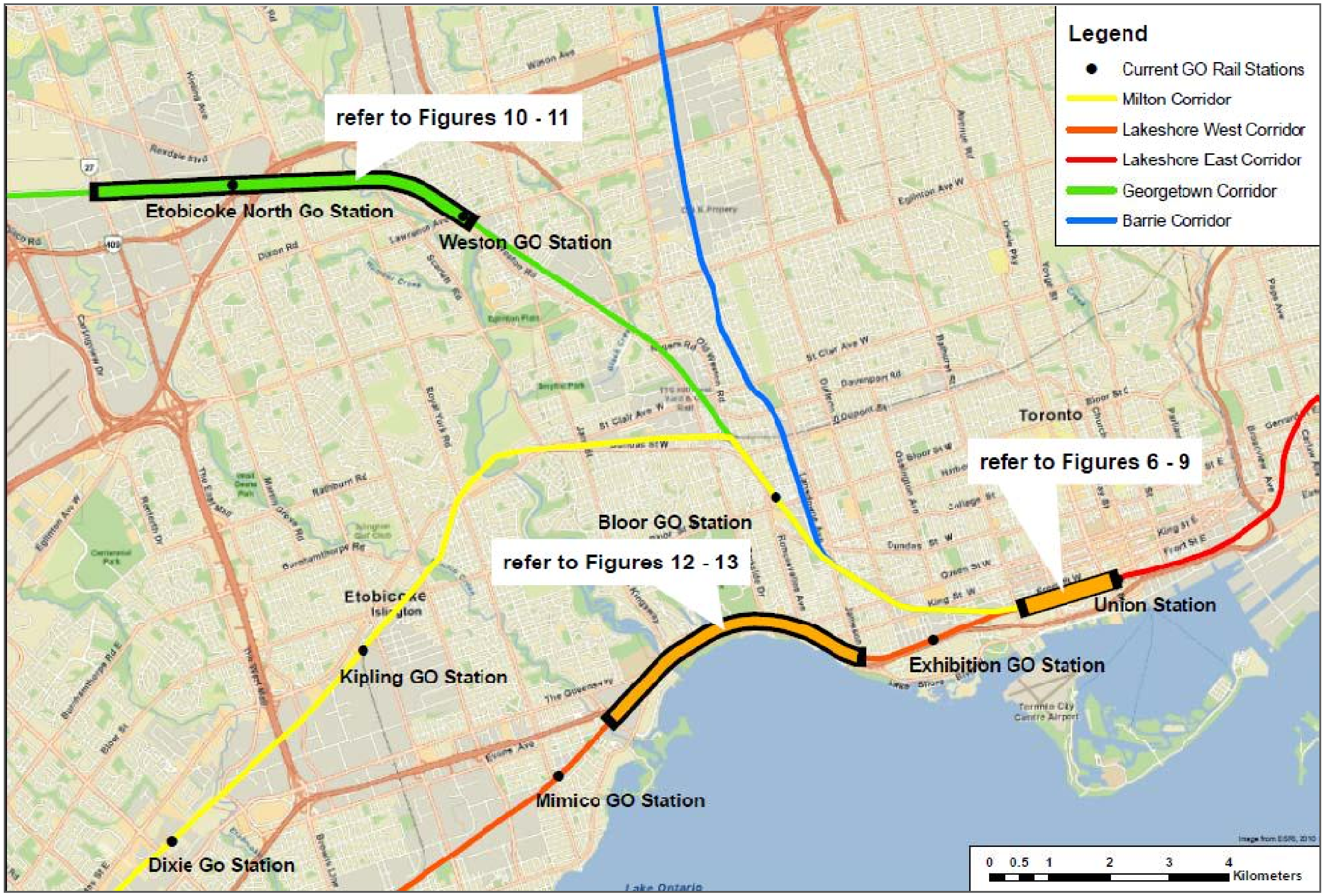

Figure 5 – Key Map for Sample Charts of Local Air Quality Results

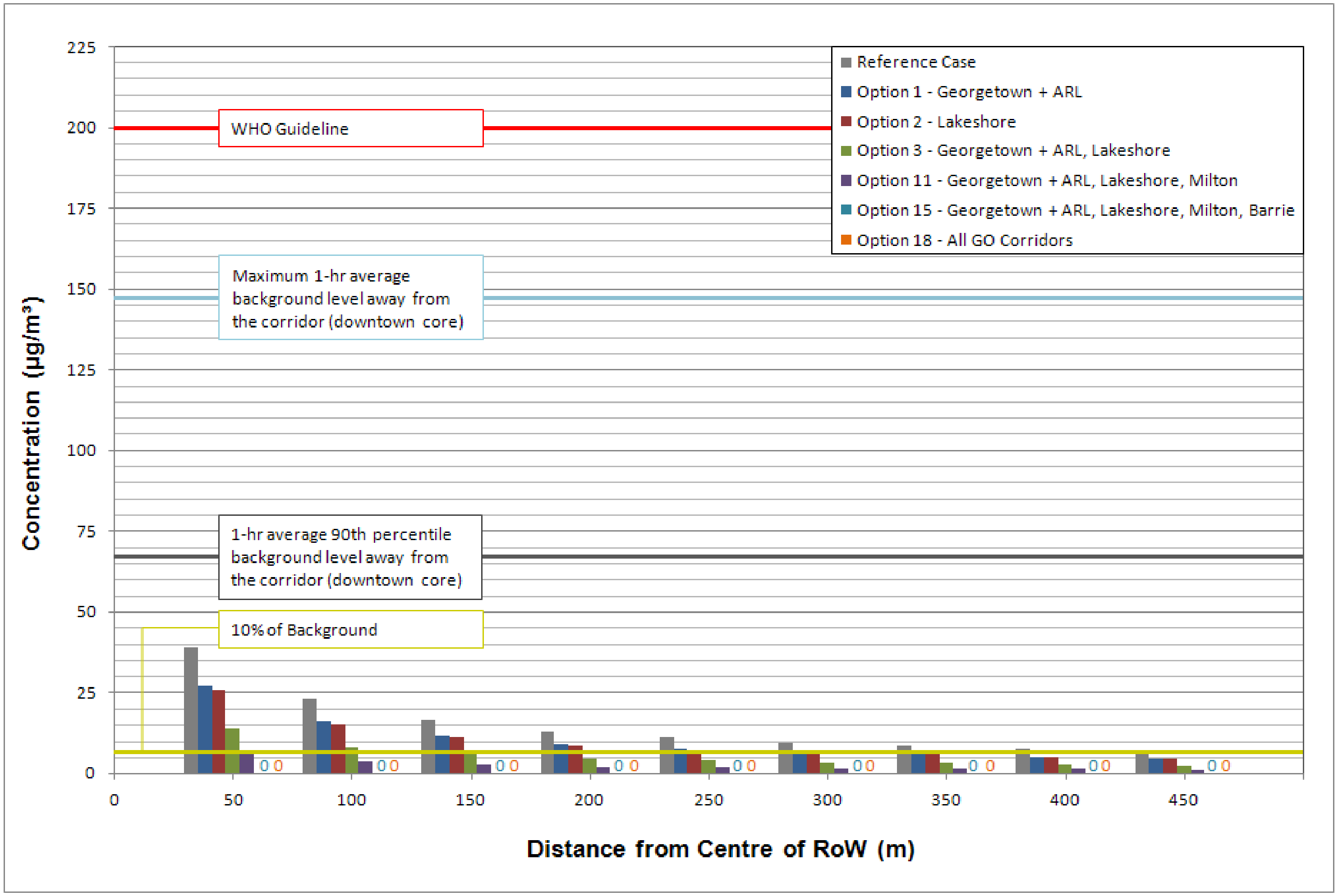

Figure 6 – Maximum 1-hr NO2 Contributions from GO & ARL (Union to the Lakeshore West Junction)

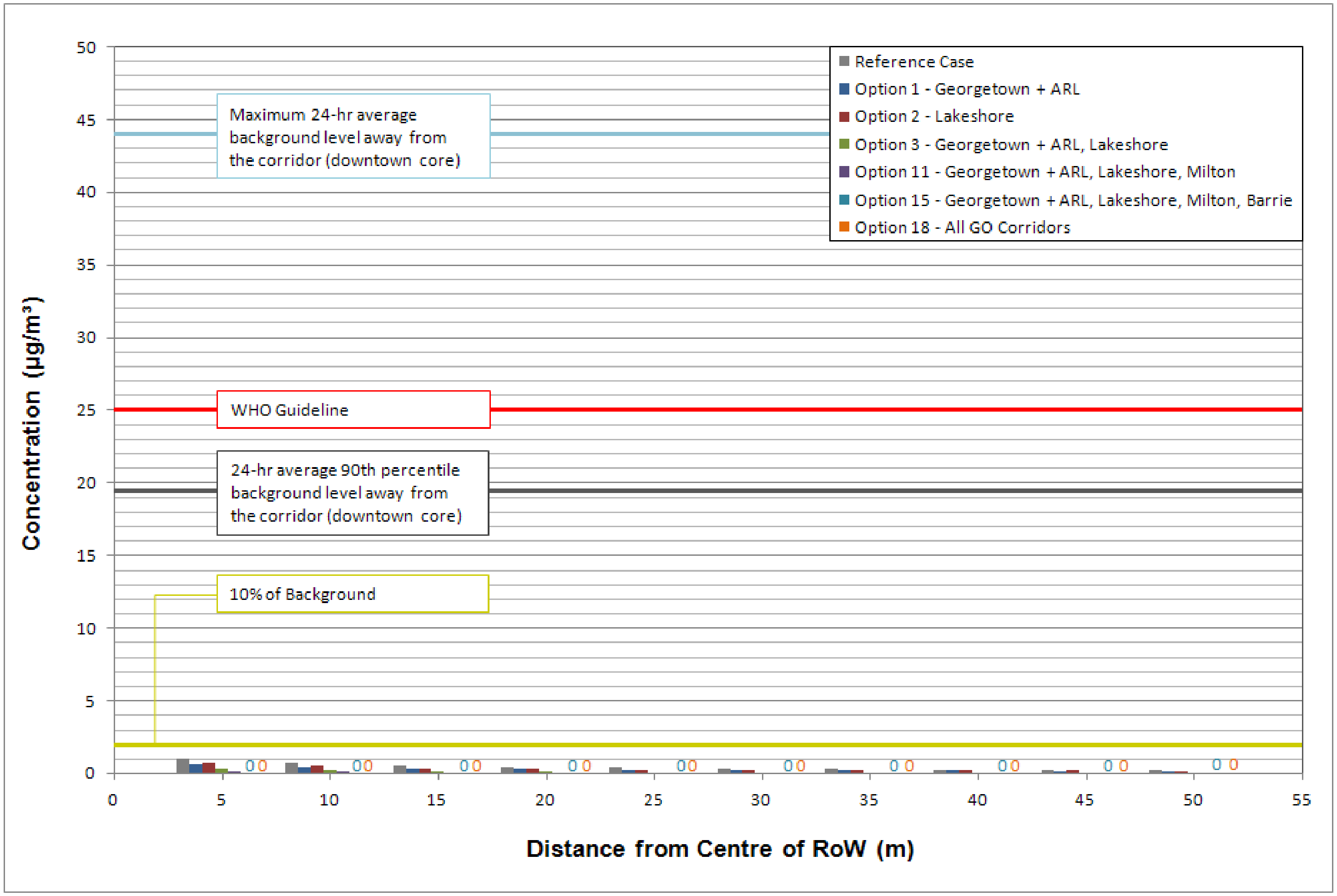

Figure 7 – Maximum 24-hr PM2.5 Contributions from GO & ARL (Union Corridor to Lakeshore West Junction)

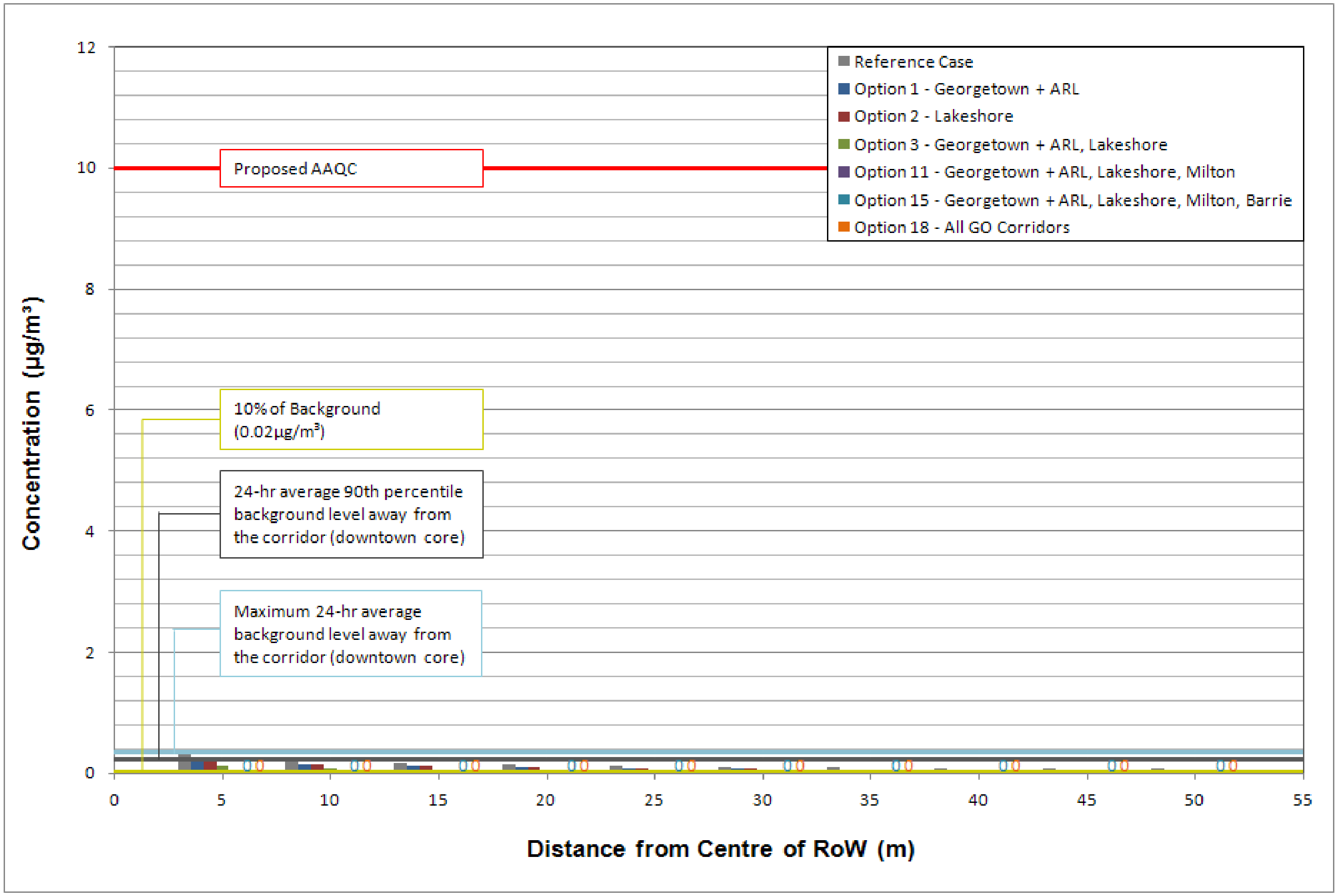

Figure 8 - 24-hr 1,3-Butadiene Contributions from GO & ARL (Union Corridor to Lakeshore West Junction)

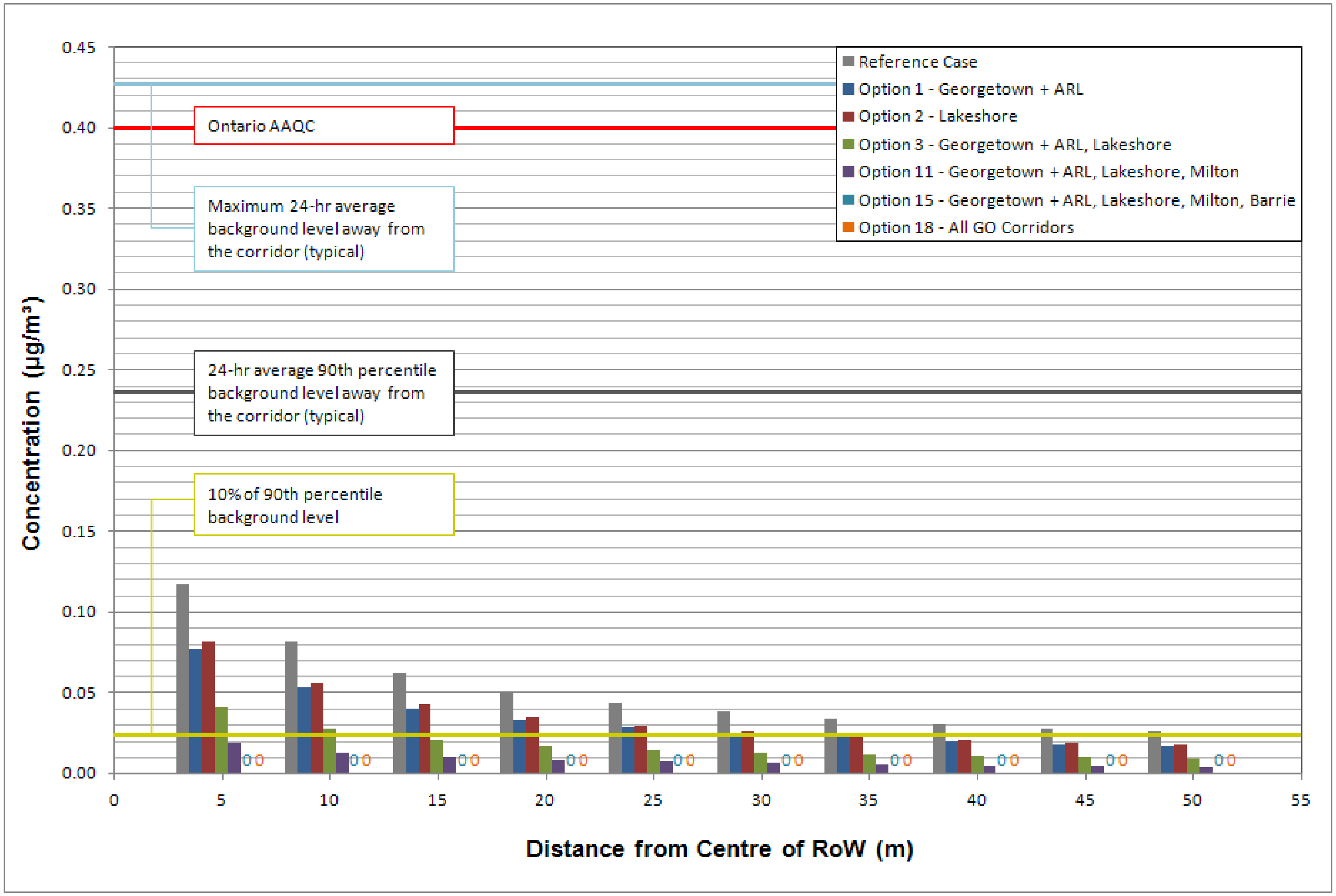

Figure 9 - 24-hr Acrolein Contributions from GO & ARL (Union Corridor to Lakeshore West Junction)

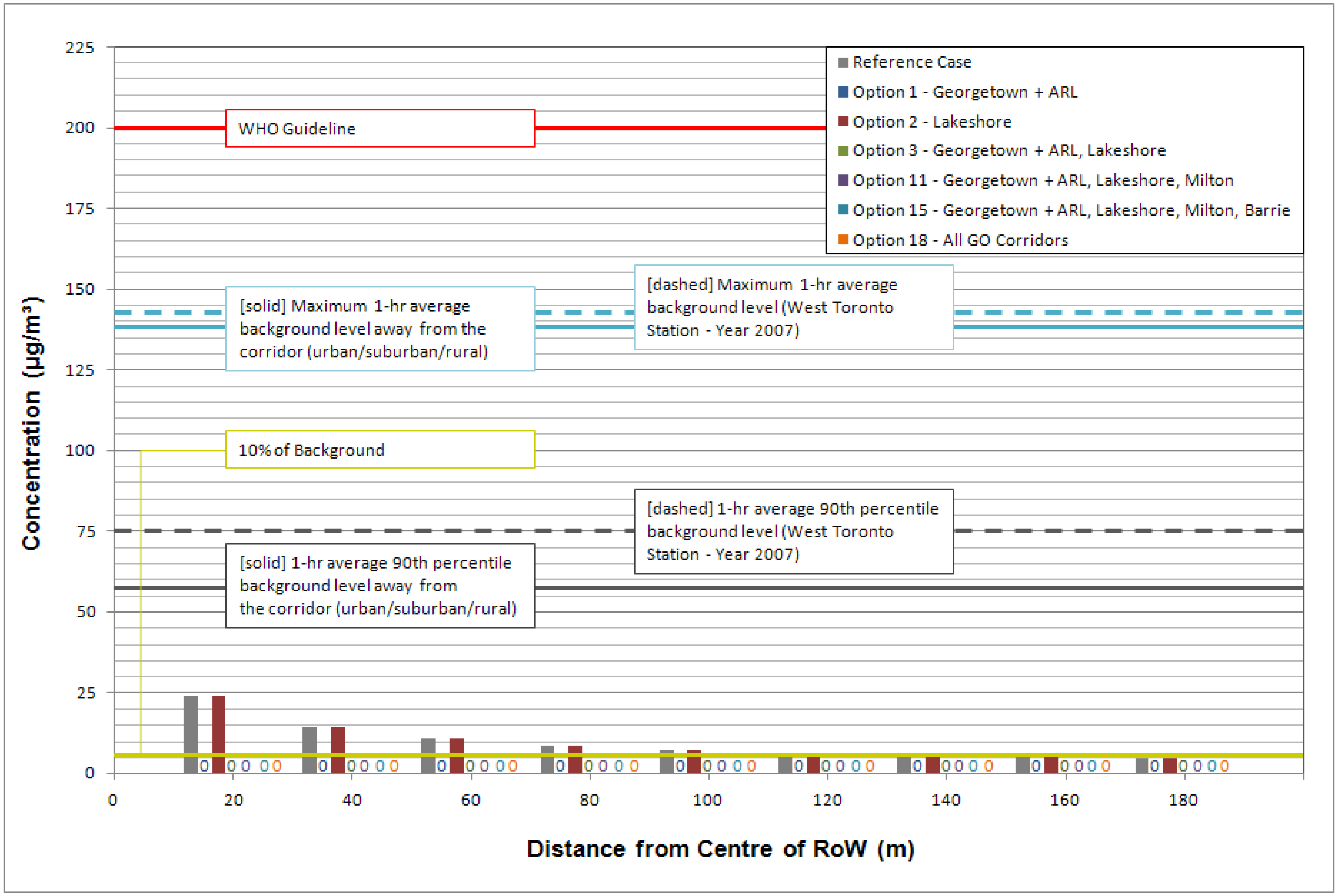

Figure 10 - 1-hr NO2 Contributions from GO & ARL (Georgetown Corridor from Weston to HWY 427)

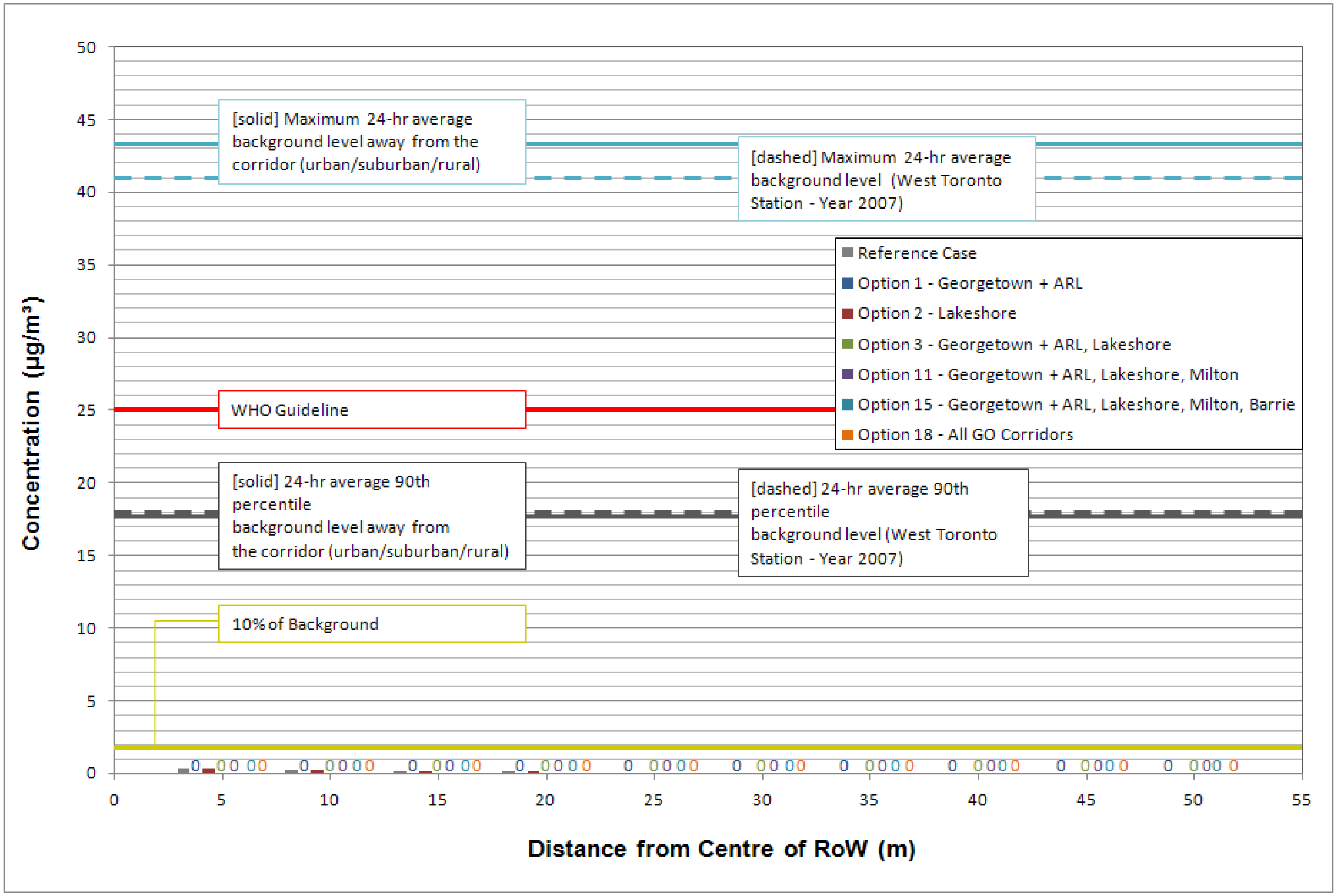

Figure 11 - 24-hr $PM_{2.5}$ Contributions from GO & ARL (Georgetown Corridor from Weston to HWY 427)

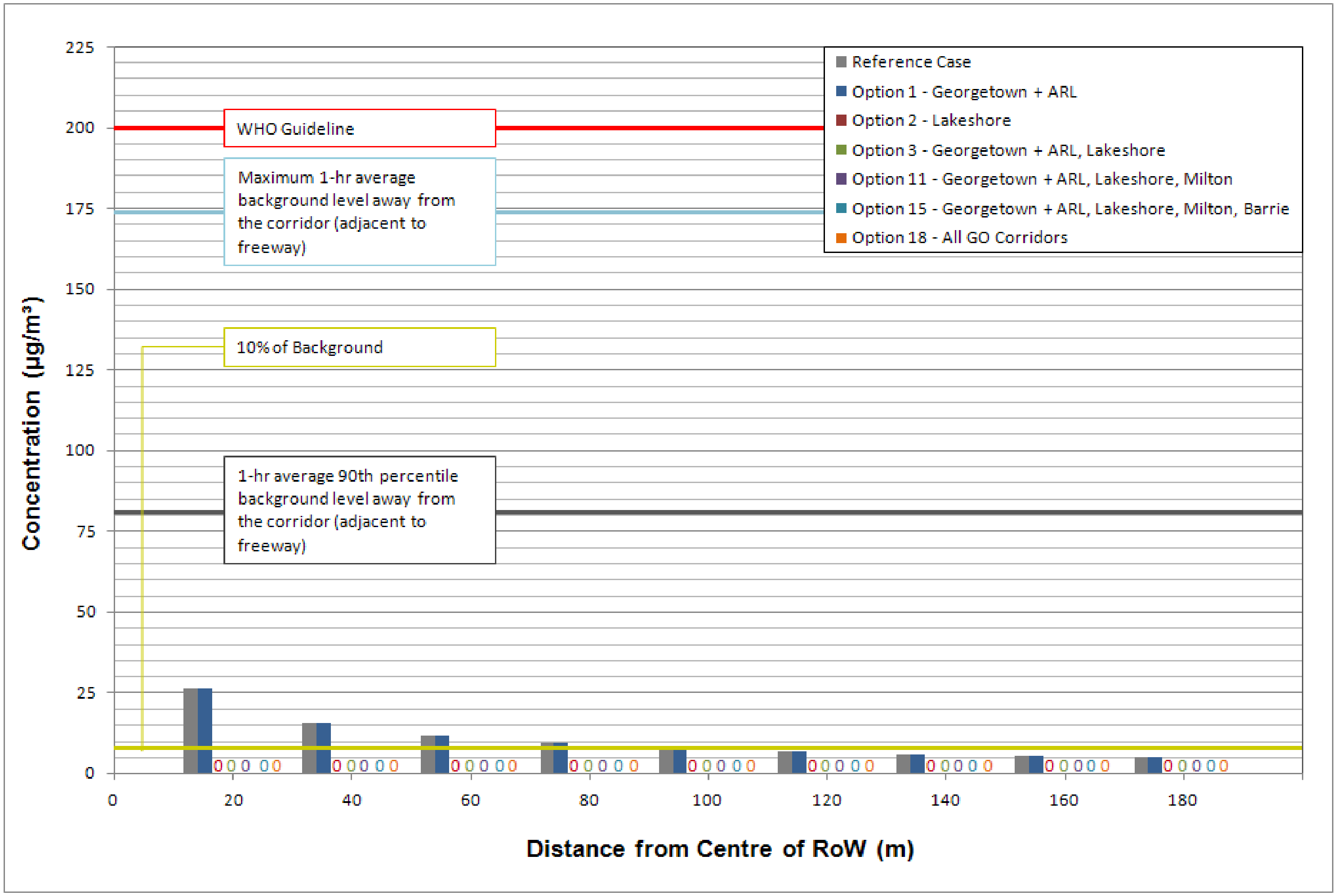

Figure 12 - 1-hr NO_2 Contributions from GO & ARL (Lakeshore West Corridor between Jamieson Ave. and Park Lawn Rd.)

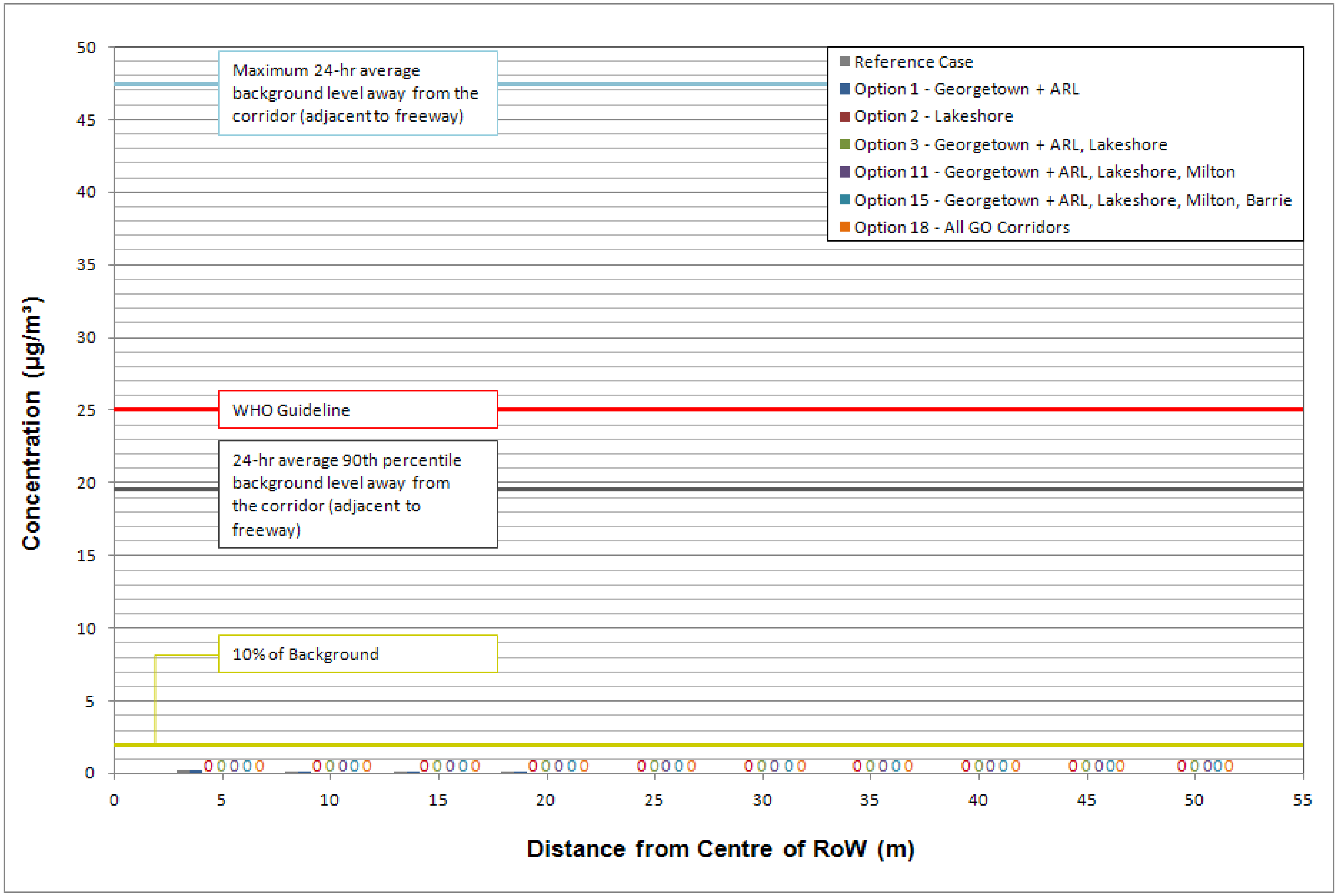

Figure 13 - 24-hr $PM_{2.5}$ Contributions from GO & ARL (Lakeshore West Corridor between Jamieson Ave. and Park Lawn Rd.)

Zones of Influence and Affected Population

For the purpose of comparing the electrification options to each other, an effort was made to determine the size of area adjacent to the rail corridors within which this small effect of the GO Transit/ARL trains would be experienced (the zone of influence). NO_2 was used as the basis to determine this area, since it had a relatively large contribution from GO Transit/ARL trains in relation to its background concentration and threshold. As previously mentioned, GO Transit's contribution was considered measurable wherever it was greater than 10% of the background. Otherwise, it is considered to be too small to be reliably distinguished from the background. This 10% threshold was used to define the zone of influence.

Figure 6 shows that the maximum 1-hour concentration of NO_2 falls to less than 10% of the background level at a distance of approximately 450m from the centreline of the corridor. Thus, the zone of influence for the section of corridor between Union Station and the Lakeshore West Junction is considered to extend to a distance of 450m on either side. Similar calculations were done for other sections of the GO Transit Network, and the resulting zones of influence are summarized in Table 9.

The table shows that the zones of influence vary widely in size throughout the network. They vary mainly as a function of train traffic volume, with less busy sections of the network having smaller zones of influence. They also vary according to the extent of electrification. On the section between Union Station and the Lakeshore West Junction, for example, the zones of influence become progressively smaller as more service routes using this corridor become electrified.

A Geographic Information System (GIS) containing demographic data for the GTHA was used to determine the size of population within the zones of influence, which would experience a measurable change in air quality if the diesel locomotives are replaced by electrification. This was done for each of the electrification options, providing a useful datum for comparison. The estimated populations within the zones of influence under the Tier 4 diesel Reference Case are shown in Table 10.

In addition to the populations residing in the vicinity of the rail corridors, passengers using GO Transit on a daily basis would also experience a measurable change in air quality as a result of electrification. Published research has consistently shown that commuter rail passengers are exposed to significantly better air quality than urban motorists (Gomez-Perales et al, 2007; Chan et al, 2002; Li et al, 2006; Chertok et al, 2004; Kingham et al, 1998). Most of the studies reviewed, however, dealt with electrified rail systems. While one study of a rail system that uses DMU diesel technology had results that were similar to the other studies (Kingham et al, 1998), it is likely that passenger exposures would be at least somewhat increased for diesel rail compared to electric. A typical daily passenger has the potential to be exposed to emissions for fewer hours of the day, but being in close proximity to the emission source over the entire trip, may receive a more consistent exposure during those hours than might occur at a residence adjacent to the corridor. Overall, the passenger exposure is thought to be comparable to that of a resident located adjacent to a busy section of the corridor.

Therefore, passengers are included as part of the population within the zones of influence. Daily one-way passenger trip data for the Reference Case were used to account for this portion of the affected population.

Table 9 – Zones of Influence (Distance from Corridor Centreline, m)

Corridor	Reference Case	Option 1	Option 2	Option 3	Option 11	Option 15	Option 18
Union to Lakeshore West Junction (Lakeshore West, Milton, ARL, Georgetown, and Barrie lines)	<450	<285	<275	<130	<45	0	0
Lakeshore West Junction to Barrie Junction (Milton, ARL, Georgetown, and Barrie lines)	<390	<155	<390	<155	<55	0	0
Barrie Junction to West Toronto Diamond (Milton, ARL, and Georgetown lines)	<215	<70	<215	<70	0	0	0
Lakeshore West Junction to Hamilton (Lakeshore West line)	<130	<130	0	0	0	0	0
Hamilton to St. Catherines (Lakeshore West line)	<20	<20	<20	<20	<20	<20	0
West Toronto Diamond to Milton (Milton line)	<80	<80	<80	<80	0	0	0
West Toronto Diamond to Goreway Drive (ARL and Georgetown lines)	<130	0	<130	0	0	0	0
Goreway Drive to Kitchener (Georgetown line)	<80	0	<80	0	0	0	0
Barrie Junction to Allandale (Barrie line)	<80	<80	<80	<80	<80	0	0
Union to Richmond Hill Junction (Lakeshore East, Stouffville, and Richmond Hill lines)	<240	<240	<105	<105	<105	<105	0
Richmond Hill Junction to Stouffville Junction (Lakeshore East, and Stouffville lines)	<185	<185	<55	<55	<55	<55	0

Corridor	Reference Case	Option 1	Option 2	Option 3	Option 11	Option 15	Option 18
Stouffville Junction to Bowmanville (Lakeshore East line)	<105	<105	0	0	0	0	0
Richmond Hill Junction to Bloomington (Richmond Hill line)	<45	<45	<45	<45	<45	<45	0
Stouffville Junction to Lincolnville (Stouffville line)	<45	<45	<45	<45	<45	<45	0

Table 10 – Estimate of Population in Zones of Influence for Tier 4 Reference Case

	Population within ZOI (2021)
Total	333,462
Daily 1-way Passenger Ridership	124,857
UE1 - Union to Don River	11,933
UE2 - Don River to Scarborough Jctn	32,085
UW1 - Union to Bathurst St	20,148
UW2 - Bathurst St to Lansdowne Av	27,177
UW3 - Lansdowne Av to Dupont St	11,544
LE1 - Union E2 to Pickering	10,790
LE2 - Pickering to Oshawa 2	1,290
LE3 - Oshawa 2 to Bowmanville	2,783
LW1 - Union W1 to Oakville	22,737
LW2 - Oakville to Hamilton-James	2,665
LW3 - Hamilton Jctn to Hamilton TH+B	531
LW4 - Hamilton-James to St Catherine's	919
MT1 - Union W3 to Meadowvale	13,680
MT2 - Meadowvale to Milton	1,225
GT1 - Union W3 to Brampton	14,215
GT2 - Brampton to Georgetown	3,848
GT3 - Georgetown to Kitchener	1,201
BA1 - Union W2 To Bradford	14,091
BA2 - Bradford to Allandale	480
RH1 - Union E1 to Richmond Hill	5,089
RH2 - Richmond Hill to Bloomington	441
ST1 - Union E2 to Mt Joy	8,319
ST2 - Mt Joy to Lincolnville	1,414

Uncertainties in the Analysis

Several sources of uncertainty affect the accuracy of the analysis. The main ones are discussed here.

1. The actual zones of influence are sensitive to how locomotives operate. They will vary considerably from place to place and somewhat unpredictably due to the complex patterns of engine operation. When accelerating away from a station, a locomotive may operate at full horsepower, while still travelling at a relatively low speed. When approaching a station, the locomotive may operate at relatively high speed but low horsepower before beginning its deceleration. Changes in grade and bends in the corridors may also affect the actual combination of horsepower and speed that occurs at these locations. This study made the simplifying assumption of a linear relationship between speed and horsepower, with full horsepower corresponding to as speed of 130 kph (80 mph). Based on speed and horsepower profiles from a simulation of train travel on one of the corridors (Union to Stouffville; data provided by CANAC Railway Services Inc.), this assumption provides a realistic representation of the average condition along a route. The use of an average condition is considered suitable for the intended purpose of population counts and comparison of one technology option to another.
2. Atmospheric turbulence and dispersal of pollutants has inherent uncertainty. The U.S. EPA indicates that dispersion model accuracies have been reported in the range of plus or minus 10% to plus or minus 40% for predicting the maximum concentration over a year, independent of time and space (U.S. Environmental Protection Agency, 2003). The accuracy is reduced when predicting at specific locations in space (typically plus or minus a factor of 2, in the present author's experience).
3. Meteorological data have some uncertainty. Meteorological conditions vary somewhat around the GTHA, and for a practical analytical approach, a single set of data (from Pearson International Airport) was used.
4. Emission factors have uncertainty. This study assumes that diesel locomotives in the Reference Case have emission corresponding to Tier 4 limits in U.S. EPA locomotive emission standards. In reality, the emissions may vary upward or downward somewhat, depending on the design of engine, its age and its level of maintenance.
5. The analysis did not include localized idling emissions and localized deadhead movements (i.e., non-revenue train movements such as movements into and out of over-night storage) associated with layovers and maintenance yards. There are also some deadhead movements that are less localized, such as mid-day empty return trips from the end of the line back to Union Station. Fuel consumption estimates provided by CANAC Railway Services Inc. indicates that these activities are a small part of the overall level of train activity (approximately 15% of total daily fuel consumption).
6. Background concentrations have uncertainty due to spatial variability. The number of monitoring stations in the region is relatively small, and a practical analytical approach requires that the data be generalized to a large extent in any case. This introduces an uncertainty on the order of plus/minus 15-20%.
7. Population data used in the analysis also have some uncertainty.
8. The overall accuracy of the analysis is considered adequate for a comparative analysis, and the various uncertainties were taken into consideration when interpreting the results of the analysis.

6.4. Nuisance Effects Related to Air Quality

This section considers effects that fall into the category of nuisance rather than impairment of health. These potential effects are threefold: (1) impairment of visibility due to particulate matter emitted with the locomotive exhaust gases and disturbance of dust on the ground near the right of way; (2) soiling of property (e.g., siding of houses) due to the emitted particulate matter and disturbed dust, and (3) adverse odours associated with the exhaust fumes.

Soiling and Visibility

In the context of soiling and visibility issues, airborne particulate matter of all types is often referred to as dust. Dust is a widely acknowledged potential nuisance resulting from both human and naturally occurring sources. The human sources include industrial and non-industrial operations such as vehicle traffic (especially on unpaved areas), domestic and commercial heating, wood stoves, campfires, pollen, burning of wastes, forest/grass fires, and various other sources.

Dust is potentially made up of particulate matter of all size fractions; however, particles larger than 100μm in diameter are likely to settle within a short distance (6 to 9 meters from their source), and particles between 30 and 100μm in diameter are likely to settle within a moderate distance (around 100 meters from their source) [Ontario Ministry of the Environment, 2004]. Since the particulate matter exhausted from diesel internal combustion engines is less 44μm in diameter, the focus in this dust assessment is on that size fraction – referred to hereafter as PM.

The two potential sources of dust associated with locomotive operations are particulate matter in the diesel exhaust and turbulent disturbance of dust settled on the ground near the right of way. The latter source of dust, however, is not known to be a common occurrence along rail corridors. The ballast that serves as the rail bed typically consists of coarse aggregate with little or no dust particles mixed in that could become airborne. Dust particles may become available when soils at sites adjacent to the right of way have been disturbed by construction activities. These activities, however, are temporary in nature and do not represent the normal condition. Therefore, only particulate emissions from diesel combustion were considered in detail in this dust assessment.

For the Reference Case, Diesel PM emissions from GO and ARL trains were estimated using emissions limits published in US EPA final rulings for control of emissions of air pollution from engines. For the Tier 4 diesel Reference Case, the PM emission rate for GO Transit and ARL locomotives is limited to a maximum of 0.03 g/bhp-hr.

This emission rate, together with rail traffic data for the Reference Case was used as input to computer dispersion modelling (the US EPA's CAL3QHCR model) to determine how dust would disperse in the atmosphere under a wide variety of meteorological conditions. The model predicted the maximum 24-hour average concentration of airborne dust contributed by GO Transit locomotives and ARL at downwind locations within 1000 metres of each segment of the rail network, under worst-case meteorological conditions. This result, which represents the upper end of the range of the GO Transit/ARL contribution, was compared against the upper end of the normal range of airborne dust levels that would be found in the surrounding area. This normal range, referred to as the background level of airborne dust, was derived from historical monitoring data for the Greater Toronto and Hamilton Area (GTHA).

In recent years, monitoring conducted in Ontario has focused only on fine particulate matter, smaller than 2.5μm in diameter ($PM_{2.5}$) rather than the total suspended dust that would be of concern from the standpoint of visibility and soiling effects. However, total suspended particulate matter (TSP) can be estimated from the $PM_{2.5}$ measurements using a known approximate relationship between the two

($PM_{2.5}$ was scaled up by an average factor of 3.3, as per research by Lall, Kendall, Ito and Thurston [2004]). It was found that normal 24-hour concentrations of TSP at an average location the GTHA range as high as approximately 60µg/m³ (90th percentile level), with higher levels occurring on occasion. For areas of the rail network that are adjacent to major freeways or in the downtown core of Toronto, the normal levels range somewhat higher (90th percentile level of 65µg/m³).

Comparing the maximum TSP contributions from GO Transit locomotives to upper end background TSP levels in the surrounding area, it was found that the GO Transit contribution falls to less than 10% of the background levels within a very short distance downwind of the right of way, even along the busiest sections of the network (less than 5 metres from the centreline of the corridor). This means that the incremental effect of exhaust particulate matter from GO/ARL operations will most likely be unnoticeable, from the standpoint of visibility and soiling issues, compared to the normal range of background dust conditions.

Electrification under any of the short-listed options would reduce PM emissions relative to the Reference Case. However, since these emissions are not likely to result in significant visibility or soiling impacts under even the Reference Case, the benefits of further reducing PM emissions, from the standpoint of soiling and visibility, would be minimal.

Electrification, on the other hand, has the disadvantage of requiring construction of new infrastructure that would otherwise not be required. The construction activity will have the potential to produce significant dust emissions during, especially activities that involve traffic of heavy equipment on unpaved areas, excavation and handling of soil, and sand blasting. The potential for dust emissions can be mitigated to a certain extent through implementation of effective dust management plans during construction, based on industry best practices. Overall, the potential for extra dust emissions during construction phase represents a slight negative effect for electrification options.

Odour

Diesel engine exhaust fumes have a characteristic odour. RWDI has previously conducted odour testing of GO Transit and other passenger locomotives using well established protocols (RWDI, 2000). Exhaust samples from the main and hotel engines of GO locomotives were collected and odour strengths quantified in terms of odour units (OU). A value of 1 odour unit per cubic metre of air (1 OU/m^3) represents the so-called 50% detection limit. When a panel of observers is exposed to this level of odour, only half of them (50%) can detect it.

The odour emissions quantified in the previous RWDI study were scaled up linearly from the 3210 hp main engine, 1000 hp hotel engine of the previous study to the 4000 hp main engine and 1000 hp hotel engine representing the Tier 4 locomotives of the Reference Case operating at full load. The resulting odour emission rate was used with the US EPA's CAL3QHCR dispersion model to determine how the odours disperse in the atmosphere under a wide variety of meteorological conditions.

Since short-term exposure to odours is enough to constitute a nuisance, the dispersion model was used to estimate maximum 10-minute average odour levels within 1000 metres of each segment of the rail network. This information was used to calculate distances from the centre of the rail corridor within which detectable odours might be encountered (threshold distances). Note that odours were considered to be detectable if they were found to be greater than 1 OU/m³, the threshold at which only 50% of people would detect an odour.

As was done for the dust assessment, these threshold distances were calculated for every segment of the GO network. The calculated distances differ from segment to segment due to variations in train traffic volume, track orientation (affects wind direction), surrounding land-use type and surface roughness. A summary of the findings for the Reference Case is presented in Table 11

Table 11 – Summary of threshold distances for odour

Corridor	Segment Description	Threshold Distance (m)
Lakeshore West + Milton + Georgetown + Barrie	Lakeshore West, Milton, Georgetown and Barrie Lines from Union to Lakeshore West Junction	<50
Milton + Georgetown + Barrie	Milton, Georgetown and Barrie Lines from Lakeshore West Junction to Barrie Junction	<30
Lakeshore East + Stouffville + Richmond Hill	Lakeshore East, Stouffville and Richmond Hill lines from Union to Richmond Hill Junction	<25
Lakeshore East + Stouffville	Lakeshore East and Stouffville lines from Richmond Hill Junction to Dundas St E	<20
Lakeshore East + Stouffville	Lakeshore East and Stouffville lines from Dundas St E Junction to Stouffville Junction	<20
Milton + Georgetown	Milton and Georgetown Lines from Barrie Junction to Milton Junction	<20
Georgetown	Georgetown Line from Milton Junction to Lawrence Ave W	<15
Georgetown	Georgetown Line from Lawrence Ave W To Woodbine Ave (HWY 27)	<15
Georgetown	Georgetown Line from Woodbine Ave (HWY 27) to Goreway Drive	<15
Lakeshore West	Lakeshore West Line from Lakeshore West Junction to Jameson Ave	<15
Lakeshore West	Lakeshore West Line from Jameson Ave to Park Lawn Rd	<15
Lakeshore West	Lakeshore West Line from Park Lawn Rd to 9th Line	<15
Lakeshore West	Lakeshore West Line from 9th Line to Oakville Station	<15
Remainder	Any segments not listed above	<10

Odour threshold distances were found to be less than 10 meters for the vast majority of the rail network. Many of the segments listed in Table 11 that have larger threshold distances are locations where multiple corridors are merged and there are multiple parallel tracks. In these locations, the right of way widens, so that much of the area within the specified distance lies within the right of way.

Note that the locomotives tested in the previous study were pre-Tier 4, meaning that they have higher emissions overall than the future Tier 4 GO locomotives, including, in all likelihood, odour. Also, the fuel used by GO locomotives during testing had a higher sulphur content than the ultra-low sulphur diesel (ULSD) presently used by GO Transit. Since sulphur is a significant component of odour in diesel exhaust, use of ULSD should significantly reduce odours and reduce threshold distances.

Taking these factors into consideration, the occurrence of detectable odours from the diesel locomotives in the Reference Case is expected to be limited to within short distances from the centre of the right of way and is not expected to be a significant nuisance effect for populations near the corridors. Therefore, the potential benefit of electrification options in this respect is small.

It should be noted that this analysis did not account for localized, short-term effects associated with idling locomotives at stations. The most significant instance of idling locomotives will be at Union Station. The range of detectable odours may extend farther in that area than reflected in the results above.

6.5. AIR QUALITY VALUATION

Section 6.2 presented emission inventory data for the GO Transit/ARL train traffic. This portion of the analysis examines the effect these emissions have on the health of the population in the GTHA region. The dollar value of the benefit that would be derived from eliminating the emissions is estimated in a preliminary, screening-level fashion.

Many toxicological and epidemiological studies have identified a relationship between outdoor levels of air pollutants and various indicators of a population's health. For nitrogen dioxide (NO_2), which is the COC of greatest potential concern in the present case, the WHO has identified a possible linkage to effects on respiratory symptoms in children, even at concentrations below 40 $\mu g/m^3$ (World Health Organization, 2005). However, there remains considerable uncertainty as to whether the effects are attributable to NO_2 or to other combustion-related pollutants that are inevitably present with it.

In the case of respirable particulate matter ($PM_{2.5}$), a linkage to both cardiovascular and respiratory symptoms has been observed, and the WHO has noted that the "low end of the range of concentrations at which adverse effect has been demonstrated is not greatly above the background concentration…".

Health Canada has developed a computer tool, the Air Quality Benefits Assessment Tool (AQBAT), as a means of estimating the human health benefits or risks associated with changes in the levels of these pollutants (Health Canada, 2008). The basic approach involves concentration response factors that have been developed for a range of health-related events or "endpoints". The tool also has estimates of the dollar cost of these health endpoints so that an economic value can be placed on predicted health outcomes. For the present study, the response factors and economic valuation data within AQBAT have been used to perform a screening-level analysis of the benefit of eliminating diesel emissions associated with the Tier 4 Reference Case.

Table 12 shows baseline occurrence rates of the health-related events that are tracked by AQBAT. The occurrence rates shown here are either national average values from within AQBAT (Health Canada, 2008), or Ontario averages as presented in a report recently published by Peel Public Health (Region of Peel, 2008).

Table 12 – Baseline Occurrence Rates for AQBAT Health Endpoints

Event	Specified Population Group	Annual Events per Million of Specified Population	Source
Mortality	Total Population	4,244	Peel Region, 2008
Child Acute Bronchitis Episode	25% of Total Population[1] (under 20 years old)	64,000	Health Canada, 2008
Cardiac Hospital Admission	Total Population	9,360	Peel Region, 2008
Cardiac Emergency Room Visit	Total Population	11,646	Peel Region, 2008
Asthma Symptom Day	6% of Total Population (Asthmatics)	48,000,000	Health Canada, 2008
Adult Chronic Bronchitis Case	68% of Population1 (over 25 years old)	6,400	Health Canada, 2008
Acute Respiratory Symptom Day	94% of Total Population (Asthmatics)	64,000,000	Health Canada, 2008
Respiratory Emergency Room Visits	Total Population	10,927	Peel Region, 2008
Respiratory Hospital Admission	Total Population	2,450	Peel Region, 2008
Minor Restricted Activity Day	94% of Total Population (Asthmatics)	8,000,000	Health Canada, 2008
Restricted Activity Day	71% of the Total Population1 (non-asthmatics over 20 years old	18,800,000	Health Canada, 2008

1. Percentages based on Ontario population data by age from www.fin.gov.on.ca/en/economy/demographics/projections/table4.html

Table 13 shows AQBAT's concentration response factors. These factors are expressed in terms of the percentage increase in baseline occurrence rates, due to a unit increase in average concentration. They were derived from statistical models, or from pooling of estimates from several studies. They are shown for the three key regional air pollutants implicated in health effects, $PM_{2.5}$, NO_2 and Ground-Level Ozone (O_3). The 1st two of these pollutants are directly emitted in diesel engine exhaust. The third one, O_3, is not directly emitted but can form in the outside air as a by-product of reactions involving NO_X and hydrocarbons that are emitted in diesel engine exhaust.

The estimates of concentration response factors vary from one study to another, indicating that the response factors have a degree of uncertainty. The level of uncertainty varies from one category of health-related event to another, but is generally on the order of plus/minus a factor of 1.5.

Table 13 also shows AQBAT economic valuation estimates. These estimates consider the economic and social consequences of adverse health effects, including medical costs, work loss, out-of-pocket expenses, pain and suffering (Health Canada, 2008). These estimates do not represent health care costs. Rather, they are indicative of the value that society places on health benefits. One of the economic measures used, known as "willingness to pay", represents the economic trade-offs that people are willing to make to reduce their risk of death or disease. Several decades of economic research has led to the techniques used to estimate the economic value of avoiding undesirable health risks. As with the concentration response factors, the valuation estimates carry significant uncertainty. The uncertainty in the mean values used here can generally be characterized as being on the order of plus/minus a factor of two.

Table 13 – AQBAT Concentration Response Factors and Valuation Estimates (Health Canada, 2008)

Event	Pollutant and Averaging Period	Excess for a Unit Concentration Increase (mean)	Central Estimate of Valuation (per Event)
Chronic Exposure Mortality	24-hour $PM_{2.5}$	0.678%	$4,506,516
Child Acute Bronchitis Episode	24-hour $PM_{2.5}$	2.760%	$343.96
Cardiac Hospital Admission	24-hour $PM_{2.5}$	0.071%	$5,689
Cardiac Emergency Room Visit	24-hour $PM_{2.5}$	0.071%	$393.85
Asthma Symptom Day	24-hour $PM_{2.5}$	0.144%	$30.29
Adult Chronic Bronchitis Case	24-hour $PM_{2.5}$	1.330%	$292,374
Acute Respiratory Symptom Day	24-hour $PM_{2.5}$	0.266%	$14.06

Event	Pollutant and Averaging Period	Excess for a Unit Concentration Increase (mean)	Central Estimate of Valuation (per Event)
Respiratory Emergency Room Visits	24-hour $PM_{2.5}$	0.075%	$393.85
Respiratory Hospital Admission	24-hour $PM_{2.5}$	0.075%	$4,595
Restricted Activity Day	24-hour $PM_{2.5}$	0.482%	$51.93
Acute Exposure Mortality	1-hour O_3	0.127%	$4,506,516
Acute Respiratory Symptom Day	1-hour O_3	0.079%	$14.06
Asthma Symptom Day	1-hour O_3	0.173%	$30.29
Minor Restricted Activity Day	1-hour O_3	0.053%	$35.70
Respiratory Emergency Room Visit	1-hour O_3	0.079%	$393.85
Respiratory Hospital Admission	1-hour O_3	0.079%	$4,595
Acute Exposure Mortality	24-hour NO_2	0.075%	$4,506,516

Table 14 shows estimates of average pollutant levels in the GTHA region, derived from 2008 monitoring data published by the MOE (Ontario Ministry of the Environment, 2008b). In the case of $PM_{2.5}$ and O_3, a significant proportion has been attributed to "transboundary" air pollution associated with emissions from upwind regions. The MOE has indicated that, during the summer season, approximately 50% of the $PM_{2.5}$ in the GTHA, and as much as 90% of the O_3 on high concentration days is due to sources outside of Ontario (Ontario Ministry of the Environment, 2005). For this screening-level assessment the transboundary component has been assumed to be 50% for both $PM_{2.5}$ and O_3, as shown in the table.

The table also shows the percentage GO/ARL contribution to the non-transboundary portion, in the Tier 4 diesel Reference Case. This is based on regional emissions data presented earlier, in Section 6.2.2. For all three pollutants, the percentage shown is the estimated GO/ARL contribution to NO_X emissions in the region. While it may seem odd to apply a value based on NO_X to all of these pollutants, there are two reasons for doing so: (1) the GO/ARL percentage contribution was higher for NO_X than for any other pollutants (refer back to Section 6.2); and (2) NO_X is involved in reactions that can lead to the formation of both O_3 and $PM_{2.5}$ in the outside air. The use of the NO_X percentage, therefore, allows for an upper-bound, screening-level estimate of the GO/ARL contribution to all three pollutants.

Table 14 – Average Regional Pollutant Concentrations and GO/ARL Contribution

Pollutant	Annual average Level in GTHA[1] (µg/m3 or ppb)	Transboundary Contribution	GO/ARL Contribution to non-Transboundary Portion (Tier 4 Reference Case)[2]	GO/ARL Contribution (µg/m^3 or ppb)
24-hour $PM_{2.5}$	8.3	50%	0.22%	0.009
1-hour O_3	29	50%	0.22%	0.032
24-hour NO_2	20	0%	0.22%	0.044

1. Conservatively based on the maximum among stations in the GTHA in 2008 (MOE, 2008b)
2. Based on GO/ARL contribution to NOX, which contributes to formation of $PM_{2.5}$ and O_3 in the outside air

The various inputs of the preceding tables were combined to predict the annual number of health-related events contributed by GO Transit/ARL emissions in the Tier 4 Reference Case, and the estimated value of those events. The baseline occurrence rates of health events were scaled to the overall population of the GTHA, which was approximately 6.3 million in 2006. Table 15 shows the results. These results represent an approximate estimate of the benefit that would be derived from electrifying the entire network (Option 18). The estimated benefits of partial electrification options have not been calculated.

The table shows that the total estimated benefit of electrification, from this approximate screening-level analysis, amounts to $17.9 million annually. While this may seem like a large number, it is actually a tiny proportion overall health and environmental cost of air pollution in Ontario. The MOE estimated that Ontario faces an annual cost of $9.6 billion in health and environmental damages due to O_3 and $PM_{2.5}$ (Ontario Ministry of the Environment, 2005).

Table 15 – Excess Events and Valuation Due to GO/ARL Emissions in the Tier 4 Reference Case

Event	Pollutant and Averaging Period	Excess Events (mean)	Annual Cost
Chronic Exposure Mortality	24-hour $PM_{2.5}$	1.7	$7,484,646
Child Acute Bronchitis Episode	24-hour $PM_{2.5}$	25.5	$8,767
Cardiac Hospital Admission	24-hour $PM_{2.5}$	0.4	$2,185
Cardiac Emergency Room Visit	24-hour $PM_{2.5}$	0.5	$188
Asthma Symptom Day	24-hour $PM_{2.5}$	239.4	$7,251
Adult Chronic Bronchitis Case	24-hour $PM_{2.5}$	3.3	$976,798
Acute Respiratory Symptom Day	24-hour $PM_{2.5}$	9,236.7	$129,867
Respiratory Emergency Room Visits	24-hour $PM_{2.5}$	0.5	$187
Respiratory Hospital Admission	24-hour $PM_{2.5}$	0.1	$490
Restricted Activity Day	24-hour $PM_{2.5}$	3,713.5	$192,844
Acute Exposure Mortality	1-hour O_3	1.1	$4,898,523
Acute Respiratory Symptom Day	1-hour O_3	9,536.2	$134,079
Asthma Symptom Day	1-hour O_3	1,004.8	$30,436
Minor Restricted Activity Day	1-hour O_3	803.8	$28,695

Event	Pollutant and Averaging Period	Excess Events (mean)	Annual Cost
Respiratory Emergency Room Visit	1-hour O_3	0.6	$687
Respiratory Hospital Admission	1-hour O_3	0.4	$1,796
Acute Exposure Mortality	24-hour NO_2	0.9	$3,979,468
TOTAL	"--"	"--"	$17,876,908

7. CONCLUSIONS

Table 16 and Table 17 summarize the findings of the assessment. Table 16 indicates the magnitude of the effect of each electrification option and Table 17 provides an overall qualitative scoring.

The “Local Air Quality and Health” column of Table 16 identifies the magnitude of effect as “small” and “positive”. This rating comes from the fact that GO Transit’s incremental contribution to background levels of COC’s in the influence areas was found to be small in relation to health-based thresholds. Therefore, the effect of electrification options in removing portions or all of this increment is considered to be small.

The “Local Air Quality and Health” column also shows the estimated local population affected by each electrification option. For the Tier 4 diesel Reference Case, the estimated population contained within the overall influence area was over 330,000, which includes not just residents who live near the corridors, but also the estimated passengers who use GO Transit daily. With each electrification option, the influence area is reduced and a portion of the population ceases to be within it, as indicated in the table.

The overall qualitative score for Local Air Quality and Health, shown in Table 17, considers both the magnitude of the effect and the relative size of affected population. Since the magnitude of effect is considered to be small, cases where a relatively large population is affected (i.e., Options 11 through 18) were assigned a score of “moderate”. All other cases were assigned a score of “small”.

Table 16 – Summary of Magnitude of Impact of Electrification

Option	Local Air Quality and Health	Regional Air Pollutants and Health	GHG’s and Global Warming
1	Small positive effect Affected population: 70,000	Much less than 1% effect on regional pollutants	Much less than 1% effect on regional GHG’s
2	Small positive effect Affected population: 130,000	“	“
3	Small positive effect Affected population: 200,000	“	“
11	Small positive effect Affected population: 250,000	“	“
15	Small positive effect Affected population: 280,000	“	“
18	Small positive effect Affected population: 330,000	“	“

Table 17 – Overall Qualitative Scoring

Option	Local Air Quality and Health	Regional Air Pollutants and Health	GHG's and Global Warming
1	Small benefit	Slight benefit	Slight benefit
2	"	"	"
3	"	"	"
11	Moderate benefit	"	"
15	"	"	"
18	"	"	"

Appendix 8D-1 - References

Chan, L.Y., W.L. Lau, S.C. Lee, C.Y. Chan. (2002). *Commuter Exposure to Particulate Matter in Public Transportation Modes in Hong Kong*. Atmos. Env. 36 (2002) 3363-3373.

Chertok, M., A. Voukelatos, V. Sheppeard, C. Rissel. (2004). *Comparison of Air Pollution Exposure for Five Commuting Modes in Sydney – Car, Train, Bus, Bycycle and Walking*. Health Promotion Journal of Australia: 15 (1).

Delcan Arup Joint Venture. (June 18, 2010). *Reference Case Final Workbook, Issue 2*. Toronto, ON: Delcan Arup Joint Venture.

Environment Canada. (2009). *National Pollutant Release Inventory Online Data Search*. Retrieved from http://www.ec.gc.ca/pdb/websol/emissions/ap/ap_query_e.cfm.

Environment Canada. (2010). The National Air Pollution Surveillance (NAPS) Network online mapping tool. Retrieved from http://www.etc-cte.ec.gc.ca/napsstations/main.aspx.

Environment Canada. (2008). Canada's Greenhouse Gas Inventory, National/Provincial/Territorial Tables. http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=83A34A7A-1

Gomez-Perales, J.E., R.N. Colvile, A.A. Fernandez-Bremauntz, V. Gutierrez-Avedoy, V.H. Paramo-Figueroa, S. Blanco-Jimenez, E. Bueno-Lopez, R. Bernabe-Cabanillas, F. Mandujano, M. Hidalgo-Navarro, M. J. Nieuwenhuijsen. (2007). *Bus, Minibus, Metro Inter-comparison of Commuters' Exposure to Air Pollution in Mexico City*, Atmos. Env. 41 (2007) 890-901.

Health Canada. (2008). *Air Quality, Climate Change and Health*, Ch. 4 of Human Health in a Changing Climate: A Canadian Assessment of Vulnerabilities and Adaptive Capacity.

Kingham, S., J. Meaton, A. Sheard, O. Lawrenson. (1998). *Assessment of Exposure to Traffic-Related Fumes During the Journey to Work.* Transportation Research, Vol. 3, No. 4, 271-274.

Intrinsik. (July 27, 2009). *Georgetown South Corridor Service Expansion and Union Pearson Rail Link Environmental Assessment, Human Health Assessment of Air Quality Impacts*. (Project #20205). Mississauga, ON: Intrinsik Environmental Sciences Inc.

Lall, R., Kendall, M., Ito, K., Thurston, G. D. (January, 2004). *Estimation of Historical Annual $PM_{2.5}$ Exposures for Health Effects Assessment*. (Atmospheric Environment 38 (2004) 5217-5226). Elsevier.

Li, Tian-Tian, Yu-Hua Bai, Zhao-Rong Liu, Jin-Feng Liu, Guang-Shan Zhang, Jin-Long Li. (2006). *Air Quality in Passenger Cars of the Ground Railway Transit System in Beijing, China*. Science of the Total Environment 367 (2006) 89-95.

Metrolinx. (July 30, 2009). *Georgetown South Service Expansion and Union-Pearson Rail Link Environmental Project Report*. Ontario: Metrolinx.

Ontario Ministry of the Environment. (January, 2004). *Technical Bulletin: Review of Approaches to Manage Industrial Fugitive Dust Sources*. Standards Development Branch. Ontario: Queen's Printer for Ontario.

Ontario Ministry of the Environment. (June 2005). *Transboundary Air Pollution in Ontario*. www.ene.gov.on.ca/envision/techdocs/518e_index.htm.

Ontario Ministry of the Environment. (May 14, 2007). *Ontario Regulation 419/05: Air Pollution – Local Air Quality: Ontario Regional Meteorological Data*, Version #2. (5081e01). Ontario: Queen's Printer for Ontario.

Ontario Ministry of the Environment. (February, 2008). *Ontario's Ambient Air Quality Criteria*. Standards Development Branch. (PIBS # 6570e). Ontario: Queen's Printer for Ontario.

Ontario Ministry of the Environment. (2008b). *Air Quality in Ontario, 2008 Report*. www.airqualityontario.com/press/publications.cfm

Ontario Ministry of the Environment. (2010a). *Search Historical Air Quality Pollutant Data*. Retrieved from http://www.airqualityontario.com/history. Ontario: Queen's Printer for Ontario

Ontario Ministry of the Environment (2010b). Retrieved online from http://www.ebr.gov.on.ca/ERS-WEB-External/displaynoticecontent.do?noticeId=MTA2Mjc1&statusId=MTU5Mzgy&language=en

Ontario Power Authority. (December 9, 2005). *Supply Mix Advice Report*. Ontario: OPA.

Pechan. (October, 2007). *Compilation of Diesel Emissions Speciation Data*. (07.10.001/9452.000).

Peel Public Health – Region of Peel. (2008). A Picture of Health, A Comprehensive Report on Health in Peel. www.peelregion.ca/health/health-status-report/chsr/chapter5.htm.

Railway Association of Canada. (2007). *Locomotive Emissions Monitoring Program 2007*. Canada: RAC.

RWDI. (July 18, 2000). *Air Quality Monitoring Program for the Rail Lands West Development, Toronto, Ontario. Final Report*. RWDI Project #00-329.

Stanek, L.W., Sacks, J., Dutton, S., Ross, M. (September, 2010). A Review of the Current State of Science for Health Effects of Particulate Matter. *Em Magazine, September, 2010 issue*, 12-19.

U.S. Environmental Protection Agency. (1995). *User's Guide to CAL3QHC Version 2.0: A Modeling Methodology for Predicting Pollutant Concentrations Near Roadway Intersections*. (EPA-454/R-92-006). North Carolina: U.S. EPA.

U.S. Environmental Protection Agency. (April, 2000). AP-42 Compilation of Air Pollution Emission Factors, Chapter 3: Stationary Internal Combustion Sources, *Section 3.1: Stationary Gas Turbines*. United States: U.S. EPA.

U.S. Environmental Protection Agency. (September, 2005). *Documentation for Aircraft, Commercial Marine Vessel, Locomotive, and Other Nonroad Components of the National Emissions Inventory*. United States: U.S. EPA.

U.S. Environmental Protection Agency. (June 30, 2008). *Control of Emissions of Air Pollution From Locomotive Engines and Marine Compression-Ignition Engines Less Than 30 Litres per Cylinder; Republication*; Final Rule. (EPA-HQ-OAR-2003-0190; FRL-8545-3). United States: U.S. EPA.

U.S. Environmental Protection Agency. (April, 2009). *Technical Highlights: Emission Factors for Locomotives*. Office of Transportation and Air Quality. (EPA-420-F-09-025). United States: U.S. EPA.

U.S. Environmental Protection Agency. (2003). *Appendix W to Part 51 – Guideline on Air Quality Models*. 40 CFR Ch. I (7-1-03 Edition), Part 51, Appendix W, Sec. 10.1.2.

World Health Organization. (2005). *WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide*. (WHO/SDE/PHE/OEH/0.6.02). Geneva, Switzerland: WHO Press.