AIR TOXICS EMISSION INVENTORY AND HEALTH RISK ASSESSMENT - SUMMARY REPORT

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EXECUTIVE SUMMARY

Air toxics, sometimes referred to as hazardous air pollutants (HAPs), are primarily generated through human activities and are known or suspected to cause harmful effects on human health or the environment. There is growing evidence that human health impacts of toxic emissions are significant. The Greater Vancouver Regional District (GVRD), in recognition of the importance of air toxics and the need to investigate the issue further, commissioned this study in partnership with Environment Canada to:

- Develop an inventory of emissions of air toxics for the Lower Fraser Valley[1] (LFV), including the spatial distribution of emissions and a forecast of emissions to 2025;
- Conduct a preliminary evaluation of the risk to human health from air toxics emissions in the LFV. It was expected from the outset that some data gaps and deficiencies would be identified and that simplifying assumptions would be needed to complete the assessment; and
- Recommend activities and methods that would yield improved future regional health risk assessments and facilitate expansion of the scope of the risk assessment to include the Georgia Basin/Puget Sound International Airshed and the rest of British Columbia

Air Toxics Emission Inventory

The air toxics emission inventory focused on the same emission sources and sectors used in existing LFV inventories for criteria air contaminants and greenhouse gases, namely point sources (large industrial), area sources (lighter industrial, commercial, institutional, residential, agricultural and naturally-occurring sources) and mobile sources (motor vehicles, non-road engines and equipment, aircraft, locomotives, and marine vessels).

A list of 291 toxic substances and/or chemical groupings were targeted for inclusion in the inventory. The substance list included in the emission inventory was developed from review of an earlier study of hazardous air pollutants in the LFV (Levelton and Alchemy, 1998), substances declared as toxic under the Canadian Environmental Protection Act and the United States Environmental Protection Agency's (U.S. EPA) list of HAPs.

Emissions were quantified for 158 substances on the list. For the remaining substances, the available methods did not lead to a quantifiable emission result, but this should not be interpreted as meaning that the emissions are zero. Table S-1 summarizes year 2000 emissions of the top 18 substances. The listing in Table S-1 is only a listing of air toxics in terms of the quantity of emissions estimated for this study, and does not imply prioritization in terms of health risk.

Regional emissions were allocated to the census tract level in the GVRD, FVRD and Whatcom County, and were also forecast, in five year increments, to the year 2025. An air toxics database system was developed for this study using MS Access, which allows custom querying and report generation, so that emissions can be analyzed by substance, source, year, location and other parameters.

[1] The Lower Fraser Valley area encompasses the Greater Vancouver Regional District, the southwestern portion of Fraser Valley Regional District and Whatcom County in the State of Washington.

Table ES-1: LFV Air Toxics Emission Estimates for 2000 (Top 18 Substances)

Substance*	Emissions (metric tonnes)				
	Point	Area	Onroad	Non-road	Total
PM_{10} (Respirable particulate matter less than or equal to 10 microns)	4,660.9	6,938.1	9,677.2	2,594.9	23,871.2
Ammonia (NH_3)	672.8	16,516.9	1,064.9	87.5	18,342.1
$PM_{2.5}$ (fine particulate matter less than or equal to 2.5 microns)	1,791.2	3,708.9	1,191.0	2,518.6	9,209.6
Methanol	77.1	6,329.3			6,406.4
Toluene	141.8	825.0	3,619.9	730.2	5,316.9
Acetone	81.4	4,755.8			4,837.3
Xylenes (mixed isomers)	129.6	732.4	2,021.5	580.0	3,463.5
Diesel particulate matter	8.2		440.0	2,215.8	2,663.9
Aluminum (fume or dust)	12.3	882.7	926.6	2.8	1,824.4
Iso-octane (2,2,4-trimethyl pentane)	0.35	20.3	1,284.3	240.9	1,545.9
Acetaldehyde	25.6	982.4	108.8	265.0	1,381.8
Benzene	20.5	176.2	654.3	322.0	1,173.0
n-Hexane	77.6	306.6	676.0	107.9	1,168.2
Formaldehyde	22.0	70.7	325.1	622.4	1,040.2
Ethylbenzene	7.0	54.4	552.3	152.3	766.0
Isopropyl alcohol	91.5	536.8			628.3
Methyl ethyl ketone (MEK)	101.3	418.0			519.4
n-Butyl alcohol	16.5	450.8			467.3

* Notes: Substances are listed in order of quantity of emissions estimated; the listing does not imply any prioritization in terms of health risk.

Particulate matter (PM) emissions include road dust.

Assessment of Human Health Risk from Exposure to Selected Air Toxics

Starting from the list of substances used in the air toxics inventory, a subset of substances was identified for inclusion in the health risk assessment, using the following criteria:

1. **Precedence in the literature** – substance identified as a priority in other health risk assessments.
2. **Availability of health risk information** from recognized sources[2] – In general this meant that concentration response factors existed to relate the exposure concentrations of substances to human health impacts. These response factors include both ***unit risk factors***, which estimate the additional risk of developing cancer, and ***reference exposure levels***, which have been established through animal or epidemiological studies and reflect concentrations below which adverse health effects are not anticipated to occur.
3. **Availability of data to estimate the concentrations** – Measurements or predictions of the average concentration of air toxics to which the public would be exposed on a long-term basis.
4. **Risk characterization** – A screening analysis was done by comparing exposure concentrations from (3) above to concentration response factors (2) which yielded estimates of 70-year lifetime cancer risk, expressed in ***cancer incidences per million population***, and a ***hazard quotient***, where a quotient below 1.0 is not anticipated to

[2] Health Canada, the U.S. EPA, World Health Organization and California Environmental Protection Agency

result in adverse (non-cancer) health effects. Substances for which the estimated cancer risk was greater than 1 in one million, or where the hazard quotient was greater than 0.1, were included in the health risk assessment. These values represent one tenth the acceptable risk thresholds[3], and are believed to provide a suitable margin of safety for substance prioritization.

Through this process, 45 substances or groupings were prioritized for inclusion in the regional health risk assessment. Exposure concentrations were developed for the prioritized substances based on existing estimates (Whatcom County) or ambient air monitoring data (Canadian LFV).

Figure S-1 shows the estimated cancer risk in 2000. The charts show the estimated 70-year lifetime cancer risk, in incidences per million population, as well as the contributions of key substances to that risk. The GVRD value is an average of five zones, which were calculated to have a median incremental lifetime cancer risks of 526 cancer incidences per million. It can be seen that diesel particulate matter (diesel PM) is a key driver of human health risk. Sources of diesel PM include on-road diesel vehicles, marine vessels, and non-road engines. Of the other significant risk drivers, three substances (benzene, formaldehyde, and 1,3-butadiene) are predominantly from mobile sources, with lesser contributions from point and area sources. Hexavalent chromium and carbon tetrachloride are more heavily influenced by point and area sources.

[3] Sources: U.S. EPA (www.epa.gov/ttn/atw/) and Health Canada (2003)

Figure ES-1: Apportionment of the 70 Year Lifetime Cancer Risk in the LFV

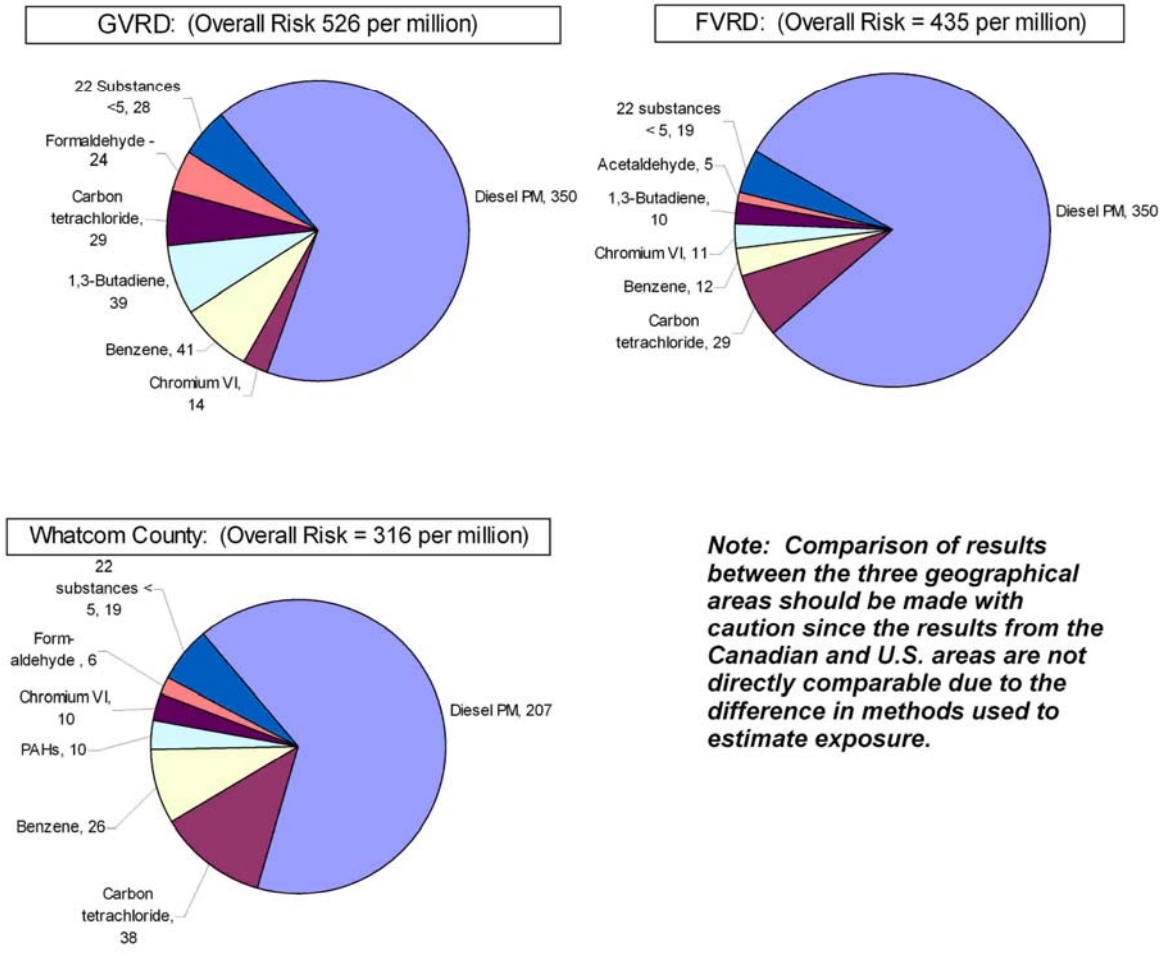
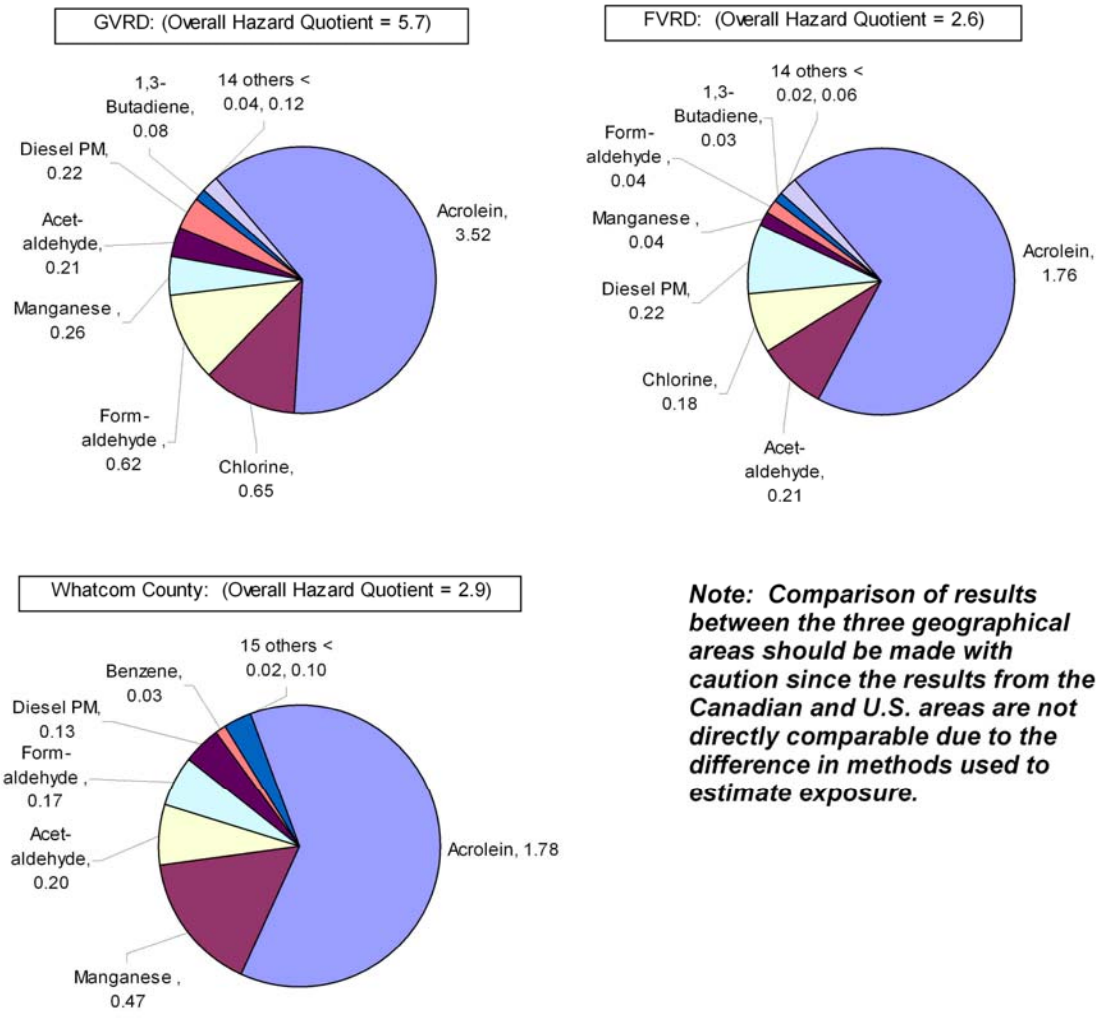


Figure S-2 shows the substance-specific hazard quotients in the three areas, as well as an overall summation of the individual quotients, sometimes referred to as a hazard index. It is important to note that the presentation of an overall hazard index shown relies on a conservative, screening level assumption that all substances shown have toxic and additive effects on a single organ system, which tends to over-estimate cumulative non-cancer risk.

Acrolein was found to be the largest contributor to the hazard index in all three areas, but this finding is based on a limited amount of monitoring data for acrolein in the GVRD and FVRD. According to the inventory, acrolein emissions originate from a variety of sources including non-road sources (commercial jets and recreational marine vessels), gasoline-fueled motor vehicles, structural fires, landclearing operations, wood and paper products industries and electric power generation.

Figure ES-2: Apportionment of the Chronic Hazard Quotient in the LFV



Note: Comparison of results between the three geographical areas should be made with caution since the results from the Canadian and U.S. areas are not directly comparable due to the difference in methods used to estimate exposure.

Comparison to Other Studies

Direct comparison of the cancer and non-cancer risk presented in this assessment with other published values is difficult since the methodology, substances included, and exposure pathways considered can vary substantially between studies. In particular, many U.S. studies have focused on the U.S. EPA's NATA list of 33 hazardous air pollutants. Since the inclusion of a greater number of substances and a conservatively high estimate of the exposure to diesel particulate matter used in this study will tend to increase the cumulative risk, the risk estimates presented for the Canadian LFV may be high relative to other studies. Although not directly comparable, a study conducted for the Puget Sound area estimated cancer risk from 447 to 622 per million population, and a hazard index of 6.2 (Keill and Maykut, 2003), based on ASPEN and NATA. Other studies conducted for Portland, Oregon, the South Coast air basin (California), Minnesota and Queen's, New York were reviewed, with cancer risk ranging from 27 to as high as 1470 per million, and hazard indices from less than 1 to nearly 60. Again, the methods used in these studies differ considerably.

Risk Forecast

Health risk was forecast to the year 2025, as summarized in Table S-2. Ambient concentrations were forecast based on the emission inventory forecast, with the assumption that concentrations change in proportion to emissions. This is compounded by uncertainty in the toxics emission inventory forecast, which as noted above, assumes that toxics emissions change in proportion to CAC emissions.

Significant reductions in per capita cancer risks are projected to occur in the GVRD and FVRD, primarily as a result of forecast reductions in diesel PM emissions. In Whatcom County, the forecast of mobile emissions was based on data provided by the Washington State Department of Ecology, and does not project a substantial reduction in diesel emissions. As a result, the per capita cancer risk in Whatcom County is not projected to show the same reduction trend as the Canadian LFV.

Table ES-2: Risk Assessment Forecast

Region	2000	2005	2010	2015	2020	2025	Percent Change 2000-2025
Projected Cancer Risk (Cancers Per Million Population per 70 Year Lifetime)							
GVRD	526	472	449	424	418	432	-17.8%
FVRD	435	360	298	233	187	163	-62.5%
Whatcom County	316	391	378	378	384	392	23.8%
Projected Changes in the Total Hazard Index							
GVRD	5.7	4.8	4.2	3.9	3.9	3.9	-31.1%
FVRD	2.6	2.1	1.9	1.7	1.6	1.6	-36.1%
Whatcom County	2.9	3.9	3.7	3.7	3.7	3.7	29.4%

Note: Predicted trends in the Projected Cancer Risks are highly sensitivity to the projected change in diesel emissions.

Assumptions and Uncertainties

The key assumptions in the health risk assessment are summarized below.

- The substance list used for the health risk assessment is derived from other lists, and only includes those substances for which ambient concentrations are monitored or could be estimated, and for which concentration response factors are available. There is a possibility that some locally significant toxics have been overlooked.
- Locally collected monitoring data was assumed to be representative of average ambient concentrations, and in some cases extrapolated to other areas or zones. Regional or zone annual average concentrations may not reflect localized hot spots or fixed duration episodes.
- The risk characterization methodology considers outdoor, inhalation exposure only.
- Toxic effects from multiple substances are assumed to act in an additive fashion on a single human organ system, with no synergistic effects. This assumption allows the summation of effects to derive cumulative cancer risk and hazard indices.
- Direct monitoring of diesel particulate matter and hexavalent chromium is not available in the Canadian LFV, necessitating an estimation from elemental carbon and total chromium measurements, respectively.
- Ambient concentrations are assumed in some cases to change in proportion to the emission inventory, i.e., scaling up ambient concentrations in Whatcom County from 1996 to 2000, and to develop forecasts of ambient concentrations to 2025.

- Emission forecasts assume that air toxics emissions change in proportion to CAC emissions.
- "Double-counting" of health effects may occur where substances assessed overlap with each other. Notably many metals and hydrocarbons may contribute to the health effects associated with Diesel PM. Since these were calculated separately in this assessment there may be overlaps in the estimated health effects.

Recommendations for Improved Future Regional Health Risk Assessments

A number of the assumptions noted above were necessitated because of data gaps and deficiencies in the information needed to prepare a regional health risk assessment. While the risk assessment is preliminary, one of the purposes in preparing it was to assess the currently available methods and make recommendations to improve future health risk assessments in the region.

Emission Inventory

- Continue partnership efforts with other programs which include air toxics reporting, such as NPRI.
- Make better use of data collected through GVRD permits.
- Maintain ongoing research on speciation, region-specific monitoring.
- Improve air toxics emissions forecasts by taking into account toxic-specific reduction initiatives, rather than assuming toxics change in proportion to CAC emissions.

Health Risk Assessment

- Additional research is needed on identifying priority toxics, using the toxics inventory, ambient monitoring data, and a review of regulated sources.
- Work with partners such as Environment Canada to apply the ASPEN model within the Canadian LFV, or if necessary, to develop a Canadian equivalent to the ASPEN model.
- Add additional air toxics monitoring capabilities in the LFV, focusing on: key risk drivers; areas which currently are under-monitored; areas of higher population or expected growth; and "hot spots" predicted by spatial data from the inventory, knowledge of the location of significant emission sources, or modeling approaches (when developed). Supplement monitoring capabilities with mobile equipment, to allow deployment for special studies.
- Work towards a combined modeling and monitoring approach for air toxics in the LFV.
- Add more temporal resolution to the health risk assessment, to examine for example, acute impacts from short term exposure and seasonal variation in ambient concentrations of air toxics.
- Risk forecasts should consider population changes and emission distribution changes.
- Future assessments would benefit from locally collected human time activity patterns or an assessment of the relationship between outdoor concentrations and personal exposure.
- Models such as those developed by the World Health Organization, evaluating indoor exposure to air toxics, should be assessed.

Emerging Issues

- Further study should be directed towards improving the estimation of exposure concentrations for two important risk drivers - diesel particulate matter and hexavalent chromium. In this study, surrogates have been used, such as elemental carbon and total chromium compounds.
- Wood smoke is believed to be an important air toxic, but data on emissions, exposure concentrations and concentration response factors needs to be improved. Studies on

residential wood burning in other parts of B.C., and underway at UBC, should continue to be monitored.

- Future attention should be paid to sensitizing agents such as toluene diisocyanates.
- Nitro-aromatics (such as nitrated PAHs and nitrated dioxins and furans) have been identified as an emerging issue. While specific substance lists are not yet available, this category could warrant additional study.

Regional Policy

- A first step in the development of GVRD policy would be to adopt a definition of "air toxics" or "hazardous air pollutants", followed by an identification of priority substances and sources.
- Use the key risk driver substances and source contributors determined in this study when developing future emission reduction plans. Note that the findings of this study have already been used in a parallel study on "Best Management Practices and Regulatory Guidelines for Managing Emissions of HAPs from Stationary Sources in the GVRD" (Stratos and Levelton, 2004).

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ASIL	Acceptable Source Impact Level
ASPEN	Assessment System for Population Exposure Nationwide
ATSDR	Agency for Toxic Substances and Disease Registry (U.S. Department of Health and Human Services
BACT	Best Available Control Technology
BC MWLAP	BC Ministry Of Water, Land and Air Protection
CACs	Criteria air contaminants
CalEPA	California Environmental Protection Agency
CARB	Air Resources Board of California
CAS	Chemical Abstracts Service
CCME	Canadian Council of Ministers of the Environment
CCPA	Canadian Chemical Producers Association
CEPA	Canadian Environmental Protection Act
COA	Canada Ontario Agreement
CRF	Concentration Response Factor
CT	Census tract
DOE	Washington State Department of Ecology
EIIP	Emission Inventory Improvement Program
FVRD	Fraser Valley Regional District
GHGs	Greenhouse gases
GLBTS	Great Lakes Binational Toxics Strategy
GVRD	Greater Vancouver Regional District
HAPEM4	Hazardous Air Pollutant Exposure Model
HAPs	Hazardous Air Pollutant
HI	Hazard index
HQ	Hazard quotient
IRIS	Integrated Risk Information System
LFV	Lower Fraser Valley
MACT	Maximum Available Control Technology
MATES-II	Multiple Air Toxics Exposure Study
Mf	Modifying factor
MRL	Minimal Risk Level
NAAEC	North American Agreement on Environmental Cooperation
NAPS	National Air Pollution Surveillance
NATA	National Air Toxics Assessment

NEI	National Emission Inventory (U.S. EPA)
NERM	National Emission Reduction Masterplan (CCPA)
NESHAPS	National Emission Standards For Hazardous Air Pollutants
NMIM	National Mobile Inventory Model
NOAEL	No observed adverse effect level
NPRI	National Pollutant Release Inventory
NWAPA	Northwest Air Pollution Authority
OEHHA	Office of Environmental Health Hazard Assessment (California)
PERC	Perchloroethylene
POI	Point of impingement
PSCAA	Puget Sound Clean Air Agency
QA/QC	Quality assurance / quality control
RCE	Ratio of concentration to emissions
REL	Reference exposure level
RfC	Reference concentration
SCC	Source classification code
SRI	Sustainable Region Initiative
TC	Tolerable concentration
TCE	Trichloroethylene
TEQ	Toxic equivalence
TLV	Threshold limit value
TSMP	Canadian Toxic Substance Management Policy
Uc	Uncertainty factor
$\mu g/m^3$	Micrograms per cubic metre
UNECE	U.N. Economic Committee for Environment
UR	Unit risk
U.S. EPA	United States Environmental Protection Agency
VOC	volatile organic compound
WHO	World Health Organization

1 INTRODUCTION

Air toxics, sometimes referred to as hazardous air pollutants (HAPs), are primarily generated through human activities and are known or suspected to cause harmful effects on human health or the environment. There is growing evidence that human health impacts of toxic emissions are significant. For example, diesel particulate matter has been implicated in cancer risk in urban areas, as well as a contributor to increased asthma attacks, excess deaths and other health issues. An air toxics evaluation prepared for the Puget Sound area in Washington in 2003 places diesel particulate matter at "somewhere between 70% to 85% of the total cancer risk from air toxics" in that area (between 420 and 531 cancer incidences per million population over a 70 year lifetime).

The Greater Vancouver Regional District (GVRD) recognizes the importance of air toxics emissions in the airshed, and the need to investigate the issue. In partnership with Environment Canada, the GVRD has commissioned this study to:

- Develop a spatially distributed air toxics emission inventory for the Lower Fraser Valley[4] (LFV) area in 2000 and forecast, in five-year increments, through to 2025;
- Evaluate the risk to human health from air toxics emissions in the LFV, using existing data and a methodology developed in the study;
- Develop a methodology to improve the above health risk assessment and to expand the scope to include the Georgia Basin/Puget Sound International Airshed and the rest of British Columbia

It should be emphasized that the intent of the health risk assessment developed in this study was to prepare a preliminary regional human health risk assessment based on the information which was available at the time this report was prepared. It was expected from the outset that some deficiencies would be identified and that some simplifying assumptions would be needed to complete the assessment. In carrying out the assessment, data gaps and deficiencies were identified, allowing for recommendations to be made on how to improve future regional health risk assessment efforts. This analysis does not generate a highly accurate assessment of regional health risk, rather it should be considered a preliminary assessment upon which further research and development can be conducted.

The key findings and recommendations of this study are summarized by task area in the following sections.

2 AIR TOXICS EMISSION INVENTORY

The air toxics emission inventory focused on the same emission sources and sectors used in existing LFV inventories for criteria air contaminants and greenhouse gases, namely point, area and mobile sources. Point sources are large industrial sources operating under a permit from one of the respective regulatory agencies in the GVRD, FVRD or Whatcom County, while area sources include lighter industrial, commercial, institutional, and residential sources as well as agricultural activities and naturally-occurring sources. Mobile sources include onroad motor vehicles, non-road engines and equipment, aircraft, railway locomotives, and marine vessels.

[4] The Lower Fraser Valley area encompasses the Greater Vancouver Regional District, the southwestern portion of Fraser Valley Regional District and Whatcom County in the State of Washington.

A list of 291 toxic substances were targeted for inclusion in the inventory. The substance list was derived primarily from an earlier assessment of hazardous air pollutants in the LFV (Levelton and Alchemy, 1998), substances declared as toxic under the Canadian Environmental Protection Act (CEPA, Schedule 1) and the United States Environmental Protection Agency's (U.S. EPA) list of 188 hazardous air pollutants. The 291 substances are not unique – there is some duplication within the list because of substance groupings, substances which are a subset of others, etc. In addition to the 291 toxics, 15 criteria air contaminants and greenhouse gases were also tracked in the inventory, to facilitate comparison to existing inventories and in an effort to harmonize inventory information.

A conventional hierarchy of emission inventory methodologies was applied in this study, ranging from air toxics sampling and monitoring data, to data reported to other emission inventory programs[5], available emission factors and models for air toxics, and speciation profiles which estimate air toxics as a fraction of total particulate or total volatile organic compound (VOC) emissions. These methods are listed in order of decreasing preference, and in this study, the estimates resulting from the least uncertain method were used. The reader is directed to Section 2 of the Technical Appendix for a detailed description of the methodologies used.

Emissions were quantified for 158 substances on the list. For the remaining substances, the available methods did not lead to a quantifiable emission result, but this should not be interpreted as meaning that the emissions are zero. Table 1 summarizes year 2000 emissions of the top 20 substances, which are also emissions estimated at greater than 100 tonnes for that year. The listing in Table S-1 is only a listing of air toxics in terms of the quantity of emissions estimated for this study – it does not imply prioritization in terms of health risk. Full results of the emissions inventory are available in Section 3 of the Technical Appendix.

An air toxics database, developed for this study using MS Access, is one of the deliverables of this project. It contains information on substances, sources, spatial data and forecasts. The database has been designed with pivot tables to allow custom querying and report generation, so that emissions can be analyzed by substance, source, year, location and other parameters.

Emissions were spatially allocated to census tracts in the GVRD, FVRD and Whatcom County. They were also forecast, in five year increments, to the year 2025. To develop the forecast, air toxic emissions were estimated to change in proportion to criteria air contaminant emissions, using the growth rates previously developed by GVRD and others for the Canadian LFV and Whatcom County. This approach does not take into account toxic-specific reduction initiatives, such as: CEPA or other regulations; substance bans, quotas or elimination programs; and product reformulation or substitution initiatives.

[5] The National Pollutant Release Inventory in Canada, and the National Emission Inventory and Toxics Release Inventory in the U.S.

Table 1: LFV Air Toxics Emission Estimates for 2000 (Top 20 Substances) *

Substance	Emissions (metric tonnes)				
	Point	Area	Onroad	Non-road	Total
PM_{10} (Respirable particulate matter less than or equal to 10	4,660.9	6,938.1	9,677.2	2,594.9	23,871.2
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Aluminum (fume or dust)	12.3	882.7	926.6	2.8	1,824.4
Iso-octane (2,2,4-trimethyl pentane)	0.35	20.3	1,284.3	240.9	1,545.9
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* Notes: Substances are listed in order of quantity of emissions estimated; the listing does not imply any prioritization in terms of health risk.

Particulate matter (PM) emissions include road dust.

3 ASSESSMENT OF HUMAN HEALTH RISK FROM EXPOSURE TO SELECTED AIR TOXICS

A preliminary assessment of regional human health risk from exposure to air toxics has been prepared based on the available information. This analysis led to an identification of data gaps and deficiencies which lead into the next task area of the study, to provide recommendations for improving future regional health risk assessments.

Starting from the list of substances used in the air toxics inventory, a subset of prioritized substances was identified for inclusion in the health risk assessment, using the following criteria:

1. Precedence in the literature, i.e., substance identified as a priority in other health risk assessments.

2. Availability of health risk information. In general this meant that concentration response factors existed to relate exposure concentrations to human health impacts. Health risk information was obtained from Health Canada, the U.S. EPA, World Health Organization and California Environmental Protection Agency. Concentration response factors included both ***unit risk factors***, which estimate the additional risk of developing cancer given a 1 $\mu g/m^3$ (one microgram per cubic metre) increase in the lifetime exposure concentration of a given substance, and ***reference exposure levels***, which are a toxicological threshold concentration below which non-cancer health risks[6] are not anticipated.

[6] Non cancer health outcomes can include a wide variety of health effects, such as liver or kidney toxicity, effects on the immune or reproductive systems, elevated blood pressure or chronic obstructive lung disease.

3. Availability of exposure estimate. In Whatcom County, limited data was available on monitored concentrations of air toxics in the ambient air. However, exposure concentrations for 33 toxic substances were available as a result of the U.S. EPA's NATA (National Air Toxics Assessment) program, which uses the ASPEN model (Assessment System for Population Exposure Nationwide) to estimate ambient concentrations of toxics, based on emission inventory and meteorological data. The model then estimates human exposure concentration with consideration of human activity patterns. NATA data was available for 1996 for all counties and census tracts in the United States. In the Canadian LFV, an equivalent model was not available, so it was necessary to rely almost exclusively on ambient air monitoring data to estimate exposure concentrations. The monitoring network in the Canadian LFV is extensive, and includes monitoring of individual VOC compounds (some of which are toxic) and metals.

4. Risk characterization. Health risk estimates existed for Whatcom County from the NATA results. For the GVRD and FVRD, monitored average annual concentrations of substances were compared to the concentration response factors described in (2) above. Application of unit risk factors to ambient concentrations yields an estimate of lifetime cancer risk, typically expressed in units of ***cancer incidences per million population***. Similarly, the ratio of observed concentration to a reference exposure levels results in a ***hazard quotient***, where a quotient below 1.0 is not anticipated to result in adverse (non-cancer) health effects. For this study; a screening comparison was done to prioritize substances for inclusion in the health risk assessment. Substances for which the estimated cancer risk was greater than 1 in one million, or where the hazard quotient was greater than 0.1, were included. These values represent one tenth the acceptable risk thresholds[7], and are believed to provide a suitable margin of safety for substance prioritization.

Through this process, 45 substances or groupings were prioritized for inclusion in the regional health risk assessment.

The first step in the assessment was to establish exposure concentrations for the prioritized substances. As noted above, exposure estimates were available for 33 substances in Whatcom County for 1996. These exposure estimates were adjusted to year 2000 values, based on the ratio of emissions in 2000 to 1996. The NATA data includes contributions of point, area and mobile sources to ambient concentrations, as well as a background component which is attributed to natural sources, emissions transported from outside the area, and pollutants which may persist from historical emissions. Only the point, area and mobile components were scaled up, with the background amounts held constant.

For the Canadian LFV, it was found that, in spite of the extensiveness of the monitoring network, toxics monitoring data was somewhat limited in terms of the substances included and the spatial coverage. To facilitate the estimation of exposure concentrations in the Canadian LFV, census tracts were grouped to form seven exposure zones, based on proximity to emission sources, land use and population distribution, overview of the regional meteorology, and location of air quality monitoring sites. Ambient concentrations were estimated for each zone, using the available monitoring data, and assumed to be constant throughout each zone (see Section 4 of the Technical Appendix). Where monitoring data was not available, ambient concentrations were estimated from the emission inventory estimates, by applying relationships between ambient concentrations and emissions, developed from the NATA data for all urban counties in Washington State (see Appendix C of the Technical Appendix).

The results of the health risk assessment for GVRD, FVRD and Whatcom County, are summarized in Sections 3.1 (Cancer Risk) and 3.2 (non-cancer risk) and discussed in greater

[7] Sources: U.S. EPA (www.epa.gov/ttn/atw/) and Health Canada (2003)

detail in Section 5 of the Technical Appendix. Comparison of results between the three geographical areas should be made with caution; the results of the Canadian and U.S. areas are not directly comparable due to the difference in methods used to estimate exposure.

3.1 CANCER RISK

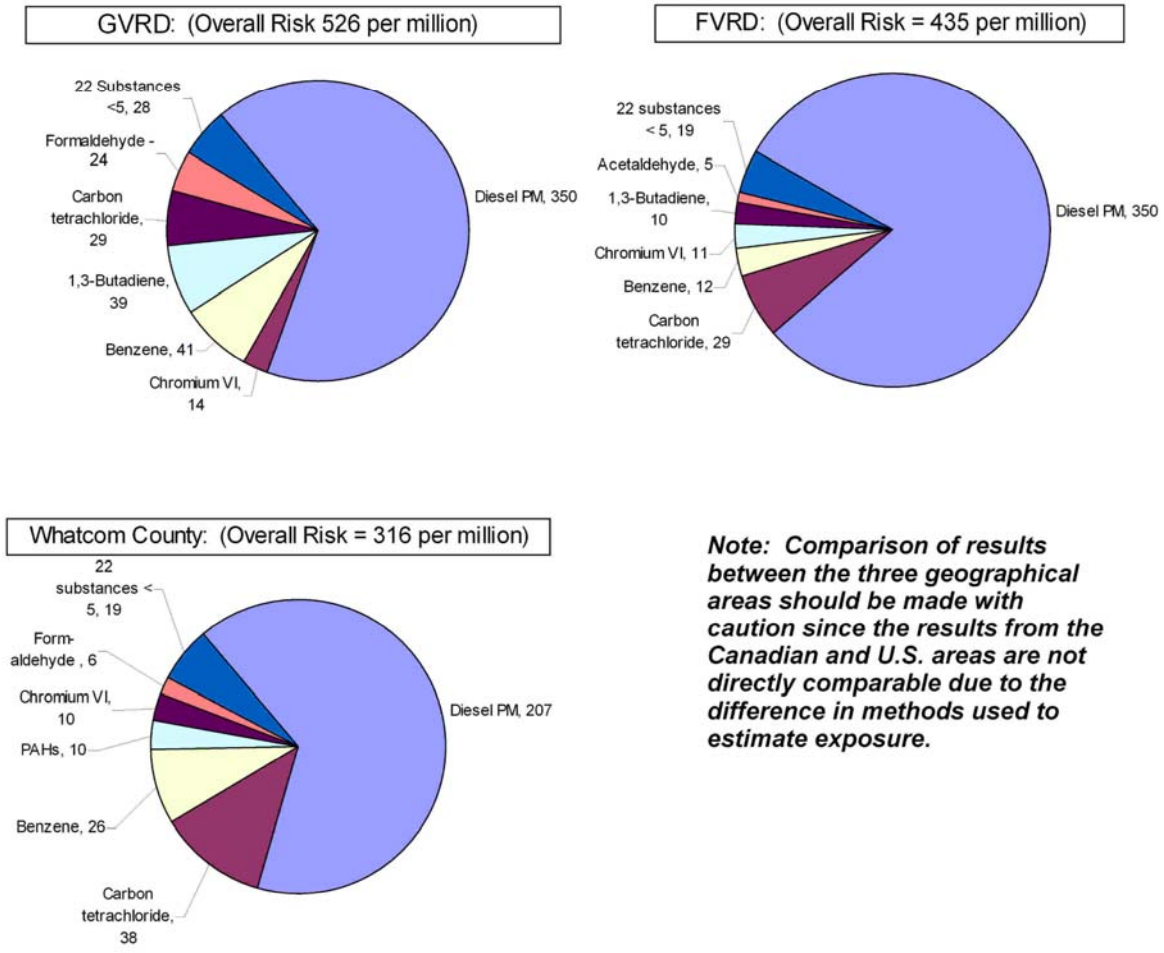
Figure 1 shows the estimated cancer risk in 2000. The charts show the predicted 70 year lifetime cancer risk per million inhabitants through inhalation exposure to the air toxics included in this assessment. There are large uncertainties involved in predicting cancer risks. The risk that is illustrated in Figure 1 represents the risk associated with exposure to the median concentration of each substance continuously for 70 years. An analysis of the 5^{th} and 95^{th} percentile concentrations monitored in the study area suggests that the actual risk may range from 302 to 1025 cancers per million inhabitants in the GVRD and 259 to 832 cancers per million population in the FVRD.

The GVRD value is an average of five zones, which ranged from 482 to 594 cancers per million inhabitants per 70 year lifetime. It can be seen that diesel particulate matter (diesel PM) is a key driver of human health risk. Sources of diesel PM include on-road diesel vehicles, marine vessels, and non-road engines. Of the other significant risk drivers, three substances (benzene, formaldehyde, and 1,3-butadiene) are predominantly from mobile sources, with lesser contributions from point and area sources. Hexavalent chromium and carbon tetrachloride are more heavily influenced by point and area sources. The fine fraction of particulate matter ($PM_{2.5}$) is estimated to be emitted from a wide variety of point, area and mobile sources.

The sensitivity of the risk assessment to the uncertainties related to diesel PM exposure and health risk factors needs to be highlighted. Inclusion of diesel particulate matter as in this assessment is based on the derivation of a unit risk factor by the California EPA that was based primarily on epidemiological studies of railway worker and, thus, has an unclear relationship to the population at large. It must also be noted that the US EPA and IARC have reviewed the same existing health research and concluded that diesel PM is a “likely” or “probably” carcinogen, but that the data was insufficient to support agreement on a unit risk factor. The link between diesel exposure and cancer remains the subject of continued scientific debate. As a result inclusion of diesel PM in this assessment may overestimate the cancer risk. A discussion of the sources of uncertainty in the risk assessment, and the effects of uncertainty in the input data on predicted health risks is provided in Section 5.6 of the Technical Appendix.

In addition, the exposure to diesel PM was estimated in this study from 3 years of ambient measurements (2003-2005) of elemental carbon (EC), which typically comprises about 75% of diesel PM, and the application of a conversion factor. The EPA has suggested that the conversion factor may range from 0.62 to 1.31. The South Coast Air Quality Management District in California estimated has used a factor to convert from EC to diesel PM of 1.24, which is the value used in this assessment. The selection of this factor can have a large influence on the predicted health outcomes in the region. This value was selected to yield a conservative estimate of exposure and one which is closer to the diesel PM values produced through other methods of estimation (Brauer, 2006). Using positive matrix factorization, the percent of diesel PM in ambient $PM_{2.5}$ in Seattle was estimated at 18% (Keill and Maykut, 2003). With the assumed conversion factor, diesel PM comprises 19% of the $PM_{2.5}$ in the LFV, similar to that found for Seattle. As an illustration of the sensitivity of the risk analysis to assumptions used to estimate exposure to diesel PM, the range of lifetime cancer risks from diesel PM can vary from 182 to 706 cancers per million depending on the combination of elemental carbon concentrations (5^{th} to 95^{th} percentile) and conversion factors used.

Figure 1: Apportionment of the 70 Year Lifetime Cancer Risk in the LFV



Note: Comparison of results between the three geographical areas should be made with caution since the results from the Canadian and U.S. areas are not directly comparable due to the difference in methods used to estimate exposure.

In addition to the other sources of uncertainty, Diesel PM is subject to large spatial variations in concentration. Spatial variation of 5x have been reported in diesel PM concentrations (Brauer 2006). As a result the use of a limited number of fixed monitoring locations to develop exposure estimates for the entire region, also introduces large amount of uncertainty in the Diesel PM estimates.

With the exception of diesel PM, this assessment did not assess the cancer risk associated with ambient particulate matter. This may underestimate the cancer risk in the region. The original health research did not distinguish between diesel PM and the remaining 80%. Thus it is unclear whether the health effects that have been associated with PM exposure are independent of the health effects associated with diesel PM exposure. If it is assumed that they are, this assessment may underestimate lifetime cancer risk by an average 15-20 cancers per million per lifetime based on ambient $PM_{2.5}$ concentrations.

3.2 NON-CANCER RISKS

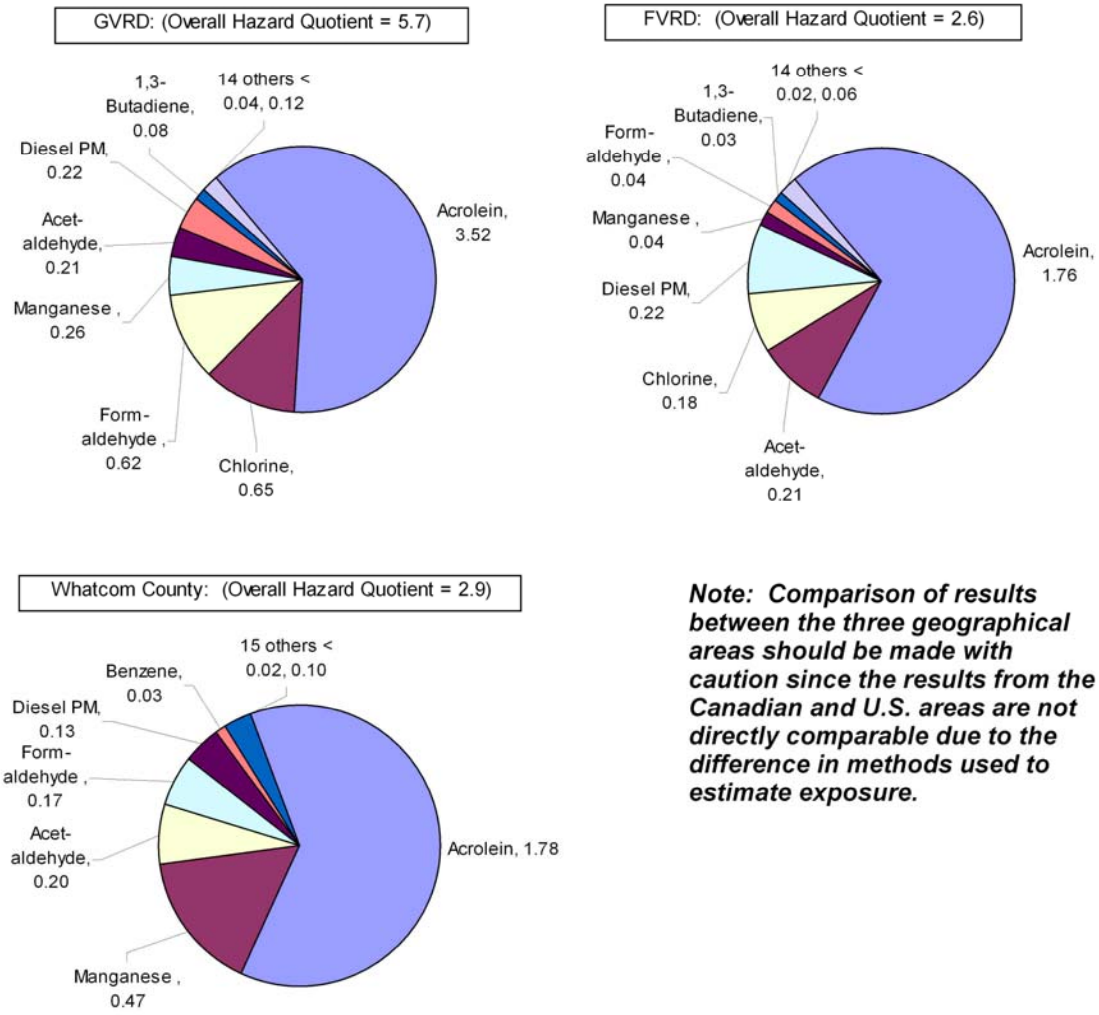
Non-cancer health outcomes can include a wide variety of health effects, such as liver or kidney toxicity, effects on the immune or reproductive systems, elevated blood pressure or chronic

obstructive lung disease. These non-cancer health outcomes are assumed to have a toxicological threshold, below which no adverse effects are anticipated. Non-Cancer health risks are measured using hazard quotients, where a value below 1.0 is not anticipated to result in adverse health effects.

Figure 2 shows the substance-specific hazard quotients in the three areas, as well as an overall summation of the individual quotients, sometimes referred to as a hazard index. It is important to note that the presentation of an overall hazard index shown relies on a conservative, screening level assumption that all substances shown have toxic and additive effects on a single organ system, which tends to over-estimate cumulative non-cancer risk.

Acrolein was found to be the largest contributor to the hazard index in all three areas, but this finding is based on a limited amount of monitoring data for acrolein in the GVRD and FVRD. According to the inventory, acrolein emissions originate from a variety of sources including non-road sources (commercial jets and recreational marine vessels), gasoline-fueled motor vehicles, structural fires, land clearing operations, wood and paper products industries and electric power generation.

Figure 2: Apportionment of the Chronic Hazard Quotient in the LFV



Note: Comparison of results between the three geographical areas should be made with caution since the results from the Canadian and U.S. areas are not directly comparable due to the difference in methods used to estimate exposure.

3.3 COMPARISON TO OTHER STUDIES

Direct comparison of the cancer and non-cancer risk presented in this assessment with other published values is difficult since the methodology, substances included, and exposure pathways considered can vary substantially between studies. In particular, many U.S. studies have focused on the U.S. EPA's NATA list of 33 hazardous air pollutants. Since the inclusion of a greater number of substances will tend to increase the cumulative risk, the risk estimates presented for the Canadian LFV may be high relative to other studies. Although not directly comparable, a study conducted for the Puget Sound area estimated cancer risk from 447 to 622 per million population, and a hazard index of 6.2 (Keill and Maykut, 2003), based on ASPEN and NATA. The results presented in this assessment are similar in magnitude to those reported by Keill and Maykut (2003). Other studies conducted in Portland, Oregon, the South Coast air basin (California), Minnesota and Queen's, New York were reviewed, with cancer risk ranging from 27 to as high as 1470 per million, and hazard indices from less than 1 to nearly 60. Again, the methods used in these studies varied considerably.

3.4 RISK FORECAST

Health risk was forecast to the year 2025, as summarized in Table 2. Ambient concentrations were forecast based on the emission inventory forecast, with the assumption that concentrations change in proportion to emissions. This is compounded by uncertainty in the toxics emission inventory forecast, which as noted above, assumes that toxics emissions change in proportion to CAC emissions.

Significant reductions in per capita cancer risks are projected to occur in the GVRD and FVRD, primarily as a result of forecast reductions in diesel PM emissions. Based on the emissions forecasts an 85% reduction in Diesel PM is expected between 2000 and 2025. Since diesel PM is the most substantial risk factor a reduction of this magnitude is expected to have large implications on the regional lifetime cancer risk. In Whatcom County the forecast of mobile emissions was based on data provided by the Washington State Department of Ecology, which projects a 77% increase in diesel emissions between 2000 and 2025. As a result, the per capita cancer risk in Whatcom County is not projected to show the same reduction trend as the Canadian LFV.

Table 2: Risk Assessment Forecast

Region	2000	2005	2010	2015	2020	2025	Percent Change 2000-2025
Projected Cancer Risk (Cancers Per Million Population per 70 Year Lifetime)							
GVRD	526	472	449	424	418	432	-17.8%
FVRD	435	360	298	233	187	163	-62.5%
Whatcom County	316	391	378	378	384	392	23.8%
Projected Changes in the Total Hazard Index							
GVRD	5.7	4.8	4.2	3.9	3.9	3.9	-31.1%
FVRD	2.6	2.1	1.9	1.7	1.6	1.6	-36.1%
Whatcom County	2.9	3.9	3.7	3.7	3.7	3.7	29.4%

4 ASSUMPTIONS AND UNCERTAINTIES

The key assumptions in the health risk assessment are summarized below.

- The substance list used for the health risk assessment is derived from other lists, and

only includes those substances for which ambient concentrations are monitored or could be estimated, and for which concentration response factors are available. There is a possibility that some locally significant toxics have been overlooked.

- Locally collected monitoring data was assumed to be representative of average ambient concentrations, and in some cases extrapolated to other areas or zones. Regional or zone annual average concentrations may not reflect localized hot spots or fixed duration episodes. It is noteworthy that significant spatial variability is expected for diesel PM and many other contaminants.
- The risk characterization methodology considers outdoor, inhalation exposure only.
- Toxic effects from multiple substances are assumed to act in an additive fashion on a single human organ system, with no synergistic or antagonistic effects. This assumption allows the summation of effects to derive cumulative cancer risk and hazard indices.
- Direct monitoring of diesel particulate matter and hexavalent chromium is not available in the Canadian LFV, necessitating an estimation based on elemental carbon and total chromium measurements, respectively.
- Ambient concentrations are assumed in some cases to change in proportion to the emission inventory, i.e., scaling up ambient concentrations in Whatcom County from 1996 to 2000, and to develop forecasts of ambient concentrations to 2025.
- Emission forecasts assume that air toxics emissions change in proportion to CAC emissions.
- "Double-counting" of health effects may occur where substances assessed overlap with each other. Notably many metals and hydrocarbons may contribute to the health effects associated with Diesel PM. Since these were calculated separately in this assessment there may be overlaps in the estimated health effects.

5 RECOMMENDATIONS FOR IMPROVED FUTURE REGIONAL HEALTH RISK ASSESSMENTS

A number of the assumptions noted above were necessitated because of data gaps and deficiencies in the information needed to prepare a regional health risk assessment. While the risk assessment is preliminary, one of the purposes in preparing it was to assess the currently available methods and make recommendations to improve future health risk assessments in the region.

Recommendations are presented in Table S-3 below, categorized by subject area.

Table 3: Recommendations for Future Regional Health Risk Assessments

Emission Inventory	
Quantification Methods	• The fact that emission inventories rely on a range of methods with varying degrees of accuracy must be acknowledged. An associated qualifier which should be stated when using inventory data for health risk assessments is that uncertainties in the inventory translate into uncertainties in the risk estimates. • GVRD should continue partnership efforts with Environment Canada and the National Pollutant Release Inventory to ensure that accurate, consistent data on air toxics is reported. This can be a challenge given the NPRI thresholds and company self-reporting. • GVRD should make better use of the data collected from permit-holders to calculate air toxics emissions in addition to CACs.

	• GVRD should maintain ongoing research on speciation profiles, or where possible, utilize the capabilities within its air monitoring and assessment group to develop LFV-specific profiles. • Efforts should be made to increase consistency in emission inventory scope and methods between the Canadian and U.S. portions of the LFV, and to take advantage of the most current estimation methods.
Spatial Resolution	• An appropriate balance needs to be achieved between the degree of spatial resolution of emission inventories and what is appropriate or practical when the end use is modelling. Census tract resolution appears to be generally accepted for regional health risk assessments. Finer resolution, such as 1 km grid squares, appears to be excessive for health risk assessment. • Although the air toxics inventory was spatially resolved to the census tract level, the spatial data was of limited or no use to the health risk assessment. An approach needs to be developed to predict local (i.e., neighbourhood) ambient exposure from spatially resolved estimates of annual emissions .
Forecasts	• A forecast of air toxics emissions was conducted in this study, but is based on the assumption that air toxics emissions change in proportion to CAC emissions, i.e. using the forecast profiles developed in earlier work on LFV CAC emission inventories and forecasts. Forecasts would be improved by taking into consideration the substance-specific impacts of programs, regulations or other initiatives to reduce air toxic emissions. • The air toxics forecast was used to estimate future ambient concentrations, relying on several simplifying assumptions: that future ambient concentrations will change in proportion to emission changes, and that the distribution of toxic emissions and the affected population are unchanged over time. The risk forecast could be improved by taking into consideration both a change in the distribution of emissions and a change in the distribution of population.
Health Risk Assessment	
Substances Included	• Additional priority air toxics could be identified with additional ambient monitoring data, or by examining the emission inventory and associated spatial data, a review of permitted sources and localized air toxics impacts (possibly using dispersion modelling), and citizen complaints in the LFV. • It should be noted that adding more substances to the list increases the cumulative risk from all assessed toxics; the focus should be on identifying all toxics which are significant contributors to human health risk.
Estimation of Exposure Concentrations	• The use of modelling vs. monitoring approaches for estimating air toxics exposure can be a subject of considerable debate. In this study, estimates for the Canadian LFV area relied almost exclusively on monitoring, while in contrast, estimates for Whatcom County were from modelling. Both approaches have advantages and disadvantages. A combined approach would likely be the best approach. • Census tract level air toxics emission inventory data have been developed as part of this study. The possibility of running the ASPEN model for the Canadian LFV, using the inventory data and local meteorology prepared to suit ASPEN input requirements should be investigated. This would allow a

	more equitable comparison to the Whatcom County risk assessment from NATA. • Work with partners (such as Environment Canada) to develop a Canadian version of the ASPEN model, and apply it to the Canadian LFV as a pilot study, using the available emissions data. • When a modeling approach is developed, the model results should be compared to available monitoring data, to assess the validity of the model. • Add additional toxics monitoring capabilities, focusing on areas which are currently under monitored, areas of higher population or where higher rates of growth are expected, or "hot spots" identified by the modelling approach recommended above. The monitoring capabilities could be mobile, to allow deployment for special studies. • Expand the capabilities of the monitoring network, so that the key risk drivers identified in this assessment are monitored at a minimum of one location in each exposure zone. The risk drivers most in need of additional monitoring are diesel PM, acrolein, chromium VI and chlorine. Monitoring of elemental and organic carbon and $PM_{2.5}$ could also be expanded. • Identify significant point sources of air toxics in the Canadian LFV (noting that significant sources of CACs are not necessarily significant sources of HAPs). Model significant point sources to assess health risks in the vicinity of major HAPs sources. The inventory information could be used to identify priority HAPs industries or sectors which should be required to perform HAPs dispersion modelling. This could be required as part of the permitting process for both existing and new sources. • Long-term exposure estimates are the appropriate basis for health risk assessment, but air toxics can also cause acute impacts at elevated exposure levels which may occur for short-term durations. Consider adding more temporal resolution to the health risk assessment, to examine for example, acute impacts from short term exposure and seasonal variation in ambient concentrations. Emission inventories typically include monthly, quarterly or seasonal estimates, which could be used in the modelling approach. Similarly, monitoring data is available for time periods other than annual averages.
Human Exposure Pathways	• Future assessments conducted in the LFV would benefit from locally collected human time activity patterns or an assessment of the relationship between outdoor concentrations and personal exposure similar to the work conducted recently in Seattle (Liu et al, 2003). • Several authors have recommended roadside or personal monitoring programs designed to capture the spatial variability of substances in the LFV since significant variability in the spatial resolution of particulate matter has been reported (Vedal et al 2003, Goswami et al 2002). • Assessment of models evaluating indoor exposure to air toxics (for example, those developed by WHO)
Spatial Resolution	• A level of spatial resolution coarser than census tracts but finer than the seven exposure zones appears to be the optimum, in terms of continuing with the exposure zone and ambient monitoring approach used here. An initial recommendation would be to prepare future assessments at the municipality level, but with consideration of the availability of monitoring

	data, the presence of significant emission levels, population density, etc. • If a modelling approach is developed, census tract resolution is desirable, since that is the level used in the emission inventory and in the ASPEN model.
Supporting Information for Human Health Risk Assessment	• A recommendation in this area could include development of regional policy on the endorsement of dose-response relationships recommended by health agencies and regulatory bodies, such as Health Canada, U.S. EPA, CalEPA and others. This policy could include guidance on the recommended approach for compounds for which Health Canada does not currently have toxicity information.
Emerging Issues	
Diesel Particulate Matter	• Continued research should be directed towards quantifying the exposure and health effects related to diesel particulate matter in the LFV. Work has been conducted in this area by researchers at UBC (Brauer and Henderson, 2002). An expansion of this study or use of its findings to establish a diesel particulate monitoring network would improve the understanding of the diesel related health effects in the region. One approach to conducting additional monitoring of diesel PM is provided by Levelton (2004b), which provides details on the location and type of monitoring that would be beneficial.
Chromium VI	• Chromium VI was identified as a major risk driver in this analysis. This assessment was based on dichotomous samplers which report total chromium. The monitored total chromium concentrations were scaled to chromium VI based on the ratio of emissions of chromium VI to chromium in the inventory. Future research should be directed towards estimating the ambient concentration of hexavalent chromium in the LFV.
Wood smoke	• Wood smoke is thought to be a significant contributor to the ambient concentration of inhalable particulate matter. The emission inventory developed for this study includes emissions from residential wood burning, but emissions were quantified in terms of individual substances contained in wood smoke, including particulate and gaseous constituents. Some studies, such as the Puget Sound Air Toxics Evaluation (Keill and Maykut, 2003) have used specific unit risk factors for wood smoke, but caution that these factors are not endorsed by U.S. EPA. In this study, it was found that there is not sufficient information available in the LFV to make an informed estimate of its contribution to the air quality and thus the public health effects in the region. Future efforts should be directed towards quantifying this source of toxics for use in future assessments. GVRD could conduct a survey of residential wood burning activities to supplement the information currently used in the LFV emission inventory. The survey could be modeled after the work done by MWLAP (2004) for areas outside of the LFV. The work underway at UBC (Larson, 2005) on assessment of exposure to traffic and woodsmoke should be monitored for future developments.
Other	• Future attention should be paid to sensitizing agents such as toluene diisocyanates. Once an individual is sensitized (through repeated exposure) to an agent, they may begin to react to lower and lower concentrations of the sensitizing agent. Furthermore, sensitization may lead to increased reactivity to additional substances. These compounds

	are poorly studied environmental toxicants, however, they are well documented occupational toxicants. • Nitro-aromatics (such as nitrated PAHs and nitrated dioxins and furans) have been identified as an emerging issue. While specific substance lists are not yet available, this category could warrant additional study.
Regional Policy Development (GVRD)	
	• The findings of this study have already been used in a parallel study on "Best Management Practices and Regulatory Guidelines for Managing Emissions of HAPs from Stationary Sources in the GVRD" (Stratos and Levelton, 2004). • A first step in the development of GVRD policy would be to adopt a formal definition of "air toxics" or "hazardous air pollutants", followed by an identification of priority substances and sources.

6 CONCLUSIONS

In this study, an emission inventory of air toxics has been developed for the Lower Fraser Valley area. The inventory includes nearly 300 toxic substances, as well as criteria air contaminants and greenhouse gases and was complied from existing sources including the GVRD 2000 emission inventory, NPRI, NEI (Whatcom) and the TRI. The inventory has been spatially resolved to show emissions within the GVRD, the southwest portion of the FVRD, and Whatcom County, and to census tracts within each of those regions.

Emissions vary significantly among census tracts based on land use practices and the influence of mobile sector emissions. In terms of cancer risk, the largest single risk factor is the concentrations of diesel PM. This is also the factor with the largest uncertainty. It is largely expected that those areas with higher emission rates, will tend to have higher ambient concentrations and public health risks, particularly for those individuals who spend large proportions of their time in areas of elevated concentrations.

The intent of this study was to conduct an assessment of human health risk from exposure to air toxics, using methods and data available in the Lower Fraser Valley. It was expected from the outset that some deficiencies would be identified and that some simplifying assumptions would be needed to complete the assessment. As such, the regional health risk assessment prepared should be considered preliminary. Based on these results the cancer and non-cancer risks in the Lower Fraser Valley are consistent with those risks observed in other cities in the pacific northwest and through out North America.

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