Evaluation of Total Cost of Air Pollution Due to Transportation in Canada

– Final Report –

RFP # T8080-06-0292

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Transport Canada

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List of Acronyms

AB	Alberta
AQBAT	Air Quality Benefits Assessment Tool
AQVM	Air Quality Valuation Model
BAU	Business As Usual
BC	British Columbia
CD	Census Division
CC	Contingent Choice
CACs	Criteria Air Contaminants
CCME	Canadian Council of Ministers of the Environment
CMA	Census Metropolitan Areas
CO	Carbon monoxide
CRF	Concentration Response Function
DFA	Damage Function Approach
DRF	Dose Response Function
EPV	Endpoint Valuations
DV	Deciview
FCI	Full Cost Investigation
LTO	Landing and Take Off
MB	Manitoba
MSC	Meteorological Service of Canada
NAPS	National Air Pollution Surveillance
NARSTO	North American Research Strategy for Tropospheric Ozone
NB	New Brunswick
NF	Newfoundland
NO_x	Nitrogen oxides
NPRI	National Pollutant Release Inventory
NRCan	Natural Resources Canada
NS	Nova Scotia
ON	Ontario
O_3	Ozone
PDF	Probability Density Function
PJ	Petajoules
PM	Particulate Matter
PM_{10}	Particulate Matter smaller than 10 microns in diameter
$PM_{2.5}$	Particulate Matter smaller than 2.5 microns in diameter
QA/QC	Quality Assurance and Quality Control
QC	Quebec
ReFSoRT	Reduced Form Source-Receptor Tool
SK	Saskatchewan
SO_2	Sulphur Dioxide
SOA	Secondary Organic Aersol
SRT	Source-Receptor Tool
TOR	Terms of Reference
VIEW	Visibility Impact Estimator of Welfare
VKT	Vehicle Kilometres Travelled
VOC	Volatile Organic Compounds
VOICCE	Value of Ozone Impacts on Canadian Crops Estimator
VSL	Value of a Statistical Life
WTP	Willing To Pay

EXECUTIVE SUMMARY

Introduction

In co-operation with provincial and territorial departments, Transport Canada initiated a project called Full Cost Investigation (FCI). This project is steered by a federal-provincial task force reporting to the Policy and Planning Support Committee of the Council of Deputy Ministers Responsible for Transportation and Highway Safety. The FCI is intended to estimate the total financial and social costs of all major modes of transport in Canada for the year 2000, in order to identify transport's total resource consumption as well as its impacts on the environment, health and well-being. All major passenger and freight modes of travel are considered in the FCI (i.e. on-road, rail, marine and air).

This project considers Phase 4 of the FCI and is focused on estimating the economic value of transport-caused air pollution, allocating these costs by transport mode and province and estimating average unit pollutant costs. The goal of the study is to provide reasonable and credible estimates of the total cost of transport-caused air pollution in Canada in the year 2000. To accomplish this goal, three objectives must be satisfied:

1. **Estimate changes in air quality for scenarios with and without transport emissions**. Determine the incremental air quality impacts attributable solely to transportation emissions.

2. **Estimate impacts and costs of transportation-caused air pollution**. Estimate and analyze the impacts on health and two environmental receptors, including changes in crop yields from ozone (agriculture) and changes in visibility from increased particulate matter leading to reduced visibility experienced by humans;

3. **Allocate Total Cost by Transportation Mode**. This included:

   - Monetize the air quality impacts caused by transportation on the health and environmental receptors and aggregate them into one total cost of transport emission in 2000;
   - Allocate the transport total cost (meaning the monetized value of the air quality environmental and health impacts) for selected modes and by province; and,
   - Allocate the total cost to each mode by transport activity level for use in the FCI.

Transport-related air pollution impacts on forestry were not assessed in this study, although they had been originally part of the Terms of Reference (TOR) for the study. There were difficulties in attaining concentration response functions and baseline impact data associated with the different forested regions in Canada. Estimations of visibility impacts were not requested in the TOR, but were provided since data and methods were readily available. The economic costs estimated in this report are therefore conservatively low since they do not reflect the full range of costs that likely can be attributable to transport emissions.

Study Results

Estimated Changes in Air Quality

The Reduced Form Source-Receptor Tool, ReFSoRT, developed by RWDI in collaboration with Environment Canada, was used to determine changes in ambient air quality attributable to year 2000 transport emissions at the census division level. The baseline emissions inventory used to evaluate the air quality impact of transportation emissions was drawn from Environment Canada's Criteria Air Contaminant Emission Inventory, 2000.

A review of the year 2000 emission inventory indicates that the transportation sector comprises a significant proportion of the total emissions for all the relevant pollutants considered (SO_2, NO_X, $PM_{2.5}$ and VOC). NO_X transportation emissions contributed the largest share of the overall emissions. Exhibit E-1 summarizes the contribution of transportation emissions to the total Emissions in the Year 2000 CAC Emission Inventory.

Exhibit E-1
Share of Transportation Emissions to Year 2000 CAC Emission Inventory

	000's of tonnes				
	NOx	**SO_2**	**VOC**	**$PM_{2.5}$ (Emission Scenario #1, No paved road dust)**	**$PM_{2.5}$ (Emission Scenario #2, Including paved road dust)**
Total Emissions	3,108	2,258	14,952	1,095	1,095
Transport Related	892	60	440	21	132
Transport's Share	29%	2.6%	2.9%	1.9%	12%

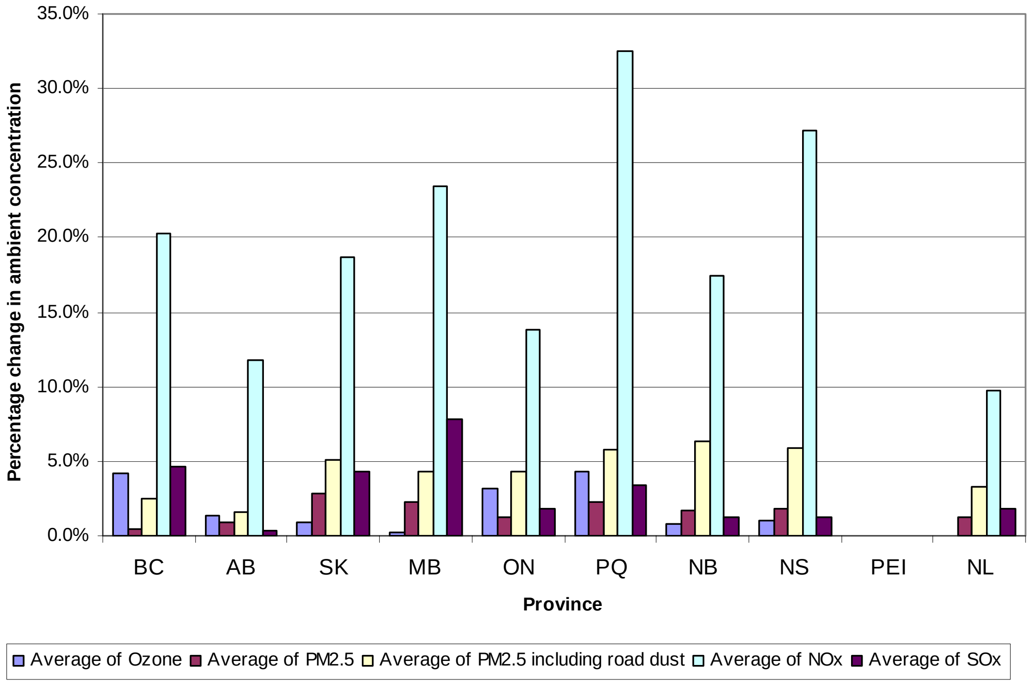
From this data, two emissions scenarios were developed that isolate transportation emissions for the purpose of estimating transport's air quality, health and environmental impacts:

1. **Emission Scenario #1** is the impact of all transportation emissions but not paved road dust (transport emissions without paved road dust);

2. **Emission Scenario #2** is the impact of all transportation emissions including paved road dust (transport emissions *with paved* road dust).

The modeling of the emission scenarios in ReFSoRT indicated that transportation emissions contribute significantly to ambient air quality in Canada. As expected when assessing transport emissions, NO_X is the transport related pollutant that contributes, on average by province, the most to baseline ambient air quality levels. Exhibit E-2 summarizes the average concentration attributable to transport in each province.

Exhibit E-2
Transport's Contribution to Average Ambient Air Concentration by Province in 2000



Estimate Impacts and Costs of Transportation-caused Air Pollution

Health and Environmental Impacts

The concentration changes by census division for the ambient air quality from ReFSoRT were used as inputs into one health and two environmental valuation models:

- The AQBAT model estimates changes in 10 morbidity and mortality health endpoints related to ambient air quality changes;
- Environment Canada's Value of Ozone Impacts on Canadian Crops Estimator (VOICCE) model was used to estimate changes in production yield for 10 different crops that are sensitive to ambient ozone; and,
- Environment Canada's Visibility Impacts Estimator of Welfare (VIEW) model was used to link changes in $PM_{2.5}$ concentrations to improvements in visibility.

A summary of the changes in annual economic values based on results from the three valuation models are provided in Exhibit E-3. The costs presented represent the central (or mean) values that can be attributed to transport emissions for the two emission scenarios.

Exhibit E-3
Summary of Total Annual Economic Valuation Attributable to Transport

	Central Estimate of Economic Value (000's 2000$)	
	Emission Scenario #1. Transport emissions without paved road dust	**Emission Scenario #2. Transport emission with paved road dust**
Health Endpoints	$3,780,000	$5,540,000
Visibility Endpoints	$62,200	$165,000
Agricultural Endpoints	$35,900	$35,900
Total Canada	**$3,880,000**	**$5,740,000**

As can be observed in Exhibit E-3, by far the most significant of all these endpoints are health endpoints representing approximately 97% of total costs of transport-caused air pollution. Visibility and agricultural endpoints contributed less than 3% to the overall cost. In terms of health endpoint costs, acute and chronic exposure mortality related to NO_X, SO_2 and $PM_{2.5}$ represent more than 96% of the total health costs in both emission scenarios and therefore these endpoints contribute the most overall to the study (more than 93% of the total costs of all health and environmental endpoints).

Exhibit E-4 and Exhibit E-5 present provincial summaries of the costs associated with health endpoints for the two emission scenarios.

Exhibit E-4
Provincial Summary of Costs of all Health Endpoints
Transport Emissions Without Paved Road Dust

Province	Total Health Endpoint Values (Dollar value in 000's 2000$)		
	Low (20th percentile)	**Central**	**High (80th Percentile)**
Newfoundland and Labrador	$7,410	$10,100	$12,800
Nova Scotia	$9,140	$11,700	$14,200
New Brunswick	$31,800	$43,100	$54,200
Quebec	$959,000	$1,300,000	$1,630,000
Ontario	$1,230,000	$1,650,000	$2,070,000
Manitoba	$80,700	$111,000	$141,000
Saskatchewan	$42,900	$56,600	$70,000
Alberta	$156,000	$214,000	$270,000
British Columbia	$288,000	$388,000	$486,000
CANADA (TOTAL)	**$2,800,000**	**$3,780,000**	**$4,750,000**

Exhibit E-5
Provincial Summary of Costs of all Health Endpoints
Transport Emissions With Paved Road Dust

Province	Total Health Endpoint Values (Dollar value in 000's 2000$)		
	Low (20th percentile)	Central	High (80th Percentile)
Newfoundland and Labrador	$14,400	$19,300	$24,000
Nova Scotia	$11,600	$14,900	$18,000
New Brunswick	$68,900	$91,500	$113,000
Quebec	$1,370,000	$1,840,000	$2,290,000
Ontario	$1,960,000	$2,610,000	$3,240,000
Manitoba	$107,000	$145,000	$182,000
Saskatchewan	$60,300	$79,000	$97,200
Alberta	$183,000	$249,000	$313,000
British Columbia	$371,000	$496,000	$618,000
CANADA (TOTAL)	**$4,150,000**	**$5,540,000**	**$6,900,000**

The low and central values in Exhibit E-4 and E-5 represent the range of cost estimates that reflect the uncertainty in the main parameters used to estimate transport costs. This range reflects the probability distributions contained in the concentration response functions and endpoint values used in the AQBAT model. The most significant determinant of health costs is the value for acute and chronic exposure mortality, which includes Transport Canada's range for the Value of a Statistical Life of $3,050,000 to $5,050,000 with a mean value of $4,050,000.

Allocation of Costs

The allocation of the costs of transport-related air pollution by mode reveals that heavy-duty freight vehicles and passenger light duty vehicles represent more than 50% of the cost of transport-related air pollution. Freight marine and rail transportation, as well as passenger light-duty gas trucks are also major contributors to air pollution costs. Exhibit E-6 summarizes the total costs and share of all transport modes considered in the study. Note that paved road dust is not included in transport mode costs since there is no credible way to allocate these emissions to the transport modes. The cost attributable to paved road dust represents almost one third of the total cost of transport-related air pollution.

Exhibit E-6
National Allocation of Air Pollution costs to Transport Canada Modes

Transport Canada Modes	National Economic Valuation of Emissions from Transport Modes (000's 2000$)			
	MIN (20th percentile)	MEAN	MAX (80th percentile)	% of Mean Value
Freight Air Transport	$1,190	$1,580	$1,970	0.0%
Freight Heavy-duty diesel vehicle	$823,000	$1,110,000	$1,390,000	19.3%
Freight Heavy-duty gas vehicle	$64,900	$87,200	$109,000	1.5%
Freight Light-duty diesel truck	$5,340	$7,100	$8,810	0.1%
Freight Light-duty gas truck	$132,000	$176,000	$219,000	3.1%
Freight Marine Transport	$367,000	$492,000	$615,000	8.6%
Freight Rail Transport	$318,000	$428,000	$537,000	7.5%
Passenger Air Transport	$21,400	$28,500	$35,500	0.5%
Passenger Interurban diesel bus	$12,000	$16,200	$20,200	0.3%
Passenger Interurban gas bus	$164	$220	$276	0.0%
Passenger Light-duty diesel truck	$12,600	$16,700	$20,700	0.3%
Passenger Light-duty diesel vehicle	$7,900	$10,500	$13,100	0.2%
Passenger Light-duty gas truck	$335,000	$446,000	$555,000	7.8%
Passenger Light-duty gas vehicle	$688,000	$917,000	$1,140,000	16.0%
Passenger Marine Transport	$34,400	$46,200	$57,700	0.8%
Passenger Rail Transport	$11,400	$15,300	$19,100	0.3%
Passenger Urban and School Diesel Bus	$64,500	$86,800	$109,000	1.5%
Passenger Urban and School Gas Bus	$45	$60	$75	0.0%
All Transport Canada Modes	**$2,900,000**	**$3,880,000**	**$4,850,000**	**67.6%**
Paved Road Dust	**$1,450,000**	**$1,860,000**	**$2,250,000**	**32.4%**
Total Canada	**$4,350,000**	**$5,750,000**	**$7,100,000**	**100.0%**

Significant Findings

The following significant findings are revealed in this study:

1. NO_x drives the overall results with a full 52% of the total value attributable to NO_x. This result is interesting since PM often is the main driver in air quality health valuation studies, but of course since we are dealing with transport that contributes to large NO_x emissions, the NO_x emissions dominate the health outcomes;

2. Acute exposure mortality is the largest single health and environmental endpoint, accounting for a full 70% of the total economic cost. Total exposure mortality (acute and chronic) account for a full 96% of the health damages;

3. Just 2 CMA's account for almost 33% of the overall valued impact under emission scenario #1 (transport emissions without paved road dust): Montréal and Toronto. Of the total economic value associated with the scenario of $3.786 billion, Montréal accounts for $620 million (16%) while Toronto accounts another $614 million (16%); and,

4. Two transport modes account for 52% of the total economic value under Emission Scenario #1: Freight heavy-duty diesel vehicle and passenger light-duty gas.

1 INTRODUCTION TO THIS REPORT

1.1 BACKGROUND

In co-operation with provincial and territorial departments, Transport Canada has initiated a project called Full Cost Investigation (FCI). This project is being steered by a federal-provincial task force reporting to the Policy and Planning Support Committee of the Council of Deputy Ministers Responsible for Transportation and Highway Safety. The FCI is intended to estimate the total financial and social costs of all major modes of transport in Canada for the year 2000, in order to identify transport's total resource consumption as well as its impacts on the environment, health and well-being. All major passenger and freight modes of travel are considered in the FCI (i.e. on-road, rail, marine and air).

The FCI is organized in five phases:

- In Phase 1 of the FCI, nationwide financial costs and revenues for major modal networks were compiled including the costs of both network infrastructure and transport services;
- In Phase 2, these same financial costs and revenues are estimated at the provincial and territorial level;
- In Phase 3 of the FCI, these costs and revenues are allocated by passenger and freight activities
- This project considers Phase 4 of the FCI and is focused on estimating the economic value of transport-caused air pollution, allocating these costs by transport mode and province and estimating average unit pollutant costs; and,
- In Phase 5 of the project, total marginal costs are estimated and compared among the different transportation modes. This type of analysis will allow a variety of modes to be compared extensively in terms of their economic impacts.

1.2 GOALS AND OBJECTIVES OF THIS PROJECT

The goal of the study is to provide reasonable and credible estimates of the total cost of transport-caused air pollution in Canada in the year 2000. To accomplish this goal, five specific objectives must be satisfied:

1. Determine the incremental air quality impacts attributable solely to transportation emissions. Two scenarios are compared to a baseline of all emissions of NO_X, PM, VOCs and SO_2 in Canada in the year 2000 to determine the increment attributable to transport:
    - Emission Scenario #1 (2000): All emissions of NO_X, PM, VOCs and SO_2 from transport but *without* paved road dust; and,
    - Emission Scenario #2 (2000): All emissions of NO_X, PM, VOCs and SO_2 from both transport *and* paved road dust.

2. Estimate and analyze the impacts on health and two environmental receptors, including changes in crop yields from ozone (agriculture) and changes in visibility from increased particulate matter leading to reduced visibility experienced by humans;

3. Monetize the air quality impacts caused by transportation on the health and environmental receptors and aggregate them into one total cost for transport emission alone in 2000;

4. Allocate the transport total cost (meaning the monetized value of the air quality environmental and health impacts) for selected modes and by province; and,

5. Allocate the total cost to each mode by activity level for use in the FCI.

Transport-related air pollution impacts on forestry were not assessed in this study, although they had been originally part of the Terms of Reference (TOR) for the study. There were difficulties in attaining concentration response functions and baseline impact data associated with the different forested regions in Canada. Estimations of visibility impacts were not requested in the TOR, but were provided since data and methods were readily available. The economic costs estimated in this report are therefore conservatively low since they do not reflect the full range of costs that likely can be attributable to transport emissions.

1.3 ABOUT THIS REPORT

The report provides estimates of the total costs attributable to transport-cause pollution so that they can be used in the Full Cost Investigation. In addition to this introductory section:

- Sections 2 and 3 of the report provide the assessment approach and methodology used in the study;
- Sections 4 and 5 present the costs of pollution for health, visibility and agricultural endpoints that were generated using cost valuation models.
- Section 6 presents a summary of the total costs of transport-caused air pollution;
- Section 7 allocates the costs that have been calculated to each of the relevant transportation modes and also presents unit pollutant costs by province;
- Section 8 examines data and model uncertainty and provides results of sensitivity testing including an estimate of minimum, mean and maximum costs; and,
- In Section 9 the conclusions of the study are presented.

2 APPROACH FOR THE ASSESSMENT OF THE SOCIAL COSTS OF AIR POLLUTION

This section provides the conceptual overview of how we modeled the total costs of air pollution attributable to transport emissions and provides specific information on the modelling components. The section is presented in three sub-sections:

1. The *Health and Environmental Impacts of Transport Emissions* identifies the major endpoints that are affected when transport-related emissions affect ambient air quality;

2. The *Damage Function Approach* introduces the approach that forms the conceptual basis for identifying, quantifying and then monetizing the total costs of transport-related emissions in Canada in 2000; and,

3. The *Modeling Approach* provides an overview of the specific models and components used to identifying, quantifying and then monetizing the total costs of air pollution from transport-related emissions. The modeling approach identifies as a first key step, how transport emissions are isolated from the overall inventory of NO_x, SO_2, PM, and VOC emissions in Canada in 2000 as well transport's incremental impact on ambient air quality.

Note that not all of the impacts attributable to transport emission are included in this study.

2.1 THE HEALTH AND ENVIRONMENTAL IMPACTS OF TRANSPORT EMISSIONS

Air pollutant emissions alter ambient air quality either directly, as in the case of particulate matter, or through the secondary formation of PM and Ozone as in the case of NO_x, SO_2 and VOCs. Studies conclude that these ambient air quality changes impact sensitive human and environmental receptors. In this study, three areas of impact are assessed in the determination of the total cost of transport-related emissions in Canada in the year 2000:

- The *human health impacts*, which are changes in mortality and morbidity associated with changes in ambient air quality and transport-related emission specifically;

- *Impacts on agriculture crops* include reductions in crop productivity and yield due to ozone attributable to transport emissions; and,

- *Visibility impacts* result when particulate emissions from transport-related activity obstruct vistas through haze formation thereby reducing the viewing pleasure enjoyed by individuals.

- A *Summary* is also provided in this section of the full range of impacts that can be attributed to transport emissions.

Human Health Impacts

The human health impacts of PM and Ozone have been reported and discussed in a number of publications including the World Health Organization's Air Quality Guidelines (World Health

Organization, 2000) and, closer to home, the Canadian Council of Ministers of the Environment's Human Health Effects of Ozone: Update in Support of the Canada-Wide Standards for Particulate Matter and Ozone (CCME, March 2003) and related documents.

The effects of air pollution have been associated with easily discernable effects such as coughs and wheezing but can also be linked to less readily identifiable consequences such as an increase in medication or loss of quality of life and productivity (MacPhail *et al.*, 1998). The effects also range in magnitude from severe events (e.g., death or mortality) to mild common effects (e.g., morbidity such as eye, nose and throat irritation that may interfere with normal activity such as driving a car and measurable changes of lung function which are asymptomatic, due to a naturally large lung reserve in healthy individuals). The extent of the effects of air pollution on an individual depend on his/her disposition and sensitivity. For those individuals who are more sensitive, the effects can be felt with the smallest increase in air pollution (MacPhail *et al.*, 1998). Because the effects of air pollution can be asymptomatic effects on well-being, the cumulative effect on all affected individuals is substantial.

With respect to ozone, the Ontario Medical Association reports that, "at current levels of exposure, pollutants such as ground-level Ozone, inhalable particulates and total sulphur compounds are responsible for adverse health effects in Ontarians" (MacPhail *et al.,* 1998). In addition, exposure to ground-level Ozone does not appear to show a threshold level below which no health effects are observed (Health Canada, 1996). A review of available evidence for the Canadian Smog Advisory Program concluded that health and health-care system effects of ground-level Ozone at levels that occur in Canada include lung inflammation, decreased lung function, airway hyper-reactivity, respiratory symptoms, possible increased medication use and physician/emergency room visits among individuals with heart or lung disease, reduced exercise capacity, increased hospital admissions and possible increased mortality (Stieb *et al.*, 1995; CCME, March 2003). Similar effects were found to occur in association with airborne particulate matter, with the exception of lung inflammation and with the additional effect of increased school absenteeism (MacPhail *et al.*, 1998). Studies have also shown an association between increased hospital admissions and mortality, and air pollutants (Pope, 1996).

The Impacts on Agriculture Crops

The environmental impacts of transport emissions through changes in ambient air quality and deposition also impact ecosystem services and functions. Notably, changes in ambient Ozone concentrations have been shown to have quantifiable impacts on vegetation productivity and growth. In assessing the impacts on agriculture crops of Ozone, and vegetation in general, the Canadian Council of Ministers of the Environment (CCME, 2003) report that "an absolute threshold Ozone concentration above or below which vegetation injury will or will not occur has not been identified in the scientific literature." Ozone uptake is almost entirely through the foliage (Emberson, 2003; CCME, 2003). Once in the plant leaf, Ozone reacts with constituents of the cell wall to form other derivatives which cause the oxidation of cell components. Visible injuries can result from this process generally associated with short-term exposures to high Ozone concentrations (Emberson, 2003). Symptoms of acute injury on broad-leafed plants include chlorosis, bleaching, bronzing, flecking, stippling, unifacial and bifacial necrosis. On conifers, tip necrosis, mottling, and banding are all common symptoms (Kley et al., 1999; CCME, 2003). Chronic exposures may or may not result in visible symptoms on the plant's foliage (usually characterized by chlorosis, premature senescence and leaf abscission). In addition, crop yields can also be affected through reductions in growth from chronic exposures and result in crop yield losses, reduction in annual biomass increments for forest trees, and shifts in species composition of semi-natural vegetation (Emberson, 2003). Secondary effects also include reduced root growth and a greater root-to-shoot ratio, reduced yield of fruits or seeds, or both (WHO, 2000; CCME, 2003).

The CCME (2003) reports that, "in Ontario, studies of the impact of Ozone on crop yield have identified the following crops to be at greatest risk: dry bean, potato, onion, hay, turnip, winter wheat, soybean, spinach, green bean, flue-cured tobacco, tomato and sweet corn. Crops estimated to be marginally at risk (insufficient data did not permit more accurate quantification of loss) included cucumber, squash, pumpkin, melon, grape, burley tobacco and beet." Other commonly grown agricultural crops in Canada which are not found in the above list should not be considered resistant to the impact of Ozone as their response is simply not known at this time. Again, the CCME (2003) reports that "tree species common to Canada that have demonstrated Ozone sensitivity with respect to a variety of endpoints (e.g. biomass, height, photosynthesis) under controlled Ozone exposure conditions include: maples (sugar, silver, red), ash (white, green), spruce (white), white pine, poplar (hybrid), cottonwood, cherry, walnut, sycamore, white birch and red oak." Overall, although some positive responses to Ozone were identified, studies on vegetation found that the average response to Ozone involves a marginal growth reduction. Aside from wild vegetation and crops, Ozone has been shown to injure many annual and perennial grass species commonly used in turfgrass production in parts of Canada (CCME, 2003).

Summary of Impacts Attributable to Transport Emissions

A summary of air quality, environmental, human health and economic implications attributable to criteria air contaminant (CAC) emissions from transport emissions is included in Exhibit 2-1. This taxonomy is not only an assessment framework but also a reporting framework where the physical impacts outlined in Exhibit 2-1 are translated, where possible into monetary values, and thus a "full cost story" emerges that includes a mix of physical and monetary indicators.

Note that not all of the impacts identified in Exhibit 2-1 are included in this study. Thus, the range of total costs calculated is conservatively low.

Exhibit 2-1
Air Quality, Human Health and Environmental Impacts Attributed to Transportation Emissions

	Transportation Emissions Lead to the:		
	Formation of $PM_{2.5}$ then results in	**Formation of Ozone then results in**	**Wet/dry acid deposition then results in**
Air Quality and Deposition Impacts	• Actual change, for example measured as μg/m^3 of PM; • % reduction from the base ambient levels; and,	• % change from the base ambient in terms of actual (ppb), • % change from the base ambient levels, and	Other impacts not assessed in this study: • % reduction from the base deposition measured in kg/ha/yr
Human Health Impacts *Changes in the incidence of:*	• Annual mortality risk – acute and chronic • Adult chronic bronchitis • Child bronchitis • Emergency room visit • Respiratory hospital admission • Cardiac hospital admission • Asthma symptom day • Acute respiratory symptom day • Restricted activity day • Minor restricted activity day	• Annual mortality risk– acute and chronic • Emergency room visit • Respiratory hospital admission • Lung inflammation • Decreased lung function • Airway hyper-reactivity • Increased medication use • Asthma symptom day • Minor restricted activity day • Acute respiratory symptom day • Reduced exercise capacity	• There is no link between human health and acid deposition
Environmental Impacts *Changes in the incidence of:*	• Deterioration of visibility Other impacts not assessed in this study: • Decrease of plant productivity (photosynthesis), • Increased plant susceptibility to disease, • Soil contamination, • Damage to lung tissue, • Effects on wildlife breathing capacity and respiratory systems • Reduced damage to materials through soiling and discoloration (metals, wood, stone, painted surfaces, electronics and fabrics)	• Reduced plant growth • Yield reduction and losses, reduction in annual biomass (trees and crops/fruits) Other impacts not assessed in this study: • Greater root to shoot ratio • Shifts in species composition • Leaf physical injury and death (chlorosis, bleaching, bronzing, flecking, mottling, banding, stippling) • Reduced root growth • Red blood cell effects, and • Inflammatory responses	Other impacts not assessed in this study: • Soil nutrient depletion • Decline of sensitive forest • Reduced tree resistance to cold, drought, insects, disease and UV radiation • Acidification of lakes and streams • Nutrient enrichment of coastal waters • Reduced fish population or elimination of species

Source: Marbek Resource Consultants

2.2 THE DAMAGE FUNCTION APPROACH

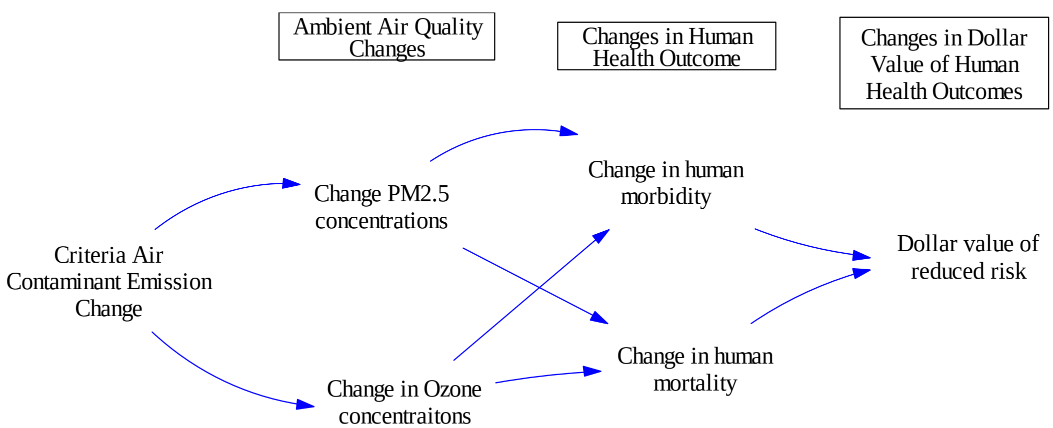
The damage function approach is the method employed to translate the three main transport-related impacts – health, crop yield and visibility, into monetary estimates for the determination of the total cost of transport-related emissions in 2000. The approach links emissions of criteria air contaminants and their precursors to quantified changes in ambient air quality such as ozone and $PM_{2.5}$. This change in ambient air concentrations is then associated with changes in health and crop yield and visibility outcomes which can also be expressed in monetary or dollar values. The incremental impact of transport-related emissions can therefore be expressed as the number of outcomes or altered health and environmental states and, as changes in economic value, which can be aggregated in dollar terms across the environmental and health outcomes (or endpoints).

The DFA is the accepted approach used to estimate the costs related to air emissions (Royal Society, 2001).

In order to measure the impact of transport related air pollution, the damage function approach is used in this study, by first estimating the total costs associated with all PM, NO_X, VOC, and SO_X emissions in Canada.[1] To isolate the impacts of transport emissions, the transport-related emissions in 2000 are removed and the impacts recalculated. The difference in the two levels of impact and the dollar value of the impacts between the "with" and "without" transport-related emissions then isolates the total costs attributable to transport emissions. These "with" and "without" transport emissions scenarios are elaborated in detail in Section 3.3.

Exhibit 2-2 provides a graphical overview of the DFA for the health module only. It illustrates the link between transport emissions and impacts. The DFA follows this same basic approach for all types of impacts, including the agriculture and visibility impacts. More detail on the DFA approach applied to these impacts is provided in Sections 2.3.

Exhibit 2-2
Damage Function Approach
How the Health Impacts of Transport Emissions are Estimated



The components of the damage function approach applied to this project include:

1. **Transport Emissions**. Transport emissions that contribute to particulate matter, ozone, NO_X and SO_2 are identified and attributed to the appropriate modes of transport and regions in Canada. Emissions are first attributed to census divisions within Canada and then aggregated at the provincial level. In this first analytical step, Environment Canada's year 2000 emission inventory for NO_X, PM, SO_2, and VOCs is used to determine transport's emissions relative to all emissions in Canada;

2. **Ambient Air Quality Changes Attributed to Transport**. The transport emission inventory (or changes in emissions) affects ambient air quality measured as changes in particulate matter ($\mu g/m^3$), ozone (ppb), NO_X ($\mu g/m^3$) and SO_2 ($\mu g/m^3$) at the regional level. An air quality model is then used to translate transport's emissions to regional changes in ambient air concentrations;

[1] These emission scenarios and source data are discussed in more detail in Section 3 below.

3. **Health and Environmental Outcome Changes**. Ambient air quality has been shown to alter health and environmental outcomes, and therefore ambient air quality can be linked to changes in the incidence of a variety of health outcomes (morbidity and mortality), agriculture outcomes (lost production yields for crops) and visibility impacts (haze). A key component of the damage function approach is the use of concentration response functions (CRFs), which are mathematically specified relationships that estimate the number of health and environmental events associated with a change in ambient $PM_{2.5}$, ozone, NO_X and SO_2 concentrations. These CRFs are based on scientific and technical studies as mentioned earlier, that have shown a relationship between ambient air quality and the incidence of endpoints such as bronchitis or crop yield reductions to corn;

4. **Monetary Value**. These changes in outcomes, or events, are then valued in dollar terms. For the health outcomes, individuals place a dollar value on the change in risk associated with the changed health outcomes. Human mortality outcomes are valued according to the willingness-to-pay of individuals to avoid mortality risk or willingness to accept compensation to incur greater mortality risks (e.g., wage premiums for riskier jobs). Morbidity outcomes are based on a combination of willingness to pay and cost of illness metrics. The dollar value to an individual of the change in risk associated with air pollution can be aggregated across a human population so that an indication of the societal value in dollar terms of ambient air quality changes can be derived. For crops, the value of the lost production indicates the costs attributable to transport emission while it is the individuals' preference for reduced haze and increased visibility that forms the basis for monetary value of the visibility impact.

The DFA can be used to predict the change in health and environmental outcomes across a population or stock in a given region. Formally, the DFA can be expressed mathematically as follows:

$$\Delta H_{p,r} = \Delta A_{p,r} * CRF_{p,h} * P_r \qquad \text{(Equation 1)}$$

where $\Delta H_{p,r}$ is the change in a health or environmental outcomes caused by pollutant p in region r to an individual living in that region; $\Delta A_{p,r}$ is the change in ambient air quality A coming from pollutant p in region r; $CRF_{p,h}$ is the concentration response function for pollutant p and health or environmental outcome h; and P_r is the population (human population or resource stock including crops) in region r exposed to the $\Delta A_{p,r}$.

Similarly, the aggregate dollar value of the health and environmental outcome changes across a population can be expressed as:

$$\Delta VH_{p,r} = \Delta A_{p,r} * CRF_{p,h} * P_r * V_{p,h} \qquad \text{(Equation 2)}$$

where $\Delta VH_{p,r}$ is the aggregate dollar value of all health outcome changes for each pollutant p and region r; and, $V_{p,h}$ is the dollar value per unit of pollutant p of damage caused by pollutant p on the health or environmental endpoint (i.e. hospital visit) h for pollutant p.

This DFA framework guides our work, with the next section providing modeling detail as well as the approaches used to operationalize the DFA for this project.

2.3 THE MODELLING APPROACH

In implementing the DFA framework, our approach is conceptually straightforward and consisted of three main task areas, each of which is described in more detail in Sections 3, 4, 5 and 7:

- **Estimate changes in air quality for scenarios with and without transport emissions in Canada in the year 2000**. Using air quality modelling output provided by Transport Canada and using Environment Canada's 2000 CAC emission inventory, RWDI used its proprietary air quality model, ReFSoRT, to determine ambient air quality concentration changes stemming from transport-related emissions of volatile organic compounds (VOCs), nitrogen oxides (NO_X), ozone (O_3), particulate matter ($PM_{2.5}$), and sulfur oxides (SO_2). We then confirmed that ReFSoRT's ambient air quality outputs are compatible with the input data requirements for AQBAT, the health valuation model, and for evaluating agricultural (crop yield) and visibility (haze impact on visibility) impacts using Environment Canada's in-house models VOICCE and VIEW respectively (discussed in Section 5).

- **Estimate impacts and costs of transportation-caused air pollution**:

  For estimating impacts on health, Health Canada's AQBAT model is used to estimate a range of health morbidity and mortality outcomes and the dollar value of those outcomes for transport-caused air pollution and ambient air concentration changes. This model is discussed in detail in Section 4. This step involved data preparation, regional apportionment of transport emissions, emission scenario development to isolate transport's share of total emissions and modelling the emission and health outcomes;

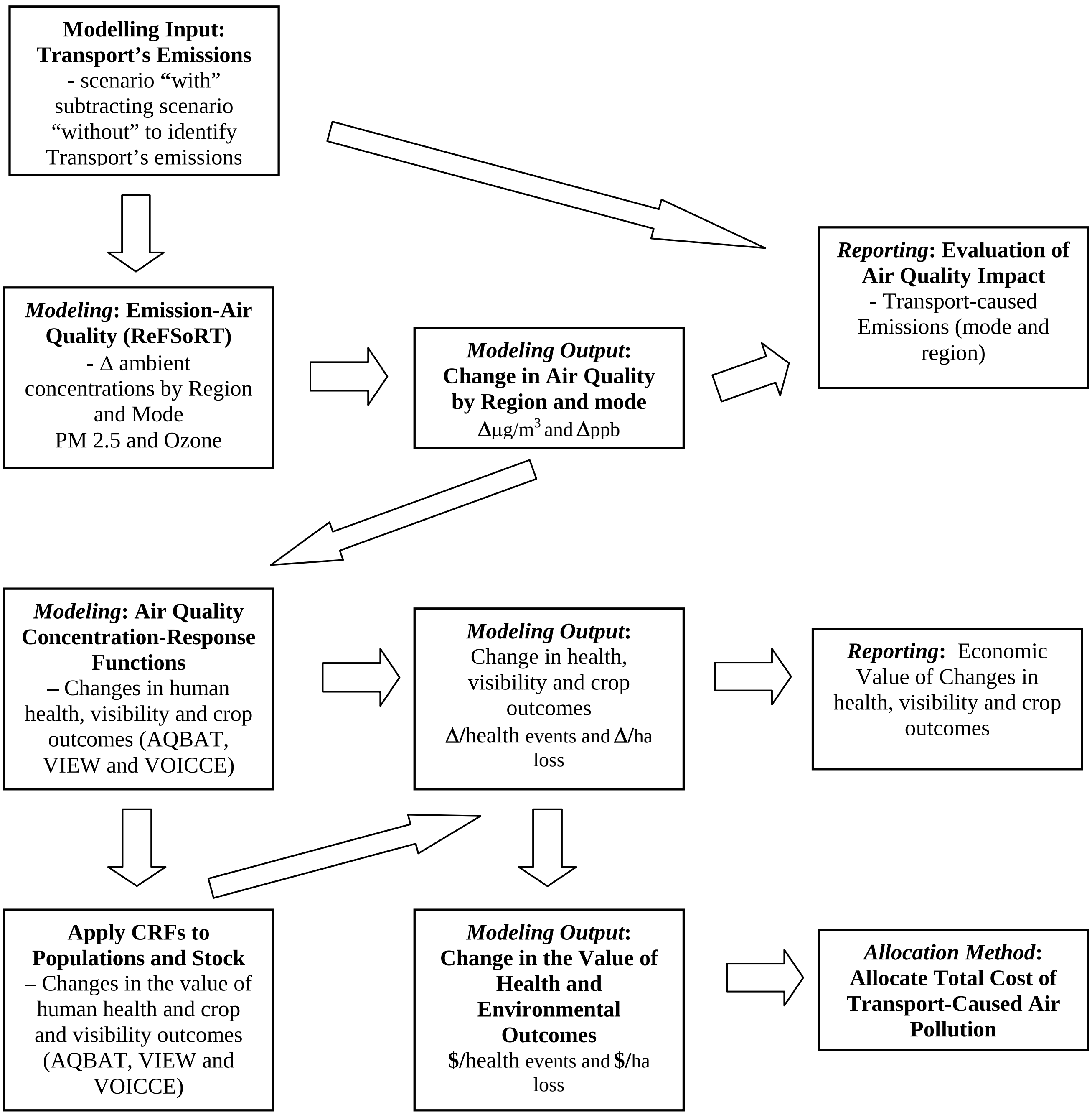
  For estimating impacts on agriculture, Environment Canada Value of Ozone Impacts on Canadian Crops Estimator (VOICCE) model was used to estimate ozone impacts on agriculture. The model works by using average yearly 1-hour ozone concentration changes of ozone within 82 agricultural regions in Canada to calculate the impacts of ozone on the production of 10 crops. The agricultural regions are within 10 provinces in Canada and can be readily related to the Census Divisions that are the basis of the input ozone levels from ReFSoRT. The model considers the major crops in Canada that are most sensitive to the effects of ozone. Section 5 provides more detail; and,

  For estimating impacts on visibility, Environment Canada's Visibility Impacts Estimator of Welfare (VIEW) model was used to translate the transport-caused $PM_{2.5}$ at the Census Division into changes in economic value. The model links changes in visibility to economic valuations of the improvement in visibility from a human perspective. Calculated annual costs represent the mean costs that a person is willing to pay (WTP) for improved (i.e., increased) visibility. Section 5 provides more detail.

- ***Allocate Total Cost by Mode***. This task allocates the total costs of transport-caused pollution by region and transport mode such as light duty trucks. The basis for the allocation is the cause of origin, where the modal share of ground level ozone and $PM_{2.5}$ is linked to health, visibility and agriculture endpoint impacts and costs.

Exhibit 2-3 provides a graphical overview of our modeling approach. The following sections deals with each of these modelling tasks.

Exhibit 2-3
Simplified Modeling and Analysis Approach



3 ESTIMATE CHANGES IN AIR QUALITY FOR TRANSPORT EMISSIONS

The inventory of transport emissions is the main driver in the analysis, and thus all results are oriented towards determining just the portion of air emission that can be ascribed to transport. It should be noted that all analysis linking transport emissions to ambient air quality presented below was completed by Marbek Resource Consultants and RWDI. This section is organized into five sections:

1. *Ambient air outcome modelling* provides detail on the ReFSoRT model;

2. *Regional Allocation of Transport Emissions and Calculation of Concentration Changes* provides the methodology for allocating provincial transport emission inventories to sub-regions and then calculating the resulting changes in concentration due to transport emissions at the census division;

3. *Emission Scenarios* identifies the "with" and "without" transport emissions scenarios used to determine transport's share of ambient air quality considered in this study;

4. *Transport-Related Ambient Air Quality Impacts* summarizes the ambient air quality changes calculated by ReFSoRT to be attributable to transport; and,

5. *Mapping ReFSoRT Concentration Changes to Health (AQBAT model) and Environmental Valuation Models (VOICCE and VIEW models)* identifies how ambient air quality changes attributed to transport are calculated with ReFSoRT for use as inputs to the three different costing (valuation) models mentioned above.

These sections correspond to the DFA approach where transport emissions are translated into regional air quality impacts. This is the first step in the DFA analysis chain.

3.1 AMBIENT AIR OUTCOME MODELLING - REFSORT

The Reduced Form Source-Receptor Tool, ReFSoRT, developed by RWDI in collaboration with Environment Canada, is designed to help decision makers and policy analysts better understand the environmental and health impacts of air quality policies and on-going emissions. As the phrase "Reduced Form" implies, ReFSoRT is a simplified model that allows the user to produce approximate results for all populated parts of Canada, for numerous policy scenarios, within a short time frame. As a matter of routine model development, the tool is calibrated and tested against parametric studies using more sophisticated atmospheric models, as well as data from published field research.

Source-receptor relationships for common air contaminants have been developed, evaluated, and integrated into ReFSoRT such that changes in ambient concentrations for primary and secondary pollutants can be estimated based on base case and scenario emission inventories. In addition, the tool also maps the comparative air quality results based on the NAPS monitoring network to census divisions. This census mapping has been done in the interest of allowing for regional-scale indications of impacts tied to census population data.

ReFSoRT uses source-receptor relationships to determine resulting ambient air quality concentrations based on changes in emissions over a specified time period. Source-receptor relationships specify the relationship between emissions of air pollutants and the resulting concentrations of pollutants in ambient air. Calculations are made using these source-receptor relationships for both a base case and emissions scenarios. The differences between the base case and emission scenarios are then output in a format that can be used for broad scale air quality analysis and decision support, such as for economic and health impact analysis.

The starting point for the source-receptor relationships used in ReFSoRT is an assumption that the relation between emissions and air quality for a given region is essentially linear, such that if initial emissions, initial observed ambient concentrations, and forecast emissions are known or specified, then future resulting ambient concentrations can be estimated. The basic linearity of these relationships is then subsequently adjusted for a number of effects to fully account for physical and chemical dynamics that influence air quality. These include adjustments for the effect of stack height for primary PM for specified sources, non-locally responsive background component of the observed concentrations, etc. Deposition relationships used by ReFSoRT are similarly linear. Section 3.2 provides a general description of the source-receptor relationships and Appendix A provides a detailed description.

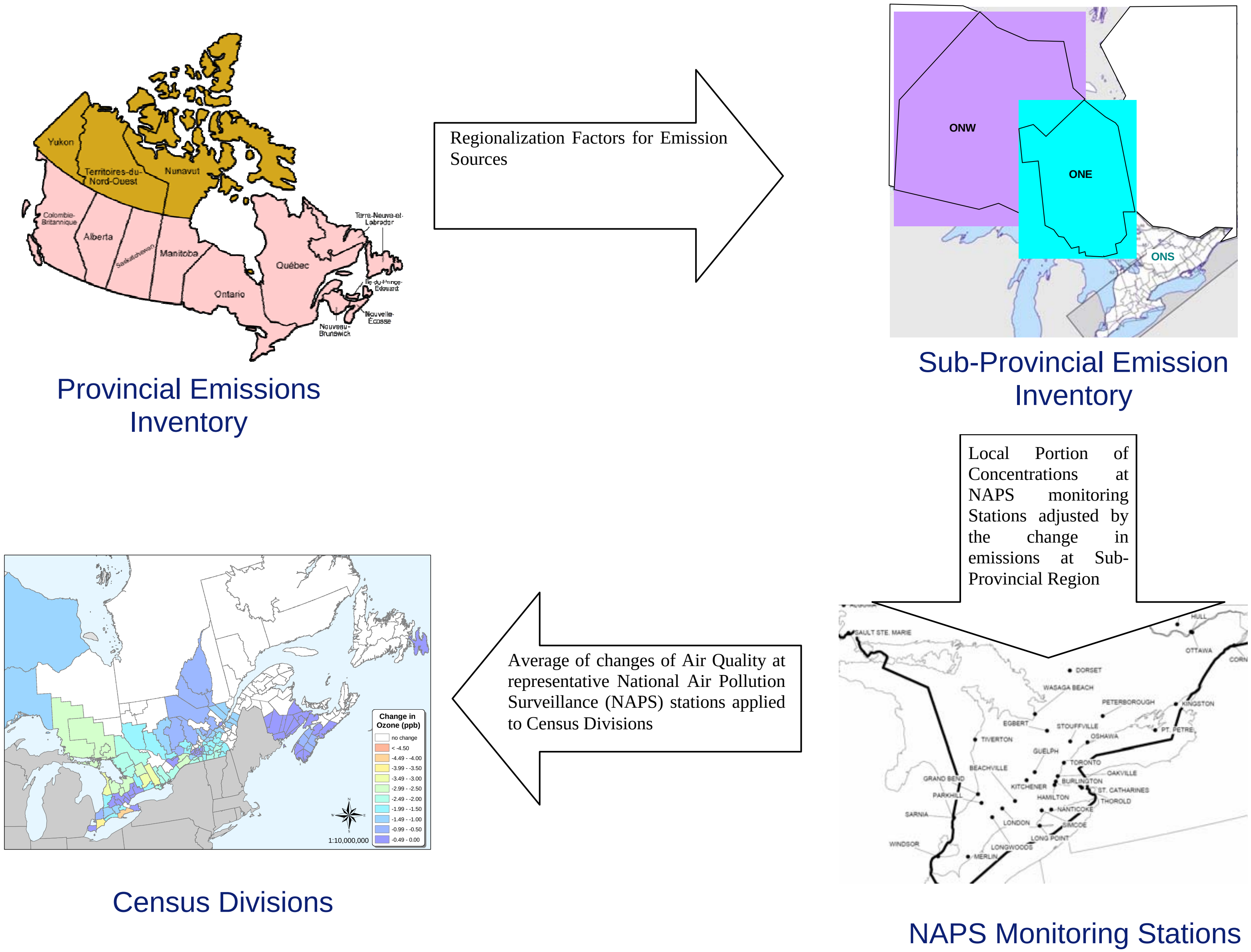
The tool covers annual average concentrations of several primary pollutants (NO_X, SO_2, total VOC, and primary PM), as well as secondary pollutants (sulphate, nitrate, ammonium, and ground-level ozone). This means that carbon monoxide is not covered in this study. In the case of $PM_{2.5}$, the calculations can only be performed for locations where the necessary precursor species are monitored (VOC, NO_X, SO_2). As such, there are numerous cases where the full suite of primary and secondary PM calculations is not feasible due to single or multiple data gaps in the monitoring record. Where possible, surrogate monitoring data for nearby stations is used to complete the calculations.

3.2 REGIONAL ALLOCATION OF TRANSPORT EMISSIONS AND CALCULATION OF CONCENTRATION CHANGES

A key feature of ReFSoRT is the integration of disparate data sets so as to determine the effect of estimated emissions on individual Census Divisions. This integration requires the transfer of information through various “regional scales” of information. The graphic presented in Exhibit 3-1 demonstrates the management of the important regional scales of data used by the model.

Each of these regional scales is discussed in the following sub-sections. This discussion is provided to demonstrate how concentration changes are estimated at the census discussion using information contained in the emission inventory and from actual monitoring stations data.

Exhibit 3-1: Schematic of ReFSoRT Modelling Approach



3.2.1 Provincial Emissions Inventory

The air pollutant emissions inventory for the year 2000 is reported by Environment Canada at the provincial level and is reported according to the following fields:

Field	Acceptable Fields
Province	BC / AB / SK / MB / ON / PQ / NB / NS / PE / NF
Pollutant	NOx / PM10 / PM2.5 / CO / SOx / VOC
Source type	**Point Sources (single, identifiable source of air pollutant emissions such as from a combustion furnace flue gas stack)** **P1** – non-ferrous refining and smelting **P2** – petroleum refining **P3** – pulp & paper **P4** – upstream oil & gas **P5** – electric power generation **Area Sources (two-dimensional source of diffuse air pollutant emissions such as from a forest fire)** **A** –*area* sources include **all transportation emissions**
Industry of origin	Description of source (e.g. “Heavy-Duty Diesel Truck”, “Biogenic”, etc.)
Emissions by Year	e.g. 1995, 2000, 2005, etc…

3.2.2 Resolution of Provincial Emissions into Sub-regional Emissions

A critical component of evaluating the air quality impacts of just transport’s share of emissions is the capacity to spatially allocate provincial emission inventories into ambient air quality changes in the regions where they are expected to occur. For example, emissions from motor vehicles should be allocated to regional ambient air quality that proportionally reflects the level of activity in the region.

As Exhibit 3-1 indicates, emission inventories are tabulated at the provincial level. To improve the spatial resolution of the model, allocation factors were developed to allocate provincial emissions to sub-provincial regions for both point and area sources based on analysis of the detailed 1995 Canadian CAC emission inventory. Sub-provincial regions were demarcated based on factors that included:

- Observations of spatial patterns in ambient concentrations and prevalent wind directions;
- Allowing for the formation of secondary pollution to the extent realistically possible; this requirement suggests regions on the order of 100s of kms in size rather than 10s of kms;
- Location of densely populated regions and location of more isolated communities where large point sources may dominate emissions;
- Spatial distribution of five particular industry types (e.g., major point source categories pulp & paper, upstream oil & gas, non-ferrous smelting, petroleum refining, electricity generation);

- Locally relevant factors, such as relatively closed airshed conditions for the Lower Fraser Valley, location of Alberta oil sands development, etc.; and,

- Minimizing trans-boundary effects between sub-regions; in particular, it is important to ensure that no major industrial sources or urban areas sources are located along downwind boundaries of the sub-regions.

This method was further developed by determining sector-specific allocation factors for primary emissions from each of the 5 point source categories used in ReFSoRT (upstream oil & gas, pulp & paper, petroleum refining, non-ferrous smelting & refining, electricity). Point sources are designated for 5 source categories to allow emissions and air quality calculations to reflect the reduced influence that these sources have in their immediate vicinity (due to release of pollutants at height). Improved resolution of this type allows ReFSoRT to more fully reflect sector-specific emission changes (e.g., for the electricity generating sector) that might otherwise be lost in summing all point source emissions together at the provincial level.

It was recently recognized that the area emissions group, which is dominated by sources related to anthropogenic activity, also includes “biogenic” sources (i.e. emissions from natural processes and independent of human activity). Biogenic emissions consist of VOCs that evaporate from vegetation in warm summer months and NO_X emissions from microbial activity in the soil. Given their relation to natural processes, biogenic emissions are generated on a spatial distribution that is independent of anthropogenic activity and therefore must be considered separately. Provincial biogenic emissions are therefore distributed in the sub-regions according to the approximate ratio of the area of each sub-region within the respective province. This distribution was developed previously by Transport Canada, in consultation with Environment Canada (Belanger, 2006). Biogenic emissions need to be included in the analysis to ensure we accurately portion all costs from all emissions in the baseline “with” transport emissions.

The allocation of anthropogenic and biogenic emissions to each of the sub-regions is the starting point or “business as usual” scenario against which transport emission can be isolated. Thus, the removal of transportation emissions from the overall emission inventory is the emission scenario of interest. The sub-regions used in this study are provided below in Exhibit 3-2.

Exhibit 3-2
Provincial Breakdown of Emissions

Province	Emissions Sub-region
British Columbia (BC)	Lower Mainland and Vancouver Island (LMVI)
	North (BCN)
	South (BCS)
Alberta (AB)	North (ABN)
	South (ABS)
Saskatchewan (SK)	North (SKN)
	South (SKS)
Manitoba (MB)	North (MBN)
	South (MBS)
Ontario (ON)	West (ONW)
	East (ONE)
	South (ONS)
Quebec (PQ)	North (PQN)
	East (PQE)
	South (PQS)
Nova Scotia (NS)	Nova Scotia (NS)
New Brunswick (NB)	New Brunswick (NB)
Prince Edward Island (PE)	Prince Edward Island (PE)
Newfoundland and Labrador (NF)	Newfoundland and Labrador (NF)

3.2.3 Conversion of Transport Emissions to Concentration Changes at the Sub-regional Level

At each monitoring station, the concentration for each pollutant is broken out into a "local" portion (C_L) that is generated locally and a "background" portion (C_B).

(3.1) $\Delta C = \Delta C_L + \Delta C_B$

The local portion of the concentration is assumed to be the result of emissions occurring within emissions sub-region that surrounds the monitoring station. The background concentration is the result of emissions that happen outside (i.e. upwind) of the monitoring station's emission sub-region. A common background is assigned to all monitoring stations within an emissions sub-region, shown in Exhibit 3.4. The local concentration at each station is calculated as the concentration above this background level.

The discussion below outlines the source-receptor relationships used to determine the local concentration change for each of the primary and secondary pollutants. The background concentration change is discussed in Section 3.2.4.

Local Concentration Changes: Primary Pollutants (NO_X, SO_2)

The starting point for developing a source-receptor algorithm is to assume a linear response of the marginal incremental emission and concentration changes:

$$(3.2) \qquad \frac{\Delta C}{C_L}100 = \frac{\Delta E}{E}100$$

This equation states that the percent change in the local or above-background portion of the ambient concentration equals the percent change in emissions in the region. For an expression of the percent change in total concentration, Equation 3.1 can be rewritten as follows:

$$(3.3) \qquad \frac{\Delta C}{C}100 = \frac{\Delta E}{E}\left(\frac{C_L}{C}\right)100$$

The linear response assumption provides a good approximation for primary pollutants, such as SO_2, total NO_X and primary PM. For example, published emission and concentration trends between 1989 and 1998 for Ontario (MOE, 2000) show a reasonably linear relationship between emissions and concentrations for SO_2 and NO_2.

However, ambient concentrations will respond differently to emissions arising from localized, elevated point sources (e.g., a large power plant) compared those arising from widely distributed, low-level sources (e.g., roadway emissions and other area sources). Additional sophistication is therefore required to address this difference in response. Equation (3.3) can be rewritten as follows:

$$(3.4) \qquad \frac{\Delta C}{C} = \frac{f\Delta E_p + \Delta E_a}{fE_p + E_a}\left(\frac{C_L}{C}\right)100$$

Where f is a "point source importance factor" representing the relative contribution of point source emissions to the ambient concentration. A value of 0.1 is applied to direct emissions of $PM_{2.5}$. Other pollutants are assumed to be conservative and are considered to have a point source factor of 1.0.

Local Concentration Changes: Secondary Pollutants ($PM_{2.5}$ and Ozone)

In the case of secondary pollutants, such as ozone and secondary PM, the precursors may respond linearly to changes in emissions, but the secondary pollutants themselves need not respond linearly to changes in the precursor concentrations. Many other limiting factors come into play, such as the meteorological conditions (e.g., amount of solar radiation) and complex interactions among the precursors and the secondary pollutants.

Fine Particulate Matter ($PM_{2.5}$)

$PM_{2.5}$ consists of primary emissions as well as various secondary species arising from several precursor gases. Exhibit 3-3 presents approximate estimates of the average breakdown of selected chemical species in Canadian $PM_{2.5}$. These data are based on 1995-98 NAPS dichotomous sampler data, 1994-99 data measured by the GAViM monitoring network (MSC, 2001) and additional denuder measurements made by Environment Canada (Brook and Dann, 1999). The nitrate values have a relatively high level of uncertainty, due to uncertainties in the monitoring techniques. Secondary organic aerosol (SOA) has not been treated explicitly in Exhibit 3-3 but is included with the Primary PM. These data show that, on average, $PM_{2.5}$ is dominated by primary particulate matter (together with SOA) and sulphate. Sulphate and ammonium play a more dominant role in Eastern Canada than in Western Canada on an annual average basis.

Exhibit 3-3
Chemical Makeup of $PM_{2.5}$ (% by mass)

	Sulphate SO_4	**Particle Nitrate p-NO_3**	**Ammonium NH_4**	**Sodium Chloride**	**Primary PM & SOA**
Dominant Precursor Emissions Source Affecting Concentration	SO_2	NO_X	Assumed Constant	Assumed Constant	$PM_{2.5}$
Western Canada	19	17	12	2	50
Windsor-Quebec Corridor	22	12	12	1	53
Atlantic Canada	34	6	15	2	43

The relationship between the precursor emissions and concentration changes is not always linear. Interactions can occur between the sulphate and nitrate components, resulting sometimes in inverse relationships (e.g. reduction in NO_X emissions resulting in increases in sulphate concentrations). However, given the large proportion of the emission inventory being considered for this assessment, these interactions were considered insignificant. A detailed summary of the relationships used to determine the incremental impact of each component is shown in Appendix A.

Ground-Level Ozone (O3)

The key precursor pollutants for ground-level ozone are NO_X and VOCs. The response of O_3 to changes in these pollutants can be very complex. Numerous studies have shown that there is an optimal level of NO_X emissions (relative to VOC emissions) for maximum production of O_3 and that, in urban areas, this optimal level is generally exceeded (Jiang, et al., 1996; Vukovich, 2000; Barna et al., 2001). In this situation, modest reductions in NO_X emissions can lead to an increase in peak O_3 levels, as has been seen in the historical trends for most Canadian urban areas. With very large reductions in NO_X emissions, the situation tends to reverse itself and O_3 levels are reduced. Some of the studies have shown that this pattern of behaviour can extend fairly far downwind of the urban core (Jiang et al., 1996). Farther downwind, the urban plume undergoes a transition to a NO_X-limited condition, in which the peak O_3 levels respond positively to all changes in NO_X emissions and are relatively insensitive to changes in VOC's. Modelling studies of selected summer smog episodes in Southern Ontario suggest that the NO_X-limited condition prevails during these episodes (Stratus Consulting Inc, 2000; RWDI, 2001).

In urban areas, where conditions are not NO_X -limited, the relationship is more complex but, for the present purpose, a reasonable estimate can be obtained by assuming that the O_3 level is related to the square root of the VOC concentration. This square root relationship seems reasonable based on inspection of typical ozone isopleths, and is supported by results of photochemical modelling for Seattle and Vancouver areas (Jiang et al., 1996; Barna and Westberg, 2001).

These relationships can be expressed as follows:

(a) Rural areas:

$$(3.5) \qquad \frac{\Delta O_3}{O_3}100 = \left(\left(1 + \frac{\Delta E_{NO_X}}{E_{NO_X}}\right)^{0.5} - 1\right)100$$

(b) Urban and nearby downwind areas:

$$(3.6) \qquad \frac{\Delta O_3}{O_3}100 = \left(\left(1 + \frac{\Delta E_{VOC}}{E_{VOC}}\right)^{0.5} - 1\right)100$$

Given that the source-receptor relationships are a simplified model, some uncertainty is to be expected in these relationships, especially given the complex reactions that lead to O_3 formation. These uncertainties are discussed in more detail in Appendix A.

3.2.4 Background Concentration

Exhibit 3-4 shows the background concentrations that are currently used in ReFSoRT. These values are extracted from the NAPS dataset, using the lowest observed concentration in each region.

The background concentration for O_3 is drawn from a statistical analysis of the NAPS dataset. Information on the background concentration of particle nitrate, p-NO_3, was not directly available and was estimated from the background concentrations for $PM_{2.5}$ and the chemical make-up of $PM_{2.5}$ shown previously in Exhibit 3-3.

Exhibit 3-4
Background Concentrations Currently Used in the Analysis

Location	Background concentration (ug/m³)				Background Ozone (ppb)	
	SO_2	NO_x	$PM_{2.5}$	SO_4	O_3	% of above-background O_3 due to long-range Transport
Halifax	4.5	7.3	3.9	0.8	30	80
Saint John	4.5	7.3	3.9	0.8	30	80
Montreal	3.5	12.1	8.4	1.4	30	40
Toronto	4.4	16.1	6.8	1.4	30	50
Windsor	4.4	16.1	6.8	1.4	30	80
Thunder Bay	0.7	6.4	6.9	1.1		
Winnipeg	0.7	6.4	6.9	1.1	30	10
Edmonton	2.0	6.4	5.9	1.1	30	10
Vancouver	4.3	17.5	6.5	1.1	30	15

Adjustable background value algorithms

A series of calculation algorithms were incorporated into ReFSoRT to allow changes in upwind ambient concentrations to carry through to downwind regions. The purpose of this change is to adjust downwind regional values for changes in air quality in upwind regions. For any given region where air quality changes are calculated, only a portion of the monitored average ambient concentration of pollutants is responsive to local changes in emissions. The comparative proportion of local to background is determined for each calculation location based on regional background values. These are presented in Table A6 in Appendix A. However, it can be expected that these background values will also change through time as a function of changes in upwind emissions.

To account for this effect, changes were made to the calculation algorithms to determine resulting downwind background concentration changes and the effect of this on final calculated concentration. To do so, for any given NAPS station where air quality changes are calculated a cross-reference is made to determine the corresponding upwind region. Upwind regions were designated based on broad patterns of air flow and pollutant transport. A detailed summary of the respective upwind regions and the algorithm for assessing upwind impacts is presented in Appendix A.

ReFSoRT accounts for the effect of US emissions changes by adjusting the background in defined regions (i.e. NF, PEI, NS, NB and ONS). In these regions, the regional background concentration of a pollutant is assumed to originate entirely from the US.

3.2.5 Application of Concentration Changes at Monitoring Stations to Census Divisions

In terms of application to health and economic impacts analysis, providing output results for as many Census Divisions (CDs) as possible, especially for those where the majority of the population resides, is imperative. To facilitate this requirement, calculations for changes in air quality are mapped to CDs in ReFSoRT.

This mapping has involved accommodating two situations. The first of these is the averaging of multiple NAPS stations that are located within a single Census Division. The second of these is the mapping of NAPS stations to CDs that do not contain their own NAPS station. This may involve one or more NAPS stations, depending on their proximity to the CDs.

The mapping of NAPS to CDs has evolved in ReFSoRT from initial mapping prepared by Environment Canada. This mapping was based on a distance threshold. With subsequent development of ReFSoRT, additional NAPS cross-referencing was added, typically for situations where conditions (in terms of known air quality, population base, or industrial development) were deemed to be similar enough to warrant extending the mapping coverage. More detailed interpolation and mapping of the existing NAPS data set allowed in some cases the distance thresholds to be extended based on the mapped concentration fields. This additional mapping was checked for selected regions of dense network coverage against the original mapping prepared by Environment Canada. A high degree of agreement was noted, and taken as an indicator of the reasonableness of this method for mapping. A detailed explanation of the mapping approach taken is provided in Appendix A.

To further expand the coverage for $PM_{2.5}$, additional stations from the PM_{10} monitoring dataset were added by applying an averaged multiplier for the relation of $PM_{2.5}$ to PM10. In this case, a ratio of 55% PM_{10} as $PM_{2.5}$ was assumed. This resulted in the addition of 51 additional stations to the basic calculation set (originally 56 stations).

3.3 EMISSIONS SCENARIOS

In order to determine the impact of transport emissions on ambient air quality, the first task was to determine transport's share of total emissions. The emissions inventory used to evaluate the air quality impact of transportation emissions was drawn from Environment Canada's "Air pollutant emissions in Canada for 2000: National Pollutant Release Inventory (NPRI), criteria air contaminants (CAC), Environment Canada" (released July, 2006). The share of emissions related to transportation for this study was based on a ReFSoRT run prepared by Frederik Belanger[2]. This ReFSoRT run considered transport's share of emissions at a sub-provincial level. These sub-regions considered are identified in Exhibit 3-2.

Transportation emissions associated with each sub-region in Exhibit 3-2 were divided up into the major transportation modes that are used by Environment Canada to generate national and provincial Criteria Air Contaminant (CAC) emission inventories. The classification of Transport Canada on-road modes that is required for the FCI approach is slightly different (and more specific) compared to the Environment Canada CAC on-road modes. A comparison of the two classifications is therefore presented below in Exhibit 3-5.

[2] Bélanger, *Frédérik. Proposed Method for the Quantification of the Costs of Air Pollution from Transport. Full-Cost Investigation Project*. Economic Analysis Directorate: Transport Canada, August 2006

Exhibit 3-5
Classification of Transportation Emission Sectors

Environnent Canada CAC Transportation Modes	Transport Canada Modes
Air Transportation Landing and Take-off (LTO)[1]	Passenger Air Transport
	Freight Air Transport
Heavy-duty diesel vehicles	Freight Heavy-duty diesel vehicle
	Passenger Interurban diesel bus
	Passenger Urban and School Diesel Bus
Heavy-duty gasoline trucks	Freight Heavy-duty gas vehicle
	Passenger Interurban gas bus
	Passenger Urban and School Gas Bus
Light-duty diesel trucks	Freight Light-duty diesel truck
	Passenger Light-duty diesel truck
Light-duty diesel vehicles	Passenger Light-duty diesel vehicle
Light-duty gasoline trucks	Passenger Light-duty gas truck
	Freight Light-duty gas truck
Light-duty gasoline vehicles	Passenger Light-duty gas vehicle
Motorcycles	
Marine Transportation	Passenger Marine Transport
	Freight Marine Transport
Rail Transportation	Passenger Rail Transport
	Freight Rail Transport
Tire wear & Brake lining (PM2.5 only)[2]	Freight Heavy-duty diesel vehicle
	Passenger Interurban diesel bus
	Passenger Urban and School Diesel Bus
	Freight Heavy-duty gas vehicle
	Passenger Interurban gas bus
	Passenger Urban and School Gas Bus
	Freight Light-duty diesel truck
	Passenger Light-duty diesel truck
	Passenger Light-duty diesel vehicle
	Passenger Light-duty gas truck
	Freight Light-duty gas truck
	Passenger Light-duty gas vehicle

Note:

1. LTO stands for "landing and take off" (Cruise emissions were stripped from model as they are not considered to make a significant contribution to tropospheric air quality).
2. We assume that PM emissions from tire wear in Air Transport are negligible.
3. Emissions inventory covers domestic transportation activities and air and marine international movements occurring on Canadian territory.

Based on the emission inventory and the classification of transportation emissions by mode several scenarios were developed to determine transport's share of the ambient air concentration in the year 2000. The inputs used in developing these scenarios for modelling in ReFSoRT are shown in Exhibit 3-6. We first developed:

1. **A "Business as Usual" (BAU) Scenario** for the 2000 base year scenario (All emissions *with* transport).

2. **Two scenarios** were then developed to isolate transport emissions in 2000 so that their health and environmental impacts could be assessed:

    - **Emission Scenario #1** isolates all transportation emissions with the exception of paved road dust (transport emissions *without* paved road dust),

    - **Emission Scenario #2** isolates all transportation emissions and includes paved road dust (transport emissions *with* paved road dust).

Exhibit 3-6
Summary of Scenario Emissions Inputs

Parameter		**Input data**
Emissions	Canadian	• **BAU (2000):** “Air pollutant emissions in Canada for 2000: National Pollutant Release Inventory (NPRI), criteria air contaminants (CAC), Environment Canada” (released July 2006). Year 2000 Biogenic emissions are included. • BAU Scenario (2000): No change • **<u>Emission Scenario #1</u> (2000):** The impact of transport emissions *without* paved road dust. • **<u>Emission Scenario #2</u> (2000):** The impact of transport emissions *with* paved road dust.
	U.S.	No changes assumed
Air Quality Data	Annual average of NO_X, SO_2, $PM_{2.5}$. Seasonal mean daily maximum hour for ozone	
Custom Modelling Approach	Linearity assumed in sulphate / nitrate production (i.e. dk/k set to zero). NO_X and SO_2 concentration changes reported by Census Division for first time.[1]	

Notes:

1. Previous versions of the tool calculated NO_X and SO_2 at the monitoring station level as part of the evaluation of $PM_{2.5}$. For this version of the tool, NO_X and SO_2 concentrations were calculated at the census-division-level using the same mapping of monitoring stations to census divisions as $PM_{2.5}$.

These two emission scenarios are considered separately in this study since the associated health and visibility costs of paved road dust can’t be reasonably allocated by mode and therefore can only be provided as lump sum costs by province. In addition there is a very large uncertainty associated with the calculation of $PM_{2.5}$ emissions from paved road dust. By considering paved road dust as a separate scenario, therefore, it is possible to assess and discuss the impacts separately from other transportation emissions.

Unpaved road dust is included in the BAU scenario, but impacts related to unpaved road dust are not assessed by the emission scenarios in this study. Discussions with Health Canada[3] concluded that the health impacts from unpaved road dust should not be considered in this study as $PM_{2.5}$ emissions associated with unpaved road dust have substantially different epidemiological characteristics and the concentration response functions for health endpoints would not apply. It

[3] Personal Communication with Barry Jessiman Health Canada. March, 2007.

is not expected that unpaved road dust contributes substantially to transport-caused air pollution costs for the following reasons:

- Unpaved road dust has a substantially different chemical composition than paved road dust. Unpaved road dust is primarily crustal dust that has a substantially lower toxicity than paved road dust that contains high concentrations of heavy metals;

- A large portion of unpaved road dust is not associated with transportation (fugitive wind-borne dust, off-road vehicles, non-public roadways);

- Unpaved road dust emissions are generally located in rural areas far from NAP stations and densely populated areas; therefore, these emissions contribute only small changes in PM2.5 concentrations despite being a large portion of the emission inventory.

The two "transport only" emission scenarios 1 and 2 are subsequently used to estimate changes in emissions relative to the BAU scenario and are then input into ReFSoRT to estimate transport's share of ambient air concentration changes (and based on the approach presented in Section 3.2 and 3.3). The share of transportation emissions to the overall emission inventory by province and pollutant is presented graphically in Exhibit 3-7 and numerically in Exhibit 3-8. Values *with* and *without* paved road dust are provided for $PM_{2.5.}$

Exhibit 3-7
Contribution of Transportation Emissions by Province

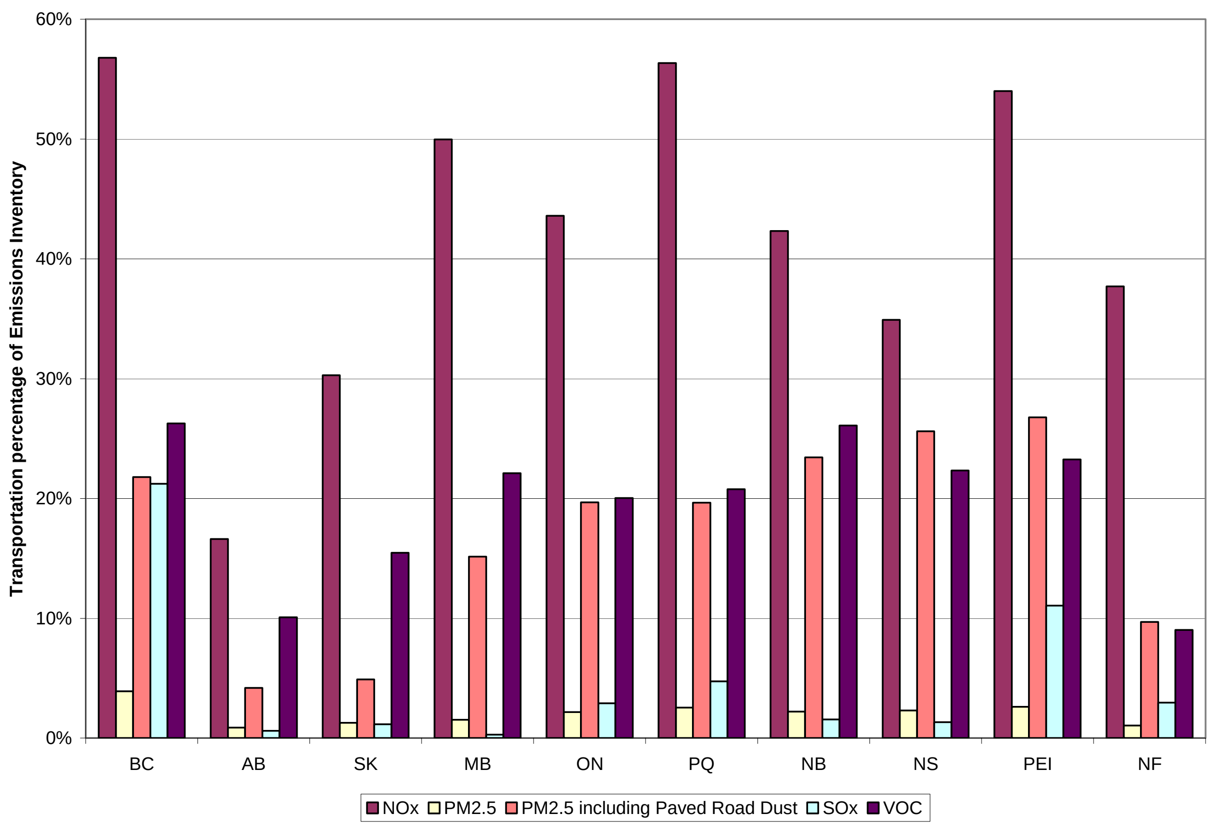


Exhibit 3-8
Total and Transport-Related Emissions by Province and Canada

		000's of tonnes				
		NOx	**SOx**	**VOC**	**PM2.5**	**PM2.5 including Paved Road Dust**
BC	Total	327	84	2458	116	116
	Transport	167	18	60	4.5	21
	Transport's Share	51%	21%	2.4%	3.9%	18%
AB	Total	869	470	2072	300	300
	Transport	125	2.8	67	2.6	10
	Transport's Share	14%	0.6%	3.2%	0.9%	3.3%
SK	Total	368	115	1272	102	102
	Transport	59	1.3	39	1.3	3.7
	Transport's Share	16%	1.1%	3.1%	1.3%	3.6%
MB	Total	162	362	1308	58	58
	Transport	42	1.0	23	0.9	7.9
	Transport's Share	26%	0.3%	1.8%	1.5%	14%
ON	Total	693	577	3291	242	242
	Transport	258	17	132	5.3	42
	Transport's Share	37%	2.9%	4.0%	2.2%	17%
PQ	Total	459	290	3347	171	171
	Transport	168	14	84	4.3	29
	Transport's Share	36%	4.7%	2.5%	2.5%	17%
NB	Total	78	141	310	34	34
	Transport	32	2.2	14	0.8	7.3
	Transport's Share	41%	1.6%	4.5%	2.2%	21%
NS	Total	71	166	184	27	27
	Transport	24	2.2	12	0.6	6.4
	Transport's Share	34%	1.3%	6.3%	2.3%	23%
PEI	Total	9	3	16	5	5
	Transport	4.4	0.3	2.3	0.1	1.2
	Transport's Share	50%	11%	15%	2.6%	24%
NF	Total	74	52	694	39	39
	Transport	14	1.5	6.5	0.4	3.4
	Transport's Share	19%	3.0%	0.9%	1.0%	8.7%
Canada	Total	3108	2258	14952	1095	1095
	Transport	892	60	440	21	132
	Transport's Share	29%	2.6%	2.9%	1.9%	12%

Source: Baseline (2000): "Air pollutant emissions in Canada for 2000: National Pollutant Release Inventory (NPRI), criteria air contaminants (CAC), Environment Canada" (released July, 2006). Total values include biogenic emissions (i.e., emissions from natural sources, such as plants and trees). Transport emissions vary slightly from emission inventory since cruise air transportation is not included.

3.4 TRANSPORT-RELATED AMBIENT AIR QUALITY IMPACTS

Changes in the emissions between the baseline (all emissions including transportation) and emission scenarios (only transportation emissions) were used in the ReFSoRT model to predict concentration changes attributable only to transport at each of the NAPS stations and corresponding census divisions relevant to the study. The results of the ReFSoRT run are presented in Exhibit 3-9 and graphically in Exhibit 3-10. In these Exhibits, the average concentration change is presented for each pollutant by province and is attributed to transport only.

Because road dust only contributes emissions that are crustal $PM_{2.5}$, road dust does not affect the formation of ozone and only contributes to endpoints that are related to changes in the concentrations of $PM_{2.5}$. *As a result all health and environmental endpoint valuations that are a result of changes in Ozone, NO_X and SO_2 are the same for both emission scenarios (Scenario #1 and Scenario #2).*

The resulting ReFSoRT ambient air concentration changes were then used as inputs in the AQBAT, VIEW, and VOICCE models to estimate the impacts on health, agriculture and visibility outcomes as discussed in the following sections (Section 4 and 5).

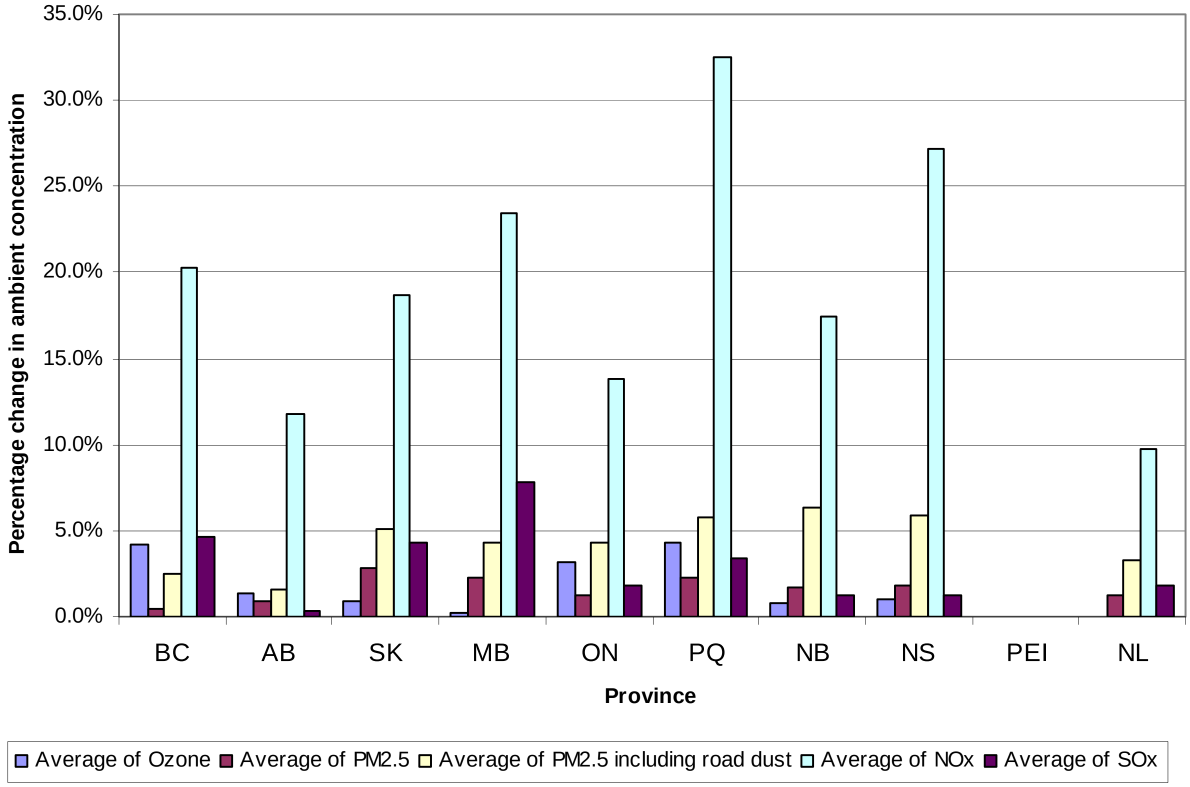
Exhibit 3-9
Change in Baseline Ambient Air Concentrations
Attributable to Transport-related Emissions, 2000

Province	Average of Ozone	Average of PM2.5	Average of PM2.5 including road dust	Average of NOx	Average of SOx
BC	4.2%	0.5%	2.5%	20.3%	4.7%
AB	1.4%	0.9%	1.5%	11.8%	0.4%
SK	1.0%	2.8%	5.1%	18.7%	4.3%
MB	0.2%	2.2%	4.3%	23.4%	7.8%
ON	3.2%	1.2%	4.3%	13.8%	1.8%
PQ	4.3%	2.3%	5.8%	32.5%	3.4%
NB	0.8%	1.7%	6.4%	17.5%	1.2%
NS	1.0%	1.8%	5.9%	27.2%	1.2%
PEI (1)	No Impact	No Impact	No Impact	No Impact	No Impact
NL	0.0%	1.3%	3.3%	9.7%	1.8%
Canada	2.8%	1.5%	4.4%	21.5%	2.8%

Source: RWDI's ReFSoRT

(1) No concentration changes were predicted for PEI since there were no suitable NAP stations available to estimate concentration changes.

Exhibit 3-10
Transport's Contribution to Average Ambient Air Concentration by Province in 2000



3.5 MAPPING REFSORT OUTPUT TO HEALTH AND ENVIRONMENTAL VALUATION MODELS

In this section we discuss how ReFSoRT output is altered and mapped to ensure it aligns with the input needs of the health and environmental valuation models used in this study. Three different models were used to assess the economic value of transportation-related air pollution:

1. AQBAT, Health Canada's valuation model for health endpoints;

2. VIEW, Environment Canada's valuation model for visibility endpoints; and,

3. VOICCE, Environment Canada's valuation model for agricultural endpoints.

To conduct the analysis, the three models require the user to input the following parameters:

- Changes in ambient concentrations relative to a baseline and a specific geographic area; and,
- "Status quo" ambient data concentrations for the year 2000 relative to a specific geographic area;

To start, we therefore needed to ensure that the geographic areas in ReFSoRT and the three valuation models align. There are 442 geographic areas in the current version of AQBAT and VIEW, based on the 2001 Census geography as determined by Statistics Canada. The lowest level of geographic area (i.e., highest resolution) is the Census Division (CD). This level of resolution matches the ReFSoRT model and is used in this study. VOICCE can also use CDs as the finest level of geographic aggregation.

Next we ensured that the model outputs provided the most extensive and appropriate coverage of the Canadian population as possible and that the model outputs from ReFSoRT used as inputs for valuation models matched or were appropriately converted between the different models:

- **Population coverage.** The AQBAT model includes historical baseline concentration data that have been derived from 329 ambient monitoring sites across Canada by the National Air Pollution Surveillance (NAPS) Programme for the years 1987 to 2002. Although, both models used the same ambient monitoring data (352 NAPS stations from the year 1998 to 2002), because AQBAT allocates ambient data only to CDs where NAPS stations are located inside the CD, and ReFSoRT assigns ambient air quality data to those CDS as well as neighbouring CDs, a higher level of population coverage is achieved in ReFSoRT. Consequently, it was determined that for coverage in this study a baseline provided by the ReFSoRT model would be used. The comparison of population coverage between ReFSoRT and the AQBAT model is provided in Exhibit 3-11.

Exhibit 3-11
Population Coverage of AQBAT and ReFSoRT Baseline Ambient Data
Scope of Impact for Transport-related Emissions on Human Receptors

Pollutant	AQBAT	ReFSoRT
Ozone	73.3%	86.3%
$PM_{2.5}$ (Includes both TEOM and dichot, and estimation of $PM_{2.5}$ from PM_{10} data)	62.5%	78.7%
SO_2	55.6%	72.1%
NO_2	59.9%	74.8%

Source: RWDI's ReFSoRT and Health Canada's AQBAT

- **Pollutant concentration measures.** Each health and environmental endpoint considered in the AQBAT, VOICCE and VIEW models relates to annual average changes in concentration of one or more of the four pollutants that have been considered in the study; NO_2, Ozone (actually May-Sept average for O_3), SO_2, and $PM_{2.5.}$ Annual averages of each pollutant are calculated based on NAPS monitoring data and are related to specific averaging time periods. Based on a review of the models, we observe that ReFSoRT output and AQBAT input concentration changes are slightly different for the air quality measures. Exhibit 3-12 provides a mapping between the ambient concentrations changes of the five pollutants generated by ReFSoRT and the health and environmental valuation models.

Exhibit 3-12
Mapping of ReFSoRT Outputs to Health and Environmental Valuation Models

ReFSoRT Output Concentration Changes and Baseline Ambient Concentrations (1998-2002)	**Mapping Conversions from ReFSoRT to Valuation Models**		
	AQBAT	**VIEW**	**VOICCE**
NO_2 - Annual average of the 1-hour concentrations (µg/m^3)	The 24-hour annual average from AQBAT is functionally equivalent to the annual average concentrations used in ReFSoRT. No adjustments were needed.	No Impact	No Impact
Ozone - Seasonal mean (May-September) of the daily maximum 1-hour concentration (ppb)	To calculate acute exposure mortality the 1-hour seasonal ozone is used as a surrogate for 1-hour annual average ozone. For all other endpoints the mapping is equivalent and no adjustments were needed.	No Impact	Seasonal mean of the daily maximum 1-hour concentration was used to derive seasonal averages of 7h, 12h and 3 months AOT40 based on statistical relationships developed from the AURAMs model.
$PM_{2.5}$ - Annual average of the 24-hour concentrations (µg/m^3)	Mapping is equivalent. No adjustments were needed.	Mapping is equivalent. No adjustments were needed.	No Impact
SO_2 - Annual average of the 1-hour concentrations (µg/m^3)	The 24-hour annual average from AQBAT is functionally equivalent to the annual average concentrations used in REFSORT. No adjustments were needed.	No Impact	No Impact

4 HEALTH OUTCOME IMPACTS AND VALUE

In this section the ambient air concentration changes for transport by Census Division are translated, using Health Canada's AQBAT model, into health outcomes changes in terms of the incidence of morbidity and mortality and the dollar value of those changes. The section is presented in four sub-sections:

1. *Health Outcome Modelling – AQBAT* introduces the AQBAT model;

2. *Health Outcome Endpoints* explores the health events covered in the AQBAT model;

3. *Health Outcomes Attributable to Transport-Related Emissions* identifies the number of occurrences of health endpoints that can be attributed to transport emissions; and,

4. *The Economic Value of the Health Changes*.

4.1 HEALTH OUTCOME MODELLING – AQBAT

Environment Canada and Health Canada jointly developed the Air Quality Valuation Model (AQVM) for monetizing health and environmental outcome changes attributable to air quality programs in Canada. Since its development in 1996, the AQVM has attracted much attention for its monetization of health outcome changes. Notably, the Royal Society of Canada was commissioned to review the techniques and assumptions employed to assess the Canada-wide Standards for PM and Ozone. In a 200-page report, the Royal Society concluded that the techniques and assumptions employed in AQVM are consistent with the theory and practice of health outcome valuation.

Health Canada in 2003 started in earnest the development of the Air Quality Benefits Assessment Tool (AQBAT, developed by Judek and Stieb). AQBAT is a computer simulation tool designed to estimate the human health and welfare benefits or damages associated with changes in Canada's ambient air quality. The AQBAT model enhances the capabilities of the previous Air Quality Valuation Model (AQVM) and provides a more open and transparent modelling environment. A key difference is that AQBAT does not include agricultural or visibility damages. The treatment of these two important impacts is addressed in the next major section of this report.

AQBAT applies the Damage Function Approach by linking databases of ambient air quality data, concentration changes in ambient air quality data, health endpoints, geographic areas and scenario years. By linking these parameters it is possible to associate a change in ambient concentration in a specific geographic area and given year to a health outcome (either a damage or benefit expressed as a count or monetary value). The model uses @Risk software to perform Monte Carlo simulation to propagate uncertainty in individual parameters and provide uncertainty bounds on the estimated change in frequency of health outcomes and associated valuation.

The model version used for this study is version 1.0 (October 2006). The only appreciable difference is that the ambient air quality baseline in the model was updated to reflect ReFSoRT's ambient air quality baseline which more fully captures transport-related emissions in the year

2000. In this report, all health impacts measured by AQBAT are annual, for the year 2000 and reflect cumulative risk aggregated over time by the concentration response functions.

4.2 HEALTH OUTCOME ENDPOINTS

The AQBAT model applies the damage function approach to calculate changes in the frequency of a total of 12 health endpoints. The health outcome triggers are changes in the ambient concentration of NO_X, Ozone, SO_2, and $PM_{2.5}$ by census division provided by the ReFSoRT model. The changes in concentration are then used to calculate changes in the 12 health endpoints for four different ambient air quality concentrations. As ambient air quality changes, the impacts on health outcomes can be thought of in two ways: first there are the ongoing damages associated with current levels of emissions, and two there is either an incremental increase in health outcomes when emissions increase or a decrease in outcomes with reduced emissions. The epidemiological literature concludes that there is no lower ambient air quality threshold below which health impacts do not occur, so all transport-related emissions lead to adverse health outcomes. Exhibit 4-1 summarizes the health endpoints and related contributing pollutants that are assessed by the AQBAT model.

Exhibit 4-1
Health Endpoints

Health Endpoints	Contributing Pollutants and Averaging Times
Acute Exposure Mortality	24-hr NO_X, 1- hr O_3, 24-hr SO_2
Acute Respiratory Symptom Days	1-hr O_3 (May-Sep), 24-hr $PM_{2.5}$
Adult Chronic Bronchitis Cases	24-hr $PM_{2.5}$
Asthma Symptom Days	1-hr O_3 (May-Sep), 24-hr $PM_{2.5}$
Cardiac Emergency Room Visits	24-hr $PM_{2.5}$
Child Acute Bronchitis Episodes	24-hr $PM_{2.5}$
Chronic Exposure Mortality	24-hr $PM_{2.5}$
Minor Restricted Activity Days	1-hr O_3 (May-Sep)
Respiratory Emergency Room Visits	1-hr O_3 (May-Sep), 24-hr $PM_{2.5}$
Restricted Activity Days	24-hr $PM_{2.5}$
Cardiac Hospital Admissions	24-hr $PM_{2.5}$
Respiratory Hospital Admissions	1-hr O_3 (May-Sep), 24-hr $PM_{2.5}$

Source: Health Canada's AQBAT

Concentration Response Functions (CRF) define the relationship between ambient air quality and health status and are a statistically derived estimate of the percentage incidence of health endpoint associated with a unit of pollutant concentration. The CRFs are derived from epidemiological studies and are defined in the model as distributions such as linear or normal. Since the CRFs are expressed as a distribution, they explicitly reflect uncertainty in their distribution form. Each health endpoint is associated with either a short-term exposure (acute), and/or a long-term exposure (chronic) meaning that each event reflects either an immediate or cumulative health impact. Each CRF is applicable to a specific population age group pre-defined in AQBAT for the year 2000. The health endpoints and the specific parameters and data sources related to each CRF applied are identified in Exhibit 4-2. Only CRFs that were included in the AQBAT model are used in this study.

Exhibit 4-2
Concentration Response Functions Contained in AQBAT

Health Endpoints	Pollutant	Baseline Rate (annual events per million population) [1]	Distribution Type	Mean Value	Standard Error	Epidemiological Study
Acute Exposure Mortality	NO2	1,220 – 16,000	Poisson	7.48E-04	2.49E-04	Burnett et al. 2004
	O3		Poisson	8.39E-04	1.36E-04	Burnett et al. 2004
	SO2		Poisson	4.59E-04	2.20E-04	Burnett et al. 2004
Acute Respiratory Symptom Days	PM2.5	64,000,000	Linear	2.66E-03	1.39E-03	Krupnick et al. 1990
	O3 (May-Sep)		Linear	7.86E-04	3.86E-04	Krupnick et al. 1990
Adult Chronic Bronchitis Cases	PM2.5	6,400	Poisson	1.32E-02	6.80E-03	Abbey et al. 1995
Asthma Symptom Days	O3 (May-Sep)	60,000,000	Poisson	1.77E-03	6.37E-04	Whittemore and Korn; Stock et al. 1988
	PM2.5	60,000,000	Linear	7.93E-04	5.13E-04	Ostro et al. 1991; Whittemore and Korn 1980
Cardiac Emergency Room Visits	PM2.5	2,000 – 12,700	Linear	7.11E-04	1.70E-04	Burnett et al. 1995; Stieb et al. 2000
Child Acute Bronchitis Episodes	PM2.5	64,000	Poisson	2.72E-02	1.68E-02	Dockery et al. 1996
Chronic Exposure Mortality	PM2.5	1,220 – 16,000	Poisson	6.76E-03	1.50E-03	Krewski et al. 2000
Minor Restricted Activity Days	O3 (May-Sep)	8,000,000	Poisson	5.30E-04	2.91E-03	Ostro and Rothschild 1989
Respiratory Emergency Room Visits	O3 (May-Sep)	18,600 – 43,200	Poisson	7.91E-04	3.55E-04	Burnett et al. 1997; Stieb et al. 2000
	PM2.5		Linear	7.54E-04	1.32E-04	Burnett et al. 1995; Stieb et al. 2000
Restricted Activity Days	PM2.5	19,000,000	Poisson	4.81E-03	1.01E-03	Ostro 1987
Cardiac Hospital Admissions	PM2.5	1,520 – 9,760	Linear	7.11E-04	1.70E-04	Burnett et al. 1995
Respiratory Hospital Admissions	O3 (May-Sep)	3,690 – 8,550	Poisson	7.91E-04	3.55E-04	Burnett et al. 1997
	PM2.5		Linear	7.54E-04	1.32E-04	Burnett et al. 1995

Source: Health Canada's AQBAT model. Version 1.0 October 2006.

Notes: [1] A range in the baseline rate indicates where different baseline rates were used for different census divisions that fall within this range.

4.3 HEALTH OUTCOMES ATTRIBUTABLE TO TRANSPORT-RELATED EMISSIONS

This section presents the results for the health endpoints under the two "transport only" emissions scenarios:

- **Emission Scenario #1.** The impact of all transportation emissions without paved road dust,
- **Emission Scenario #2.** The impact of all transportation emissions with paved road dust.

4.3.1 Emission Scenario #1: The Impact of Transport Emissions Without Paved Road Dust

A total of 18 CRFs related to four pollutants were used to determine the mean probability of 12 health endpoints for each census division where ambient concentration changes were determined by ReFSoRT. The health outcomes are expressed as net counts of morbidity or mortality for each of the endpoints. Netting is intended to address the issue that a single episode of morbidity could be counted more than once as different endpoints, for example an individual with pneumonia might first visit the emergency department and then be admitted to hospital. In order to avoid double counting the number of occurrences of the two outcomes need to be subtracted prior to applying valuation estimates. The AQBAT model tracks "additivity" or "non-additivity" of health endpoints and calculates net and gross health endpoints. In this report only net health endpoints are presented. Exhibit 4-3 and Exhibit 4-4 aggregate the health endpoints for all census divisions in each province to indicate provincial and national summaries.

Exhibit 4-3
Provincial Summary of Health Endpoints (1 of 2)

Province	Health Outcomes (Counts)					
	Acute Exposure Mortality	Chronic Exposure Mortality	Adult Chronic Bronchitis Cases	Child Acute Bronchitis Episodes	Asthma Symptom Days	Acute Respiratory Symptom Days
	O_3, SO_2, NO_2	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	O_3, $PM_{2.5}$	O_3, $PM_{2.5}$
Newfoundland and Labrador	1	1	2	12	78	2,730
Nova Scotia	3	0	0	2	627	4,060
New Brunswick	6	4	4	31	603	9,360
Quebec	222	88	100	700	22,500	274,000
Ontario	282	112	134	1,080	35,600	410,000
Manitoba	18	8	8	64	560	14,900
Saskatchewan	6	7	7	65	985	16,900
Alberta	39	12	16	143	3,860	47,900
British Columbia	82	12	14	103	8,810	72,000
CANADA (TOTAL)	**659**	**245**	**284**	**2,200**	**73,600**	**852,000**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

Exhibit 4-4
Provincial Summary of Health Endpoints (2 of 2)

Province	Health Outcomes (Counts)					
	Respiratory Hospital Admissions	Cardiac Emergency Room Visits	Cardiac Hospital Admissions	Minor Restricted Activity Days	Respiratory Emergency Room Visits	Restricted Activity Days
	O_3, $PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	O_3	O_3, $PM_{2.5}$	$PM_{2.5}$
Newfoundland and Labrador	0	0	0	0	0	1,730
Nova Scotia	0	0	0	1,050	2	275
New Brunswick	1	0	0	687	3	4,410
Quebec	21	3	7	29,900	84	112,000
Ontario	32	3	9	49,000	131	149,000
Manitoba	1	0	1	280	3	8,580
Saskatchewan	1	0	1	1,050	5	7,780
Alberta	3	0	1	5,130	13	18,100
British Columbia	8	0	1	13,800	31	15,200
CANADA (TOTAL)	**67**	**7**	**19**	**101,000**	**272**	**316,000**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

4.3.2 Emission Scenario #2 – The Impact of Transport Emissions and Paved Road Dust

Health endpoints related to pollutants other than $PM_{2.5}$ (O_3, SO_2 and NO_2) are identical to Emission Scenario #1. Exhibit 4-5 and Exhibit 4-6 aggregate the health endpoints for all Census Divisions in each province to indicate provincial and national summaries.

Exhibit 4-5
Provincial Summary of Health Endpoints (1 of 2)

Province	Health Outcomes (Counts)					
	Acute Exposure Mortality	Chronic Exposure Mortality	Adult Chronic Bronchitis Cases	Child Acute Bronchitis Episodes	Asthma Symptom Days	Acute Respiratory Symptom Days
	O_3, SO_2, NO_2	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	O_3, $PM_{2.5}$	O_3, $PM_{2.5}$
Newfoundland and Labrador	1	3	4	31	202	7,050
Nova Scotia	3	1	1	6	654	4,990
New Brunswick	6	15	15	118	1,170	29,300
Quebec	222	208	236	1,650	29,300	509,000
Ontario	282	323	381	3,070	48,300	857,000
Manitoba	18	16	15	123	922	27,700
Saskatchewan	6	13	12	108	1,230	25,900
Alberta	39	20	26	234	4,410	67,400
British Columbia	82	36	40	306	10,100	118,000
CANADA (TOTAL)	**659**	**634**	**730**	**5,650**	**96,300**	**1,650,000**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

Exhibit 4-6
Provincial Summary of Health Endpoints (2 of 2)

Province	Health Outcomes (Counts)					
	Respiratory Hospital Admissions	Cardiac Emergency Room Visits	Cardiac Hospital Admissions	Minor Restricted Activity Days	Respiratory Emergency Room Visits	Restricted Activity Days
	O_3, $PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	O_3	O_3, $PM_{2.5}$	$PM_{2.5}$
Newfoundland and Labrador	0	0	0	0	1	4,450
Nova Scotia	1	0	0	1,050	2	883
New Brunswick	2	0	1	687	6	16,900
Quebec	31	6	17	29,900	126	265,000
Ontario	52	9	26	49,000	210	425,000
Manitoba	1	0	1	280	6	16,400
Saskatchewan	2	0	1	1,050	6	13,000
Alberta	4	1	2	5,130	16	29,700
British Columbia	10	1	3	13,800	40	43,800
CANADA (TOTAL)	**102**	**18**	**50**	**101,000**	**413**	**815,000**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

4.4 THE ECONOMIC VALUE OF THE HEALTH CHANGES

Monetary valuations of health outcomes are calculated in AQBAT for each of the included Census Divisions based on health Endpoint Valuations (EPV) that assign monetary value to the specific health endpoints. In AQBAT, two endpoint valuations relate to either mortality or morbidity outcomes: for mortality, the value of a statistical life (VSL) is used, which is a measure of people's willingness to accept different levels of risk, and for morbidity, the combined value of lost wages, cost of treatment, averting expenditures and pain and suffering related to morbidity outcomes. Each EPV is referenced to a base year Canadian dollar value that has been adjusted in this study to year 2000$ dollars. The values are annual estimates.

The 12 endpoint valuations used in this study have been endorsed by Health Canada for use in all Census Divisions in Canada.

Exhibit 4-7 summarizes the specific model parameters related to the EPV probability distribution and type of valuation by endpoint.

Exhibit 4-7
Endpoint Valuations Defined
Value per Endpoint in 2000$ and Probability Distributions

Health Endpoint	Type of Value	Type of Probability Distribution	Low	Central	High	Standard Error
Acute Exposure Mortality and Chronic Exposure Mortality[(1)]	VSL/Wage Risk	Triangular	$3,050,000	$4,050,000	$5,050,000	-
Acute Respiratory Symptom Days	WTP	Normal	-	14	-	7
Adult Chronic Bronchitis Cases	WTP	Discrete	175,000	266,000	465,000	-
			33%	34%	33%	
Asthma Symptom Days	WTP	Triangular	7	28	120	-
Cardiac Emergency Room Visits[(2)]	WTP	Normal	-	4,400	-	590
Child Acute Bronchitis Episodes	WTP	Discrete	150	310	460	-
			33%	34%	33%	
Minor Restricted Activity Days	WTP	Normal	-	22	-	9
Respiratory Emergency Room Visits	WTP	Normal	-	2,000	-	210
Restricted Activity Days	WTP	Normal	-	48	-	18

Source: Health Canada's AQBAT

(1) Value of a Statistical Life in AQBAT model modified to match the VSL used by Transport Canada[4]

(2) Includes valuation of subsequent admission to hospital

4.4.1 Emission Scenario #1 – Transport Emissions Without Paved Road Dust

Exhibit 4-8 and Exhibit 4-9 aggregate the monetary valuations for each health endpoint in all Census Divisions aggregated by province and nationally. **The total transport related health impacts cost in 2000 is estimated to have a central value of $3.78 billion (estimated low of $2.8 billion and high of $4.75 billion).** The provincial breakdown is provided in both Exhibit 4-10 and Exhibit 4-11.

[4] Personal Communication with Transport Canada. Rosy Anne Amourdon, February 2, 2007.

Exhibit 4-8
Provincial Summary of 10 Health Endpoints (1 of 2)

Province	Health Endpoint Valuations (Dollar value in 000's 2000$)				
	Acute Exposure Mortality	Chronic Exposure Mortality	Adult Chronic Bronchitis Cases	Child Acute Bronchitis Episodes	Asthma Symptom Days
	O_3, SO_2, NO_2	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	O_3, $PM_{2.5}$
Newfoundland and Labrador	$4,300	$5,190	$496	$4	$4
Nova Scotia	$10,200	$1,330	$82	$1	$34
New Brunswick	$26,000	$15,400	$1,280	$10	$33
Quebec	$898,000	$356,000	$32,400	$230	$1,220
Ontario	$1,140,000	$453,000	$43,300	$355	$1,930
Manitoba	$73,700	$34,100	$2,480	$21	$30
Saskatchewan	$23,800	$29,900	$2,230	$21	$54
Alberta	$158,000	$48,400	$5,210	$47	$210
British Columbia	$332,000	$49,500	$4,430	$34	$478
CANADA (TOTAL)	**$2,670,000**	**$993,000**	**$91,900**	**$723**	**$4,000**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

Exhibit 4-9
Provincial Summary of 10 Health Endpoints (2 of 2)

Province	Health Endpoint Valuations (Dollar value in 000's 2000$)				
	Acute Respiratory Symptom Days	Cardiac Emergency Room Visits	Minor Restricted Activity Days	Respiratory Emergency Room Visits	Restricted Activity Days
	O_3, $PM_{2.5}$	$PM_{2.5}$	O_3	O_3, $PM_{2.5}$	$PM_{2.5}$
Newfoundland and Labrador	$38	0	0	$1	$88
Nova Scotia	$56	0	$24	$4	$14
New Brunswick	$129	0	$16	$5	$223
Quebec	$3,780	$12	$696	$176	$5,650
Ontario	$5,640	$15	$1,140	$277	$7,530
Manitoba	$206	$1	$7	$7	$434
Saskatchewan	$233	$1	$24	$10	$394
Alberta	$660	$2	$120	$28	$916
British Columbia	$991	$2	$322	$66	$767
CANADA (TOTAL)	**$11,700**	**$33**	**$2,350**	**$574**	**$16,000**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

Exhibit 4-10
Provincial Breakdown for All Modes Transport-caused Emissions Without Paved Road Dust Economic Value in 000's 2000$

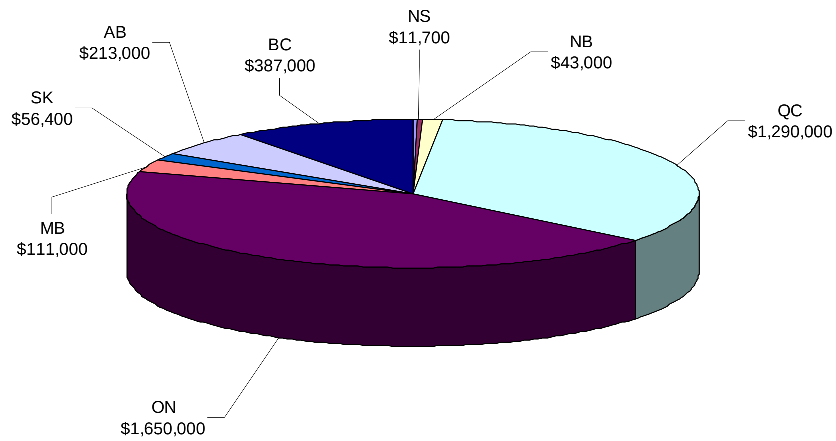


Exhibit 4-11

Provincial Summary of Costs of all Health Endpoints (Without Paved Road Dust)

Province	Total Health Endpoint Valuations (Dollar value in 000's 2000$)		
	Low (20th percentile)	Central	High (80th Percentile)
Newfoundland and Labrador	$7,410	$10,100	$12,800
Nova Scotia	$9,140	$11,700	$14,200
New Brunswick	$31,800	$43,100	$54,200
Quebec	$959,000	$1,300,000	$1,630,000
Ontario	$1,230,000	$1,650,000	$2,070,000
Manitoba	$80,700	$111,000	$141,000
Saskatchewan	$42,900	$56,600	$70,000
Alberta	$156,000	$214,000	$270,000
British Columbia	$288,000	$388,000	$486,000
CANADA (TOTAL)	**$2,800,000**	**$3,780,000**	**$4,750,000**

Note: The minimum and maximum represent the probability distribution of concentration response functions and endpoint valuations considered in the AQBAT modeling (See Exhibit 4-2 and 4-7). The most significant of the probability distributions is the range of VSL for acute and chronic exposure mortality (i.e., $3,050,000 to $5,050,000 with a mean value of $4,050,000). Therefore, the minimum value could be considered to reflect a VSL of $3,050,000 and the maximum value could be considered to reflect a VSL of $5,050,000.

4.4.2 Emission Scenario #2 – Transport Emissions With Paved Road Dust

Exhibit 4-12 and Exhibit 4-13 aggregate the monetary valuations for each health endpoint in all census divisions aggregated by province and nationally. **The total transport related health impacts cost in 2000 is estimated to have a central value of $5.54 billion (estimated low of $4.15 billion and high of $6.9 billion)**. The provincial break down is provided in both Exhibit 4-14 and Exhibit 4-15.

Exhibit 4-12
Provincial Summary of 10 Health Endpoints (1 of 2)

Province	Health Endpoint Valuations (Dollar value in 000's 2000$)				
	Acute Exposure Mortality	Chronic Exposure Mortality	Adult Chronic Bronchitis Cases	Child Acute Bronchitis Episodes	Asthma Symptom Days
	O_3, SO_2, NO_2	$PM_{2.5}$	$PM_{2.5}$	$PM_{2.5}$	O_3, $PM_{2.5}$
Newfoundland and Labrador	$4,300	$13,400	$1,270	$10	$11
Nova Scotia	$10,200	$4,280	$260	$2	$36
New Brunswick	$26,000	$59,200	$4,890	$39	$64
Quebec	$898,000	$841,000	$76,300	$545	$1,600
Ontario	$1,140,000	$1,310,000	$123,000	$1,010	$2,630
Manitoba	$73,700	$65,600	$4,730	$40	$51
Saskatchewan	$23,800	$50,400	$3,710	$36	$67
Alberta	$158,000	$79,600	$8,530	$77	$240
British Columbia	$332,000	$147,000	$12,800	$101	$550
CANADA (TOTAL)	**$2,670,000**	**$2,570,000**	**$236,000**	**$1,860**	**$5,250**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

Exhibit 4-13
Provincial Summary of 10 Health Endpoints (2 of 2)

Province	Health Endpoint Valuations (Dollar value in 000's 2000$)				
	Acute Respiratory Symptom Days	Cardiac Emergency Room Visits	Minor Restricted Activity Days	Respiratory Emergency Room Visits	Restricted Activity Days
	O_3, $PM_{2.5}$	$PM_{2.5}$	O_3	O_3, $PM_{2.5}$	$PM_{2.5}$
Newfoundland and Labrador	$98	$0	$0	$2	$225
Nova Scotia	$69	$0	$24	$5	$45
New Brunswick	$408	$2	$16	$13	$856
Quebec	$7,080	$28	$696	$266	$13,400
Ontario	$11,900	$44	$1,140	$443	$21,500
Manitoba	$386	$2	$7	$12	$829
Saskatchewan	$360	$1	$24	$13	$656
Alberta	$936	$3	$120	$34	$1,500
British Columbia	$1,630	$5	$322	$83	$2,220
CANADA (TOTAL)	**$22,900**	**$85**	**$2,350**	**$872**	**$41,200**

Source: Marbek using Health Canada's AQBAT and RWDI's REFSORT

Exhibit 4-14
Provincial Breakdown for All Modes Transport-caused Emissions With Paved Road Dust
Economic Value in 000's 2000$

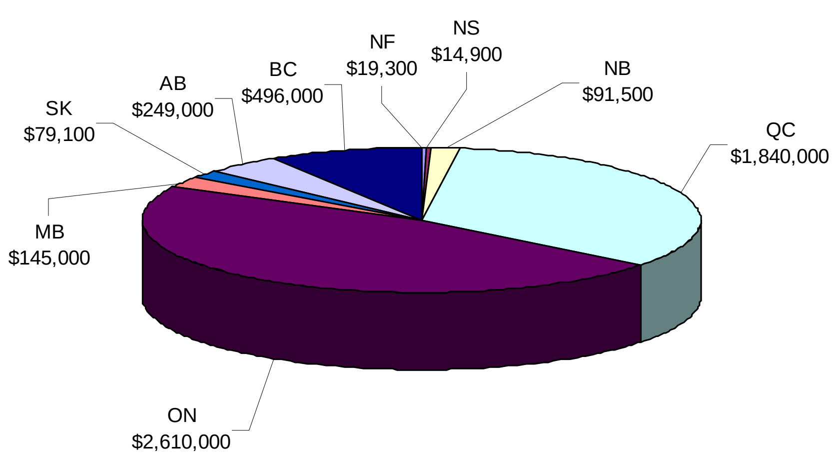


Exhibit 4-15

Provincial Summary of Costs of all Health Endpoints (With Paved Road Dust)

Province	Total Health Endpoint Valuations (Dollar value in 000's 2000$)		
	Low (20th percentile)	Central	High (80th Percentile)
Newfoundland and Labrador	$14,400	$19,300	$24,000
Nova Scotia	$11,600	$14,900	$18,000
New Brunswick	$68,900	$91,500	$113,000
Quebec	$1,370,000	$1,840,000	$2,290,000
Ontario	$1,960,000	$2,610,000	$3,240,000
Manitoba	$107,000	$145,000	$182,000
Saskatchewan	$60,300	$79,000	$97,200
Alberta	$183,000	$249,000	$313,000
British Columbia	$371,000	$496,000	$618,000
CANADA (TOTAL)	**$4,150,000**	**$5,540,000**	**$6,900,000**

5 AGRICULTURE AND VISIBILITY IMPACT RESULTS

5.1 AGRICULTURE

In this section the ambient air concentration changes by census division are translated, using Environment Canada's Value of Ozone Impacts on Canadian Crops Estimator (VOICCE) model into changes in production yield of agricultural crops and the dollar value of those changes. The section is presented in four sub-sections:

1. *Agricultural Modelling – VOICCE*, which introduces the VOICCE model;
2. *Agricultural Outcome Endpoints*, which explains the environmental impacts of transport-related air pollution on crops covered by the VOICCE model.
3. *Agricultural Outcomes Attributable to Transport-Related Emissions*, which identifies the number of occurrences of endpoints that can be attributed to transport emissions; and,
4. *The Economic Value of the Agricultural Endpoints*.

5.1.1 Agricultural Modelling - VOICCE

Ozone can impair the growth and significantly reduce yields of many agricultural crops primarily by inhibiting photosynthesis and limiting the availability of photosynthate needed for biomass production. Estimates indicate ozone-induced yield losses at current concentrations ranging from negligible to approximately 20% or more in some areas, depending on the crop species and environmental conditions during plant growth and exposure.

Environment Canada has developed the Value of Ozone Impacts on Canadian Crops Estimator (VOICCE) model to estimate ozone impacts on agriculture. The model works by using average yearly 1-hour ozone concentration changes of ozone within 82 agricultural regions in Canada to calculate the impacts of ozone on the production of 10 crops. The agricultural regions are within 10 provinces in Canada and can be readily related to the Census Divisions that are the basis of the input ozone levels from ReFSoRT. These are the 10 major crops in Canada that are most sensitive to the effects of ozone.

The VOICCE model includes Dose Response Functions (DRF) that relate concentration changes in the level of ozone and changes in the production yield of individual crops. Based on the production levels in each of the agricultural regions in all 10 provinces the value of decreased output is translated into costs by considering the decrease in revenue to the farmer. The model has the ability to consider price elasticities; however, historic crop commodity prices are used to estimate the impact on farmer revenue for this study.

5.1.2 Agricultural Outcome Endpoints

The crops that are covered in the VOICCE model include spring wheat, winter wheat, canola, soybeans, corn for grain, corn for feed, alfafa, hay, potatoes and tobacco. These are the crops where there is sufficient scientific study to determine dose response functions (DRF). The DRFs relate changes in ozone concentrations to a percent reduction in production yields of the crops. In the development of the model over 25 DRFs were considered. These DRFs are summarized in the Kulshreshta 2005 study. Ultimately the DRFs selected for the VIEW model were those that met a number of criteria including: goodness of fit of estimator, geographical location of test and the flexibility of estimator.

5.1.3 Agricultural Outcomes Attributable to Transport-Related Emissions

Based on the modelled ReFSoRT concentration changes of ozone between the BAU scenario and the removal of all transportation emissions (the emission scenarios), Environment Canada ran the VOICCE model to predict changes in production yield of 10 different crops and the economic value of this change. The base yields of each crop (tonnes) were calculated using the hectares seeded per crop and average production yield data (tonnes/hectare) derived from historical year 2000 data.

Exhibit 5-1 identifies the predicted change in crop yields as a result of the removal of all transportation emissions. Note that these results do not change if paved road dust were included in the results (Emission Scenario #2) since paved road dust does not impact ozone levels.

Exhibit 5-1
Estimated Change in Crop Yields by Province caused by Transport Emissions (tonnes)

	Spring wheat	Winter wheat	Canola	Soybean	Corn for grain	Corn for silage	Alfalfa and alfalfa mixtures	Hay and fodder crops	Potatoes	Tobacco
Newfoundland and Labrador	0	0	0	0	0	0	0	2	0	0
Prince Edward Island	0	0	0	0	0	0	0	0	0	0
Nova Scotia	38	8	0	0	25	86	95	499	207	0
New Brunswick	31	2	0	2	3	65	91	657	1,460	0
Quebec	1,140	16	23	5,550	15,900	8,630	0	22,900	4,510	0
Ontario	12,700	3,840	104	25,300	27,500	18,900	20,500	14,500	3,640	175
Manitoba	1,960	91	193	0	64	115	642	204	274	0
Saskatchewan	19,800	162	1,330	0	0	0	2,990	1,060	108	0
Alberta	29,300	86	2,400	0	3	625	14,100	8,440	1,740	0
British Columbia	773	0	126	0	0	1,660	9,420	9,400	791	0
Total (in tonnes)	**65,800**	**4,200**	**4,170**	**30,800**	**43,500**	**30,100**	**47,800**	**57,700**	**12,700**	**175**

5.1.4 The Economic Value of the Agricultural Endpoints

The economic value of a change in crop yield as a result of air pollution is calculated by multiplying the change in production (using the stock level of year 2000) by the crop price ($/tonne) at the year 2000$ market value. Estimated changes in the economic value of the crops are provided in Exhibit 5-2. A provincial summary of the total economic change and the per cent contribution is provided in Exhibit 5-3.

Exhibit 5-2
Estimated Change in Agricultural Crop Value of Ozone Related Transport Emissions (000's 2000$)

Crops	Spring wheat	Winter wheat	Canola	Soybean	Corn for grain	Corn for silage	Alfalfa and alfalfa mixtures	Hay and fodder crops	Potatoes	Tobacco
Newfoundland and Labrador	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Prince Edward Island	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Nova Scotia	$6	$1	$0	$0	$3	$2	$10	$52	$45	$0
New Brunswick	$5	$0	$0	$1	$0	$2	$10	$69	$218	$0
Quebec	$173	$2	$6	$1,390	$1,870	$216	$0	$1,830	$857	$0
Ontario	$1,940	$584	$26	$6,320	$3,240	$473	$1,640	$1,160	$698	$887
Manitoba	$298	$14	$48	$0	$8	$3	$35	$11	$48	$0
Saskatchewan	$3,010	$25	$327	$0	$0	$0	$164	$58	$37	$0
Alberta	$4,450	$13	$589	$0	$0	$15	$774	$464	$291	$0
British Columbia	$118	$0	$31	$0	$0	$40	$518	$517	$304	$0
Total	**$10,000**	**$639**	**$1,030**	**$7,700**	**$5,130**	**$750**	**$3,150**	**$4,170**	**$2,500**	**$887**

Exhibit 5-3
Estimated Change in Agricultural Crop Value of Ozone Related Transport Emissions

	Change in Economic Value (000's 2000$)	Percent of Total Impact (%)
Newfoundland and Labrador	$0	0.0%
Prince Edward Island	$0	0.0%
Nova Scotia	$120	0.0%
New Brunswick	$304	1.0%
Quebec	$6,340	18.0%
Ontario	$17,000	47.0%
Manitoba	$464	1.0%
Saskatchewan	$3,620	10.0%
Alberta	$6,600	18.0%
British Columbia	$1,530	4.0%
Total	$35,900	**100.0%**

5.2 VISIBILITY

In this section the ambient air concentration changes of PM by Census Division are translated, using Environment Canada's Visibility Impacts Estimator of Welfare (VIEW) model, into changes in visibility and the dollar value of those changes. Essentially, we estimate the value people place when their view is reduced through an increase in haze and a reduction in visibility associated with $PM_{2.5}$ from transport emissions. The section is presented in four sub-sections:

1. *Visibility Modelling – VIEW*, which introduces the VIEW model;
2. *Visibility Outcome Endpoints*, which explains the environmental impacts of transport-related air pollution on visibility covered by the VIEW model;
3. *Visibility Outcomes Attributable to Transport-Related Emissions*, which identifies the number of occurrences of endpoints that can be attributed to transport emissions; and,
4. *The Economic Value of the Agricultural Endpoints*.

5.2.1 Visibility Modelling – VIEW

A draft version of Environment Canada's Visibility Impacts Estimator of Welfare (VIEW) model was used to estimate potential visibility impacts from transportation emissions. The model is in development by the Valuation and Market Instrument Design Division and is intended to provide "directional'" or indicative results. Therefore the model does estimate order of magnitude visibility costs that are useful in this study.

The model links changes in visibility to economic valuations of the improvement in visibility from a human perspective. Calculated annual costs represent the mean costs that a person is willing to pay (WTP) for improved (i.e., increased) visibility

Determination of the costs that people are willing to pay for a single improvement in visibility is based on surveys of the population using the contingent choice (CC) methodology (sometimes referred to as a Discrete Choice Experiment). The contingent choice methodology forces respondents to repeatedly choose between various improvements at various costs and has been used to estimate the value of a wide variety of environmental goods and services, and has been applied extensively in the fields of applied decision making and market research.

5.2.2 Visibility Outcome Endpoints

The VIEW model includes conversion factors to transform annual ambient $PM_{2.5}$ data based on 24-hour concentrations into "deciviews". The deciview (dv) is an atmospheric haze index that expresses changes in visibility. This visibility metric expresses uniform changes in haziness in terms of common increments across the entire range of human-perceived visibility conditions, from pristine to extremely hazy conditions. A one dv change is approximately a 10% change in the extinction coefficient, which is a small, but usually perceptible scenic change. The dv scale is near zero for a pristine atmosphere (dv = 0 for Rayleigh conditions at approximately 1.8km elevation) and increases as visibility degrades. Baseline annual $PM_{2.5}$ concentrations by Census Division from the REFSORT model were entered into the model along with scenario concentration changes to produce estimates of the average annual change in deciviews. The following relationships are used to relate ambient baseline concentrations to changes in deciviews (dv).

Variable	Description	Relationship
$PM_{2.5}$	Mean annual concentration of 24-hour PM2.5	-
Bscat	Light scattering coefficient	Bscat = (3.1 * $PM_{2.5}$) /1000
VR	Visual range – measure of transparency in atmosphere	VR = 3.91 / (Bscat / 0.64)
dv	Deciview – measure of perceived change in visibility	dv = 10 * ln (391 / VR)

A linear cost function is included with the model to estimate welfare and provide economic valuations. The cost function is based on a study that was conducted for the Lower Mainland of British Columbia. All sampling was conducted within this region and a total of 227 respondents were included in the study and derivation of the cost function. As a result, the study likely shows substantial bias to the region and demographic of the study area. A detailed sensitivity analysis is conducted to determine the expected range of uncertainty and if it influences the overall results.

Economic valuations are multiplied by the historic population levels in 2000 to determine overall benefits in all regions of the country for which $PM_{2.5}$ emissions have been attributed to transportation.

5.2.3 Visibility Outcomes Attributable to Transport-Related Emissions

Baseline annual $PM_{2.5}$ concentrations by Census Division from the ReFSoRT model were entered into the model along with scenario concentration changes. No other modifications were made to model parameters. The resulting change in visibility measured in deciviews was calculated for each Census Division. The average provincial change in deciviews for the two emission scenarios are presented in Exhibit 5-4.

Exhibit 5-4
Average Change in Visibility by Province attributable to Transport-related Emissions

	Average Provincial Change in Visibility due to Transport Emissions	
	Scenario #1 Without Paved Road Dust (Deciviews)	**Scenario #2 With Paved Road Dust (Deciviews)**
Newfoundland and Labrador	0.13	0.34
Nova Scotia	0.19	0.61
New Brunswick	0.17	0.66
Quebec	0.23	0.59
Ontario	0.13	0.44
Manitoba	0.22	0.45
Saskatchewan	0.28	0.53
Alberta	0.10	0.17
British Columbia	0.05	0.26
Canada	0.15	0.46

5.2.4 The Economic Value of the Agricultural Endpoints

Emission Scenario #1: Transport Emissions Without Paved Road Dust. Exhibit 5-5 identifies the economic value that people are willing to pay (WTP) for the change in visibility.

Exhibit 5-5
Provincial Summary of Annual Economic Value
Changes to Visibility Attributable to Transport-related Emissions

	Change in Economic Value (000's 2000$)	Percent of Total Impact (%)
Newfoundland and Labrador	$450	1.0%
Nova Scotia	$87	0.0%
New Brunswick	$1,220	2.0%
Quebec	$20,200	32.0%
Ontario	$28,900	47.0%
Manitoba	$2,240	4.0%
Saskatchewan	$1,120	2.0%
Alberta	$3,900	6.0%
British Columbia	$4,050	7.0%
Canada	**$62,200**	**100.0%**

Emission Scenario #2: Transport Emissions With Paved Road Dust. Exhibit 5-6 identifies the economic value that people are willing to pay (WTP) for the change in visibility.

Exhibit 5-6
Provincial Summary of Annual Economic Value
Changes to Visibility Attributable to Transport-related Emissions

	Change in Economic Value (000's 2000$)	Percent of Total Impact (%)
Newfoundland and Labrador	$1,170	1.0%
Nova Scotia	$285	0.0%
New Brunswick	$4,740	3.0%
Quebec	$49,100	30.0%
Ontario	$85,300	52.0%
Manitoba	$4,300	3.0%
Saskatchewan	$1,940	1.0%
Alberta	$6,440	4.0%
British Columbia	$11,500	7.0%
Canada	**$165,000**	**100.0%**

6 SUMMARY VALUE OF THE IMPACTS OF AIR POLLUTION FROM TRANSPORT-RELATED EMISSIONS

This section summarizes the total cost in terms of economic value of air pollution from transport-related emissions. Only the central economic values are presented in this section. Low and high values are presented in Section 4 for health endpoints and discussed in detail in Section 8. The presented values represent the cost to each province of transport-related emissions related to the health, visibility and agricultural endpoints. In some cases a portion of the transport related air emissions may actually originate in another upwind province. Section 7.1.2 provides estimates of costs borne by provinces that can be associated with air pollution from upwind provinces. Please note these are conservatively low estimates since not all costs could be credibly monetized and included in the study.

6.1 EMISSION SCENARIO #1: TRANSPORT EMISSIONS WITHOUT PAVED ROAD DUST

Exhibit 6-1 identifies the economic value for all endpoints considered in this study by province and Exhibit 6-2 indicates the relative contribution of the different endpoints to the total national cost of the scenario.

Exhibit 6-1
Emission Scenario #1
Changes Attributable to Transport Emissions Without Paved Road Dust
Provincial Summary of Annual Economic Value

	Change in Economic Value (000's 2000$)		
	Health Endpoints	**Visibility Endpoints**	**Agriculture Endpoints**
Newfoundland and Labrador	$10,100	$450	$0
Prince Edward Island	-	-	-
Nova Scotia	$11,700	$87	$120
New Brunswick	$43,100	$1,220	$304
Quebec	$1,300,000	$20,200	$6,340
Ontario	$1,650,000	$28,900	$17,000
Manitoba	$111,000	$2,240	$464
Saskatchewan	$56,600	$1,120	$3,620
Alberta	$214,000	$3,900	$6,600
British Columbia	$388,000	$4,060	$1,530
Total Canada	**$3,780,000**	**$62,200**	**$35,900**

Exhibit 6-2
Emission Scenario #1
Changes Attributable to Transport Emissions Without Paved Road Dust
Summary of Annual Economic Value Changes

	Change in Economic Value (000's 2000$)	Contribution to Total Economic Impact (%)
Health Endpoints	$3,780,000	97.0%
Visibility Endpoints	$62,200	2.0%
Agricultural Endpoints	$35,900	1.0%
Total Canada	**$3,880,000**	**100.0%**

6.2 EMISSION SCENARIO #2: TRANSPORT EMISSIONS WITH PAVED ROAD DUST

Exhibit 6-3 identifies the economic value for all endpoints considered in this study by province and Exhibit 6-4 indicates the relative contribution of the different endpoints to the total national cost of the scenario.

Exhibit 6-3
Emission Scenario #2
Changes Attributable to Transport Emissions With Paved Road Dust
Provincial Summary of Annual Economic Valuation Changes

	Change in Economic Value (000's 2000$)		
	Health Endpoints	Visibility Endpoints	Agriculture Endpoints
Newfoundland and Labrador	$19,300	$1,170	$0
Prince Edward Island	-	-	-
Nova Scotia	$14,900	$285	$120
New Brunswick	$91,500	$4,740	$304
Quebec	$1,840,000	$49,100	$6,340
Ontario	$2,610,000	$85,300	$17,000
Manitoba	$145,000	$4,300	$464
Saskatchewan	$79,000	$1,940	$3,620
Alberta	$249,000	$6,440	$6,600
British Columbia	$496,000	$11,500	$1,530
Total Canada	**$5,540,000**	**$165,000**	**$35,900**

Exhibit 6-4
Emission Scenario #2
Changes Attributable to Transport Emissions With Paved Road Dust
Summary of Annual Economic Valuation Changes

	Change in Economic Value (000's 2000$)	Contribution to Total Economic Impact (%)
Health Endpoints	$5,540,000	97.0%
Visibility Endpoints	$165,000	3.0%
Agricultural Endpoints	$35,900	1.0%
Total Canada	**$5,740,000**	**100.0%**

7 ALLOCATION OF COSTS

7.1 ASSIGNMENT OF COSTS BY CENSUS DIVISION TO EMISSIONS SOURCE

In order to allocate costs to specific transportation modes or to emissions it is necessary to determine how the original transportation emissions contributed to changes in air pollution that resulted in the health, agricultural and visibility impacts that have been assessed in this study. In essence this is working backwards from the total costs projected to determine the associated concentration changes of each pollutant (i.e., NOx, SO_2, $PM_{2.5}$ and O_3) to the costs that was assessed for each NAP station and then determine what emissions contributed to the change. The emissions that contributed to the change include precursors to the ambient pollutants such as VOC, SO_2, NO_X and $PM_{2.5}$ that contribute to ozone formation and SO_2 and NO_X that contribute to $PM_{2.5}$ formation.

The assignment of costs to the various modes of emission consists of the following steps. Exhibit 7-1 graphically represents the steps that were taken.

1. For each Census Division, disaggregate the economic impact of each pollutant to the respective emission source (as shown in Exhibit 7-2);
2. Aggregate each province's emissions contribution to upwind and local impacts;
3. Apportion each provinces emissions contribution to the ReFSoRT modes of Transportation Emissions; and,
4. Apportion the transportation emissions impact according to the freight/passenger split for each mode.

Exhibit 7-1
Graphical Representation of Steps Required to Attribute Air Pollution Costs to Transport Modes

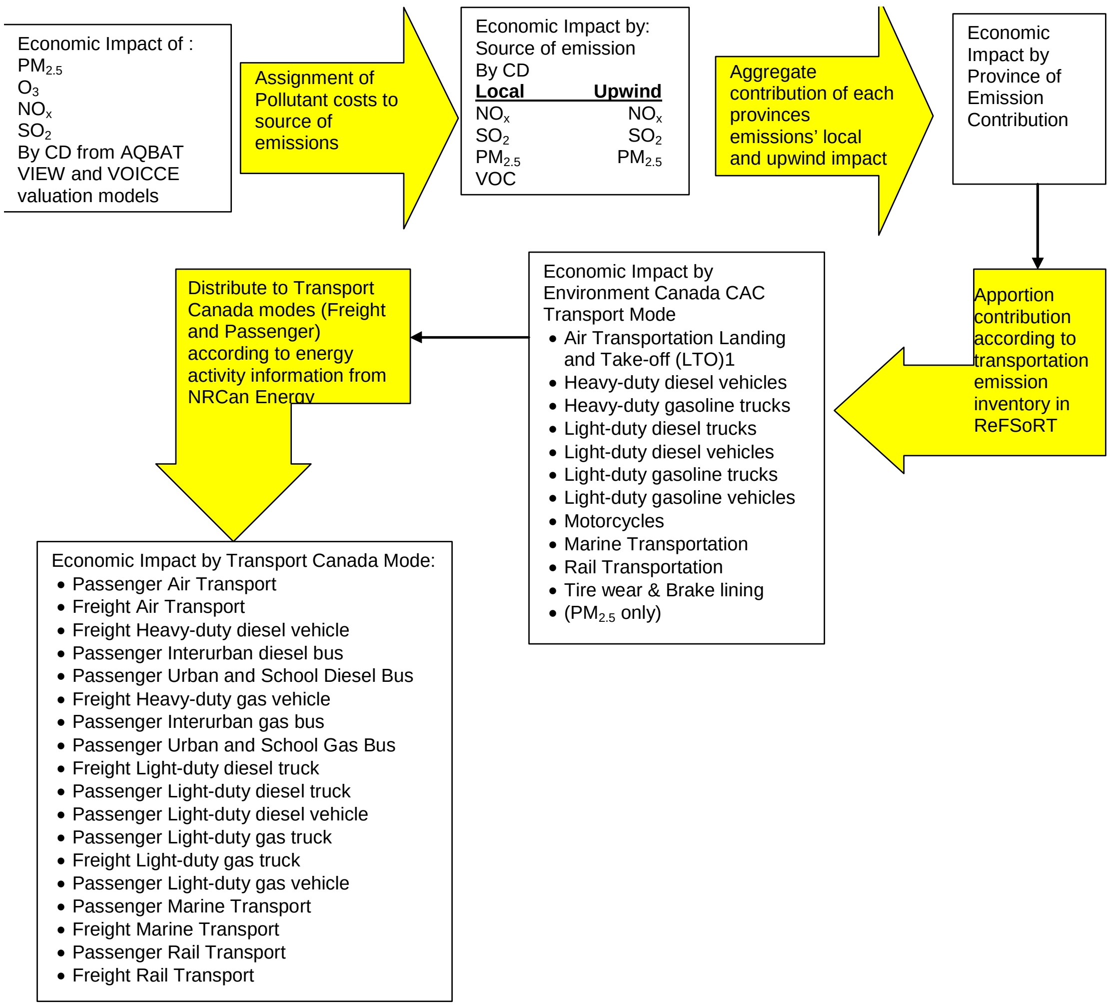
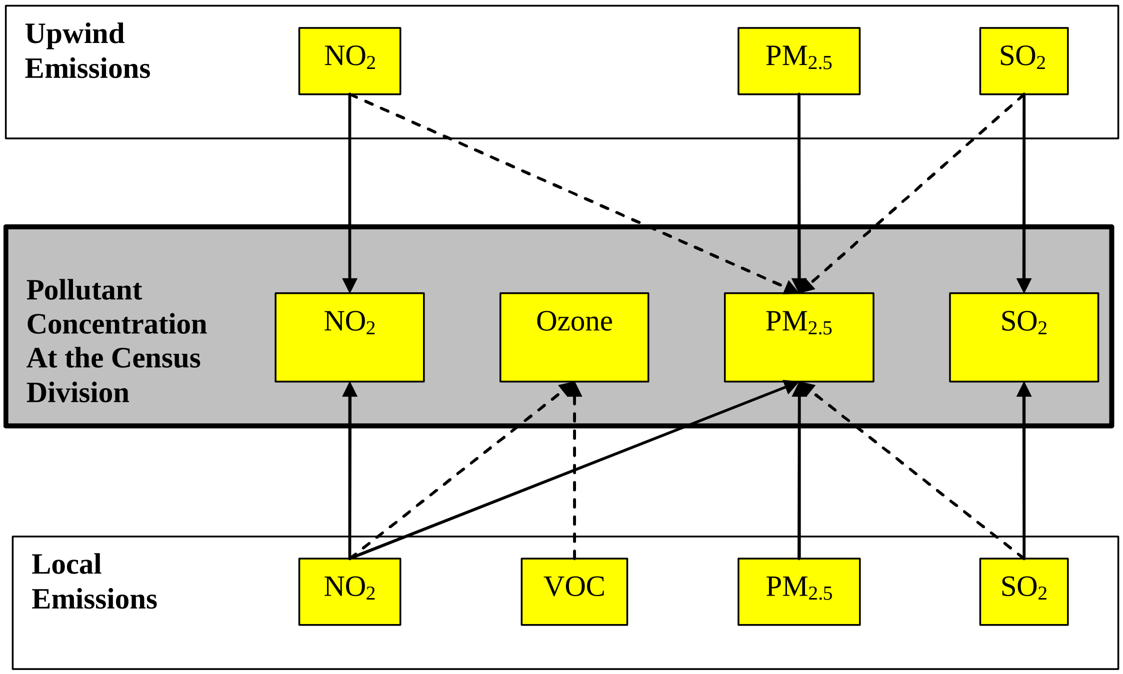


Exhibit 7-2
Contribution of Emission Sources to Pollutant Concentrations



7.1.1 Transposing Emissions from Environment Canada Modes to Transport Canada Modes

The emissions inventory used to evaluate the air quality impact of transportation emissions was drawn from Environment Canada's "Air pollutant emissions in Canada for 2000: National Pollutant Release Inventory (NPRI), criteria air contaminants (CAC), Environment Canada" (released July, 2006). As discussed in Section 3.2 the Environment Canada emission inventory divides transportation emissions into a total of 11 modes relevant to this study. Transport Canada uses a different classification system that is more specific and a total of 18 different modes have been identified. A comparison of the two classifications is presented in Exhibit 3-5 and also in Exhibit 7-3 below.

Transposing the Environment Canada CAC modes to the Transport Canada modes is not a straightforward exercise. The most rigorous method would require that sufficient information would have to be assembled to recreate the emission inventory for the Transport Canada Modes. This information would include provincial activity level data (i.e., vkt, fuel usage) and pollutant emission factors related to the activity and fuel type (NO_X, SO_2, $PM_{2.5}$, VOC) for each mode. Unfortunately vehicle emission factors have only been developed for Environment Canada CAC transportation modes that focus on fuel type (e.g., gasoline or diesel) and vehicle class (e.g., size and weight) and not on the distinction between freight and passenger vehicles used by Transport Canada modes. Correlating the two different classification systems is also complicated by the fact that:

1. Transport Canada passenger and freight modes use different activity level metrics (i.e., passenger kilometres travelled versus freight tonne kilometres transported);

2. Activity level data that is based on the same metric (e.g., vkt) is not differentiated by fuel-type (i.e., gasoline, diesel) that is the basis of the Environment Canada modes.

The Natural Resources Canada (NRCan) Energy Use Database does provide provincial activity level data that can be consistently compared for all modes and also provides a break-out by fuel type. The database provides provincial tables that divide transportation energy use by transportation mode and by fuel use type so that they can be mapped to Environment Canada CAC transportation modes.

The approach used in this study was to use the energy use (i.e., PJ of energy) data by province, mode and fuel type extracted from the NRCan database to provide the activity level data necessary to allocate emissions from EC modes to the Transport Canada modes. The allocation of emissions was based simply on the share of total energy use of the relevant mode. As an example, if passenger rail energy use was 3.4% of the total energy use for rail transportation (passenger and freight), then 3.4% of the emissions of the Environment Canada CAC transportation mode for rail transportation was allocated to this mode. Exhibit 7-3 provides a mapping of how NRCan Energy Use database modes relate to the Transport Canada and Environment Canada CAC transportation modes.

Exhibit 7-3
Mapping of EC modes to Transport Canada Modes using
NRCan Energy Use Database Modes

Environnent Canada CAC Transportation Modes	NRCan Energy Use Database Transportation Modes	Transport Canada Modes
Air Transportation Landing and Take-off (LTO)[1]	Passenger Air	Passenger Air Transport
	Freight Air	Freight Air Transport
Heavy-duty diesel vehicles	Heavy Trucks Diesel	Freight Heavy-duty diesel vehicle
	Medium Trucks Diesel	
	Intercity Buses Diesel	Passenger Interurban diesel bus
	Urban Transit Diesel	Passenger Urban and School Diesel Bus
	School Buses Diesel	
Heavy-duty gasoline trucks	Heavy Trucks Gasoline	Freight Heavy-duty gas vehicle
	Medium Trucks Gasoline	
	Intercity Buses Gasoline	Passenger Interurban gas bus
	Urban Transit Gasoline	Passenger Urban and School Gas Bus
	School Buses Diesel	
Light-duty diesel trucks	Freight Light Trucks Diesel	Freight Light-duty diesel truck
	Passenger Light Trucks Diesel	Passenger Light-duty diesel truck
Light-duty diesel vehicles	Large Cars Diesel	Passenger Light-duty diesel vehicle
	Small Cars Diesel	
Light-duty gasoline trucks	Passenger Light Trucks Gasoline	Passenger Light-duty gas truck

Environnent Canada CAC Transportation Modes	**NRCan Energy Use Database Transportation Modes**	**Transport Canada Modes**
	Freight Light Trucks Gasoline	Freight Light-duty gas truck
Light-duty gasoline vehicles	Small Cars Gasoline	Passenger Light-duty gas vehicle
	Large Cars Gasoline	
Motorcycles	Motorcycles	
Marine Transportation	Passenger Marine	Passenger Marine Transport
	Freight Marine	Freight Marine Transport
Rail Transportation	Passenger Rail	Passenger Rail Transport
	Freight Rail	Freight Rail Transport

Allocating emissions from each Environment Canada (EC) mode to Transport Canada modes based simply on the share of total energy use has inherent limitations. This approach does not consider that the individual Transport Canada modes that are within a particular EC mode have different emission factors. For example, the three Transport Canada modes: freight heavy-duty gas vehicle, passenger interurban gas bus and passenger urban and school gas bus, more than likely have different pollutant emission factors (e.g., gram SO2 emissions per vkt). Allocating emissions to these modes by energy use would not account for the difference in pollutant emission factors that could be substantial. However, it should be noted that allocating emissions to Transport Canada modes within each EC mode based on the share of total energy potentially only introduces error at the disaggregated level, and does not impact the uncertainty of total costs predicted.

Additional error may be introduced from the fact that the Environment Canada emission inventory may be generated from more specific activity level data or more accurate activity level data than the energy use data in the NRCan database.

Tire and brake wear PM emissions cannot be transposed to Transport Canada modes in the same manner, since, the inventory data that is used in ReFSoRT does not disaggregate between the EC CAC transportation modes. Detailed disaggregated provincial PM emission data was obtained from Environment Canada for the year 2000. This data was used to allocate the ReFSoRT emission data to each CAC transportation mode. PM emissions by CAC transportation mode could then be allocated based on the energy activity level data.

Exhibit 7-4 indicates the factors that were used to transpose the emissions from each EC CAC transportation mode to the Transport Canada transportation modes.

Exhibit 7-4
Provincial allocation of emissions to Transport Canada Transportation modes as a percentage of EC mode based on NRCan energy activity data

Environment Canada CAC Classifications	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NF	Transport Canada FCI Classifications
Air Transportation Landing and Take-off (LTO)[1]	94.5%	95.2%	95.5%	95.3%	94.6%	94.9%	95.6%	96.4%	95.7%	96.4%	Passenger Air Transport
	5.5%	4.8%	4.5%	4.7%	5.4%	5.1%	4.4%	3.6%	4.3%	3.6%	Freight Air Transport
Heavy-duty diesel vehicles	92.0%	92.5%	87.3%	86.1%	91.7%	91.5%	93.3%	92.8%	98.5%	92.5%	Freight Heavy-duty diesel vehicle
	1.3%	1.1%	1.9%	2.1%	1.3%	1.4%	0.9%	1.0%	0.2%	1.1%	Passenger Interurban diesel bus
	6.8%	6.4%	10.8%	11.9%	7.0%	7.1%	5.7%	6.1%	1.3%	6.4%	Passenger Urban and School Diesel Bus
Heavy-duty gasoline trucks	99.8%	99.8%	99.8%	99.6%	99.6%	99.6%	99.3%	99.6%	99.9%	99.3%	Freight Heavy-duty gas vehicle
	0.2%	0.2%	0.2%	0.3%	0.3%	0.3%	0.5%	0.3%	0.1%	0.6%	Passenger Interurban gas bus
	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%	0.1%	0.0%	0.2%	Passenger Urban and School Gas Bus
Light-duty diesel trucks	28.8%	37.4%	37.7%	26.4%	26.1%	30.3%	24.1%	24.0%	24.2%	23.9%	Freight Light-duty diesel truck
	71.2%	62.6%	62.3%	73.6%	73.9%	69.7%	75.9%	76.0%	75.8%	76.1%	Passenger Light-duty diesel truck
Light-duty diesel vehicles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	Passenger Light-duty diesel vehicle
Light-duty gasoline trucks	71.2%	62.4%	62.0%	73.7%	73.9%	70.1%	76.1%	76.2%	75.8%	76.1%	Passenger Light-duty gas truck
	28.8%	37.6%	38.0%	26.3%	26.1%	29.9%	23.9%	23.8%	24.2%	23.9%	Freight Light-duty gas truck
Light-duty gasoline vehicles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	Passenger Light-duty gas vehicle
Motorcycles	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	
Marine Transportation	81.1%	0.0%	0.0%	0.0%	96.2%	94.9%	97.5%	98.8%	60.8%	96.2%	Passenger Marine Transport
	18.9%	0.0%	0.0%	0.0%	3.8%	5.1%	2.5%	1.2%	39.2%	3.8%	Freight Marine Transport
Rail Transportation	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	3.4%	Passenger Rail Transport
	96.6%	96.6%	96.6%	96.6%	96.6%	96.6%	96.6%	96.6%	96.6%	96.6%	Freight Rail Transport

Source: NRCan Energy Use Handbook. Transportation Worksheet. Year 2000.

7.1.2 Allocation of Air Pollution Costs by Transport Canada Mode

Air pollution costs calculated for health, visibility and agricultural endpoints associated with transportation emissions were allocated to each of the 18 Transport Canada modes (see Exhibit 7-3). The costs represent the cause (emissions from transport) and not the effect (costs incurred at endpoints). Exhibit 7-5 and 7-6 summarize the costs of each mode for each of the provinces. Exhibit 7-7 indicates the total national costs by mode. Note that paved road dust is not included in these aggregated costs by mode. This is a result of the difficulty in aggregating paved road dust to transportation emission sources. The total costs of paved road dust by province are summarized in Section 7.2.

Exhibit 7-5
Provincial Allocation of Air Pollution Costs to Transport Canada Modes (1 of 2)
(Without Paved Road Dust)

Transport Canada Modes	Provincial Economic Value of Emissions from Transport Modes (000's 2000$)				
	NF	PEI [(1)]	NS	NB	QC
Freight Air Transport	$4	$0	$3	$4	$323
Freight Heavy-duty diesel vehicle	$2,670	$0	$4,510	$19,600	$299,000
Freight Heavy-duty gas vehicle	$138	$0	$199	$568	$14,800
Freight Light-duty diesel truck	$9	$0	$16	$67	$2,410
Freight Light-duty gas truck	$339	$0	$457	$1,350	$46,500
Freight Marine Transport	$3,900	$0	$2,090	$7,820	$227,000
Freight Rail Transport	$458	$0	$418	$2,410	$60,200
Passenger Air Transport	$104	$0	$87	$82	$6,030
Passenger Interurban diesel bus	$31	$0	$49	$198	$4,490
Passenger Interurban gas bus	$1	$0	$1	$3	$47
Passenger Light-duty diesel truck	$30	$0	$51	$211	$5,550
Passenger Light-duty diesel vehicle	$4	$0	$33	$83	$4,540
Passenger Light-duty gas truck	$1,080	$0	$1,460	$4,300	$109,000
Passenger Light-duty gas vehicle	$1,450	$0	$2,220	$6,530	$292,000
Passenger Marine Transport	$154	$0	$25	$202	$12,200
Passenger Rail Transport	$16	$0	$15	$86	$2,150
Passenger Urban and School Diesel Bus	$185	$0	$299	$1,200	$23,300
Passenger Urban and School Gas Bus	$0	$0	$0	$1	$13
All Transport Canada Modes	**$10,600**	**$0**	**$11,900**	**$44,700**	**$1,110,000**

Note: [(1)] PEI does not have any costs associated with transport-related air pollution because no concentration changes were predicted for PEI since there were no suitable NAP stations available to estimate concentration changes.

Exhibit 7-6
Provincial Allocation of Air Pollution Costs to Transport Canada Modes (2 of 2)
(Without Paved Road Dust)

Transport Canada Modes	Provincial Economic Valuation of Emissions from Transport Modes (000's 2000$)				
	ON	MB	SK	AB	BC
Freight Air Transport	$977	$32	$10	$75	$155
Freight Heavy-duty diesel vehicle	$557,000	$28,500	$27,600	$98,000	$70,300
Freight Heavy-duty gas vehicle	$35,700	$2,690	$3,400	$10,900	$18,700
Freight Light-duty diesel truck	$2,430	$204	$667	$1,100	$191
Freight Light-duty gas truck	$89,000	$4,010	$5,950	$17,000	$11,500
Freight Marine Transport	$130,000	$108	$0	$0	$121,000
Freight Rail Transport	$259,000	$17,100	$14,600	$22,600	$51,900
Passenger Air Transport	$17,200	$640	$211	$1,490	$2,670
Passenger Interurban diesel bus	$7,960	$680	$589	$1,200	$963
Passenger Interurban gas bus	$106	$7	$6	$17	$34
Passenger Light-duty diesel truck	$6,870	$569	$1,100	$1,840	$472
Passenger Light-duty diesel vehicle	$4,940	$99	$97	$178	$558
Passenger Light-duty gas truck	$252,000	$11,300	$9,700	$28,100	$28,300
Passenger Light-duty gas vehicle	$493,000	$16,200	$14,400	$40,200	$51,500
Passenger Marine Transport	$5,160	$108	$0	$0	$28,300
Passenger Rail Transport	$9,240	$610	$522	$807	$1,850
Passenger Urban and School Diesel Bus	$42,500	$3,930	$3,400	$6,750	$5,170
Passenger Urban and School Gas Bus	$28	$2	$2	$5	$9
All Transport Canada Modes	**$1,910,000**	**$86,800**	**$82,200**	**$230,000**	**$394,000**

Exhibit 7-7
National Allocation of Air Pollution costs to Transport Canada Modes
(Without Paved Road Dust)

Transport Canada Modes	National Economic Value of Emissions from Transport Modes (000's 2000$)	
	Total	% of Total
Freight Air Transport	$1,580	0.0%
Freight Heavy-duty diesel vehicle	$1,110,000	29.0%
Freight Heavy-duty gas vehicle	$87,200	2.0%
Freight Light-duty diesel truck	$7,100	0.0%
Freight Light-duty gas truck	$176,000	5.0%
Freight Marine Transport	$492,000	13.0%
Freight Rail Transport	$428,000	11.0%
Passenger Air Transport	$28,500	1.0%
Passenger Interurban diesel bus	$16,200	0.0%
Passenger Interurban gas bus	$220	0.0%
Passenger Light-duty diesel truck	$16,700	0.0%
Passenger Light-duty diesel vehicle	$10,500	0.0%
Passenger Light-duty gas truck	$446,000	11.0%
Passenger Light-duty gas vehicle	$917,000	24.0%
Passenger Marine Transport	$46,200	1.0%
Passenger Rail Transport	$15,300	0.0%
Passenger Urban and School Diesel Bus	$86,800	2.0%
Passenger Urban and School Gas Bus	$60	0.0%
All Transport Canada Modes	**$3,880,000**	**100.0%**

The results in Exhibit 7-7 indicate that heavy-duty freight vehicles and passenger light duty vehicles represent more than 50% of the cost of transport-related air pollution. Freight marine and rail transportation, as well as passenger light-duty gas trucks are also major contributors to air pollution costs.

Note that the total costs allocated to provincial emissions are not the same as the total costs of air pollution incurred by each province (i.e., the provincial total cost for all modes in Exhibits 7-5 and 7-6 do not match total provincial costs for all endpoints presented in Exhibit 6-1). This is because the release of emissions does not necessarily occur in the same location where health, agricultural and visibility impacts occur. A proportion of emissions are transported from upwind provinces (Alberta, Saskatchewan and Ontario) to downwind provinces (Saskatchewan, Manitoba and Quebec). For New Brunswick and the other Maritime provinces, all upwind emissions are assumed to originate in the United States. The effects of changes in transportation emissions from the United States have not been assessed in this study and as a result there are no predicted upwind impacts for New Brunswick.

Exhibit 7-8 summarizes the cost of air pollution that is predicted to be transported from upwind provinces to downwind provinces.

Exhibit 7-8
Cost of Air Pollution Related to Emissions Originating in Upwind Province and Incurred in a Province Downwind

Upwind Province	Downwind Province	Cost of Emissions from Upwind Province (000's 2000$)
Alberta	Saskatchewan	$6,190
Saskatchewan	Manitoba	$26,900
Ontario	Quebec	$214,000

7.2 PROVINCIAL ALLOCATION OF AIR POLLUTION COSTS RELATED TO PAVED ROAD DUST

In this study two emission scenarios were considered: Emission Scenario #1 transportation emissions without paved road dust and Emission Scenario #2 transportation emissions with paved road dust. The difference between the resulting health and visibility endpoint valuations of these two scenarios is the total cost that can be attributed to paved road dust. Because paved road dust was not attributed to different transportation modes we have considered the emission scenarios separately. Exhibit 7-9 presents the total costs of paved road dust by province.

Exhibit 7-9
Provincial Allocation of Total Costs of Paved Road Dust by Province

	Change in Economic Value (000's 2000$)	Percent of Total Impact (%)
Newfoundland and Labrador	$9,890	0.5%
Prince Edward Island	-	-
Nova Scotia	$3,370	0.2%
New Brunswick	$51,800	2.8%
Quebec	$570,000	30.6%
Ontario	$1,010,000	54.4%
Manitoba	$36,400	2.0%
Saskatchewan	$23,300	1.3%
Alberta	$37,900	2.0%
British Columbia	$115,000	6.2%
Canada Total	**$1,860,000**	**100.0%**

7.3 UNIT COST OF TRANSPORTATION POLLUTANT BY PROVINCE

It is also possible to express the total costs of transport-related emission on an emission basis ($ / tonne). These results provide an indication of the value in terms of avoided air pollution costs of reducing a unit of pollution for any transport related activity.

Exhibit 7-10
Unit Cost of Air Pollution by Pollutant Emitted and by Province

Unit Cost by Pollutant and Province ($ / tonne of emissions)					
Province	**Pollutants**				
	$PM_{2.5}$	**$PM_{2.5}$ Including Paved Road Dust**	**SO_2**	**NO_X**	**VOC**
Newfoundland and Labrador	$2,900	$2,900	$2,020	$456	$0
Prince Edward Island	$0	$0	$0	$0	$0
Nova Scotia	$561	$533	$176	$468	$0
New Brunswick	$7,150	$7,150	$2,450	$1,060	$0
Quebec	$13,200	$13,000	$4,680	$5,590	$594
Ontario	$29,100	$28,600	$6,520	$5,940	$877
Manitoba	$2,710	$2,690	$9,860	$1,740	$86
Saskatchewan	$7,750	$9,150	$3,790	$1,070	$116
Alberta	$4,080	$4,050	$617	$1,630	$213
British Columbia	$5,200	$5,150	$2,110	$2,010	$87
Canada (TOTAL)	**$12,600**	**$13,900**	**$3,960**	**$3,580**	**$436**

Exhibit 7-10 indicates that the highest unit costs of air pollution are in the provinces of Quebec and Ontario. Transportation emissions of $PM_{2.5}$ have by far the highest cost on a mass emission basis. Based on these results reducing transportation emissions of $PM_{2.5}$ in urban centres in Ontario would result in approximately an annual savings of avoided health, visibility and agricultural endpoints of almost $30,000 per tonne of emission reduced. On an average basis across Canada the unit cost of $PM_{2.5}$ is 3 to 4 times higher than SO_2 and NO_2 and 30 times higher than VOC.

7.4 UNIT COST OF AIR POLLUTION BY LEVEL OF ACTIVITY

It is also possible to express the total costs of transport-related emission by the level of activity. The cost of transport-related emissions related to freight activity can generally be expressed for each tonne·km travelled and passenger vehicle activity for each passenger·km travelled. A tonne·km can be defined as the transport of one tonne of freight over a distance of 1 kilometre. A passenger·km can be defined as the transport of one passenger over a distance of 1 kilometre. These results provide an indication of the value in terms of air pollution costs by unit of activity. Exhibit 7-11 indicates a summary of provincial activity level data by mode that was used to estimate unit costs. The activity level data was taken from NRCan data.[5]

[5] Natural Resources Canada. Office of Energy Efficiency data received from Transport Canada February 8, 2007.

Exhibit7-11
Activity Level Data by Transport Mode and Province (Year 2000)

Transport Canada Freight Modes	Tonne-km Travelled (millions)									
	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NFL
Freight Air Transport	656	332	26	85	704	321	30	71	1	102
Freight Heavy-duty diesel vehicle	20,000	30,000	5,400	4,460	59,100	33,200	8,250	5,290	893	3,690
Freight Heavy-duty gas vehicle	3,000	4,220	1,060	663	5,010	2,450	259	358	54	108
Freight Light-duty diesel truck	92	126	62	18	118	128	9	9	1	3
Freight Light-duty gas truck	2,080	2,490	674	466	5,090	2,580	352	426	67	190
Freight Marine Transport	66,700	0	0	0	26,300	51,500	14,200	30,500	1,980	19,100
Freight Rail Transport	62,300	85,000	20,300	14,900	82,600	39,600	11,300	3,660	0	0
Transport Canada Passenger Modes	**Passenger-km Travelled (millions)**									
	BC	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Air Transport	29,500	14,900	1,150	3,840	31,700	14,500	1,350	3,220	64	4,620
Passenger Interurban diesel bus	719	969	317	286	2,230	1,320	214	150	5	109
Passenger Interurban gas bus	38	46	12	12	101	53	9	8	0	4
Passenger Light-duty diesel truck	656	656	331	160	1,010	973	94	90	14	31
Passenger Light-duty diesel vehicle	182	106	46	52	708	834	70	103	9	8
Passenger Light-duty gas truck	14,900	12,800	3,560	4,130	44,000	20,000	3,680	4,500	687	2,000
Passenger Light-duty gas vehicle	29,600	24,500	7,220	8,290	111,000	65,600	7,860	10,300	1,640	4,130
Passenger Rail Transport	299	408	97	72	396	190	54	18	0	0
Passenger Urban and School Diesel Bus	5,080	6,640	1,900	1,820	14,000	7,800	1,260	906	31	615
Passenger Urban and School Gas Bus	16	19	5	6	38	19	4	4	0	2
All Transport Canada Modes	**Passengers Travelled**									
	BC	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Marine Transport	28,100,000	0	0	0	2,180,000	5,700,000	366,000	366,000	800,000	744,000

Exhibit 7-12 indicates the cost of transport related air pollution by activity level for the different transport Canada modes by province. Detailed tables by air pollutant are provided in Appendix C.

Exhibit7-12
Cost of Transport-Related Air Pollution by Activity Level

Transport Canada Freight Modes	Cost by Activity Level ($ / million tonne-km Travelled)									
	BC	AB	SK	MB	ON	QC	NB	NS	PEI	NFL
Freight Air Transport	$295	$281	$468	$466	$1,730	$1,250	$157	$55	-	$7
Freight Heavy-duty diesel vehicle	$4,400	$4,100	$6,260	$8,120	$11,800	$11,300	$2,960	$1,030	-	$567
Freight Heavy-duty gas vehicle	$7,800	$3,240	$3,940	$5,150	$8,920	$7,540	$2,740	$672	-	$673
Freight Light-duty diesel truck	$2,590	$10,900	$13,200	$14,100	$25,700	$23,400	$9,110	$2,260	-	$6,630
Freight Light-duty gas truck	$6,880	$8,490	$10,800	$10,900	$21,700	$22,400	$4,800	$1,300	-	$1,090
Freight Marine Transport	$2,270	-	-	-	$6,170	$5,510	$687	$83	-	$64
Freight Rail Transport	$1,040	$334	$883	$1,450	$3,930	$1,900	$266	$138	-	-
Transport Canada Passenger Modes	**Cost by Activity Level ($ / million Passenger-km Travelled)**									
	BC	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Air Transport	$113	$124	$223	$208	$675	$517	$76	$33	-	$28
Passenger Interurban diesel bus	$1,670	$1,560	$2,280	$3,010	$4,470	$4,240	$1,150	$396	-	$354
Passenger Interurban gas bus	$1,130	$463	$550	$741	$1,310	$1,110	$402	$98	-	$237
Passenger Light-duty diesel truck	$895	$3,500	$4,070	$4,480	$8,430	$7,090	$2,780	$685	-	$1,190
Passenger Light-duty diesel vehicle	$3,810	$2,090	$2,600	$2,400	$8,690	$6,780	$1,470	$384	-	$673
Passenger Light-duty gas truck	$2,380	$2,730	$3,320	$3,440	$7,140	$6,800	$1,460	$394	-	$679
Passenger Light-duty gas vehicle	$2,170	$2,040	$2,430	$2,480	$5,550	$5,520	$1,040	$261	-	$440
Passenger Rail Transport	$7,750	$2,490	$6,580	$10,800	$29,200	$14,100	$1,980	$1,030	-	-
Passenger Urban and School Diesel Bus	$1,270	$1,280	$2,200	$2,750	$3,810	$3,740	$1,190	$399	-	$378
Passenger Urban and School Gas Bus	$700	$300	$419	$529	$929	$836	$324	$77	-	$200
All Transport Canada Modes	**Cost by Activity Level ($ / Passengers Travelled)**									
	BC	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Marine Transport	$1	-	-	-	$3	$3	$1	$0	-	$0

Note: Freight and Passenger Air Transportation only includes emissions from Take-off and Landing, as cruise emissions were not considered as they were not considered to make a significant contribution to tropospheric air quality.

8 FINDINGS AND UNCERTAINTIES

This section first brings forward a number of interesting *findings* and then explores analytical *uncertainties*. We focus exclusively on the health outcome values since they dominate the overall results and account for about 97 % of the total Canadian economic value in 2000 (see Exhibit 6-2). Indeed, the mean economic value of all health endpoints in Emission Scenario #1 (transportation emissions without paved road dust) that represents a VSL of $4.05 million, is 10 times larger than the mean economic value of the visibility and agriculture endpoints combined. That is, the standard deviation of the health endpoints value is in the order of $984 million and the visibility and agriculture combined is $98 million. So the focus on the health endpoint seems reasonable.

The *findings* section answers a number of relevant questions:

1. Which pollutants impact the health economic costs the most?
2. Which endpoints impact the health results the most?
3. Which geographic areas impact the overall Canada results the most?
4. Which modes are the most important from a cost perspective?

For *uncertainties*, there are at least three areas in the damage function approach that need to be discussed:

1. First there is the uncertainty about the emission inventory;
2. Next, there is uncertainty in ReFSoRT; and,
3. Finally there is uncertainty in AQBAT in terms of both the health endpoints and the economic value of changes in health outcomes.

These findings and uncertainty questions are dealt in separate section below.

8.1 FINDINGS

As discussed above, there are a number of interesting findings that emerge from the analysis. These are presented below as a series of questions.

1. Which pollutants impact the results most?

NO_2 drives the overall results with a full 52% of the total value attributable to NO_2 (Exhibit 8-1). This result is interesting since PM often is the main driver in air quality health valuation studies, but of course since we are dealing with transport that contributes to large NO_2 emissions, the NO_2 emissions dominate the health outcomes.

Exhibit 8-1
Ranking of Total Canadian Economic Value (Health) by Pollutant

Rank	Pollutant	Central Value (10^6 in 2000)	Share of Scenario 1
1	NO_2	$2,021.83	53.40%
2	$PM_{2.5}$	$1,109.63	29.31%
3	O_3 (May-Sep)	$624.24	16.49%
4	SO_2	$30.65	0.81%

2. Which endpoints impact the results the most?

Without question it is the acute exposure mortality that drives the results. As Exhibit 8-2 indicates, acute exposure mortality accounts for a full 70% of the total economic cost. Total exposure mortality (acute and chronic) account for a full 96% of the health damages.

Exhibit 8-2
Ranking Of Total Canadian Economic Value (Health) by Endpoint

Rank	Endpoint	Central Value (10^6 in 2000)	Share of Scenario 1
1	Acute Exposure Mortality	$2,665.93	70%
2	Chronic Exposure Mortality	$993.13	26%
3	Adult Chronic Bronchitis Cases	$91.88	2%
4	Restricted Activity Days	$16.02	0.4%
5	Acute Respiratory Symptom Days	$11.73	0.3%
6	Asthma Symptom Days	$4.00	0.1%
7	Minor Restricted Activity Days	$2.35	0.1%
8	Child Acute Bronchitis Episodes	$0.72	0.0%
9	Respiratory Emergency Room Visits	$0.57	0.0%
10	Cardiac Emergency Room Visits	$0.03	0.0%
11	Cardiac Hospital Admissions	$0.00	0.0%
12	Respiratory Hospital Admissions	$0.00	0.0%

3. Which geographic areas impact the results the most?

Just 2 CMA's account for almost 33% of the overall valued impact under scenario one (without road dust): Montréal and Toronto. Of the total economic value associated with the scenario of $3.786 billion, Montréal accounts for $620 million (16%) while Toronto accounts another $614 million (16%). We found this result to be somewhat counter intuitive since we know that the Toronto census division population is larger (Toronto population is 2.8 million vs. 1.8 million for Montreal) and that baseline ambient concentrations in Toronto are also higher. We therefore conducted extensive QA/QC on the models and the data runs. In targeting our review, we determined that NO_2 emission account for the majority of the economic value, in both cases in the order of 60% of the total "costs" in each CMA. We thus concentrated our review efforts on the NO_2 emissions. Based on our review, we concluded that the results are reasonable for the following reasons:

- The ambient background levels from REFSORT reasonably match the NAP station data in AQBAT, which uses roughly 35 μg/m^3 for Montreal and 45 μg/m^3 for Toronto;

- The transport-related emissions as a share of total emission in Montreal makes up for the population differences:

	Ambient NO_2:	Change in NO_2:	Transports Share of Total:
Montréal:	19	8	42%
Toronto:	24	6.46	27%

Although NO_2 ambient air quality is worse in Toronto than in Montréal, emission sources other than transportation contribute a significant share to the NO_2 levels. Since the relative share, 42%, of transport-related NO_2 air pollution is much greater in Montréal than in Toronto, 27%; if all transport-related emissions were removed we would expect to have greater changes in ambient air quality in Montréal than in Toronto. The greater change in ambient air quality in Montréal is what leads to higher costs for the municipality despite having a lower population.

Exhibit 8-3 ranks the top ten regions in terms of costs from transport. As can be seen, the top 10 CDs/CMAs account for about 56% of the impact. Clearly, the costs of transport-related air pollution are focused in a few key geographic areas in Canada.

Exhibit 8-3
Ranking Of Total Canadian Economic Value (Health) by Geographic Area

Rank	CMA or CD	Central Value (10^6 in 2000)	Share of Scenario 1
1	QC- Communauté-Urbaine-de-Montréal (CD2466)	$620.02	16.4%
2	ON- Toronto Division (CD3520)	$614.12	16.2%
3	BC- Greater Vancouver Regional District (CD5915)	$219.57	5.8%
4	QC- Communauté-Urbaine-de-Québec (CD2423)	$127.39	3.4%
5	ON- Peel Regional Municipality (CD3521)	$122.73	3.2%
6	ON- Hamilton Division (CD3525)	$91.69	2.4%
7	QC- Laval (CD2465)	$88.43	2.3%
8	AB- Division No. 6 (CD4806) Calgary	$84.51	2.2%
9	AB- Division No. 11 (CD4811) Edmonton	$84.22	2.2%
10	ON- Niagara Regional Municipality (CD3526)	$77.26	2.0%
	Top 10 Regions Total	**$2,129.93**	**56%**

4. Which modes are the most important from a cost perspective?

Exhibit 8-4 indicates that the first 5 modes account for 87% of the total economic value under scenario 1. Freight Heavy-duty diesel vehicle and Passenger Light-duty gas vehicle alone account for 52% of the economic value.

Exhibit 8-4
Emission Scenario 1: Transportation Emissions Without Paved Road Dust
Ranking of Economic Value by Mode

Rank	Transport Canada Modes	National Economic Valuation of Emissions from Transport Modes (000's 2000$)		
		Low (20th percentile)	Central	High (80th percentile)
1	Freight Heavy-duty diesel vehicle	$822,800	$1,107,700	$1,386,500
2	Passenger Light-duty gas vehicle	$688,300	$917,400	$1,141,400
3	Freight Marine Transport	$367,400	$492,500	$614,700
4	Passenger Light-duty gas truck	$334,700	$446,000	$554,600
5	Freight Rail Transport	$318,100	$428,500	$536,600
6	Freight Light-duty gas truck	$132,200	$176,100	$218,900
7	Freight Heavy-duty gas vehicle	$64,900	$87,200	$109,000
8	Passenger Urban and School Diesel Bus	$64,500	$86,800	$108,700
9	Passenger Marine Transport	$34,400	$46,200	$57,700
10	Passenger Air Transport	$21,400	$28,500	$35,500
11	Passenger Light-duty diesel truck	$12,600	$16,700	$20,700
12	Passenger Interurban diesel bus	$12,000	$16,200	$20,200
13	Passenger Rail Transport	$11,400	$15,300	$19,100
14	Passenger Light-duty diesel vehicle	$7,900	$10,500	$13,100
15	Freight Light-duty diesel truck	$5,300	$7,100	$8,800
16	Freight Air Transport	$1,200	$1,600	$2,000
17	Passenger Interurban gas bus	$200	$200	$300
18	Passenger Urban and School Gas Bus	$40	$100	$100
	All Transport Canada Modes	**$2,899,400**	**$3,884,500**	**$4,847,900**

8.2 UNCERTAINTY IN THE DAMAGE FUNCTION APPROACH

8.2.1 Uncertainty in the Emission Inventory

Many different agencies and stakeholders contribute data to the Canadian CAC inventory, and it has been found that uncertainties are not rigorously quantified[6]. For example, almost no emission estimation models, including the widely used MOBILE and NONROAD models for mobile source emissions, and BEIS3 for biogenic emissions, contain a component that can assess uncertainty in model inputs and structure. Emission inventories developed based upon these models rarely quantify uncertainty in emission estimates. Unlike the Greenhouse Gas Inventory, Environment Canada does not publish a detailed document that assesses the uncertainty of the CAC emission inventory, and therefore no ranges of uncertainty are available for analysis.

Exhibit 8-5 summarizes our perceptions of the estimated uncertainty in the various sources of pollutant emissions in the Canada CAC emission inventory. The estimates are based on a review conducted by NARSTO (North American Research Strategy for Tropospheric Ozone) and interpreted by Marbek.

[6] NARSTO. August 2005. Improving Emission Inventories for Effective Air Quality Management Across North America.

Exhibit 8-5
Estimated Relative Confidence Levels of Canadian Emission Inventory

Pollutants	Source	Estimated Confidence Levels in Overall Inventory
SO_2	Utilities	High
	Other point sources	Medium
	On-road mobile	Medium
	Nonroad mobile	low-medium
	Stationary nonpoint sources	low-medium
	Biogenic source	low-medium
	Other man-made sources (noncombustion)	low-medium
NO_X	Utilities	medium-high
	Other point sources	Medium
	On-road mobile	medium-high
	Nonroad mobile	medium
	Stationary nonpoint sources	low
	Biogenic source	low
	Other man-made sources (noncombustion)	medium
VOC	Utilities	medium-high
	Other point sources	low-medium
	On-road mobile	low-medium
	Nonroad mobile	low-medium
	Stationary nonpoint sources	low
	Biogenic source	low
	Other man-made sources (noncombustion)	medium

Source: NARSTO. 2004. *Particulate Matter Science for Policy Makers*, Cambridge University Press, Cambridge, UK. ISBN 0-521-84287-5.

Exhibit 8-5 indicates that there is a low confidence in the emission inventory for biogenic emissions, stationary nonpoint sources (i.e., fugitive emissions) and some transportation sources of emissions. It is impossible to estimate what level of uncertainty the emission inventory contributes to this study; however, it is clearly significant. In order to illustrate some of the uncertainties that can arise from measurement or sampling error, mobile emission sources that include transportation are discussed in further detail.

Mobile Sources

Significant uncertainties exist in mobile source inventories with regard to the temporal trend of NO_X emissions, the representativeness of the emission projections from MOBILE6, and the accuracy of emission estimates for nonroad sources.

Some of the major concerns related to the uncertainty of onroad mobile emission source estimates are:

- Standard test procedure measurements made using dynamometers, whether chassis or engine, may not adequately capture the effects of real world conditions that could substantially affect emissions;

- Existing on-road emission factor models, such as MOBILE, are not well suited to deal with mesoscale or microscale emission estimates that take into account local effects of specific transportation control measures or highly resolved (both temporally and spatially) characterization of emission hotspots, such as at intersections;

- Treatment of the effects of emission spikes that come from variability in engine loads and the importance that such spikes have in overall emission inventories are not adequately addressed;

- A disproportionate amount of emissions are typically attributed to a relatively small percentage of high-emitting motor vehicles; however, high emitters are probably not adequately treated by current mobile source emission models; and,

8.2.2 Uncertainty in ReFSoRT

The following list identifies the major input and computational parameters that are important in considering uncertainty in ReFSoRT:

- Baseline emission inventory data;
- Future emission inventory data (base case forecast and scenario);
- Baseline air quality data;
- Background concentrations of pollutants;
- Relative local contributions to above-background concentrations;
- Point source importance factor;
- Secondary response factors; and,
- Misclassification of ozone monitors as ‘rural’ or ‘urban’.

ReFSoRT is a reduced form model that synthesizes input data and the form of its algorithms from available monitoring, research and large-scale modelling results. The monitoring database covers long, continuous records of the target pollutants for a large portion of Canada (and the adjacent US). The research and modelling results, however, are generally confined to episodes. The data from these studies must be aggregated and synthesized to develop the relationships in ReFSoRT that estimate annual average changes in air quality to match the resolution of the basic emission inventories, as described in earlier reports.

A reduced form model such as ReFSoRT cannot aspire to a well-defined ‘accuracy’ in the statistical sense. That is, the regional nature of the emission inventory inputs and air quality change outputs cannot capture the spatially-resolved, temporal detail of the best of the current generation of source-oriented or regional-scale photochemical dispersion models. The output from ReFSoRT needs to agree generally with the predictions of such detailed scientific models, but it cannot agree in detail. There is inherent uncertainty, then, arising from the spatial and temporal averaging features of ReFSoRT. This uncertainty cannot be quantified except by comparing the results of ReFSoRT with those of the large-scale models for similar emission reduction scenarios. As demonstrated in earlier phases of this work, ReFSoRT does perform acceptably well in such comparisons – but the available results for direct comparison are sparse.

Keeping in mind the nature of ReFSoRT, it is instructive to assign quantitative estimates to the major parameters in the above list to gain a sense of the potential range of uncertainty in the output results. For the Sulphur-in-Fuels study that provided several of the input values to the initial version of ReFSoRT, a formal Monte Carlo uncertainty analysis was carried out based on distributions assigned to the major input parameters. Like ReFSoRT, the Sulphur-in-Fuels model for estimating changes in sulphate and $PM_{2.5}$ concentration in response to changes in SO_2 emissions from gasoline and diesel fuels employed a number of emissions, air quality and technology-specific inputs (six major contributors to uncertainty). Uncertainty distributions were estimated for each of the major input parameters, and a Monte Carlo simulation of the propagation of uncertainty through the algorithms was carried out. Some of the parameters, e.g., the percent conversion of exhaust SO_2 to directly emitted sulphate from a light duty vehicle, had maximum to minimum ranges of a factor of 3 to 5. The resulting relative standard deviation of the output (standard deviation divided by the mean value), however, was only approximately 25-30%.

One of the important aspects of ReFSoRT to recognise is that the final output – changes in ambient concentrations of the various pollutants – is determined by taking the difference between two scenarios: the baseline and the emission scenarios. The baseline forecast value is subtracted from the scenario forecast value of the estimates. The forecasts for the baseline and emission scenarios are not independent, since many of the forecast parameters are common to both – the scenario forecast being modified only by the implementation of the emission scenarios. Thus, the uncertainty in the output concentration changes is determined essentially by the uncertainty in the emission scenario alone and needs to be treated so in uncertainty analysis. A second-order influence of uncertainty in the baseline forecasts on the outcome differences between the two forecasts would have a minor influence on the uncertainty of the output concentration changes.

8.2.3 Uncertainty in AQBAT

A key element of the damage function approach employed in AQBAT is Monte Carlo sampling, which is a statistical technique where uncertainties related to key variables are combined into one overall estimate of uncertainty. In AQBAT, probability density functions (PDF) representing uncertainty ranges are provided for all health endpoints and economic values. When a simulation is run it is probabilistic, with calculations in the analysis chain (See Equation 1 on page 6 for example) sampling the PDFs a large number of times (5,000 iterations in this report). As this occurs, the Monte Carlo software @Risk compiles a probability density function of outputs or computational results for the change in health endpoints and the associated total economic value. From this distribution, a number of characteristics can be estimated including a mean, standard deviations and minima and maxima. In Exhibits 8-6 and 8-7 the means (50th percentile) and majority of the range around the mean (20th and 80th percentiles) for both emission scenarios are provided for the Total Canada health endpoint costs (from Exhibits 6-1 and 6-3).

For Emission Scenarios 1 and 2, it is interesting to note that the standard deviation represents about 26% of the central value in both scenarios. That is, although the $PM_{2.5}$ emissions are much greater under Scenario 2, with paved road dust, and the mean is correspondingly larger than Scenario 1, the range is the same percent of the mean (26%). This "linear result" is a key feature of the damage functions approach in AQBAT where results can be easily scaled to emissions.

For each scenario:

- **Emission Scenario #1. Transportation emissions without paved road dust.** Output from AQBAT indicates that the uncertainty in the output values has a standard deviation of about 26% of the mean, as is indicated by the 20th and 80th percentiles in Exhibit 8-6 below.

Exhibit 8-6
Uncertainty Range of Emission Scenario #1
Transportation Emissions Without Paved Road Dust
Provincial and Canadian Total

Province	**Total Health Endpoint Valuations (Dollar value in 000's 2000$)**		
	Low (20th percentile)	**Central**	**High (80th Percentile)**
Newfoundland and Labrador	$7,400	$10,100	$12,800
Nova Scotia	$9,100	$11,700	$14,200
New Brunswick	$31,800	$43,100	$54,200
Quebec	$959,500	$1,297,600	$1,628,500
Ontario	$1,225,700	$1,652,300	$2,069,300
Manitoba	$80,700	$111,000	$140,700
Saskatchewan	$42,900	$56,600	$70,000
Alberta	$156,200	$213,500	$269,600
British Columbia	$287,900	$388,000	$485,900
CANADA (TOTAL)	**$2,801,300**	**$3,784,000**	**$4,745,200**

- **Emission Scenario #2. Transportation Emissions with Paved Road Dust.** As can be observed from comparing Exhibit 8-6 and 8-7 paved road dust adds significantly to the results, with a mean value of $1.76 billion annually in 2000$ (**estimated low of $1.35 billion and high of $2.15 billion)**. This figure is less than the total cost of transport paved road dust ($1.86 billion), because it includes only health endpoints and not visibility and agriculture endpoints.

Exhibit 8-7
Uncertainty Range of Emission Scenario #2
Transportation Emissions With Paved Road Dust
Provincial and Canadian Total

Province	Total Health Endpoint Valuations (Dollar value in 000's 2000$)		
	Low (20th percentile)	Central	High (80th Percentile)
Newfoundland and Labrador	$14,400	$19,300	$24,000
Nova Scotia	$11,600	$14,900	$18,000
New Brunswick	$68,900	$91,500	$113,300
Quebec	$1,374,000	$1,838,500	$2,289,700
Ontario	$1,956,500	$2,608,600	$3,240,600
Manitoba	$107,300	$145,300	$182,400
Saskatchewan	$60,300	$79,000	$97,200
Alberta	$183,200	$248,900	$312,900
British Columbia	$370,700	$496,000	$618,100
CANADA (TOTAL)	$4,146,900	$5,542,000	$6,896,100

Uncertainty ranges by mode and by province are provided in Appendix C.

9 SUMMARY AND CONCLUSION

This study provides credible estimates of the total costs of transport-caused air pollution in Canada in the year 2000. Estimates of the impacts and costs of transportation-caused air pollution were made by predicting ambient air quality concentration changes at the census division level in Canada and then by evaluating the impact of these concentration changes on health and environmental endpoints. The approach used was to develop emission scenarios that considered the change in emissions for just transport emissions at the regional level and then use an air quality model, ReFSoRT to relate these changes in emissions to changes in ambient air quality concentrations at the census division level.

Three different valuation models were then used to assess the impacts of these ambient air quality concentration changes at the census division level on health endpoints (AQBAT model), visibility (VIEW model) and agricultural production (VOICCE model). These models also related changes in these endpoints to costs (e.g., acute exposure mortality counts or changes in deciviews of visibility). These transport-related air pollution costs could then be allocated to different transportation modes, expressed as unit costs (e.g., cost $ / tonne of pollutant) and by level of activity (e.g., cost $ / passenger vehicle kilometre travelled).

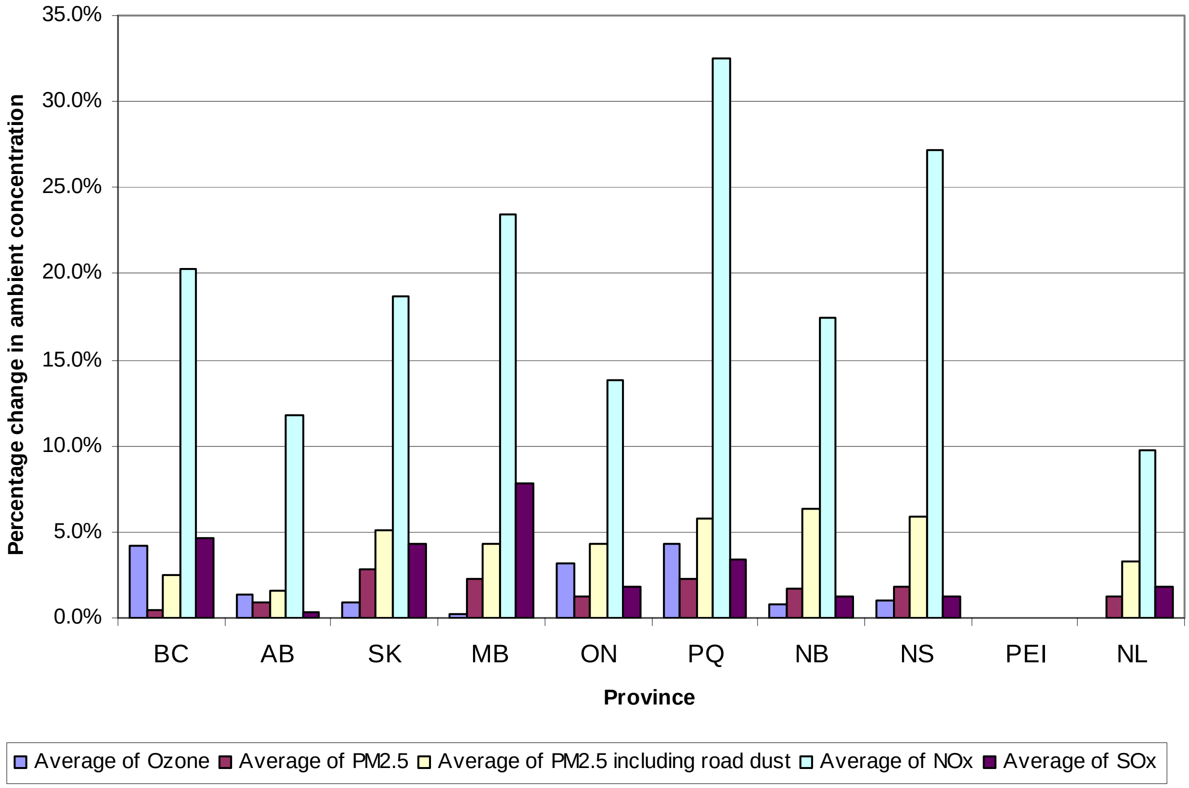
A review of the year 2000 emission inventory indicates that the transportation sector comprises a significant proportion of the total emissions for all the relevant pollutants considered (SO_2, NO_x, $PM_{2.5}$ and VOC). NO_X transportation emissions contributed the largest share of the overall emissions. Separate scenarios were developed to consider transportation emissions of $PM_{2.5}$ with and without paved road dust. Exhibit 9-1 summarizes the contribution of transportation emissions to the total emissions in the Year 2000 from environment Canada's Criteria Air Contaminant Emission Inventory.

Exhibit 9-1
Share of Transportation Emissions
Year 2000 CAC Emission Inventory

	000's of tonnes				
	NOx	**SO_2**	**VOC**	**$PM_{2.5}$**	**$PM_{2.5}$ Including Paved Road Dust**
Total Emissions	3108	2258	14952	1095	1095
Transport Related	892	60	440	21	132
Transport's Share	29%	2.6%	2.9%	1.9%	12%

The modeling of the emission scenarios in ReFSoRT indicated that transportation emissions account for a significant portion of ambient air quality at the Census Division. As expected NO_X concentrations attributable to transportation were highest, and typically represent between 10% and 30% in each of the census divisions considered in the study. Exhibit 9-2 summarizes the average concentration changes predicted in ReFSoRT for each of the provinces.

Exhibit 9-2
Transport's Contribution to Average Ambient Air Concentration by Province in 2000



The concentration changes by census division for the four pollutants from ReFSoRT were used as inputs into one health and two environmental valuation models. The AQBAT model considered a total of 10 health endpoints related to concentration response functions to the pollutants for both morbidity and mortality. By far the most significant in terms of cost of these endpoints were acute and chronic exposure mortality related to NO_X, SO_2 and $PM_{2.5}$ (more than 96% of the total health costs). If paved road dust is included the majority of cost is related to $PM_{2.5}$.

Visibility and agricultural endpoints contributed less than 3% to the overall cost of transport-related air pollution and therefore health endpoints dominated the costs. The specific contribution of acute and chronic exposure mortality of NO_X and $PM_{2.5}$ represented approximately 80% of the total costs. Exhibit 9-3 summarizes the transport-related costs of air pollution (without paved road dust) for each of the types of health endpoints and provinces.

Exhibit 9-3
Emission Scenario #1: Transport Emissions with No Paved Road Dust
Provincial Summary of Annual Economic Value

	Central Economic Value (000's 2000$)		
	Health Endpoints	**Visibility Endpoints**	**Agriculture Endpoints**
Newfoundland and Labrador	$10,100	$450	$0
Prince Edward Island	-	-	-
Nova Scotia	$11,700	$87	$120
New Brunswick	$43,100	$1,220	$304
Quebec	$1,300,000	$20,200	$6,340
Ontario	$1,650,000	$28,900	$17,000
Manitoba	$111,000	$2,240	$464
Saskatchewan	$56,600	$1,120	$3,620
Alberta	$214,000	$3,900	$6,600
British Columbia	$388,000	$4,060	$1,530
Total Canada	**$3,780,000**	**$62,200**	**$35,900**

The allocation of the costs of transport-related air pollution by mode reveals that heavy-duty freight vehicles and passenger light duty vehicles represent more than 50% of the cost of transport-related air pollution. Freight marine and rail transportation, as well as passenger light-duty gas trucks are also major contributors to air pollution costs. Exhibit 9-4 summarizes the total costs and share of all transport modes considered in the study. Note that paved road dust is not included in transport mode costs and these costs are provided separately. The cost attributable to paved road dust represents almost one third of the total cost of transport-related air pollution.

Exhibit 9-4
National Allocation of Air Pollution Costs to Transport Canada Modes

Transport Canada Modes	**National Economic Valuation of Emissions from Transport Modes (000's 2000$)**			
	Low (20th percentile)	**Central**	**High (80th percentile)**	**% of Mean Value**
Freight Air Transport	$1,190	$1,580	$1,970	0.0%
Freight Heavy-duty diesel vehicle	$823,000	$1,110,000	$1,390,000	19.3%
Freight Heavy-duty gas vehicle	$64,900	$87,200	$109,000	1.5%
Freight Light-duty diesel truck	$5,340	$7,100	$8,810	0.1%
Freight Light-duty gas truck	$132,000	$176,000	$219,000	3.1%
Freight Marine Transport	$367,000	$492,000	$615,000	8.6%
Freight Rail Transport	$318,000	$428,000	$537,000	7.5%
Passenger Air Transport	$21,400	$28,500	$35,500	0.5%
Passenger Interurban diesel bus	$12,000	$16,200	$20,200	0.3%
Passenger Interurban gas bus	$164	$220	$276	0.0%
Passenger Light-duty diesel truck	$12,600	$16,700	$20,700	0.3%
Passenger Light-duty diesel vehicle	$7,900	$10,500	$13,100	0.2%
Passenger Light-duty gas truck	$335,000	$446,000	$555,000	7.8%
Passenger Light-duty gas vehicle	$688,000	$917,000	$1,140,000	16.0%
Passenger Marine Transport	$34,400	$46,200	$57,700	0.8%
Passenger Rail Transport	$11,400	$15,300	$19,100	0.3%
Passenger Urban and School Diesel Bus	$64,500	$86,800	$109,000	1.5%
Passenger Urban and School Gas Bus	$45	$60	$75	0.0%
All Transport Canada Modes	**$2,900,000**	**$3,880,000**	**$4,850,000**	**67.6%**
Just Paved Road Dust	**$1,450,000**	**$1,860,000**	**$2,250,000**	**32.4%**
Total Canada Transport and Paved Road Dust	**$4,350,000**	**$5,750,000**	**$7,100,000**	**100.0%**

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APPENDIX A
Technical Documentation

Appendix A – Technical Documentation
Source Receptor Relationships

A1. Primary Pollutants

The starting point for developing a source-receptor algorithm is to assume a linear response of the marginal incremental emission and concentration changes (effectively, a logarithmic response):

$$(1) \qquad \frac{\Delta C}{C_L}100 = \frac{\Delta E}{E}100$$

This equation states that the percent change in the local or above-background portion of the ambient concentration equals the percent change in emissions in the region. For an expression of the percent change in total concentration (including background), Equation 1 can be rewritten as follows:

$$(2) \qquad \frac{\Delta C}{C}100 = \frac{\Delta E}{E}\left(\frac{C_L}{C}\right)100$$

To a good approximation, the linear response assumption holds true for primary pollutants, such as CO, SO_2, total NO_X and primary PM. For example, published emission trends and concentration trends between 1989 and 1998 for Ontario (MOE, 2000) show a reasonably linear response for CO, SO_2, and NO_2.

The response, however, depends to some degree on the type of emission source involved, and the type of pollutant emitted. Ambient concentrations arising from localized, elevated point sources (e.g., a large power plant) will respond differently from those arising from widely distributed, low-level sources (e.g., roadway emissions and other area sources). To address this problem, equation (2) can be rewritten as follows:

$$(3) \qquad \frac{\Delta C}{C} = \frac{f\Delta E_p + \Delta E_a}{fE_p + E_a}\left(\frac{C_L}{C}\right)100$$

where f is a "point source importance factor" representing the relative contribution of point source emissions to the ambient concentration. The scale factor, f, will be essentially the same for all primary pollutants, and can be estimated from historical data on annual emissions and ambient concentrations of SO_2 and CO. The assumption is made that observed SO_2 concentrations in any region arise mainly from point source emissions and observed CO concentrations arise mainly from area source emissions. Then an average value of f for a region can be calculated by taking the ratio of average local SO_2 concentration to annual SO_2 emission, divided by the ratio of average CO concentration to annual CO emission. This is written as follows:

(4) $$f = \frac{SO_{2L} / E_{SO_2}}{CO_L / E_{CO}}$$

Table A1 shows estimated values of f for selected regions in Canada. Values range from 0.001 on the prairies to just over 0.1 in Quebec and the LFV. This wide range of values arises partly from true spatial variation in the relationship between sources and monitors and partly from uncertainties in the estimates. The sensitivity of the results to the f factor was examined using the CIMSII emission scenario (2015 emissions) that was adopted for testing of the prototype S-R Tool. When the value of f was changed from 0.01 to 0.1, the predicted change in $PM_{2.5}$ within the scenario from base year to 2015, which ranged from 0 to approximately 0.3 µg/m^3 concentration was altered by no more than 0.09 µg/m^3. Predicted changes in ground-level ozone were altered by less than 10%. These findings suggest that the end results of the analysis are not very sensitive to the value used for the point source importance factor.

Table A1: Point Source Importance Factors (f)

	Annual SO_{2L}		**Annual CO_L**		
Location	**(ppb)**	**(ktonnes)**	**(ppb)**	**(ktonnes)**	**f factor**
Maritimes (1995)	6.1	350	400	926	0.04
Quebec (1995)	5.6	374	300	2171	0.11
Ontario (1989 to 1998)	3.6	860	570	3170	0.023
Saskatchewan (1995)	0.1	131	360	549	0.001
Alberta, 1995	0.9	608	460	2000	0.006
LFV, 1995	1.7	4.5	610	217	0.13

There are some limits to this approximation in deriving the f-factor, given the relatively short life of SO_2 in the atmosphere. As an alternate approach, the f-factor could be derived using a multi-variate regression analysis. However, to do so would be a relatively significant undertaking when considered in the present context of the application of the source-receptor relationships. In light of these issues, a conservative value of 0.1 was adopted for the current application as an alternative to the multivariate approach. In addition, there are some issues with adopting the point source importance factor and discrete treatment of elevated sources for analysis of precursors of secondary pollutants (e.g., secondary PM, O_3) given the lag time and distances involved in their formation after release to the atmosphere. Therefore, the point source importance factor has not been applied to the gaseous precursors of the secondary pollutants.

In initial applications of the source-receptor tool, a single value of 0.03 had been specified for the point source importance factor. The effect on results of changing the specification and application of the point source importance factor are discussed below in the section on Sensitivity and Uncertainty

A2. Secondary Pollutants

In the case of secondary pollutants, such as ozone and secondary PM, the precursors may respond linearly to changes in emissions, but the secondary pollutants themselves need not respond linearly to changes in the precursor concentrations. Many other limiting factors come into play, such as the meteorological conditions (e.g., amount of solar radiation) and complex interactions among the precursors and the secondary pollutants.

Universally applicable relationships for the response of secondary pollutants to changes in emissions will not be obtained easily, particularly in the case of secondary PM, which consists of several interacting chemical species. In general, the relationships need to be estimated for specific emission change scenarios using the best available photochemical modelling techniques. This approach was taken for PM in the Sulphur in Gasoline and Diesel Fuels study (Atmospheric Science Expert Panel, 1997) and in the report on The Environmental and Health Co-Benefits of Actions to Mitigate Climate Change (EHI Subgroup, 2000).

In the following sections, we explore the applicability of linear relationships as a screening-level assumption for secondary pollutants.

A3 $PM_{2.5}$

A3.1 Chemical Makeup of $PM_{2.5}$

$PM_{2.5}$ consists of primary emissions as well as various secondary species arising from several precursor gases. Table 3 presents approximate estimates of the average breakdown of selected chemical species in Canadian $PM_{2.5}$. These data are based on 1995-98 NAPS dichotomous sampler data, 1994-99 data measured by the GAViM monitoring network (MSC, 2001) and additional denuder measurements made by Environment Canada (Brook and Dann, 1999). The nitrate values have a relatively high level of uncertainty, due to uncertainties in the monitoring techniques. Secondary organic aerosol (SOA) has not been treated explicitly in Table A2 but is included with the Primary PM. These data show that, on average, $PM_{2.5}$ is dominated by primary particulate matter (together with SOA) and sulphate. Sulphate and ammonium play a more dominant role in Eastern Canada than in Western Canada on an annual average basis.

Table A2: Chemical Makeup of $PM_{2.5}$ (% by mass)

	Sulphate SO_4	**Particle Nitrate p-NO_3**	**Ammonium NH_4**	**Sodium Chloride**	**Primary PM & SOA**
Western Canada	19	17	12	2	50
Windsor-Quebec Corridor	22	12	12	1	53
Atlantic Canada	34	6	15	2	43

In developing a source-receptor response algorithm for annual average $PM_{2.5}$, we can safely neglect the sodium chloride (sea salt) whose contribution is very small. As discussed later, we will also neglect the SOA. The basic model for $PM_{2.5}$ response, then, is as follows:

$$(5) \qquad \frac{\Delta PM_{2.5}}{PM_{2.5}}100 = \frac{\left(\Delta \Pr + f_1 \Delta SO_4 + f_2 \Delta NO_3 + f_3 \Delta NH_3\right)}{PM_{2.5}}100$$

The factors, f_1 through f_3, are response factors that account for differentiation in the response of total PM to changes in sulphate, nitrate and ammonia. The differentiation can arise for a variety of reasons. For example, a change in sulphate concentration can induce a change in particle nitrate that either enhances or partially off-sets the change in sulphate, depending on the circumstances. In the case of nitrate, factors affecting the equilibrium between gas-phase and particle nitrate can cause the particle nitrate to respond non-linearly to changes in total nitrate. The response factors for sulphate and nitrate also account for changes in the concentration of ammonium ion that may occur when sulphate and nitrate levels change. These response factors were not included in the prototype version of the source-receptor tool, and have been implemented as part of the current project.

Pandis (2002) conducted aerosol thermodynamic modelling to predict response factors for Southern Ontario. Table 3 summarizes the annual average response factors that were obtained from this study. These values may vary from region to region but, in the absence of data for other regions of Canada, the average values at the bottom of Table A3 are used for all parts of Canada as an approximation.

Table A3: Annual Average Response Factors for Southern Ontario Predicted by Pandis (2002)

	Sulphate Response f_1	**Nitrate Response f_2**	**Ammonia Response f_3**
Egbert	1.29	0.60	0.68
Windsor	1.29	0.55	1.14
Hamilton	1.47	0.49	0.46
Average	1.35	.55	0.76

Sensitivity tests were initially conducted using the CIMSII emission scenario (2015 emissions) that was implemented in the S-R Tool during development of the prototype. When the sulphate response factor was changed from 1.35 to 1.0, the predicted change in overall $PM_{2.5}$, which ranged from 0 to 0.26 $\mu g/m^3$, was altered by no more than 0.04 $\mu g/m^3$. When the nitrate response factor was changed from 0.55 to 1.0, the predicted change in overall $PM_{2.5}$ was altered by no more than 0.05 $\mu g/m^3$.

The individual terms on the right side of Equation 5 are further discussed in the following sections.

A3.2 Primary PM (Pr) and Ammonia (NH_3)

Primary PM concentrations respond linearly to changes in primary PM emissions, so that Equation 2 applies and we can write the following expression:

$$(6) \qquad \frac{\Delta \mathrm{Pr}}{\mathrm{PM}_{2.5}}100 = \frac{\Delta \mathrm{E}_{\mathrm{Pr}}}{\mathrm{E}_{\mathrm{Pr}}}\left(\frac{\mathrm{Pr}_{\mathrm{L}}}{\mathrm{PM}_{2.5}}\right)100$$

A similar expression to Equation 6 can be implemented for ammonia. However, the response to changes in ammonia has not been implemented in the current prototype of the source-receptor tool.

A3.3 Sulphate (SO_4)

Sulphate responds positively to changes in SO_2 concentration, but can respond negatively to changes in NO_X and VOC emissions. A reduction in NO_X or VOC increases the OH radicals available for oxidation of SO_2, which can lead to an increase in sulphate.

Photochemical modelling conducted for the Sulphur in Gasoline and Diesel Fuels study (Atmospheric Science Expert Panel, 1997) suggested that, in the absence of any changes in other pollutants, the above-background portion of the sulphate concentration will respond linearly to SO_2 changes. If, on the other hand, a change in SO_2 is accompanied by a change in NO_X or VOC, then the response will not be linear. A decrease in SO_2 emissions, accompanied by decreases in both NO_X and VOC emissions, produced a change in sulphate levels (% change) that was a factor of 0.65 lower, on average, than the change in SO_2 concentration.

Starting with the expression $SO_{4L} = k\ SO_2$, one can derive the following equation:

$$\text{(7)} \qquad \frac{\Delta SO_4}{PM_{2.5}}100 = \left(\frac{\Delta k}{k}\frac{\Delta SO_2}{SO_2} + \frac{\Delta k}{k} + \frac{\Delta SO_2}{SO_2} \right) \frac{SO_{4L}}{PM_{2.5}}100$$

The value of k in this equation is allowed to change with changing concentrations of SO_2, NO_X and VOC. In the case where k is constant, equation 7 collapses to a linear relationship between SO_4 and SO_2. It is reasonable to assume that the value of k is inversely related to the change in the sum SO_2+NO_X+VOC, so that the following holds true:

$$\text{(8)} \qquad \frac{\Delta k}{k} = \left(1 + \frac{\Delta SO_2 + \Delta NO_x + \Delta VOC}{SO_2 + NO_x + VOC} \right)^{-1} - 1$$

Equations 7 and 8 provide a means of estimating the behaviour of the sulphate concentration in response to any combination of changes in emissions of SO_2, NO_X and VOC.

A3.5 Nitrate (NO_3)

It seems likely that the issues described in the preceding section for sulphate would apply equally to nitrate and, therefore, an analogous expression to equation 7 can be used, with NO_2 substituted in place of SO_2, and total NO_3 (gas-phase plus particle-phase) in place of SO_4. This approach requires ambient monitoring data for total nitrate, which is currently limited in Canada. In the absence of monitoring data, an estimate of annual average can be derived from $PM_{2.5}$ data using the approximate data in Table A4 (adapted from MSC, 2001).

Table A4: Average Factors for Nitrate

Region	100 x ($p\text{-}NO_3$ / $PM_{2.5}$)	100 x ($p\text{-}NO_3$ / $tot\text{-}NO_3$)
Western Canada	17	57
Windsor-Quebec Corridor	12	43
Atlantic Canada	6	37

A3.6 Secondary Organic Aerosol (SOA)

In its analysis of SOA, the Meteorological Service of Canada (2001) defined SOA as organic aerosol that forms in the outside air through oxidation of primary VOC emissions. Semi-volatile and non-volatile compounds that are emitted directly from a source and rapidly condense in the outside air were assumed to be included in the primary PM emissions. The available evidence, although limited by lack of data, suggests that SOA is generally a minor contributor to $PM_{2.5}$ in Canada. On an annual average basis, therefore, it seems reasonable to neglect the contribution of SOA to $PM_{2.5}$. In any case, for most of the energy scenarios to be tested, VOC emissions do not change as much as NO_x or SO_2.

A3.7 PM_{10}

Table A5 presents a summary of available data on the chemical makeup of PM_{10} in Canada (annual average basis), similar to that presented earlier for $PM_{2.5}$. The source-receptor relationships for PM_{10} are essentially the same as those set out in Equations 5 through 9 for $PM_{2.5}$. The calculations for PM_{10} have not been implemented in the current prototype of the source-receptor tool.

Table A5: Chemical Makeup of $PM_{2.5}$ (% by mass)

	Sulphate SO_4	Nitrate NO_3	Ammonium NH_4	Sodium Chloride	Primary PM & SOA
Western Canada	10	17	3	5	65
Windsor-Quebec Corridor	14	12	5	5	64
Atlantic Canada	13	6	7	8	66

A4. Ground-Level Ozone (O_3)

The key precursor pollutants for ground-level ozone are NO_X and VOC's. The response of O_3 to changes in these pollutants can be very complex. An assessment of Canadian trends in O_3 and its precursors was conducted in the mid-1990's, and a succinct summary can be found in Wolff et al. (2001). The study indicated that across Canada, NO_X emissions declined by an average of 1.8% per year from 1986 to 1993. During this period, monitored daily maximum O_3 levels at rural sites decreased slightly in most Canadian regions (0.05 to 0.27% per year), increased slightly in Saskatchewan and Alberta (0.07% per year) and showed no change in Southern Ontario. At urban sites, the ozone levels increased significantly, by 0.45% per year in the Lower Fraser Valley, 1.2% per year in Ontario, and 2.2% per year in the Atlantic Region. The exception was Montreal, where the levels decreased by 0.87% per year.

Numerous studies have shown that there is an optimal level of NO_X emissions (relative to VOC emissions) for maximum production of O_3 and that, in urban areas, this optimal level is generally exceeded (Jiang, et al., 1996; Vukovich, 2000; Barna et al., 2001). In this situation, modest reductions in NO_X emissions can lead to an increase in peak O_3 levels, as has been seen in the historical trends for most Canadian urban areas. With very large reductions in NO_X emissions, the situation tends to reverse itself and O_3 levels are reduced. Some of the studies have shown that this pattern of behaviour can extend fairly far downwind of the urban core (Jiang et al., 1996). Farther downwind, the urban plume undergoes a transition to a NO_x -limited condition, in which the peak O_3 levels respond positively to all changes in NO_X emissions and are relatively insensitive to changes in VOC's. Modelling studies of selected summer smog episodes in Southern Ontario suggest that the NO_x -limited condition prevails during these episodes (Stratus Consulting Inc, 2000; RWDI, 2001).

In the Sulphur in Gasoline and Diesel Fuels study (Atmospheric Science Expert Panel, 1997), the assumption was made that O_3 responds linearly to changes in both NO_x and VOC's. Data presented by Barna et al. (2001) shows that the response is actually complex and non-linear. Ainslie and Steyn (2001) provided a review of studies on empirical relationships between O_3 and its precursors. These studies suggest that under NO_x -limited conditions, the O_3 level is related to the square root of the NO_x level. This would be a suitable relationship to apply in rural areas that are upwind or far downwind of major urban areas.

In urban areas, where conditions are not NO_x -limited, the relationship is more complex but, for the present purpose, a reasonable estimate can be obtained by assuming that the O_3 level is related to the square root of the VOC concentration. This square root relationship seems reasonable based on inspection of typical ozone isopleths, and is supported by results of photochemical modelling for Seattle and Vancouver areas (Jiang et al., 1996; Barna and Westberg, 2001).

These relationships can be expressed as follows.

(a) Rural areas:

$$(9) \qquad \frac{\Delta O_3}{O_3}100 = \left(\left(1+\frac{\Delta E_{NO_X}}{E_{NO_X}}\right)^{0.5} - 1\right)100$$

(b) Urban and nearby downwind areas:

$$(10) \qquad \frac{\Delta O_3}{O_3}100 = \left(\left(1+\frac{\Delta E_{VOC}}{E_{VOC}}\right)^{0.5} - 1\right)100$$

Given that the source-receptor relationships are a simplified model, some uncertainty is to be expected in these relationships, especially given the complex reactions that lead to O_3 formation. There are some limits to the application of these calculations, such as urban cases (VOC-limited regimes) where ozone is weakly responsive to changes in NO_x (as discussed above). In the application of these relationships, the source-receptor tool is not responsive to this response to NO_x. This is a reasonable approximation for small changes, but can lead to some uncertainty if large decreases in urban NO_x emissions may occur.

A5. Background Concentration

Table A6 shows the background concentrations that are currently used in the S-R Tool. The values for CO are taken from the Sulphur in Fuel Study. The values for SO_2, SO_4 and $PM_{2.5}$ as per rural CAPMoN sites (1995-1999). NO_X background levels are not easily determined due to detection threshold limitations of the field instrumentation. The value is estimated at 10 ppb for all locations.

The background concentration for O_3 is taken directly from the Sulphur in Fuels Study (40 ppb plus estimated contribution from long range transport). Information on the background concentration of particle nitrate, p-$NO_{3,}$ was not directly available and was estimated from the background concentrations for $PM_{2.5}$ and the chemical make-up of $PM_{2.5}$ shown previously in Table A5.

Table A6: Background Concentrations Currently Used in the Analysis

Location	SO_2	NO_2	$PM_{2.5}$	SO_4	O_3 ppb	% of above-background O_3 due to long-range Transport
Halifax	4.5	7.3	3.9	0.8	30	80
Saint John	4.5	7.3	3.9	0.8	30	80
Montreal	3.5	12.1	8.4	1.4	30	40
Toronto	4.4	16.1	6.8	1.4	30	50
Windsor	4.4	16.1	6.8	1.4	30	80
Thunder Bay	0.7	6.4	6.9	1.1	30	10
Winnipeg	0.7	6.4	6.9	1.1	30	10
Edmonton	2.0	6.4	5.9	1.1	30	10
Vancouver	4.3	17.5	6.5	1.1	30	15

Adjustable background value algorithms

A series of calculation algorithms were incorporated into the SRT to allow changes in upwind ambient concentrations to carry through to downwind regions. The purpose of this change is to adjust downwind regional values for changes in air quality in upwind regions. For any given region where air quality changes are calculated, only a portion of the monitored average ambient concentration of pollutants is responsive to local changes in emissions. The comparative proportion of local to background is determined for each calculation location based on regional background values. These are presented in Table A7 in Appendix A. However, it can be expected that these background values will also change through time as a function of changes in upwind emissions.

To account for this effect, changes were made to the calculation algorithms to determine resulting downwind background concentration changes and the effect of this on final calculated concentration. To do so, for any given NAPS station where air quality changes are calculated a cross-reference is made to determine the corresponding upwind region. Upwind regions were designated based on broad patterns of air flow and pollutant transport. As such, not all provinces are listed as upwind regions (e.g., BC, Quebec). Table 7 lists upwind relations for regions in the SRT.

Table 7. Upwind-downwind regions

DOWNWIND REGION	UPWIND REGION
NF	US
PEI	US
NS	US
NB	US
PQS	ONS
PQW	ONS

DOWNWIND REGION	UPWIND REGION
PQN	N/A
ONS	US
ONE	N/A
ONW	N/A
MBS	SKS
MBN	SKN
SKS	ABS
SKN	ABN
ABS	N/A
ABN	N/A
LMVI	N/A
BCS	LMVI
BCN	N/A

The relative change in the local component of pollutant concentration for each station in the upwind region was averaged. This term was then used as a multiplier to the referenced background concentration value for the station in question, and added to the local change in concentration to determine a total change in concentration at each station:

$$C_i = C_o + \Delta C_l + \left[\overline{\Delta C_{l_u}} \times C_b\right]$$

where C_i is resulting concentration, C_o is initial concentration, ΔC_l is the absolute change in local component of pollutant concentration, $\overline{\Delta C_{l_u}}$ is the mean percent change in pollutant concentration for the local component of upwind locations, and C_b is background pollutant concentration.

The importance of upwind US emissions and the effect they have on air quality has long been recognized. At this phase of development, full analysis of US emission projects through the time period considered by the SRT has not been made. Instead, the calculation algorithm has been developed to allow for the inclusion of US emissions and air quality changes, and a placeholder value has been provided for each pollutant. These may be set to more fully represent expected changes in US emissions and air quality and allow this effect to be incorporated into calculations of Canadian air quality.

ReFSoRT accounts for the effect of US emissions changes by adjusting the background in defined regions (i.e. NF, PEI, NS, NB and ONS). In these regions, the regional background concentration of a pollutant is assumed to originate entirely from the US. The methods for adjusting $PM_{2.5}$ and O_3 concentrations are discussed below. ReFSoRT calculates changes in $PM_{2.5}$ concentrations by determining changes in concentrations for primary $PM_{2.5}$ and the SO_4, and NO_3 fractions. For each of these species, the change in both local concentrations and background concentrations are calculated. Percent changes in background primary PM is assumed to be the same as the percent change in $PM_{2.5}$ emissions. Changes in background SO_4 and NO_3 concentrations are assumed to be directly related to changes in U.S. SO_2 and NO_x emissions. For ozone, the portion of ozone concentrations that are attributed to long-range transport (i.e. from U.S. sources) are adjusted by the square root of the percentage change in U.S. NO_x emissions.

A6. **Smooth Network Data and Create Wider Census Division Coverage**

In terms of application to health and economic impacts analysis, providing output results for as many census divisions as possible, especially for those where the majority of the population resides, is imperative. To facilitate this requirement, calculations for changes in air quality are mapped to census division (CD) output spatial units in the SRT.

This mapping has involved accommodating two situations. The first of these is the averaging of multiple NAPS stations that are located within a single census division. The second of these is the mapping of NAPS stations to CDs that do not contain their own NAPS station. This may involve one or more NAPS stations, depending on proximity to CDs.

The mapping of NAPS to CDs has evolved in the SRT from initial mapping prepared by Environment Canada. This mapping was based on a distance threshold. With subsequent development of the SRT, additional NAPS cross-referencing was added, typically for situations where conditions (in terms of known air quality, population base, or industrial development) were deemed to be similar enough to warrant extending the mapping coverage. As part of this, slightly different mapping cross-referencing was developed for $PM_{2.5}$ and O_3, due to the limited extent of full primary and secondary $PM_{2.5}$ NAPS coverage.

In the current phase of development, possibilities for further extending this coverage were investigated and changes to the mapping cross-referencing made.

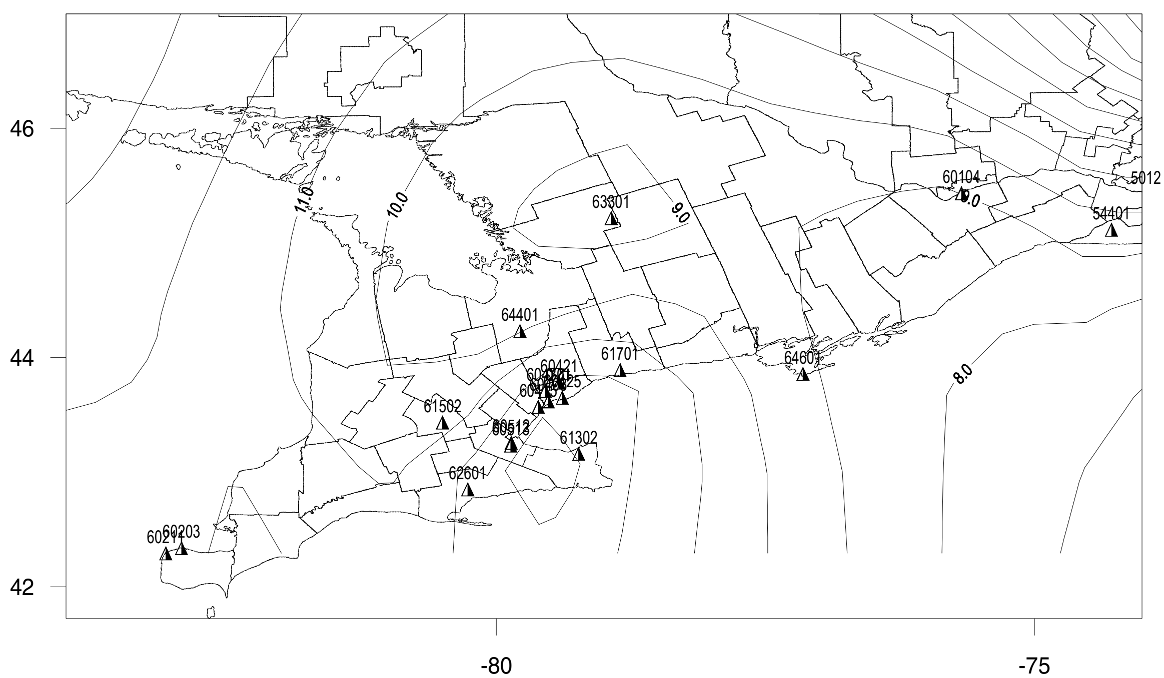
Opportunities for adding to the base monitoring data network used for the source-receptor calculations were investigated from the point of view of extending the spatial coverage of the results (rather than simply adding to the quantity of data used for averaging purposes). Of primary importance were monitoring data for $PM_{2.5}$ or contributors to secondary $PM_{2.5}$ (e.g., SO_2, NO_2, VOC), that would allow extending the coverage for $PM_{2.5}$. The SRT to date has been somewhat limited in terms of output coverage for $PM_{2.5}$ in particular, owing to the limited network of $PM_{2.5}$ monitoring. Compounding this is the limit on calculating changes to secondary $PM_{2.5}$ due to lack of monitoring data for SO_2, NO_2 or VOC. In some cases, cross-referencing to nearby stations has allowed this data record to be filled. However, in some cases the absence of these other data has limited full calculation of changes to $PM_{2.5}$.

The possibility of using data from provincial monitoring networks was investigated. In particular, data for Ontario, Alberta, and British Columbia were considered. However, in almost all locations where the full suite of pollutants was available, the locations corresponded to places where NAPS stations also exist (e.g., additional stations for Toronto, Windsor, etc.). As such, adding this data would do nothing to extend the coverage. In almost all other cases where station locations would add to the network coverage of the SRT, no monitoring for $PM_{2.5}$ occurred. Therefore, no additional data were added to the base monitoring data set from provincial records.

A review of the full NatChem database was undertaken with the purpose of identifying potential additional data to add to the SRT. In most cases, these additional data networks did not include relevant coverage in terms of pollutant or temporal coverage. The CAPMON network, however, was considered for this task, but as most of the monitoring sites in this data set are for rural locations, this data was not integrated at this time for the basic calculations. As well, the data record for the NAPS network was revisited, as data for the monitoring period 2001 is now available. However, this was not further pursued at this time, as it would only result in the addition of 1 station of relative regional importance.

The existing NAPS data set was then interpolated and mapped to contours for each pollutant. A default kriging option and a specified high degree of smoothing were used in this analysis. The results were overlaid with a basemap of CDs for all regions of Canada and the locations of all NAPS stations. An example map is shown in Figure 1.

Figure 1. Example contour plot of $PM_{2.5}$ concentration field for Southern Ontario.



Inspection of the maps for SO_2, NO_2, and VOC allowed some further cross-referencing of the data set for cases were the absence of these pollutants had previously prevented full calculation of secondary $PM_{2.5}$. These changes were incorporated on a case by case basis within the 'Station List' calculation sheet of the SRT.

Contour plots for $PM_{2.5}$ and O_3 were also inspected. The potential for adding US monitoring data was also considered at this point for cases where its inclusion might better inform the contoured data. However, for the most part there were no cases where inclusion of this data would add materially to the results given the present use of the contoured data.

Based on the contour plots, new NAPS to CD cross-reference tables were prepared. NAPS stations were mapped directly to CDs where they occurred. In addition, NAPS stations were further mapped to nearby CDs in cases when no NAPS stations were present and/ or in cases where the NAPS station was deemed sufficiently close to the boundary of an adjacent CD. Although partially subjective, this method was informed by the concentration field as indicated by the contour gradient. In general, NAPS stations were not mapped across extended distances nor across steep concentration gradients. In addition, mapping to nearby CDs for $PM_{2.5}$ was done somewhat more conservatively than for O_3, reflecting the potential for sharper differences between urban and non-urban areas for $PM_{2.5}$ concentrations than for O_3.

The resulting mapping essentially mirrored the original mapping, but with cases of extended distance thresholds based on the mapped concentration field. This mapping was checked for selected regions of dense network coverage against the original mapping prepared by Environment Canada. A high degree of agreement was noted, and taken as an indicator of the reasonableness of this method for mapping.

To further expand the coverage for $PM_{2.5}$, additional stations from the PM_{10} monitoring dataset were added by applying an averaged multiplier for the relation of $PM_{2.5}$ to PM10. In this case, a ratio of 55% PM_{10} as $PM_{2.5}$ was assumed. This resulted in the addition of 51 additional stations to the basic calculation set (originally 56 stations).

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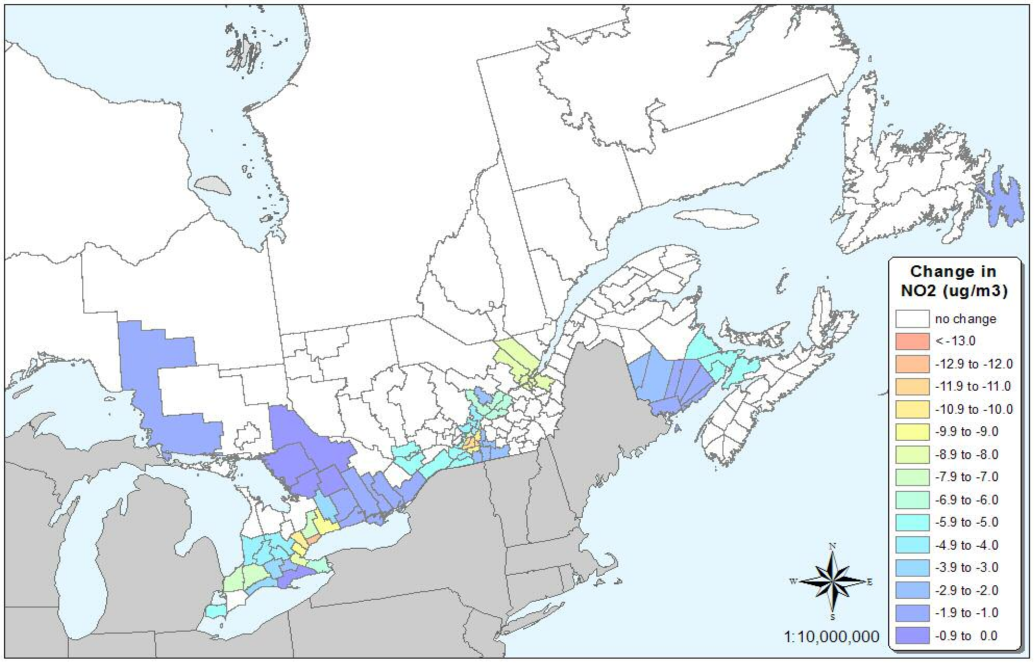
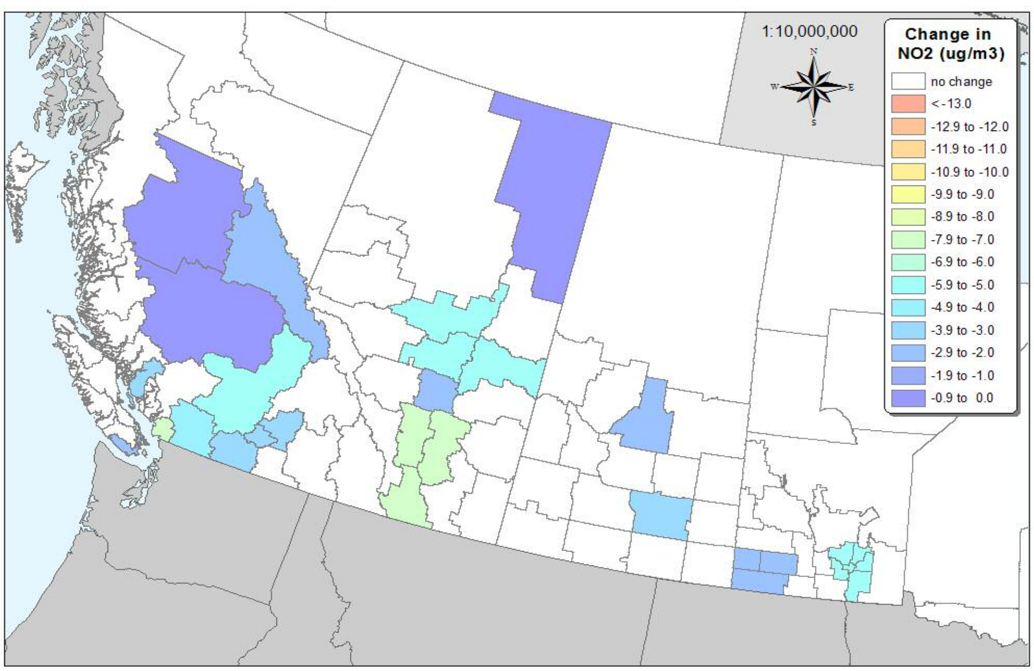
APPENDIX B
Air Quality Impacts

a) EAST



b) WEST



Nationwide Changes in NO_2 concentration by CD

Figure No.: #B-1

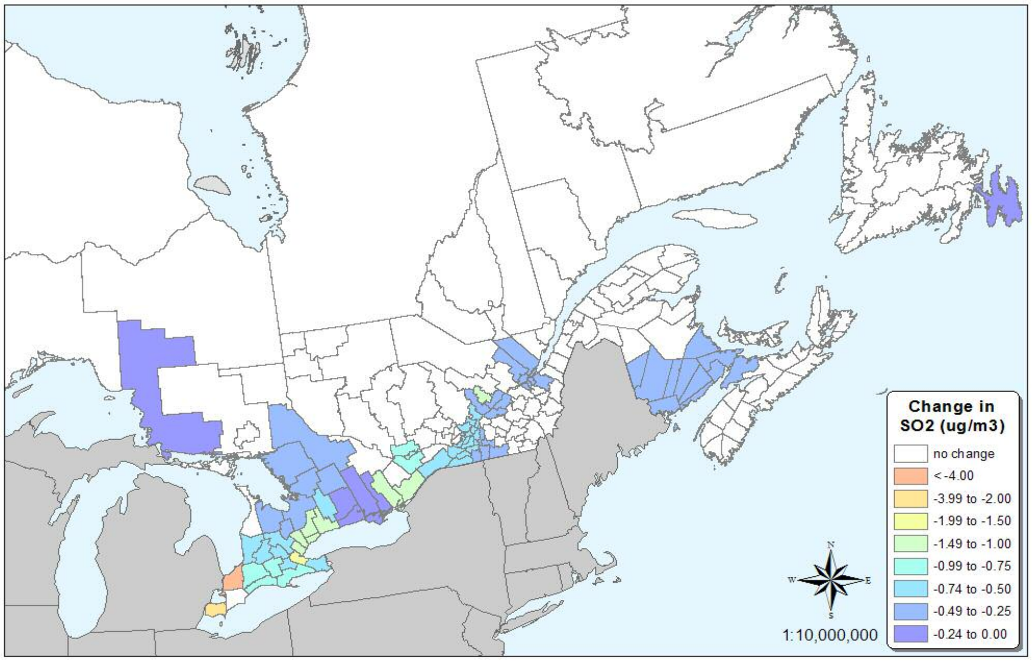
Date: March 13, 2007

Transport Canada - Full Cost Investigation - Air Pollution

Project #W07-5055A

RWDI

a) EAST



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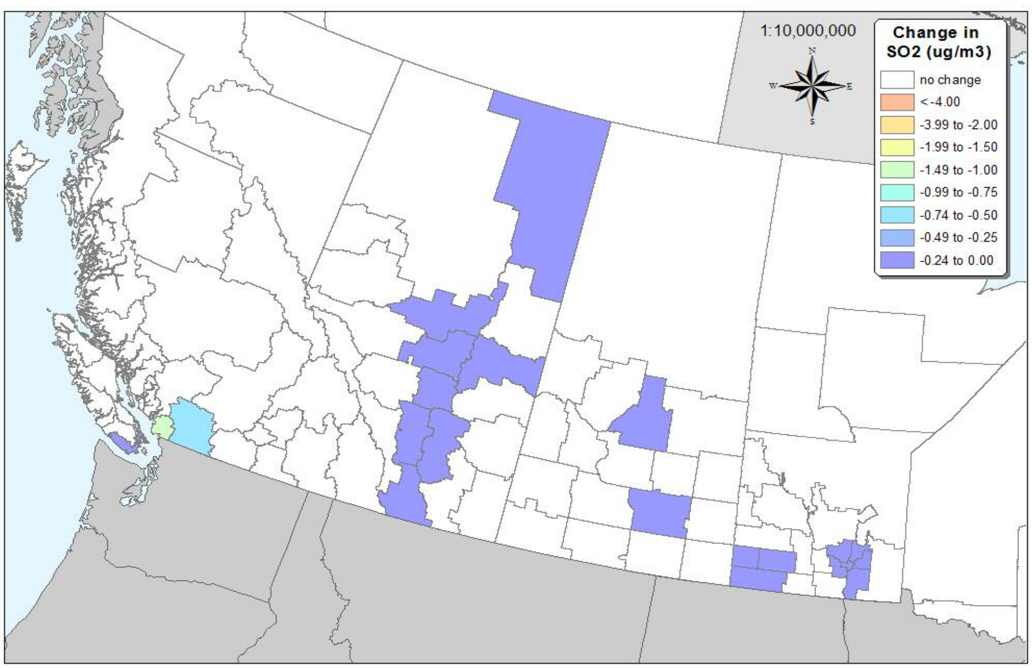


Nationwide Changes in SO_2 concentration by CD

Figure No.: #B-2

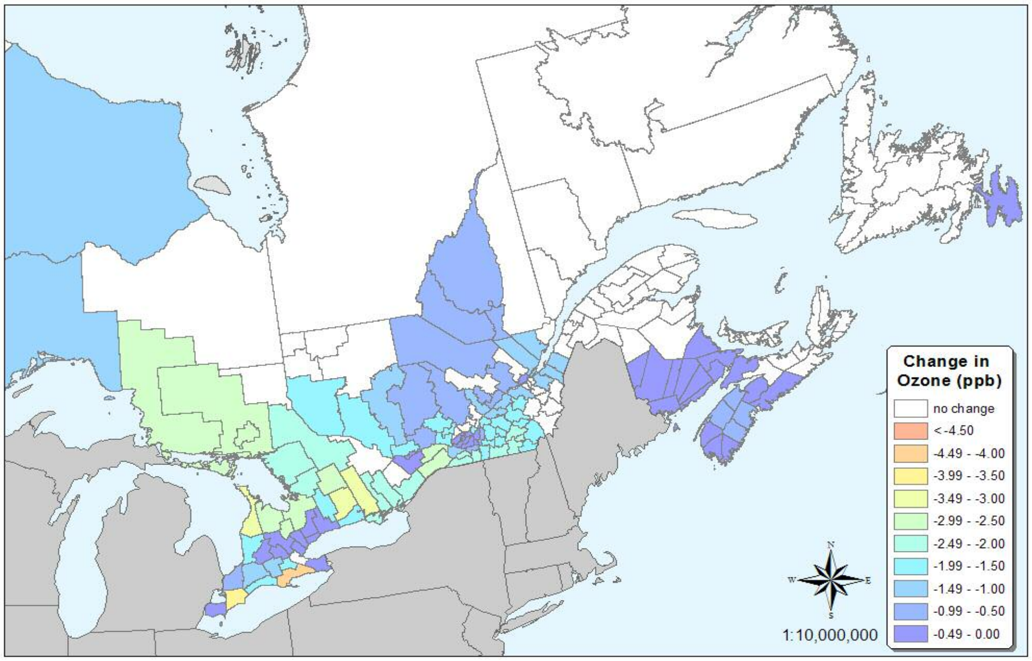
Date: March 13, 2007

RWDI

Transport Canada - Full Cost Investigation - Air Pollution

Project #W07-5055A

a) EAST



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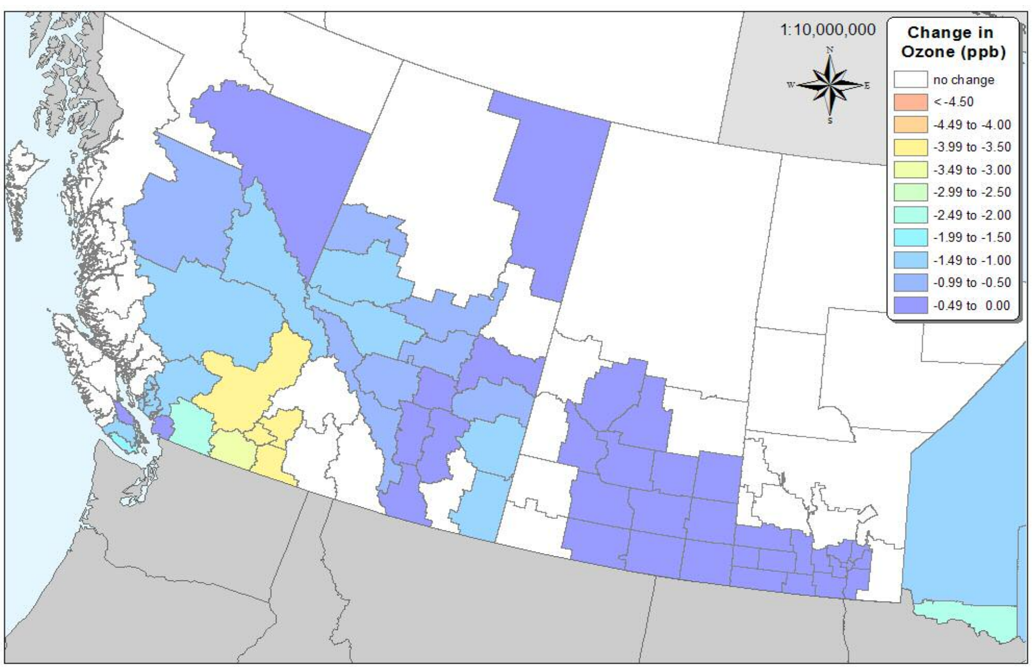
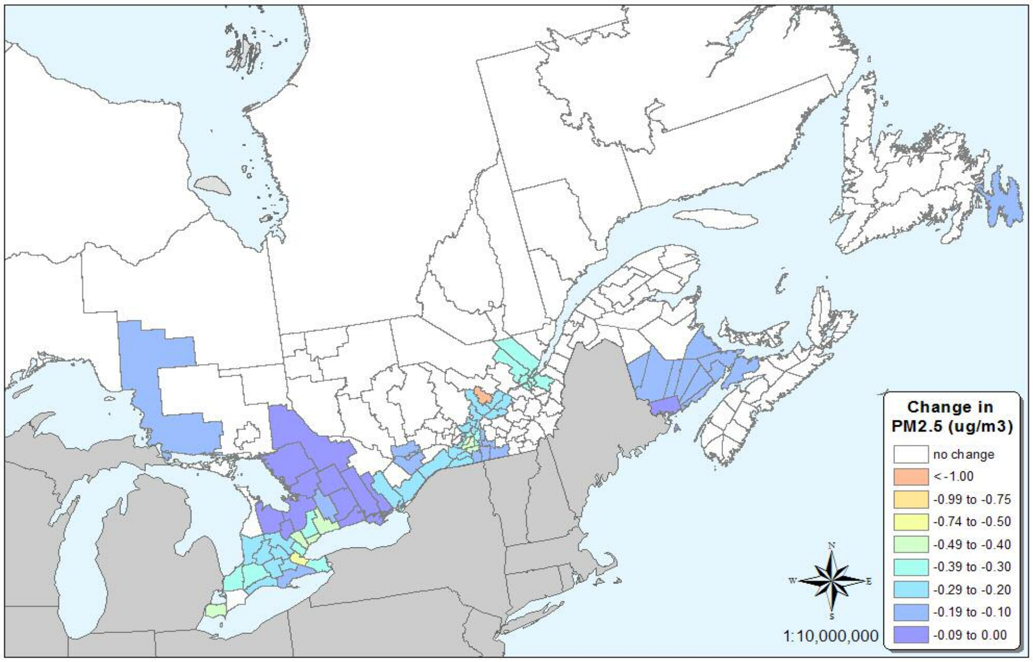
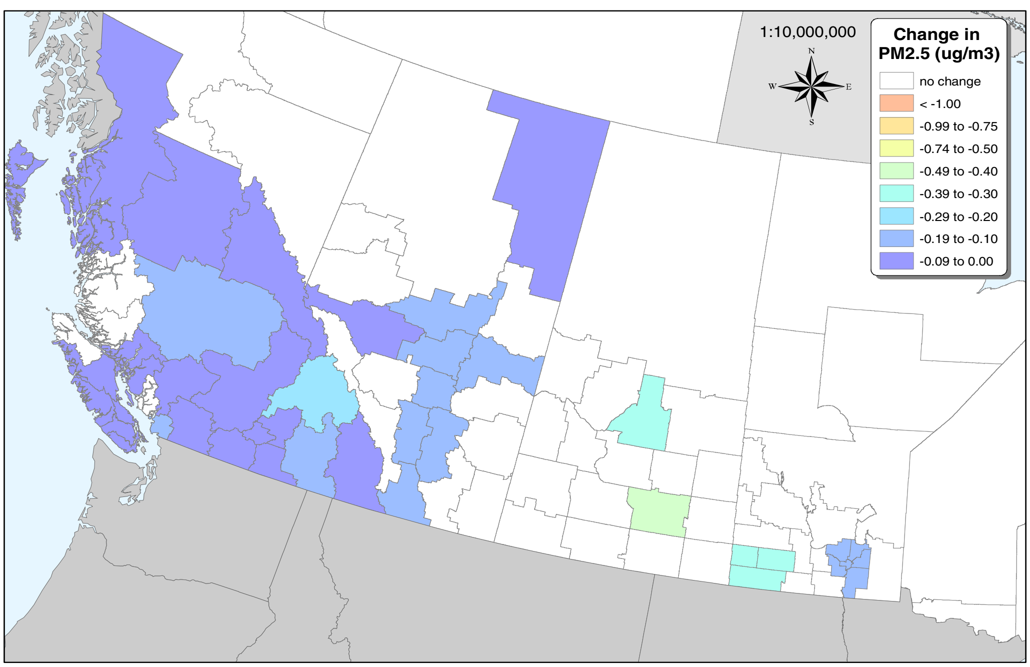


Nationwide Changes in O_3 concentration by CD Transport Canada - Full Cost Investigation - Air Pollution Project #W07-5055A	Figure No.: #B-3 Date: March 13, 2007	RWDI

a) EAST



b) WEST



Nationwide Changes in $PM_{2.5}$ concentration by CD

Transport Canada - Full Cost Investigation - Air Pollution	Figure No.: #B-4	RWDI
Project #W07-5055A	Date: March 13, 2007	

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APPENDIX C
Detailed Costs of Transport

APPENDIX C

DETAILED COSTS OF TRANSPORT-RELATED AIR POLLUTION BY MODE AND PROVINCE

Transport Canada Modes	**National Economic Valuation of Emissions from Transport Modes (000's 2000$)**		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$1,189	$1,583	$1,968
Freight Heavy-duty diesel vehicle	$822,841	$1,107,678	$1,386,487
Freight Heavy-duty gas vehicle	$64,865	$87,167	$108,995
Freight Light-duty diesel truck	$5,340	$7,098	$8,815
Freight Light-duty gas truck	$132,239	$176,085	$218,935
Freight Marine Transport	$367,449	$492,479	$614,709
Freight Rail Transport	$318,092	$428,492	$536,560
Passenger Air Transport	$21,434	$28,532	$35,468
Passenger Interurban diesel bus	$12,004	$16,159	$20,227
Passenger Interurban gas bus	$164	$220	$276
Passenger Light-duty diesel truck	$12,556	$16,696	$20,741
Passenger Light-duty diesel vehicle	$7,905	$10,538	$13,111
Passenger Light-duty gas truck	$334,738	$445,954	$554,646
Passenger Light-duty gas vehicle	$688,276	$917,413	$1,141,377
Passenger Marine Transport	$34,447	$46,221	$57,735
Passenger Rail Transport	$11,351	$15,291	$19,148
Passenger Urban and School Diesel Bus	$64,492	$86,816	$108,669
Passenger Urban and School Gas Bus	$44	$60	$75
All Transport Canada Modes	**$2,899,426**	**$3,884,484**	**$4,847,939**

Transport Canada Modes	**NEWFOUNDLAND - Economic Valuation of Emissions from Transport Modes (000's 2000$)**		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$3	$4	$5
Freight Heavy-duty diesel vehicle	$1,972	$2,665	$3,344
Freight Heavy-duty gas vehicle	$102	$138	$174
Freight Light-duty diesel truck	$7	$9	$12
Freight Light-duty gas truck	$250	$339	$427
Freight Marine Transport	$2,933	$3,902	$4,846
Freight Rail Transport	$338	$458	$575
Passenger Air Transport	$77	$104	$130
Passenger Interurban diesel bus	$23	$31	$38
Passenger Interurban gas bus	$1	$1	$1
Passenger Light-duty diesel truck	$22	$30	$37
Passenger Light-duty diesel vehicle	$3	$4	$5
Passenger Light-duty gas truck	$797	$1,081	$1,360
Passenger Light-duty gas vehicle	$1,066	$1,447	$1,820
Passenger Marine Transport	$115	$154	$191
Passenger Rail Transport	$12	$16	$21
Passenger Urban and School Diesel Bus	$137	$185	$233
Passenger Urban and School Gas Bus	$0	$0	$0
All Transport Modes	**$7,858**	**$10,568**	**$13,217**

Transport Canada Modes	**NOVA SCOTIA - Economic Valuation of Emissions from Transport Modes (000's 2000$)**		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$3	$3	$4
Freight Heavy-duty diesel vehicle	$3,540	$4,512	$5,456
Freight Heavy-duty gas vehicle	$156	$199	$240
Freight Light-duty diesel truck	$13	$16	$19
Freight Light-duty gas truck	$359	$457	$553
Freight Marine Transport	$1,625	$2,086	$2,534
Freight Rail Transport	$328	$418	$506
Passenger Air Transport	$68	$87	$106
Passenger Interurban diesel bus	$39	$49	$60
Passenger Interurban gas bus	$1	$1	$1
Passenger Light-duty diesel truck	$40	$51	$62
Passenger Light-duty diesel vehicle	$26	$33	$40
Passenger Light-duty gas truck	$1,149	$1,465	$1,772
Passenger Light-duty gas vehicle	$1,740	$2,218	$2,683
Passenger Marine Transport	$19	$25	$30
Passenger Rail Transport	$12	$15	$18
Passenger Urban and School Diesel Bus	$234	$299	$361
Passenger Urban and School Gas Bus	$0	$0	$0
All Transport Modes	**$9,351**	**$11,934**	**$14,445**

Transport Canada Modes	NEW BRUNSWICK - Economic Valuation of Emissions from Transport Modes (000's 2000$)		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$3	$4	$5
Freight Heavy-duty diesel vehicle	$14,601	$19,555	$24,402
Freight Heavy-duty gas vehicle	$422	$568	$710
Freight Light-duty diesel truck	$51	$67	$83
Freight Light-duty gas truck	$1,005	$1,350	$1,688
Freight Marine Transport	$5,859	$7,823	$9,742
Freight Rail Transport	$1,799	$2,412	$3,013
Passenger Air Transport	$61	$82	$103
Passenger Interurban diesel bus	$148	$198	$247
Passenger Interurban gas bus	$2	$3	$4
Passenger Light-duty diesel truck	$159	$211	$261
Passenger Light-duty diesel vehicle	$63	$83	$103
Passenger Light-duty gas truck	$3,201	$4,302	$5,380
Passenger Light-duty gas vehicle	$4,858	$6,534	$8,175
Passenger Marine Transport	$151	$202	$251
Passenger Rail Transport	$64	$86	$108
Passenger Urban and School Diesel Bus	$897	$1,201	$1,499
Passenger Urban and School Gas Bus	$1	$1	$1
All Transport Modes	**$33,344**	**$44,682**	**$55,775**

Transport Canada Modes	QUEBEC - Economic Valuation of Emissions from Transport Modes (000's 2000$)		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$244	$323	$401
Freight Heavy-duty diesel vehicle	$222,976	$299,421	$374,235
Freight Heavy-duty gas vehicle	$11,018	$14,782	$18,466
Freight Light-duty diesel truck	$1,811	$2,410	$2,996
Freight Light-duty gas truck	$34,961	$46,490	$57,758
Freight Marine Transport	$170,023	$227,457	$283,604
Freight Rail Transport	$44,835	$60,225	$75,288
Passenger Air Transport	$4,542	$6,029	$7,482
Passenger Interurban diesel bus	$3,346	$4,493	$5,616
Passenger Interurban gas bus	$35	$47	$58
Passenger Light-duty diesel truck	$4,168	$5,548	$6,896
Passenger Light-duty diesel vehicle	$3,404	$4,542	$5,653
Passenger Light-duty gas truck	$82,140	$109,229	$135,703
Passenger Light-duty gas vehicle	$219,007	$291,546	$362,452
Passenger Marine Transport	$9,150	$12,241	$15,262
Passenger Rail Transport	$1,600	$2,149	$2,687
Passenger Urban and School Diesel Bus	$17,381	$23,340	$29,172
Passenger Urban and School Gas Bus	$9	$12	$16
All Transport Modes	**$830,650**	**$1,110,286**	**$1,383,746**

Transport Canada Modes	ONTARIO - Economic Valuation of Emissions from Transport Modes (000's 2000$)		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$734	$977	$1,215
Freight Heavy-duty diesel vehicle	$413,161	$557,213	$698,210
Freight Heavy-duty gas vehicle	$26,551	$35,743	$44,738
Freight Light-duty diesel truck	$1,829	$2,432	$3,022
Freight Light-duty gas truck	$66,788	$89,025	$110,752
Freight Marine Transport	$96,688	$129,869	$162,291
Freight Rail Transport	$191,798	$258,787	$324,354
Passenger Air Transport	$12,932	$17,218	$21,405
Passenger Interurban diesel bus	$5,899	$7,956	$9,969
Passenger Interurban gas bus	$78	$106	$132
Passenger Light-duty diesel truck	$5,166	$6,871	$8,536
Passenger Light-duty diesel vehicle	$3,709	$4,943	$6,148
Passenger Light-duty gas truck	$189,401	$252,463	$314,078
Passenger Light-duty gas vehicle	$370,019	$493,333	$613,830
Passenger Marine Transport	$3,843	$5,162	$6,451
Passenger Rail Transport	$6,844	$9,235	$11,575
Passenger Urban and School Diesel Bus	$31,541	$42,538	$53,301
Passenger Urban and School Gas Bus	$21	$28	$35
All Transport Modes	**$1,427,003**	**$1,913,900**	**$2,390,042**

Transport Canada Modes	MANITOBA - Economic Valuation of Emissions from Transport Modes (000's 2000$)		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$24	$32	$40
Freight Heavy-duty diesel vehicle	$20,644	$28,483	$36,183
Freight Heavy-duty gas vehicle	$1,957	$2,693	$3,416
Freight Light-duty diesel truck	$150	$204	$256
Freight Light-duty gas truck	$2,937	$4,010	$5,063
Freight Marine Transport	$81	$108	$134
Freight Rail Transport	$12,472	$17,083	$21,610
Passenger Air Transport	$476	$640	$799
Passenger Interurban diesel bus	$493	$680	$863
Passenger Interurban gas bus	$5	$7	$9
Passenger Light-duty diesel truck	$419	$569	$715
Passenger Light-duty diesel vehicle	$73	$99	$125
Passenger Light-duty gas truck	$8,245	$11,257	$14,213
Passenger Light-duty gas vehicle	$11,867	$16,245	$20,542
Passenger Marine Transport	$81	$108	$134
Passenger Rail Transport	$445	$610	$771
Passenger Urban and School Diesel Bus	$2,847	$3,928	$4,990
Passenger Urban and School Gas Bus	$2	$2	$3
All Transport Modes	**$63,218**	**$86,756**	**$109,866**

Transport Canada Modes	SASKATCHEWAN - Economic Valuation of Emissions from Transport Modes (000's 2000$)		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$8	$10	$12
Freight Heavy-duty diesel vehicle	$21,164	$27,567	$33,824
Freight Heavy-duty gas vehicle	$2,616	$3,397	$4,160
Freight Light-duty diesel truck	$514	$667	$816
Freight Light-duty gas truck	$4,613	$5,951	$7,256
Freight Marine Transport	$0	$0	$0
Freight Rail Transport	$11,218	$14,615	$17,935
Passenger Air Transport	$163	$211	$257
Passenger Interurban diesel bus	$452	$589	$723
Passenger Interurban gas bus	$4	$6	$7
Passenger Light-duty diesel truck	$849	$1,101	$1,347
Passenger Light-duty diesel vehicle	$75	$97	$119
Passenger Light-duty gas truck	$7,520	$9,701	$11,829
Passenger Light-duty gas vehicle	$11,148	$14,401	$17,576
Passenger Marine Transport	$0	$0	$0
Passenger Rail Transport	$400	$522	$640
Passenger Urban and School Diesel Bus	$2,613	$3,403	$4,176
Passenger Urban and School Gas Bus	$1	$2	$2
All Transport Modes	**$63,357**	**$82,239**	**$100,678**

Transport Canada Modes	ALBERTA - Economic Valuation of Emissions from Transport Modes (000's 2000$)		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$56	$75	$93
Freight Heavy-duty diesel vehicle	$72,420	$97,961	$122,973
Freight Heavy-duty gas vehicle	$8,088	$10,905	$13,663
Freight Light-duty diesel truck	$823	$1,101	$1,373
Freight Light-duty gas truck	$12,751	$16,986	$21,125
Freight Marine Transport	$0	$0	$0
Freight Rail Transport	$16,711	$22,618	$28,404
Passenger Air Transport	$1,117	$1,488	$1,851
Passenger Interurban diesel bus	$888	$1,201	$1,507
Passenger Interurban gas bus	$13	$17	$21
Passenger Light-duty diesel truck	$1,377	$1,844	$2,299
Passenger Light-duty diesel vehicle	$133	$178	$222
Passenger Light-duty gas truck	$21,121	$28,137	$34,994
Passenger Light-duty gas vehicle	$30,088	$40,150	$49,987
Passenger Marine Transport	$0	$0	$0
Passenger Rail Transport	$596	$807	$1,014
Passenger Urban and School Diesel Bus	$4,993	$6,753	$8,478
Passenger Urban and School Gas Bus	$3	$5	$6
All Transport Modes	**$171,177**	**$230,226**	**$288,009**

Transport Canada Modes	BRITISH COLUMBIA - Economic Valuation of Emissions from Transport Modes (000's 2000$)		
	MIN (20th percentile)	**MEAN**	**MAX (80th percentile)**
Freight Air Transport	$116	$155	$193
Freight Heavy-duty diesel vehicle	$52,363	$70,301	$87,859
Freight Heavy-duty gas vehicle	$13,954	$18,743	$23,429
Freight Light-duty diesel truck	$144	$191	$238
Freight Light-duty gas truck	$8,577	$11,476	$14,313
Freight Marine Transport	$90,240	$121,236	$151,559
Freight Rail Transport	$38,593	$51,874	$64,875
Passenger Air Transport	$1,996	$2,673	$3,335
Passenger Interurban diesel bus	$717	$963	$1,203
Passenger Interurban gas bus	$25	$34	$42
Passenger Light-duty diesel truck	$355	$472	$587
Passenger Light-duty diesel vehicle	$419	$558	$695
Passenger Light-duty gas truck	$21,165	$28,319	$35,318
Passenger Light-duty gas vehicle	$38,484	$51,539	$64,312
Passenger Marine Transport	$21,088	$28,331	$35,417
Passenger Rail Transport	$1,377	$1,851	$2,315
Passenger Urban and School Diesel Bus	$3,850	$5,169	$6,459
Passenger Urban and School Gas Bus	$7	$9	$11
All Transport Modes	**$293,468**	**$393,893**	**$492,161**

DETAILED UNIT COSTS OF TRANSPORT-RELATED AIR POLLUTION BY ACTIVITY LEVEL AND POLLUTANT

Unit Cost of Transport Related Air Pollution by Activity Level (All Pollutants)

	Cost by Activity Level ($ / million tonne-km Travelled)									
Transport Canada Freight Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Freight Air Transport	$295	$281	$468	$466	$1,726	$1,248	$157	$55	-	$7
Freight Heavy-duty diesel vehicle	$4,404	$4,100	$6,258	$8,118	$11,815	$11,280	$2,956	$1,031	-	$567
Freight Heavy-duty gas vehicle	$7,798	$3,236	$3,935	$5,155	$8,921	$7,535	$2,739	$672	-	$673
Freight Light-duty diesel truck	$2,590	$10,898	$13,200	$14,139	$25,666	$23,356	$9,106	$2,258	-	$6,627
Freight Light-duty gas truck	$6,880	$8,492	$10,765	$10,866	$21,740	$22,393	$4,797	$1,297	-	$1,093
Freight Marine Transport	$2,272	-	-	-	$6,174	$5,509	$687	$83	-	$64
Freight Rail Transport	$1,041	$334	$883	$1,447	$3,928	$1,899	$266	$138	-	-
	Cost by Activity Level ($ / million Passenger*km Travelled)									
Transport Canada Passenger Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Air Transport	$113	$124	$223	$208	$675	$517	$76	$33	-	$28
Passenger Interurban diesel bus	$1,673	$1,556	$2,282	$3,014	$4,470	$4,238	$1,153	$396	-	$354
Passenger Interurban gas bus	$1,129	$463	$550	$741	$1,309	$1,109	$402	$98	-	$237
Passenger Light-duty diesel truck	$895	$3,505	$4,072	$4,475	$8,427	$7,091	$2,776	$685	-	$1,193
Passenger Light-duty diesel vehicle	$3,812	$2,092	$2,602	$2,401	$8,690	$6,782	$1,473	$384	-	$673
Passenger Light-duty gas truck	$2,376	$2,731	$3,321	$3,439	$7,138	$6,798	$1,463	$394	-	$679
Passenger Light-duty gas vehicle	$2,173	$2,039	$2,433	$2,477	$5,554	$5,523	$1,040	$261	-	$440
Passenger Rail Transport	$7,752	$2,486	$6,575	$10,771	$29,237	$14,137	$1,982	$1,030	-	-
Passenger Urban and School Diesel Bus	$1,273	$1,277	$2,197	$2,748	$3,806	$3,741	$1,192	$399	-	$378
Passenger Urban and School Gas Bus	$700	$300	$419	$529	$929	$836	$324	$77	-	$200
	Cost by Activity Level ($ / Passengers Travelled)									
All Transport Canada Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Marine Transport	$1.26	-	-	-	$2.96	$2.68	$0.69	$0.08	-	$0.26

Unit Cost of Transport Related Air Pollution by Activity Level (PM2.5)

	Cost by Activity Level ($ / million tonne-km Travelled)									
Transport Canada Freight Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Freight Air Transport	$7.94	$8.68	$32.96	$7.32	$81.51	$30.60	$12.72	$1.03	-	$2.48
Freight Heavy-duty diesel vehicle	$307.02	$261.80	$1,181.53	$344.63	$1,208.26	$709.98	$422.16	$34.69	-	$157.28
Freight Heavy-duty gas vehicle	$252.95	$87.70	$276.90	$76.79	$477.30	$192.87	$186.70	$9.63	-	$96.84
Freight Light-duty diesel truck	$624.47	$2,311.13	$5,428.19	$1,689.25	$8,736.61	$4,865.15	$3,535.88	$270.85	-	$1,296.59
Freight Light-duty gas truck	$196.00	$208.31	$676.22	$147.47	$1,099.82	$481.40	$300.15	$17.18	-	$119.16
Freight Marine Transport	$184.48	-	-	-	$908.96	$477.48	$99.78	$4.39	-	$26.91
Freight Rail Transport	$48.48	$15.25	$97.92	$33.75	$326.54	$80.60	$28.33	$3.22	-	-
	Cost by Activity Level ($ / million Passenger*km Travelled)									
Transport Canada Passenger Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Air Transport	$3.04	$3.82	$15.69	$3.27	$31.87	$12.67	$6.17	$0.61	-	$1.48
Passenger Interurban diesel bus	$116.67	$99.35	$430.83	$127.95	$457.12	$266.79	$164.71	$13.34	-	$61.41
Passenger Interurban gas bus	$36.63	$12.56	$38.69	$11.04	$70.04	$28.38	$27.39	$1.40	-	$14.20
Passenger Light-duty diesel truck	$215.65	$743.24	$1,674.39	$534.66	$2,868.52	$1,477.03	$1,078.04	$82.22	-	$392.40
Passenger Light-duty diesel vehicle	$846.01	$404.54	$1,049.83	$264.39	$2,712.82	$1,153.51	$518.18	$38.14	-	$203.73
Passenger Light-duty gas truck	$67.69	$66.99	$208.59	$46.67	$361.11	$146.15	$91.51	$5.21	-	$36.06
Passenger Light-duty gas vehicle	$39.71	$28.36	$74.16	$20.77	$234.42	$106.90	$50.51	$2.99	-	$21.63
Passenger Rail Transport	$360.86	$113.49	$728.90	$251.23	$2,430.67	$599.98	$210.85	$23.95	-	-
Passenger Urban and School Diesel Bus	$88.73	$81.57	$414.81	$116.67	$389.25	$235.49	$170.15	$13.42	-	$65.73
Passenger Urban and School Gas Bus	$22.71	$8.13	$29.49	$7.88	$49.71	$21.41	$22.12	$1.10	-	$11.99
	Passengers Travelled									
All Transport Canada Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Marine Transport	$0.10	-	-	-	$0.44	$0.23	$0.10	$0.00	-	$0.03

Unit Cost of Transport Related to Air Pollution by Activity Level (SO_2)

	Cost by Activity Level ($ / million tonne-km Travelled)									
Transport Canada Freight Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Freight Air Transport	$14.62	$9.64	$120.56	$180.43	$136.34	$80.59	$35.74	$2.10	-	$2.48
Freight Heavy-duty diesel vehicle	$47.07	$17.84	$197.71	$475.74	$209.74	$178.91	$101.17	$7.19	-	$10.43
Freight Heavy-duty gas vehicle	$131.61	$23.57	$206.89	$484.89	$379.05	$163.12	$141.72	$6.67	-	$21.34
Freight Light-duty diesel truck	$70.91	$170.35	$1,080.15	$2,776.97	$1,377.18	$1,256.63	$907.12	$65.89	-	$29.95
Freight Light-duty gas truck	$173.00	$81.84	$674.78	$1,370.20	$1,460.72	$680.81	$359.53	$20.15	-	$35.78
Freight Marine Transport	$361.89	-	-	-	$1,508.46	$975.16	$297.33	$11.41	-	$26.71
Freight Rail Transport	$35.66	$5.42	$109.41	$282.11	$172.90	$67.00	$22.75	$2.38	-	-
	Cost by Activity Level ($ / million Passenger*km Travelled)									
Transport Canada Passenger Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Air Transport	$5.61	$4.24	$57.39	$80.62	$53.31	$33.36	$17.32	$1.25	-	$8.34
Passenger Interurban diesel bus	$17.89	$6.77	$72.09	$176.63	$79.35	$67.23	$39.47	$2.76	-	$21.17
Passenger Interurban gas bus	$19.06	$3.38	$28.91	$69.71	$55.63	$24.01	$20.79	$0.97	-	$21.14
Passenger Light-duty diesel truck	$24.49	$54.78	$333.19	$878.94	$452.17	$381.51	$276.57	$20.00	-	$220.58
Passenger Light-duty diesel vehicle	$85.43	$22.93	$163.41	$356.90	$320.44	$267.40	$109.87	$7.78	-	$92.67
Passenger Light-duty gas truck	$59.74	$26.32	$208.14	$433.68	$479.60	$206.69	$109.61	$6.12	-	$96.11
Passenger Light-duty gas vehicle	$42.99	$14.85	$120.80	$257.10	$317.20	$157.59	$71.03	$3.91	-	$62.14
Passenger Rail Transport	$265.46	$40.32	$814.42	$2,099.97	$1,286.99	$498.73	$169.38	$17.72	-	-
Passenger Urban and School Diesel Bus	$13.60	$5.56	$69.41	$161.06	$67.57	$59.34	$40.77	$2.78	-	$22.65
Passenger Urban and School Gas Bus	$11.82	$2.19	$22.03	$49.75	$39.48	$18.11	$16.79	$0.76	-	$17.86
	Cost by Activity Level ($ / Passengers Travelled)									
All Transport Canada Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Marine Transport	$0.20	-	-	-	$0.72	$0.47	$0.30	$0.01	$0.00	$0.15

Unit Cost of Transport Related to Air Pollution by Activity Level (NO_2)

	Cost by Activity Level ($ / million tonne-km Travelled)									
Transport Canada Freight Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Freight Air Transport	$259.75	$223.02	$252.96	$251.47	$1,286.62	$996.84	$108.94	$51.99	-	$2.48
Freight Heavy-duty diesel vehicle	$4,043.05	$3,801.69	$4,856.49	$7,283.35	$10,349.58	$10,352.11	$2,433.11	$988.95	-	$399.16
Freight Heavy-duty gas vehicle	$7,314.85	$2,980.53	$3,241.24	$4,494.52	$7,746.12	$7,007.69	$2,410.09	$656.02	-	$554.41
Freight Light-duty diesel truck	$1,860.97	$8,006.62	$6,417.22	$9,493.19	$14,748.52	$16,563.77	$4,663.14	$1,921.30	-	$5,300.58
Freight Light-duty gas truck	$6,181.69	$6,960.54	$7,961.03	$8,739.02	$16,613.38	$18,963.09	$4,137.23	$1,259.65	-	$937.91
Freight Marine Transport	$1,723.98	-	-	-	$3,690.38	$4,019.90	$290.29	$67.21	-	$10.61
Freight Rail Transport	$955.31	$311.43	$672.51	$1,128.54	$3,404.66	$1,742.90	$215.15	$132.79	-	-
	Passenger*km Travelled (millions)									
Transport Canada Passenger Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Air Transport	$99.56	$98.16	$120.41	$112.36	$503.12	$412.67	$52.81	$31.02	-	$18.44
Passenger Interurban diesel bus	$1,536.32	$1,442.79	$1,770.85	$2,704.05	$3,915.54	$3,889.95	$949.31	$380.37	-	$271.08
Passenger Interurban gas bus	$1,059.24	$426.87	$452.92	$646.18	$1,136.76	$1,031.28	$353.61	$95.71	-	$201.90
Passenger Light-duty diesel truck	$642.66	$2,574.85	$1,979.47	$3,004.68	$4,842.43	$5,028.66	$1,421.73	$583.24	-	$580.04
Passenger Light-duty diesel vehicle	$2,839.85	$1,600.09	$1,342.47	$1,753.82	$5,432.18	$5,206.52	$844.57	$338.16	-	$377.10
Passenger Light-duty gas truck	$2,134.76	$2,238.44	$2,455.67	$2,765.98	$5,454.73	$5,757.08	$1,261.38	$382.38	-	$546.94
Passenger Light-duty gas vehicle	$1,995.21	$1,719.24	$1,938.29	$2,073.19	$4,338.46	$4,746.66	$918.16	$254.20	-	$356.73
Passenger Rail Transport	$7,111.02	$2,318.17	$5,005.99	$8,400.55	$25,343.24	$12,973.66	$1,601.52	$988.46	-	-
Passenger Urban and School Diesel Bus	$1,168.47	$1,184.50	$1,705.03	$2,465.67	$3,334.18	$3,433.69	$980.64	$382.59	-	$290.11
Passenger Urban and School Gas Bus	$656.71	$276.43	$345.19	$461.12	$806.69	$777.95	$285.49	$74.72	-	$170.59
	Cost by Activity Level ($ / Passengers Travelled)									
All Transport Canada Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Marine Transport	$0.96	-	-	-	$1.77	$1.95	$0.29	$0.07	$0.00	$0.08

Unit Cost of Transport Related to Air Pollution by Activity Level (VOC)

	Cost by Activity Level ($ / million tonne-km Travelled)									
Transport Canada Freight Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Freight Air Transport	$12.34	$40.08	$61.54	$27.02	$221.35	$139.99	$0.00	$0.00	$0.00	$0.00
Freight Heavy-duty diesel vehicle	$6.78	$18.46	$22.24	$13.94	$47.06	$38.60	$0.00	$0.00	$0.00	$0.00
Freight Heavy-duty gas vehicle	$98.97	$143.93	$210.17	$98.71	$318.68	$171.36	$0.00	$0.00	$0.00	$0.00
Freight Light-duty diesel truck	$34.06	$409.62	$274.14	$179.48	$803.46	$670.33	$0.00	$0.00	$0.00	$0.00
Freight Light-duty gas truck	$329.72	$1,241.28	$1,452.76	$609.08	$2,566.05	$2,267.76	$0.00	$0.00	$0.00	$0.00
Freight Marine Transport	$1.61	-	-	-	$66.56	$35.99	$0.00	$0.00	$0.00	$0.00
Freight Rail Transport	$1.95	$1.91	$3.50	$2.59	$23.63	$8.74	$0.00	$0.00	$0.00	$0.00
	Cost by Activity Level ($ / million Passenger*km Travelled)									
Transport Canada Passenger Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Air Transport	$4.73	$17.64	$29.29	$12.07	$86.56	$57.95	$0.00	$0.00	$0.00	$0.00
Passenger Interurban diesel bus	$2.58	$7.00	$8.11	$5.18	$17.80	$14.50	$0.00	$0.00	$0.00	$0.00
Passenger Interurban gas bus	$14.33	$20.61	$29.37	$14.19	$46.77	$25.22	$0.00	$0.00	$0.00	$0.00
Passenger Light-duty diesel truck	$11.76	$131.73	$84.56	$56.81	$263.80	$203.51	$0.00	$0.00	$0.00	$0.00
Passenger Light-duty diesel vehicle	$40.69	$64.10	$46.26	$25.50	$224.55	$154.28	$0.00	$0.00	$0.00	$0.00
Passenger Light-duty gas truck	$113.86	$399.18	$448.12	$192.78	$842.52	$688.48	$0.00	$0.00	$0.00	$0.00
Passenger Light-duty gas vehicle	$94.65	$276.85	$299.72	$125.89	$664.24	$511.78	$0.00	$0.00	$0.00	$0.00
Passenger Rail Transport	$14.49	$14.25	$26.06	$19.25	$175.86	$65.03	$0.00	$0.00	$0.00	$0.00
Passenger Urban and School Diesel Bus	$1.96	$5.75	$7.81	$4.72	$15.16	$12.80	$0.00	$0.00	$0.00	$0.00
Passenger Urban and School Gas Bus	$8.89	$13.35	$22.38	$10.13	$33.19	$19.02	$0.00	$0.00	$0.00	$0.00
	Cost by Activity Level ($ / Passengers Travelled)									
All Transport Canada Modes	**BC**	**AB**	**SK**	**MB**	**ON**	**QC**	**NB**	**NS**	**PEI**	**NFL**
Passenger Marine Transport	$0.00	-	-	-	$0.03	$0.02	$0.00	$0.00	$0.00	$0.00