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New Brunswick Shale Gas Air Monitoring Study – Interim Report 02

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New Brunswick Shale Gas Air Monitoring Study – Interim Report 02

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Contents

List of abbreviations

AQS	air quality standard
BAM	beta Attenuation Mass
BTEX	benzene, toluene, ethylbenzene and xylenes
CAAQS	Canadian Ambient Air Quality Standard
CO	carbon monoxide
CWS	Canada-wide Standard
DELG	(New Brunswick) Department of Environment and Local Government
EC	elemental carbon
GC	gas chromatography
H_2S	hydrogen sulphide
ICPMS	inductively coupled plasma mass spectrometry
LPM	litre per minute
MDDEFP	Ministère du Développement Durable, de l’Environnement, de la Faune et des Parcs
MOA	Memorandum of Agreement for Services
MS	mass spectrometry
MSD	mass selective detector
NAAQO	National Ambient Air Quality Objective
NAPS	National Air Pollution Surveillance
NB	New Brunswick
NBAAQO	New Brunswick Ambient Air Quality Objective
NO	nitrogen oxide
NO_2	nitrogen dioxide
NOx	nitrogen oxides
NPRI	National Pollutant Release Inventory
O_3	ozone
OC	organic carbon
OMOE	Ontario Ministry of Environment
OVM	organic vapour monitoring
PAH	polycyclic aromatic hydrocarbon
PM	particulate matter
$PM_{2.5}$	particulate matter $\leq$ 2.5 µm in diameter; fine particulate matter
ppb	part per billion
ppm	part per million
PUF	polyurethane foam
SO_2	sulphur dioxide
TPH	total petroleum hydrocarbon
TPM	total particulate matter
TRS	total reduced sulphur
TSP	total suspended particulates
VOC	volatile organic compound
WHO	World Health Organization

Summary

In the fall of 2012, a Memorandum of Agreement for Services (MOA no. 4500290325) between Health Canada and the New Brunswick Department of Environment and Local Government was established to conduct an air monitoring study around shale gas activities in the province of New Brunswick. Environment Canada was also involved in this project through the National Air Pollution Surveillance Memorandum of Understanding and other interdepartmental agreements. The study consisted of four phases that represented as much as possible the different stages of shale gas development in New Brunswick: Phase I – baseline conditions prior to any development; Phase II – well development and gas production; Phase III – natural gas processing and distribution; and Phase IV – well closure.

A first interim report (Interim report 01) was released in February 2014. The report outlined the different study phases, the data collection approach, the monitoring and sampling methodologies, and quality assurance and quality control procedures. The Interim report 01 presented the monitoring data collected between October 2012 and April 2013 at the Phase I site, along with some preliminary analyses of the data set.

The second interim report (Interim report 02) presents analyses of the data from Phases I, III and IV. These data were collected over 12 months – from October 2012 to October 2013 – at three locations around Sussex, New Brunswick.

Phase I data provided information on regional pollutant levels that can be considered as "normal" (i.e., baseline) for the area in which the study sites were located. The pollutants that were monitored included criteria air contaminants, such as carbon monoxide, nitrogen oxides, ozone and particulate matter, as well as non-criteria air pollutants and air toxics, such as metals and polycyclic aromatic compounds. For the criteria pollutants, the results showed that pollutant levels were similar to, or lower than average pollutant levels reported at air monitoring stations across New Brunswick. Pollutant levels were notably lower than those recorded in the larger urban centres of New Brunswick – that is, Fredericton, Moncton and Saint John. Although comparisons were not possible for all pollutants, the absence of significant emission sources of pollutants upwind of the Phase I site suggested that the levels observed were not significantly influenced by local anthropogenic sources. Thus, the site allowed the collection of regionally representative air pollutant data that could be used to assess the influence of local sources on pollutant levels in the region of Sussex, New Brunswick.

Phase II of the study – that is, air quality monitoring during well completion and gas production activities – was initiated in June 2014 at a well site in Penobsquis, New Brunswick. A hydraulic fracturing event occurred in early September 2014. Monitoring activities ended in March 2015. Data collected during this phase of the study will be presented and analyzed in a subsequent report, tentatively planned for release in 2016.

Phase III of the study involved the collection of data around an existing natural gas treatment facility in Penobsquis, New Brunswick. Data collected during Phase III indicated that emissions from the gas treatment facility had a measurable but limited influence on air pollutant concentrations, notably for volatile organic compounds (VOCs). Higher concentrations were reported for some VOCs at sampling locations downwind from the facility compared with sampling locations positioned upwind. Several VOCs could be associated with natural gas operations, such as butane, hexane, pentane and propane. Nonetheless, the results suggested that measured concentrations were below levels considered as being a risk to human health. For example, they were lower than air quality standards that have been adopted by some Canadian jurisdictions and similar to, or lower than levels measured across New Brunswick.

Samples collected at a site with two suspended natural gas wells (Phase IV) showed low concentrations of VOCs and methane. Some compounds were measured at higher levels compared with Phase I and Phase III, notably decane and undecane. Additional information was considered necessary to identify potential sources and causes of these higher concentrations. Nonetheless, these compounds were not measured at concentrations that are of concern to human health.

The study was conducted in a geographic range not covered in previous air quality reports. Although the study has the potential to indicate possible human health-related concerns associated with air quality that could be transferable to other jurisdictions, additional data analysis and potentially air monitoring are considered necessary to extrapolate the results from this study to other shale gas plays. It must also be noted that the data analyses in the Interim report 02 are subject to additional revisions and, as such, they should not be considered final.

1. Background and scope

In the fall of 2012, Health Canada and the New Brunswick Department of Environment and Local Government (DELG) signed a Memorandum of Agreement for Services (MOA no. 4500290325) to conduct an air monitoring study around shale gas activities in the province of New Brunswick. The study was also conducted in collaboration with Environment Canada, which provided technical and analytical support through the National Air Pollution Surveillance (NAPS) Memorandum of Understanding and other interdepartmental agreements. The overall objective of this project was to gather information needed to assess the potential risks to public health from air emissions associated with shale gas development and operations. The study consisted of four air monitoring phases that represented as much as possible the different stages of shale gas development: Phase I – baseline conditions prior to any development; Phase II – well development and gas production; Phase III – natural gas processing and distribution; and Phase IV – well closure.

The study phases were sequentially numbered to reflect a schematic of natural gas development from an undeveloped site to gas production, gas transport and, finally, well closure. However, they were not completed in that particular order. Further, as it was not feasible to monitor air pollutant levels during all phases at a single site, several sites were selected to investigate specific phases. All sites were located near Sussex, New Brunswick, within the Kennebecasis River valley (see Figures 1 and 2). As such, it was expected that the overall air monitoring would be representative of the life cycle stages of an individual well or installation in that area.

Figure 1. General location of the study phases in southern New Brunswick
(*Source*: Coloured image generated with Google Earth; Canada outline from Natural Resources Canada (http://ftp2.ctis.nrcan.gc.ca/pub/geott/atlas_tif/atlas6/Reference/Bilingual/canada01.pdf))

A first interim report (Interim report 01) was released in February 2014 (Health Canada 2014). It provided an overview of the study phases, the data collection approach, the monitoring approach and methodologies, and the quality assurance and quality control procedures. This information will not be covered in the current report and it is recommended that readers consult the Interim report 01 for further details regarding these topics. The Interim report 01 also presented a preliminary analysis of data collected at the baseline or Phase I site from October 2012 to April 2013, through descriptive statistics and time series.

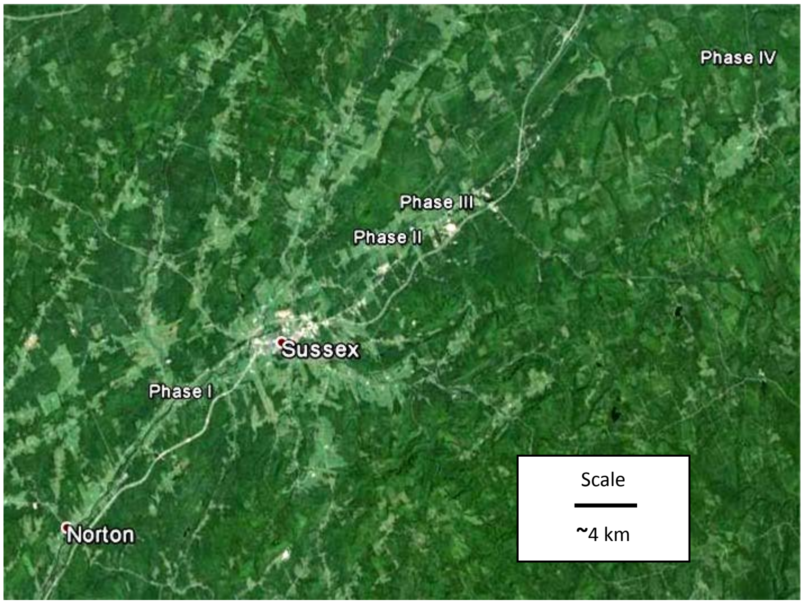

Figure 2. Regional view of the study phases near Sussex, New Brunswick
(*Source*: Image generated with Google Earth)

This second report, Interim report 02, presents an analysis of the full data set for Phases I, III and IV. The data include continuous measurements for carbon monoxide (CO), ozone (O_3), sulphur dioxide (SO_2), total reduced sulphur (TRS), fine particulate matter ($PM_{2.5}$), total suspended particulates (TSP) and nitrogen oxides (NOx), as well as laboratory measurements of integrated samples for volatile organic compounds (VOCs), polycyclic aromatic hydrocarbons (PAHs), elemental carbon (EC) and organic carbon (OC), and markers of biomass burning (galactosan, levoglucosan and mannitol).

The report is organized as follows. Chapter 2 presents results for Phase I, whereas Chapters 3 and 4 present the results for Phase III and Phase IV, respectively. Data for the different phases are discussed and compared in Chapter 5, in which key differences and potential pollutants of concern associated with natural gas development are highlighted. Conclusions and next steps are included in Chapter 6.

Tables, figures and time series representing the data for Phase I, Phase III and Phase IV are included in Appendices A, B and C, respectively. Appendix D provides a summary of pollutants that were measured as well as methodological considerations, whereas Appendix E presents air quality objectives in New Brunswick and Canada.

2. Phase I – Baseline conditions prior to any development

2.1 Overview of site location and data collection

The baseline site was in Apohaqui, located southwest of Sussex (see Figure 2). This site was located near an area of interest where shale gas development and associated air quality impacts may occur in the future. It was suitable as a baseline site because it was not affected by natural gas development at the time the monitoring occurred. The Phase I site was located upwind of the other designated sampling sites (i.e., Phase II, Phase III and Phase IV) and also upwind of Penobsquis, where multiple natural gas wells and two gas plants were in operation.[1]

The site was selected based on local knowledge, DELG expertise and industry interest (reflected by oil and natural gas licences and leases).[2] The mobile monitoring unit (see Photo 1) was deployed at this location, and data collection commenced, in October 2012. Data collection ended in October 2013. A full year of data improved the likelihood of identifying any seasonal variations in background air quality. The site and its surroundings were described as being mostly agricultural in nature, with a few scattered woodlots and small hills (see Photo 1). No industrial facility was located near the site, and the population density was very low. No physical obstructions were located within several hundred metres of the monitoring station.

Photo 1. Mobile monitoring unit at the baseline site in Apohaqui, New Brunswick

Continuous (e.g., every 5 minutes) and integrated (e.g., filter- or canister-based samples) data were collected during Phase I. Table D1 in Appendix D shows the air quality and environmental parameters monitored at the baseline site. Specifications for the monitoring equipment used to

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[1] All sampling locations were situated within the Kennebecasis River valley. Winds in New Brunswick are predominantly from the south, the southwest and the west in the summer and from the southwest to northwest during the winter.

[2] www.gnb.ca/0078/minerals/ONG_Data-e.aspx#RightsMaps (accessed February 5, 2013)

measure these parameters were provided in the Interim report 01 (Health Canada 2014). The air inlet for monitors and samplers were located on the top of the trailer, at approximately 3.0–3.5 m above ground level, except for the meteorological data that were measured at 10 m above ground level.

Most instruments were active on October 1, 2012. The analyzer for TSP was activated on November 1, 2012. Sampling for methane was initiated in June 2013. Further details on the sampling and the laboratory analysis methods are available in Appendix D of the current report and in the Interim report 01 (Health Canada 2014).

2.2 Results and analyses

Continuous data and integrated data collected between October 1, 2012, and October 17, 2013, were included in the current analysis. The monitoring period included 382 sampling days. The number of measurements differed substantially between PM (fine and total) (i.e., 9146 measurements) and other pollutants (i.e., 109 740 measurements). For SO_2, TRS, nitrogen dioxide (NO_2), nitrogen oxide (NO), CO and O_3 measurements were recorded every five minutes, whereas PM data were collected every hour; as a result, the numbers of measurements differ by a factor of 12. Table A1 in Appendix A summarizes the descriptive statistics for the continuous data. Figure A1 and Figure A2 present time series for O_3 and $PM_{2.5}$, respectively, whereas Figures A3, A4 and A5 display annual, summer and winter wind speed and direction via wind roses.

In Table A1 in Appendix A, the row *No. of valid measurements* shows the number of measurements in the data set that were considered to be suitable in terms of quality and quantity. From a data validation perspective, at least 75% of a data set had to be valid.[3] For the entire Phase I sampling period (i.e., 382 days), this requirement was met for all pollutants except TSP (54% valid measurements). In fact, TSP data collection suffered from equipment malfunctions for extended periods of time. However, the quality of the TSP data was acceptable for the months when the TSP monitor was working properly. As such, monthly averages could be calculated for comparisons with TSP data from other study phases or provincial monitoring data, if necessary (see Section 2.3).

For the mean, median, minimum, maximum and percentile values shown in Table A1, the descriptive statistics for a pollutant were calculated for the average period of the corresponding air quality standard (AQS) (*Avg period for stats* row). This allows for a relevant comparison with the reference AQS (*Air quality standard (AQS)* row). For example, 1 h averages were determined for CO based on the valid 5 minute data (75% of the 5 minute data had to be valid for the 1 h average to be considered valid), and the mean of the 1 h averages was included in the *Mean* row (75% of the 1 h averages had to be valid for the statistic to be valid).

For PM, the same approach was used; in this case, however, the 1 h data were averaged on a daily basis (75% of 1 h data were required to be valid). The daily average values were then used to

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[3] The 75% criterion applies to the monitoring period under consideration and is not associated with a specific duration. For example, it can be applied to weekly, monthly, seasonal or annual datasets, in accordance with the study objectives.

calculate the statistics in Table A1 for $PM_{2.5}$. Note that although descriptive statistics for TSP are included in Table A1, the TSP dataset did not meet the required criteria for the entire Phase I period.

For O_3, the 5 minute data were initially converted to hourly averages. The hourly data were then used to generate 8 h rolling averages, and the daily 8 h maximum value was retained. Both hourly averages and the 8 h daily maximum value were used to calculate statistics for O_3. The 75% completeness criterion applies to the 5 minute data and the hourly data. For example, no fewer than six hourly values per each rolling 8 h segment must be valid.

Also included in Table A1 are the relevant Canadian (federal and New Brunswick) air quality objectives for comparative purposes (*Reference* row).

Data collected at the baseline site were compared with data from nearby provincial monitoring sites, as shown in *Air quality monitoring results* reports produced by the New Brunswick DELG (NB DELG 2012, 2013a, 2013b), or with data available from the NAPS program.[4] For O_3, data were available from two rural sites, Norton and Fundy National Park. The Norton site is located approximately 20 km southwest of Sussex, whereas the Fundy National Park site is located approximately 50 km southeast of Sussex. For pollutants other than O_3, comparisons were made with monitoring sites located in urban areas, including Moncton, Fredericton and Saint John. Although the Phase I site was not an urban site, these urban sites were selected for comparison because they included the most complete set of pollutants. Further, they were located in the southern part of the province, within 150 km of the Phase I site, and are possibly impacted by similar regional air quality and weather patterns.

The following sections provide information regarding the measured criteria air contaminants (i.e., O_3, $PM_{2.5}$, CO, SO_2, VOCs and NO_2) and other measured pollutants or parameters (i.e., TRS, PAHs and meteorological data). Section 2.3 covers data limitations and uncertainties during Phase I.

2.2.1 Ozone

Based on hourly data, a mean value of 25.9 ppb was reported. Figure A1 in Appendix A shows a time series for 1 h average data. Seasonal variations are expected and are dependent on several environmental and anthropogenic factors. A maximum of 57.3 ppb was observed on September 21, 2013, which is below the 1 h national air quality objective of 82 ppb (i.e., no exceedance reported). Based on the maximum daily 8 h rolling average for O_3, a mean of 34.4 ppb was recorded during Phase I. Refer to Table A1 in Appendix A for more descriptive statistics.

The 1 h average O_3 concentrations during Phase I were comparable to the levels recorded from October 2012 to October 2013 at the Norton monitoring station, which averaged 26 ppb (NAPS 2012, 2013). Analysis of hourly data from the NAPS program for the Norton station between 2005 and 2010 showed an overall mean annual O_3 concentration of 25.8 ppb during that period.[5] Concentrations during Phase I were slightly lower than the O_3 levels reported from January to

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[4] http://maps-cartes.ec.gc.ca/rnspa-naps/data.aspx?lang=en (accessed February 2, 2015)

[5] Mean annual 1 h O_3 concentrations of 26.6, 25.6, 25.8, 26.4, 24.5 and 26.0 ppb, respectively, for 2005, 2006, 2007, 2008, 2009 and 2010.

December 2011 at the Fundy National Park site, which averaged 31 ppb and varied generally between 15–55 ppb (NAPS 2011). O_3 concentration data for the Fundy station in 2012 and 2013 were incomplete and did not allow for a direct comparison.

Across all air monitoring sites in the province of New Brunswick and based on data from 2002 to 2010, hourly O_3 concentrations averaged 26 ppb (NB DELG 2012). This is also comparable with the mean value at Phase I.

2.2.2 Fine particulate matter

2.2.2.1 Continuous measurements

The average 24 h or daily $PM_{2.5}$ concentration from October 2012 to October 2013 was 5.0 $\mu g/m^3$ (Table A1 in Appendix A). The continuous $PM_{2.5}$ data, reported as daily 24 h averages, are shown as a time series in Figure A2 in Appendix A. Daily $PM_{2.5}$ concentrations were higher in summer (6.1 $\mu g/m^3$ for June to September, 2013) compared with the rest of the monitoring period (4.5 $\mu g/m^3$). These seasonal variations have also been observed for data from the provincial monitoring network (NB DELG 2012, 2013b). Daily $PM_{2.5}$ concentrations during Phase I were similar to those reported for Saint John, Fredericton and Moncton in 2012 and 2013 (NAPS 2012, 2013).

The highest daily $PM_{2.5}$ value during Phase I was recorded at 35.5 $\mu g/m^3$ on February 9, 2013. New Brunswick and most provincial jurisdictions have adopted the Canada-wide Standard (CWS) for $PM_{2.5}$, which is set at 30 $\mu g/m^3$. However, the CWS is not directly comparable as it refers to the 24 h 98th percentile $PM_{2.5}$ ambient measurement annually, averaged over three consecutive years (OMOE 2012). As only one year of data was available, a direct comparison was not possible. The same applies to the $PM_{2.5}$ Canadian Ambient Air Quality Standards (CAAQS) of 28 $\mu g/m^3$ scheduled for 2015. Nonetheless, the 98th percentile value for $PM_{2.5}$ was 14.3 $\mu g/m^3$ during Phase I, lower than the CWS and the CAAQS. The WHO has defined a 24 h air quality guideline of 25 $\mu g/m^3$ based on the 24 h 99th percentile ambient measurement annually (WHO 2006). Although the highest value during Phase I exceeded the WHO limit, the 99th percentile for the dataset was approximately 18 $\mu g/m^3$. The Province of British Columbia has adopted a similar $PM_{2.5}$ air quality standard of 25 $\mu g/m^3$ and it is based on the 98th percentile value.[6]

This high daily measurement (35,5 $\mu g/m^3$) was considered unusual as winter $PM_{2.5}$ concentrations in rural areas of New Brunswick rarely reach such high levels. Upon investigation, it was determined that this exceedance may have resulted from an extreme meteorological event that affected the Beta Attenuation Mass (BAM) monitor measurements. More details regarding this event are provided in Section 2.3.

2.2.2.2 Gravimetric samples

Gravimetric measurements were made from 47 mm Teflon filters that were collected using ChemComb Speciation Cartridges and a Partisol 2300 sampling system. These were 24 h integrated samples. The sampling method is outlined in Appendix D. Table A2 in Appendix A shows gravimetric

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[6] www.bcairquality.ca/regulatory/pm25-objective.html (accessed February 23, 2015)

$PM_{2.5}$ data for Phase I. Median and mean $PM_{2.5}$ concentrations were calculated at 3.8 µg/m^3 and 4.0 µg/m^3, respectively. The mean $PM_{2.5}$ concentration calculated from the gravimetric samples was lower than the mean estimated from the continuous data, by approximately 20%. This difference was not unexpected owing to methodological considerations that are addressed in Section 2.3. Similar discrepancies have been observed by other authors (e.g., Hauck et al. 2004).

2.2.2.3 Galactosan, levoglucosan and mannitol

Forty-seven of the total 47 mm Teflon filters used to collect $PM_{2.5}$ samples were analyzed for galactosan, levoglucosan and mannitol, which are considered markers of biomass burning (e.g., wood stoves and forest fires). Data on galactosan, levoglucosan and mannitol were collected to address potential contributions to $PM_{2.5}$ measurements from biomass burning, which could possibly affect data comparisons among seasons and sites. Natural gas production processes and activities were not expected to affect the levels of these compounds.

Phase I results are shown in Table A3 in Appendix A. On average, levoglucosan contributed 0.82% to $PM_{2.5}$ mass, whereas mannitol contributed 0.06%. Galactosan levels were below detection limits. These very low levels suggested that emissions from biomass combustion were negligible during Phase I.

2.2.2.4 Metals

Inductively Coupled Plasma Mass Spectrometry (ICPMS) analysis was conducted for 52 Teflon filters used to measure metals. The results are presented in Table A4 in Appendix A. The results showed that the metals detected and measured by ICPMS accounted for 9.4% (374 ng/m^3) of the $PM_{2.5}$ concentrations. Sodium, aluminum and calcium had the highest concentrations, on average, and accounted for 82% of the total metal concentration that was estimated.[7] Air quality standards targeting metals have not been adopted by the Government of New Brunswick, but air quality standards exist in Alberta (Alberta Government 2013), Ontario (OMOE 2012) and Quebec (MDDEFP 2013). The measured concentrations for metals during Phase I were considerably lower than air quality standards available for those provinces.

2.2.2.5 Elemental carbon / Organic carbon

EC and OC measurements were conducted on 54 quartz filter samples. Results are shown in Table A5 in Appendix A. $PM_{2.5}$ concentrations for the quartz filters were not determined using a gravimetric method. EC and OC were determined directly from the filters (the analytical method is outlined in Appendix D).

The data showed that OC compounds accounted for 87% of total carbon concentration, on average, varying from 72–99%. Similar OC to EC ratios were observed in 2012 and 2013 for the Mountain Road monitoring station in Moncton (NAPS 2012, 2013).

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[7] The total concentration value was based on metals that were detected and measured, exclusively.

2.2.3 Carbon monoxide

CO concentrations measured at the Phase I site are described in Table A1 in Appendix A. During the period covered, a mean of 0.2 ppm and a median of 0.2 ppm were reported. A maximum value of 1.2 ppm was reached on July 15, 2013, at 13h00.[8] Levels were considerably lower than the 1 h air quality standard of 13 ppb (see Table E1 in Appendix E). The CO levels for Phase I were comparable to concentrations recorded at other monitoring sites in New Brunswick (i.e., Fredericton, Moncton and Saint John), which showed means of 0.1 ppb in 2012 and 0.2 ppb in 2013 (NAPS 2012, 2013; NB DELG 2012, 2013b).

2.2.4 Sulphur dioxide and total reduced sulphur

Average hourly SO_2 levels were very low, with a mean of 0.1 ppb (see Table A1 in Appendix A). TRS levels observed during Phase I were also very low, averaging 0.2 ppb and reaching a maximum value of 1.9 ppb. Both SO_2 and TRS concentrations were considerably lower than their respective air quality standards (see Table E1 in Appendix E). These very low levels were due to the absence of a significant source of SO_2 or TRS emissions near the baseline site.

In comparison, hourly SO_2 data for 2012 and 2013 were available from the NAPS program for monitoring sites located in Saint John. Means of 1 to 2 ppb were reported with 99th percentile values reaching 20–25 ppb (NAPS 2012, 2013).

Hourly TRS data for 2011 were available from monitoring sites located in Saint John (NB DELG 2013b). The TRS data for Saint John showed levels of 1 ppb or less on most days, with a few peaks of 3 ppb or more. Some measurements exceeded the 11 ppb New Brunswick Ambient Air Quality Objective [NBAAQO] for hydrogen sulphide (H_2S). The higher SO_2 and TRS levels observed in Saint John were possibly associated with industrial activities in that region (e.g., petroleum refinery, pulp and paper facilities), which were absent near the Phase I site.

2.2.5 Nitrogen oxides

A mean NO_2 level of 1.2 ppb was reported during Phase I, based on hourly average NO_2 data. Levels were considerably below the 1 h air quality standard of 210 ppb (see Table E1 in Appendix E). For example, during Phase I, a maximum NO_2 measurement of 14.9 ppb was reached on February 26. NO and NOx hourly results showed means of 0.3 ppb and 1.5 ppb, respectively.

NO, NO_2 and NOx concentrations measured during Phase I were lower than levels observed at urban sites across the province in 2012 and 2013 (NAPS 2012, 2013). For example, average NOx concentrations of 3–10 ppb were reported in Fredericton, Moncton and Saint John. Higher combustion emissions associated with commercial, industrial and transportation activities are possibly responsible for the higher NOx levels in urban areas.

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[8] The 1.2 ppm value was much higher than hourly values recorded immediately prior to and following that 1 h period (i.e., less than 0.3 ppm), reflecting a very short CO emission event.

2.2.6 Volatile organic compounds

VOC concentrations were measured for 41 compounds based on organic vapour monitoring (OVM) badge samples and 154 compounds based on Summa canister samples.

2.2.6.1 Organic vapour monitoring badge samples

Table A6 in Appendix A shows the OVM badge results (25 weekly samples) for a limited list of VOCs. Table A6 includes VOC species that are commonly reported near oil and gas operations, such as benzene, toluene, xylenes, hexane and pentane (e.g., Bunch et al. 2014; McKenzie et al. 2012; PADEP 2011). They are shown to provide an indication of the baseline pollutant levels and identify VOCs with the highest concentrations. The purpose is not to identify potential sources for these pollutants at the Phase I site but to show regional VOC composition for a comparative analysis with VOCs measured at the other study sites. It must be considered that even in remote locations, pollutants such as particulates and VOCs will be detected in ambient air samples. The presence and detection of air pollutants in ambient air reflect local, regional and trans-boundary effects.

Tetradecane (1.49 µg/m^3), dodecane (1.28 µg/m^3), 2,2,4-trimethylpentane (0.79 µg/m^3) and α-pinene (0.65 µg/m^3) were associated with higher mean concentrations than other VOCs. Benzene levels showed a mean of 0.34 µg/m^3.

2.2.6.2 Summa canister samples

Table A7 in Appendix A shows the Summa canister results for a limited number of VOCs. Ethane (2.87 µg/m^3), Freon 12 (2.50 µg/m^3) and propane (1.70 µg/m^3) were associated with higher mean concentrations compared with other measured VOCs. In comparison, annual average ethane levels of 2.01–5.53 µg/m^3, annual average Freon 12 levels of 2.48–2.58 µg/m^3 and annual average propane levels of 1.19–9.94 µg/m^3 have been reported for monitoring sites in Saint John in 2012 (Champlain Heights, Forest Hills and Point Lepreau; NAPS 2012).

Benzene levels measured from Summa canister samples showed a mean of 0.27 µg/m^3. The annual mean benzene levels calculated for the Champlain Heights, Forest Hills and Point Lepreau monitoring stations (all in the Saint John region) in 2012 were approximately 1.45 µg/m^3, 1.41 µg/m^3 and 0.20 µg/m^3, respectively (NAPS 2012).[9] Point Lepreau is considered a background reference site. These benzene concentrations in 2012 were fairly representative of the benzene levels reported over the last decade at these three urban stations (DELG 2013a).

Air quality standards for individual VOCs have not been adopted in New Brunswick, and very few of the VOCs detected at higher concentrations are covered by air quality objectives adopted in other Canadian jurisdictions. Notably, air quality objectives are scarce for alkanes (e.g., butane, ethane and propane). Hence, when possible, measured VOC concentrations were compared with available air quality standards from Alberta (Alberta Government 2013), Ontario (OMOE 2012) and Quebec (MDDEFP 2013). No exceedance was noted during Phase I.

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[9] The VOC data available on the NAPS website were not recovery and blank corrected.

2.2.7 Polycyclic aromatic hydrocarbons

PAH concentrations were measured for 30 compounds based on modified high-volume samples and 16 compounds based on URG pesticide personal samplers.

Table A8 in Appendix A1 shows descriptive statistics of PAH data for modified high-volume sampler samples collected at the Phase I site. Data from 28 samples were available. The highest mean values corresponded with phenanthrene (1.36 ng/m^3), fluorene (0.44 ng/m^3) and fluoranthene (0.36 ng/m^3). A mean of 0.02 ng/m^3 was reported for benzo(a)pyrene, which is often used as a surrogate for all PAHs in health studies. The sum of all detected and measured PAHs was approximately 3.67 ng/m^3. The 2012 PAH results for the Forest Hills site in Saint John were available for a comparative analysis (NAPS 2012). These samples were collected and analyzed using similar methods. However, as the available NAPS data were not recovery or blank corrected, they are not directly comparable. Nonetheless, PAH results for the Forest Hills site showed that phenanthrene (2.14 ng/m^3), fluorene (0.78 ng/m^3) and fluoranthene (0.57 ng/m^3) were also associated with the highest mean values (NAPS 2012). Benzo(a)pyrene concentrations averaged 0.03 ng/m^3.[10] Overall, the sum of the mean PAH values was 6.09 ng/m^3. The analysis suggests that PAH levels at the background site were lower than levels associated with one of the largest urban area in New Brunswick. This was expected owing to the rural nature of the Phase I site and the greater number of sources of pollution in urban areas.

Table A9 in Appendix A1 shows descriptive statistics for PAH data from URG pesticide personal sampler collected during Phase I. Data were available for 50 samples. The highest mean concentrations were reported for naphthalene (3.51 ng/m^3), phenanthrene (3.25 ng/m^3) and fluorene (1.49 ng/m^3). A mean of 0.15 ng/m^3 was reported for benzo(a)pyrene. The two methods used to sample PAHs provided different results in terms of absolute concentrations and the relative contributions of individual compounds. Some limitations and uncertainties are addressed in Section 2.3.

Air quality objectives for PAHs have not been adopted in New Brunswick or at the Federal level. Air quality standards have been adopted for three PAHs – that is, benzo(a)pyrene, naphthalene and pyrene – in other Canadian jurisdictions (Alberta, Ontario and Quebec). Measured concentrations of naphthalene and pyrene were below available air quality standards.

Levels of benzo(a)pyrene in the URG and the modified high-volume samples were lower than the annual criteria for Alberta (0.3 ng/m^3 or 0.0003 µg/m^3) and Quebec (0.9 ng/m^3 or 0009 µg/m^3), but higher than the Ontario annual standard (0.01 ng/m^3 or 0.00001 µg/m^3). However, the benzo(a)pyrene concentrations measured during Phase I were comparable to, or lower than historical values collected at National Pollutant Surveillance station across Canada (Environment Canada 2013). Hence, benzo(a)pyrene concentrations measured during Phase I were not necessarily high, and possibly reflected regional background conditions.

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[10] Several values for benzo(a)pyrene were below the instrument detection limit and considered as not detected.

2.2.8 Methane

Table A10 in Appendix A shows the methane and ethane concentration data from Phase I, as measured from air bag samples. An average methane concentration of 1.99 ppm was reported based on four air bag samples collected in May and July, 2013. All ethane measurements were below method detection limits. Limited measurements conducted in May 2013 with a continuous methane monitor showed an average CH_4 concentration of 1.90 ppm. The small difference between the air bag and continuous methods was possibly related to sampling and analytical considerations.

In comparison, global background concentrations have been estimated at 1.8 ppm (Kirschke et al. 2013).

2.2.9 Meteorological data

Wind speed and direction data are represented in wind roses in Figures A3, A4 and A5 in Appendix A, for annual, summer (May to September) and winter (October to April) data, respectively. The annual data are also presented in Figure 3, which shows the wind rose overlaid onto a satellite image of the Phase I area. In general, summer winds were characterized as blowing predominantly from the southwest, whereas they blew primarily from the northwest during winter months. No significant source of emissions was identified upwind of the Phase I site based on knowledge of the area and satellite photography (e.g., Google Earth; see Figure 3).

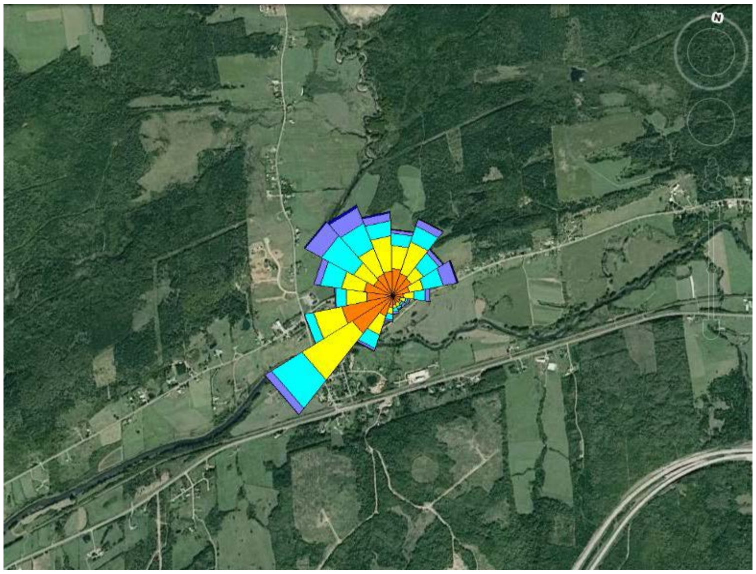

Figure 3. Wind rose indicates the frequency and directions of winds (blowing from) at the Phase I site between October 2012 and October 2013

Note: This image was generated using Lakes Environmental WRPLOT View Freeware 7.0.0 and Google Earth.

Based on wind data collected over the entire Phase I period, wind speeds averaged approximately 3.01 m/s (13 km/h) and rarely exceeded 11 m/s (40 km/h). Less than 1.4% of wind data were characterized as calm wind conditions. The dominant vector calculated for the annual data indicated that winds were blowing predominantly from the northwest (see Figure A3). Nonetheless, a contribution from southerly winds (during summer) is clearly visible in Figure 3.

The average annual temperature was 6.4°C, with seasonal averages of 17.2°C in summer, 5.6°C in the fall, -5.0°C in winter and 8.3°C in spring.

2.3 Limitations and uncertainties

Data collection and analyses during Phase I were affected by limitations and uncertainties. Some minor equipment malfunctions caused a series of invalid or missing data collection periods during Phase I. For example, blocks of data over hours or days were missing owing to power interruptions (e.g., April 29 and 30, 2013) or equipment replacement (e.g., O_3 module in May 2013). Nonetheless, these relatively short events did not have a considerable impact on data collection efficiency. In fact, more than 90% of the continuous data collected during Phase I were considered valid (see Table A1 in Appendix A), except for TSP, which suffered from an important equipment breakdown.

On February 8, 2013, water intrusion through the inlet head damaged electronic components of the TSP monitor. The TSP monitor was repaired and re-deployed on March 7, 2013, resulting in approximately one month of missing data. TSP data were also missing for most of July and August 2013 owing to a malfunction of the sampling pump for the BAM unit. Overall, only 54% of the TSP measurements were considered valid. The TSP monitor did function properly between March 19 and July 10, 2013, during which 78% of the daily values were considered valid. TSP concentrations showed a mean of 7.46 $\mu g/m^3$ during that period, a value comparable to the mean calculated from all available data for this parameter (see Table A1 in Appendix A).

Technical issues were also encountered with the continuous methane monitor. The Thermo Fischer IRIS 5500 continuous methane monitor was found in failure mode on May 27, 2013, and had to be sent back to the supplier for repairs. It was never re-deployed. As a result, continuous methane data were very limited during Phase I and no detailed analysis was possible.

As mentioned in Section 2.2.2, high $PM_{2.5}$ concentrations were recorded during Phase I over several hours on February 9, 2013, resulting in exceedances of the CWS and CAAQS reference values for $PM_{2.5}$ of 30 $\mu g/m^3$ and 28 $\mu g/m^3$, respectively. Additional investigations indicated that elevated $PM_{2.5}$ levels were observed simultaneously at several monitoring locations in southern New Brunswick. However, across the monitoring stations and at the Phase I site, pollutants other than PM did not show any noticeable variation during the same period. Analysis of the meteorological data for February 9 showed that recorded wind speeds at the Phase I site averaged nearly 40 km/h. Meteorological data from Environment Canada for Moncton and Saint John showed average wind speeds between 50 and 60 km/h for most of that day.[11] Gusts up to 160 km/h were even reported in Nova Scotia.[12] Severe winds and snowfall corresponded with a major winter storm that hit the whole northeastern United States and eastern Canada between February 8 and 10, 2013. Although the exact cause of elevated $PM_{2.5}$ levels has not been determined, it is suggested that the violent winds may have affected the BAM monitors that were part of the provincial air monitoring network, in addition to the BAM unit at the Phase I site. BAM monitors accurately determine $PM_{2.5}$

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[11] http://climate.weather.gc.ca/index_e.html (accessed January 23, 2015)

[12] http://en.wikipedia.org/wiki/February_2013_nor'easter (accessed January 23, 2015)

concentrations by measuring the difference in beta ray transmission of a filter area prior to and following exposure in the inlet port of the unit. By considerably shaking the inlet ports, the unusually strong winds may have dislodged some of the accumulated dust within them. It is not unusual for dust to accumulate in the inlet ports, and under normal conditions it does not impact measurements. Therefore, the high $PM_{2.5}$ measurements for February 9 could possibly be considered an outlier. It is still included in the descriptive statistics in Table A1 in Appendix 1 as its effect on final results was minimal. In fact, when removed from the data set, the mean and median decreased to 4.95 $\mu g/m^3$ and 4.27 $\mu g/m^3$, respectively, compared with 5.04 $\mu g/m^3$ and 4.29 $\mu g/m^3$.

PAH concentrations reported for the modified high-volume samples were generally lower than concentrations reported for the URG samples. The reason for the lower concentrations could not be identified. As the modified high-volume method samples a higher volume of air than the URG method, lower measurements were not necessarily expected. Furthermore, the modified high-volume method collects TPM, whereas the URG samples were based on $PM_{2.5}$ – that is, the sample from the high-volume method should have collected more particulate material and PAHs than the URG samples. Presumably, higher PAH values should have been expected from the TPM samples (e.g., Guo et al. 2003), but this was not the case. Moreover, several negative PAH concentration values were observed for the high-volume samples following blank correction procedures, including acenaphthene, anthracene and naphthalene. Note that these PAHs are generally found in gaseous form under ambient conditions. As ambient levels of these PAHs were generally low, it is possible that some relatively high blank values influenced the concentration estimates. In contrast, URG samples were not associated with any negative values. Additional analyses and comparisons of the different sampling and analytical methods for PAHs used in this study, and considerations of possible sampling artefacts (Ravindra et al. 2008), are necessary at this time.

Data for integrated samples can be affected by variations in sampler handling and deployment, laboratory analysis methods and several other methodological factors. For example, handling procedures for the Health Canada passive VOC samplers (i.e., OVM badges) were modified in April 2013 owing to a sampler deployment error. Prior to this date, the diffusion membrane on the samplers was removed before the exposure period. The diffusion membrane provides a unique and constant sampling rate for each molecule to the surface, allowing the diffusion of molecules and attenuating the transfer of compounds via turbulence. It is used to determine the effective air volume sampled during exposure. Removing the diffusion membrane increases the sampling rate by an unknown amount as no information is available regarding the transfer rates associated with turbulence. Consequently, the concentrations estimated for badges exposed without diffusion membranes were invalid (22 invalid samples out of a total of 45 samples during Phase I). The diffusion membrane was left on during the exposure period, as per the correct sampler handling guidelines, as of April 24, 2013.

Another example was the PAH measurements, in which the PAH samples (field samples and field blanks), in April 2013, were voided owing to low recoveries. In this particular case, an equipment failure during the extraction process caused the samples to dry up. PAH samples were also voided owing to negative masses; verification of the initial filter masses suggested that these were incorrect and too high. PAH samples were voided as well when the sampling duration did not meet the sampling criteria of 23–25 h (target duration of 24 h).

In addition, a few of the $PM_{2.5}$ filter data points were invalidated as they appeared too high compared with co-located and other monthly data.

An air quality advisory was issued by the Government of New Brunswick on July 1st 2013.[13] The poor air quality resulted from the transport of smoke originating from forest fires in northern Quebec. Only northern New Brunswick was expected to be affected by the smoke-related pollutants, and $PM_{2.5}$ concentrations at the Phase I site (located in southern New Brunswick) did not show abnormally high levels during that period.

3. Phase III – Natural gas processing and distribution

3.1 Overview of site location and data collection

Air monitoring was conducted at an existing gas plant (Phase III) to assess the potential impact of natural gas processing and distribution on air quality.[14] The facility is owned and operated by Corridor Resources Inc. and is located on Route 114 in Penobsquis, New Brunswick (see Photo 2). Natural gas from regional wells is collected and treated at this facility, before market distribution via pipeline. The facility has a design capacity of 35 million cubic feet per day of raw natural gas.

Photo 2. General view of the Corridor Resources Inc. gas plant in Penobsquis, New Brunswick

The gas plant is connected to the Maritimes and Northeast Pipeline. The natural gas processed at this site originates from both conventional and unconventional wells in the McCully field. When the natural gas reaches the gas plant for treatment and distribution, the type of resource (i.e.,

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[13] http://www2.gnb.ca/content/gnb/en/news/news_release.2013.06.0619.html (accessed February 23, 2015)

[14] Phase III is not an assessment of the Corridor Resources Inc. gas plant per se, but rather an evaluation of potential air quality impacts associated with any gas treatment plants possibly required to process natural gas extracted from shale formations in New Brunswick.

conventional or unconventional) and extraction method (i.e., with or without hydraulic fracturing) are not expected to influence facility emissions considerably. A flare stack is located on the gas plant site, equipped with an electric auto-igniter and a continuous nitrogen purge. The flare is used intermittently. The emission rate per annum for fugitive organic compounds has been estimated at 30 tonnes, based on 2010 operation conditions (Stantec Consulting Ltd. 2014). In the past, this facility has not been required to report to the National Pollutant Release Inventory (NPRI), as its emissions did not meet the reporting requirements. As such, historical emissions data were not publicly available.

Data collection at this site was conducted over 12 weeks, between June 7 and August 26, 2013. A more intensive sampling program was implemented during the first six weeks. The land directly surrounding the gas plant was mainly agricultural or forested (see Figure 4). The monitoring period was selected in order to avoid unnecessary confounding due to major summer agricultural operations, such as manure spreading and harvesting that may, for example, result in excessive particulate matter emissions. However, it was not possible to avoid all confounding operations, as outlined in Section 3.3.

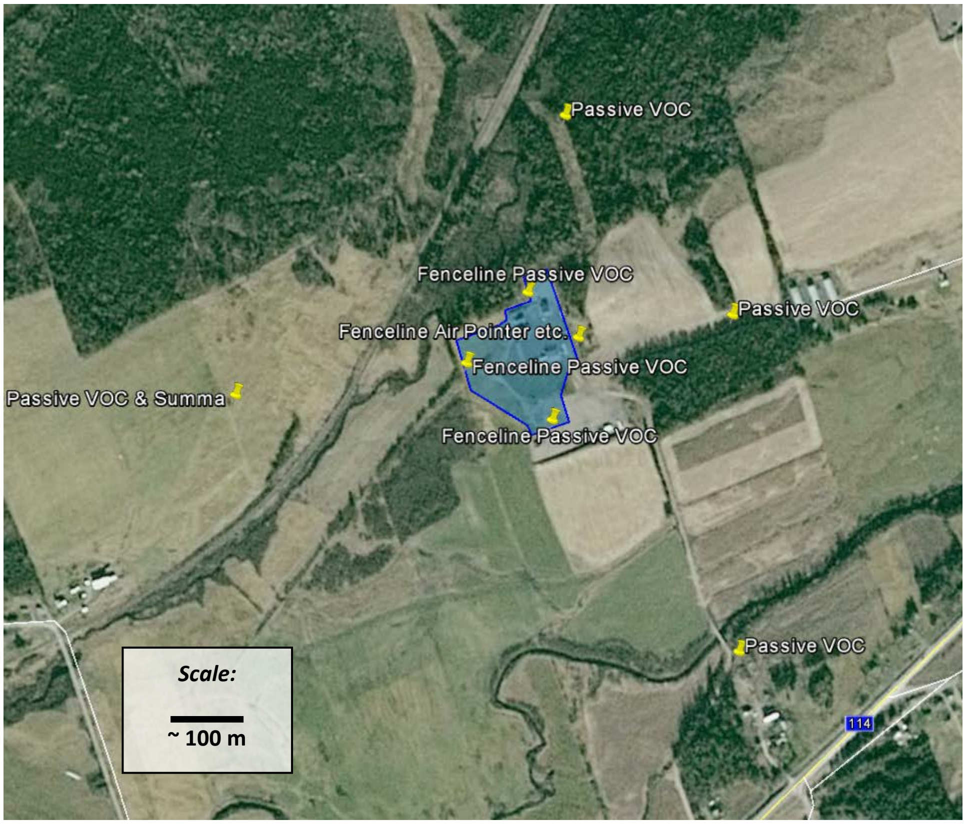

Figure 4. Aerial schematic of sampling locations at the Phase III site (*Source*: Darrell Welles, DELG, and Google Earth) *Legend*: The area outlined in blue is the gas plant fence line perimeter; sampling locations are identified by the yellow pins.

The monitoring approach for Phase III consisted of an inner and an outer ring, each with four sampling locations. They are represented in Figures 4 and 5. Locations 31, 32, 33 and 34 were located on the fence line of the gas plant. Locations 35, 36, 37 and 38 were approximately 300, 565, 470 and 280 m, respectively, from the nearest point of the facility fence line.

A 4D Airpointer ambient air quality monitoring system was deployed at location 31. This unit provided 1 h concentrations for NO_X, SO_2, TRS, O_3 and $PM_{2.5}$ based on 1 minute measurements. The air inlet for the monitors was located approximately 2.5 m above ground level. Meteorology was measured using a Vaisala WXT 520 unit, which was included in the Airpointer system, with measurements collected at approximately 3.0 m above ground level. The Airpointer was calibrated on site according to standard procedures prior to the start of data collection. For the first six weeks of monitoring (June 7 to July 19, 2013), $PM_{2.5}$ 24 h integrated samples were collected at location 31 using ChemComb Speciation Cartridges (ThermoScientific, Waltham, MA, USA) with a BGI pump (10 LPM Model 40010s, BGI Inc., Waltham, MA, USA). PAH samples were also collected at location 31, using the URG Personal Pesticide sampler, similar to the method outlined in Phase I. Sampling was conducted for methane using the lung sampling method.

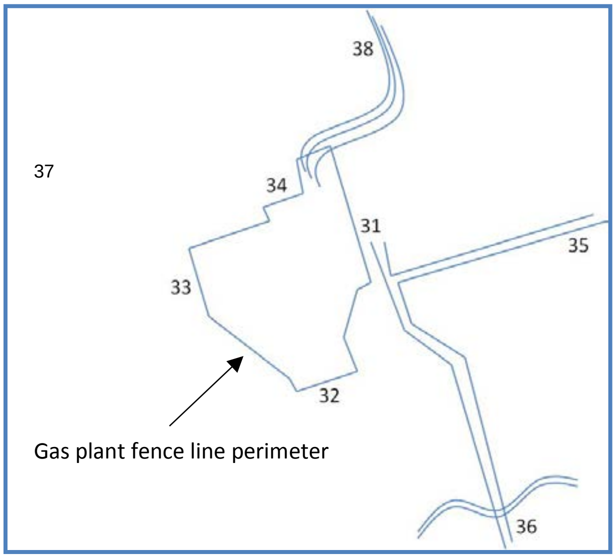

Figure 5. Schematic of sampling locations at the Phase III site (not to scale)

During the first six weeks of monitoring, passive OVM badges were deployed at all eight locations, and Summa canisters were installed at locations 31 and 37 (refer to Figure 5). OVM badges were approximately 1.2–1.5 m above ground level (i.e., attached to the fence itself or on tripods), whereas the Summa canisters were approximately 0.3 m above ground level (i.e., on concrete blocks).

After the first six weeks, continuous air quality monitoring was continued for an additional six weeks with the Airpointer unit (i.e., NO_X, O_3, $PM_{2.5}$, SO_2 and TRS) at location 31, whereas integrated sampling was discontinued. Continuous CO measurements were only collected during the additional six-week period, owing to equipment failure at the onset of Phase III. As no significant seasonal variations in facility operations were projected, the 12-week monitoring period was considered sufficient to adequately characterize how emissions from the gas treatment facility potentially influence the local air quality.

3.2 Results and analyses

Continuous data and integrated data collected between June 7 and August 26, 2013, were analyzed. Table B1 in Appendix B summarizes the descriptive statistics for the continuous data.[15] The period covered 80 sampling days, resulting in 1930 hourly measurements for H_2S, NO, NO_2, O_3, $PM_{2.5}$ and SO_2. CO hourly data were limited to 929 measurements over 39 days. At least 75% of the data set had to be valid; this requirement was met for all pollutants.

Tables B2–B8 in Appendix B present integrated data. These data originate from passive and active samples (e.g., badges, filters or canisters) collected during Phase III. Figures B1–B8 in Appendix B present time series for air pollutant and meteorological data.

Data collected at the Phase III site were compared with data from Phase I. For the comparisons, Phase I data were often limited to the period that coincided with Phase 3 – that is, June 7 to August 26, 2013. This was necessary to control for seasonal variations in background ambient air pollutant levels. When necessary, comparisons were also made with air monitoring data from NAPS (2012, 2013) and reports produced by the New Brunswick DELG (NB DELG 2012, 2013a, 2013b) for nearby provincial monitoring sites. Comparisons were also made with air quality standards for New Brunswick or other Canadian jurisdictions.

The following sections provide information regarding the measured criteria air contaminants (i.e., O_3, $PM_{2.5}$, CO, SO_2, NO_2 and VOCs) and other measured pollutants or parameters (i.e., H_2S, PAHs and meteorological data). Section 3.3 covers data limitations and uncertainties during Phase III.

3.2.1 Ozone

The mean hourly O_3 concentration was estimated at 19.6 ppb. Figure B1 in Appendix B shows 1 h data. Daily maximum 8 h O_3 concentrations showed a mean of 29.1 ppb. These results were comparable to the means estimated during Phase I based on measurements collected during the same period (21.3 ppb for hourly O_3 and 31.6 ppb for daily maximum 8 h O_3).

Figure B2 in Appendix B shows a time series comparing the 8 h daily maximum O_3 concentrations at the Phase I and Phase III sites. The similarities between Phase I and Phase III results were expected as tropospheric O_3 levels are generally dependent on regional conditions, especially in areas with few or no major sources of NOx or VOC emissions. In general, O_3 concentrations appear to be homogenous throughout the study region. It is reasonable to presume that emissions from the gas treatment plant did not affect downwind fence line O_3 concentrations. However, O_3 measurements were not collected farther downwind and it was not possible to assess if and how the emissions from the gas treatment facility may influence O_3 concentrations at other locations.

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[15] Refer to Section 2.2 for explanations regarding table rows, such as averaging periods, data validation criteria and methods used to calculate descriptive statistics.

3.2.2 Fine particulate matter

3.2.2.1 Continuous measurements

The average daily $PM_{2.5}$ concentration from June 7 to August 26, 2013, was 7.3 µg/m^3 (Table B1 in Appendix B). In comparison, the average daily $PM_{2.5}$ concentration for the same period during Phase I was 7.1 µg/m^3. Figure B3 in Appendix B is a time series comparing the Phase I and Phase III data, which demonstrated a similar trend for $PM_{2.5}$ at both sites during the same period of time. No exceedance of the CWS and CAAQS reference values for $PM_{2.5}$ of 30 µg/m^3 and 28 µg/m^3, respectively, were reported during Phase III.

The similarity in the time series underlines the regional constituent of $PM_{2.5}$ concentrations. Corresponding low and high $PM_{2.5}$ concentration periods were observed in both data sets (e.g., July 2, July 16 and August 22). It appears that PM levels at the Phase III site were lower than those at the Phase I site in June, whereas levels at the Phase III site were higher in August. The reason for this shift is unknown. Nonetheless, higher $PM_{2.5}$ concentrations during Phase III were to be expected owing to the presence of the gas treatment plant. In fact, the Airpointer was located between the two entrance gates to the facility, where light-duty and heavy-duty vehicles were regularly driving by. It is also possible that the $PM_{2.5}$ concentrations were affected by emissions originating from the PotashCorp mine or the Town of Sussex, located 5 km and 12 km upwind of the gas treatment plant, respectively. The PotashCorp facility released approximately 51 tonnes of $PM_{2.5}$ in 2013, with monthly releases estimated at 5 tonnes in June, 5 tonnes in July and 1 tonne in August.[16] Wind data (see Section 3.2.2.9) showed that dominant winds at the Phase III site blew from the direction of the PotashCorp mine and the Town of Sussex.

3.2.2.2 Gravimetric samples

$PM_{2.5}$ filter-based samples were collected using a Chemcomb cartridge and BGI pump sampling system. Gravimetric data are shown in Table B2 in Appendix B. The mean $PM_{2.5}$ concentration was estimated at 8.4 µ/m^3. This value compares favourably with the mean estimated from continuous measurements (7.3 µg/m^3).

Overall, the filter samples collected at the Phase III site (8.4 µg/m^3) showed higher $PM_{2.5}$ concentrations than those recovered during the entire length of Phase I (4.0 µg/m^3). However, several factors needed to be considered when comparing these two data sets. For example, only six samples were available for Phase III compared with 49 samples available for Phase I. Seasonal considerations were also important for ambient $PM_{2.5}$ concentrations. Consequently, an analysis of Phase I samples coinciding with Phase III (i.e., June 7 to July 18, 2013) was also conducted, which resulted in a mean of 6.6 µg/m^3 for Phase I.

With only six samples being considered for the comparison between Phase I and Phase III $PM_{2.5}$ concentrations, the mean estimates were highly dependent on extreme values. For example, a relatively high value of 13.7 µg/m^3 was reported at the gas treatment facility on July 3, 2013. In

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[16] PotashCorp New Brunswick Division, National Pollutant Release Inventory, Environment Canada; available at: http://ec.gc.ca/inrp-npri (accessed February 3, 2015)

contrast, a very low value of 0.1 µg/m^3 was recorded at the Phase I site on July 9, 2013.[17] These values can disproportionally influence mean estimates and amplify differences between data sets. In addition, the gravimetric samples were collected using different methods during Phase I and Phase III. A Chemcomb cartridge and BGI pump sampling system was used during Phase III, whereas a Partisol sampling system was used at Phase I (see Table D2 in Appendix D for more details). Although these methods should provide equivalent measurements, it was likely that there were some biases.

3.2.2.3 Galactosan, levoglucosan and mannitol

Some of the Teflon filter samples collected for gravimetric measurements were also analyzed for markers of biomass burning – that is, galactosan, levoglucosan and mannitol concentrations (see Table D2 in Appendix D for more details). The gravimetric data for these Teflon filters collected between June 7 and July 18, 2013 showed a mean $PM_{2.5}$ concentration of 7.3 µg/m^3 during Phase III and 6.6 µg/m^3 during Phase I. Levoglucosan and mannitol levels during Phase III (55.5 ng/m^3 and 6.0 ng/m^3, respectively) were also comparable to those recorded during the same period at Phase I (43.6 ng/m^3 and 6.0 ng/m^3, respectively). Galactosan levels were below detection limits during Phase I and Phase III. The results are summarised in Table B3 in Appendix B.

On average during Phase III, it was estimated that levoglucosan contributed 0.76% to $PM_{2.5}$ mass, whereas mannitol contributed 0.08%. These results were similar to the contributions estimated in Phase I (0.66% and 0.09%, respectively). These very low and comparable levels suggest that emissions from biomass combustion were negligible during Phase III, and they were presumably representative of regional conditions.

3.2.2.4 Metals

Some of the Teflon filter samples collected for gravimetric measurements were also analyzed for metals via ICPMS (see Table D1 in Appendix D for more details). The gravimetric data for these Teflon filters collected between June 7 and July 18, 2013, showed a mean of 9.5 µg/m^3 during Phase III. The results showed that the metals detected and measured in Phase III samples accounted for 4.5% or 423 ng/m^3 of the $PM_{2.5}$ concentrations. Aluminum, potassium and iron had the highest concentrations, on average, and accounted for 72% of the metal concentrations (i.e., detected and measured).

In comparison, gravimetric data for Phase I samples collected between June 7 and July 18, 2013, were associated with a mean of 6.6 µg/m^3. The ICPMS results showed that metals accounted on average for 6.6% or 437 ng/m^3 of the $PM_{2.5}$ concentrations.[18] These values were similar to the Phase

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[17] The latter sample was valid but considered below the method detection limit. Valid samples with values below the method detection limit were given a mass of 2 µg, equivalent to half the detection limit.

[18] Based on the entire Phase I period, metals accounted for 10.8% or 431 ng/m^3 of the $PM_{2.5}$ concentrations. The higher values possibly resulted from the higher number of samples collected during Phase I (i.e., 52 samples) compared with Phase III (i.e., three samples).

III results. In addition, it was observed that aluminum, calcium, potassium, iron and sodium were associated with the highest concentrations in Phase I and Phase III samples, whereas beryllium, cadmium, cobalt and mercury were associated with some of the lowest concentrations. Overall, preliminary analyses suggested that activities conducted at the gas treatment facility had negligible effects on the concentration and composition of metals in ambient air at the fence line location. Results from the analysis of Teflon filters are presented in Table B4 in Appendix B.

3.2.3 Carbon monoxide

The mean hourly CO concentration was 0.2 ppm during Phase III (Table B1 in Appendix B), similar to the estimate for Phase I over the same period. A maximum hourly value of 0.5 ppm was recorded during Phase III. CO levels were much lower than the existing air quality standards (13 ppm or 30 ppm; Table E1 in Appendix E). Figure B4 compares the CO concentration time series for Phase I and Phase III, for data collected between July 18 and August 26, 2013.

Elevated CO concentrations or considerable variations were not expected during Phase III. In fact, vehicle traffic was relatively sparse and the flare was operated intermittently. The monitoring data indicated that emissions from the gas treatment facility were not affecting CO levels at the downwind fence line location.

3.2.4 Sulphur dioxide and hydrogen sulphide

The mean hourly SO_2 concentration was 0.1 ppb. Hourly and daily H_2S concentrations resulted in a mean of 0.2 ppb. These estimates were similar to those for Phase I over the same period.

The Phase III H_2S data were compared with the Phase I TRS measurements.[19] Figure B5 shows that concentrations were generally similar. More than 98% of the H_2S concentration measurements were below 1 ppb during Phase III. However, Phase III data were associated with several peaks above 1 ppb, including values above the 1 h NBAAQO for H_2S of 11 ppb. Two exceedances of the H_2S hourly NBAAQO were reported in the morning hours of August 1, 2013. The data showed that H_2S concentrations were 14.4 ppb at 7h00 and 32.2 ppb at 8h00. Levels dropped to 1–2 ppb between 9h00–15h00 and decreased to less than 1 ppb afterwards. Natural gas in New Brunswick is characterized as being low in sulphur (i.e., sweet gas). Thus, high SO_2 and H_2S levels were not expected. Further, the facility operators did not report any unusual activity (e.g., flaring or venting) that could have affected ambient H_2S levels.[20] As discussed in Section 3.3, agricultural activities, notably manure spreading in the vicinity of the gas treatment facility, may have influenced ambient H_2S levels on August 1, 2013.

Overall, emissions originating from the gas treatment facility appeared to have a negligible influence on SO_2 fence line concentrations, whereas H_2S concentrations were slightly and intermittently affected (i.e., small peaks of short duration).

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[19] TRS is equivalent to the sum of H_2S, methyl mercaptan, ethyl mercaptan and dimethyl disulphide.

[20] David Graves, Corridor Resources Inc. Personal communications. November 12, 2014.

3.2.5 Nitrogen oxides

Based on hourly measurements, NO, NO_2 and NOx concentrations showed a mean of 0.4 ppb, 1.2 ppb and 1.6 ppb, respectively (Table B1 in Appendix B). The NOx measurements in the current study were actually the sum of NO and NO_2 concentrations. Figure B6 in Appendix B shows a time series of NO, NO_2 and NOx mean hourly concentrations. The results suggested that NO_2 concentrations were generally responsible for most of the NOx concentrations. In fact, the contribution from NO to NOx concentrations was considerable only during the NOx peaks that are visible in the time series, such as on June 11 and between August 2 and August 9, 2013.

The combustion of hydrocarbon fuels, such as in vehicle engines or flares, generates NOx emissions that consist mainly of NO. The NO molecule that is emitted will quickly react in the atmosphere to form NO_2. As noted previously, the monitoring data showed that NO_2 was associated with the baseline or "non-peak" NOx concentrations. This is an indication that aged-NOx molecules (i.e., NO_2) were mostly being measured. In contrast, the NOx peaks corresponded with elevations in NO, which may be considered as "fresh" NOx molecules – that is, recently emitted NO molecules that have not yet reacted to form NO_2. Subsequently, the NO peaks were potentially related to emissions originating from the gas treatment plant, such as vehicle activity or flaring, whereas NO_2 levels were presumably representative of background NOx conditions.

The NOx concentrations at the Phase I and Phase III sites were comparable in June and July 2013, but they were higher at the Phase III site in August 2013 (see Figure B7). The results suggested that activities at the gas treatment plant possibly led to a slight increase in NOx levels compared with background levels. Nonetheless, the change in concentrations of NO_2 was minimal and recorded levels were considerably below the air quality standard for NO_2 (Table E1 in Appendix E).

3.2.6 Volatile organic compounds

OVM badge samples were analyzed for 41 VOCs and Summa canister samples were analyzed for 154 compounds.

3.2.6.1 Organic vapour monitoring badge samples

Table B5 in Appendix B shows the OVM badge results for a partial list of VOCs detected and measured at Phase III. Data were available for eight sampling locations where OVM badges were deployed every week. One sample from location 34 was invalided and excluded from the analysis, since the sample was broken when received by the laboratory. The VOCs listed in Table B5 include those that are commonly reported near oil and gas operations, as well as species that were associated with the highest concentrations during Phase III.

The mean concentration results at each sampling location suggested that α-pinene, benzene, carbon tetrachloride, heptanes, hexane, 2-methylhexane, pentane, tetradecane and 2,2,4-trimethylpentane were the VOCs associated with the highest values. Based on available information, most of these VOCs are to some degree linked to the manufacture, treatment, use or disposal of petroleum products. For example, the industrial manufacture, use and disposal of gasoline and petroleum-related products, as well as automotive exhaust and evaporative emissions, are considered important sources of 2,2,4-trimethylpentane in ambient air (US EPA 2007b). Benzene and toluene are known tracers of motor vehicle gasoline combustion (Schauer and Cass 2000). Benzene is potentially released during the production, use (e.g., automotive exhaust and fugitive emissions) and disposal of petroleum products. 2-methylhexane has been identified as a marker of gasoline exhaust (Watson et al. 2001). Heptanes, hexane and pentane can be found naturally in natural gas, and they are removed during gas treatment and processing.[21] Tetradecane may be released to the environment as a fugitive emission during its production and use, in the exhaust of motor vehicles, and via industrial processes.[22] In contrast, vegetation is a major source of biogenic VOC, such as monoterpenes, which include α-pinene (Slowik et al. 2010).

At location 31, butane, ethane, Freon 12, pentane, propane and 2-methylhexane showed the highest concentrations. Ethane and propane are key markers of natural gas, whereas butane is generally associated with evaporative emissions from fuel storage (e.g., gasoline fuel; McCarthy et al. 2013). Natural gas condensates, which are separated and collected on site, can also be a source of butane, pentane and propane emissions (US EIA 2013). At location 31, mean (and maximum) concentrations of pentane, hexane and heptanes were 9.53 µg/m^3 (21.74 µg/m^3), 4.10 µg/m^3 (10.77 µg/m^3) and 2.00 µg/m^3 (6.08 µg/m^3), respectively. In comparison, air quality standards for hexane have been set at 2500 µg/m^3 (24 h) in Ontario (OMOE 2012) and 140 µg/m^3 (annual mean) in Quebec (MDDEFP 2013), whereas an air quality criterion of 11000 µg/m^3 has been defined for heptanes in Ontario (OMOE 2012). An air quality standard for pentane of 240 µg/m^3 has also been adopted in Quebec (MDDEFP 2013). Hence, VOCs with the highest concentrations were found at levels lower than air quality objectives adopted in Canadian jurisdictions.

Benzene is a pollutant of concern and is associated with adverse health effects. Mean benzene concentrations were reported at 0.30–0.53 µg/m^3. These levels were lower than the 24 h air quality standards that exist for benzene in Ontario (2.3 µg/m^3; OMOE 2012) and Quebec (10 µg/m^3; MDDEFP 2013), and lower than the Alberta annual mean standard (3 µg/m^3; Alberta government 2013). However, the mean benzene concentration estimated for location 31 (0.53 µg/m^3) exceeded the OMOE's annual benzene air quality standard of 0.45 µg/m^3. It must be noted that the samples reflected a weekly sample, which was not directly comparable with annual standards owing to potential seasonal variations. Further, concentrations measured upwind of the gas treatment plant (e.g., 0.40 µg/m^3 at location 37) were relatively high compared to the OMOE (2012) annual standard, suggesting that background levels were contributing considerably to ambient benzene concentrations. Possible sources nearby include on-road, industry and agricultural activities, and contributions from long-distance atmospheric transport cannot be discounted.

Mean and maximum concentrations for individual VOCs at locations 32–38 were less than 1.6 µg/m^3, and more than half of the VOC species were associated with mean concentrations less than 0.1 µg/m^3 (Figure 6; Table B5 in Appendix B).

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[21] www.png.ca/natural-gas-faqs/ (accessed October 21, 2014)

[22] http://pubchem.ncbi.nlm.nih.gov//compound/12389?from=summary#section=Non-Human-Toxicity-Excerpts (accessed October 21, 2014)

Figure 6 shows the cumulative concentrations for VOCs measured from OVM samples collected during Phase I and Phase III. The 15 VOCs with the highest concentrations at each sampling location were retained to generate the stacked columns. As the 15 VOCs with the highest concentrations differed slightly among sampling locations, this actually resulted in a total of 24 species per column.[23] The results clearly show that location 31 was associated with higher VOC levels than Phase I and other Phase III locations. The increase in VOC levels at location 31 was related to higher concentrations of heptanes, hexane, 2-methylhexane and pentane; all compounds linked to natural gas production or vehicle use. The VOC compositions and concentrations were similar across the other Phase III locations. They were also comparable to Phase I VOC results, although a relatively high dodecane value during Phase I led to a higher overall VOC concentrations (based on the species considered for Figure 6).

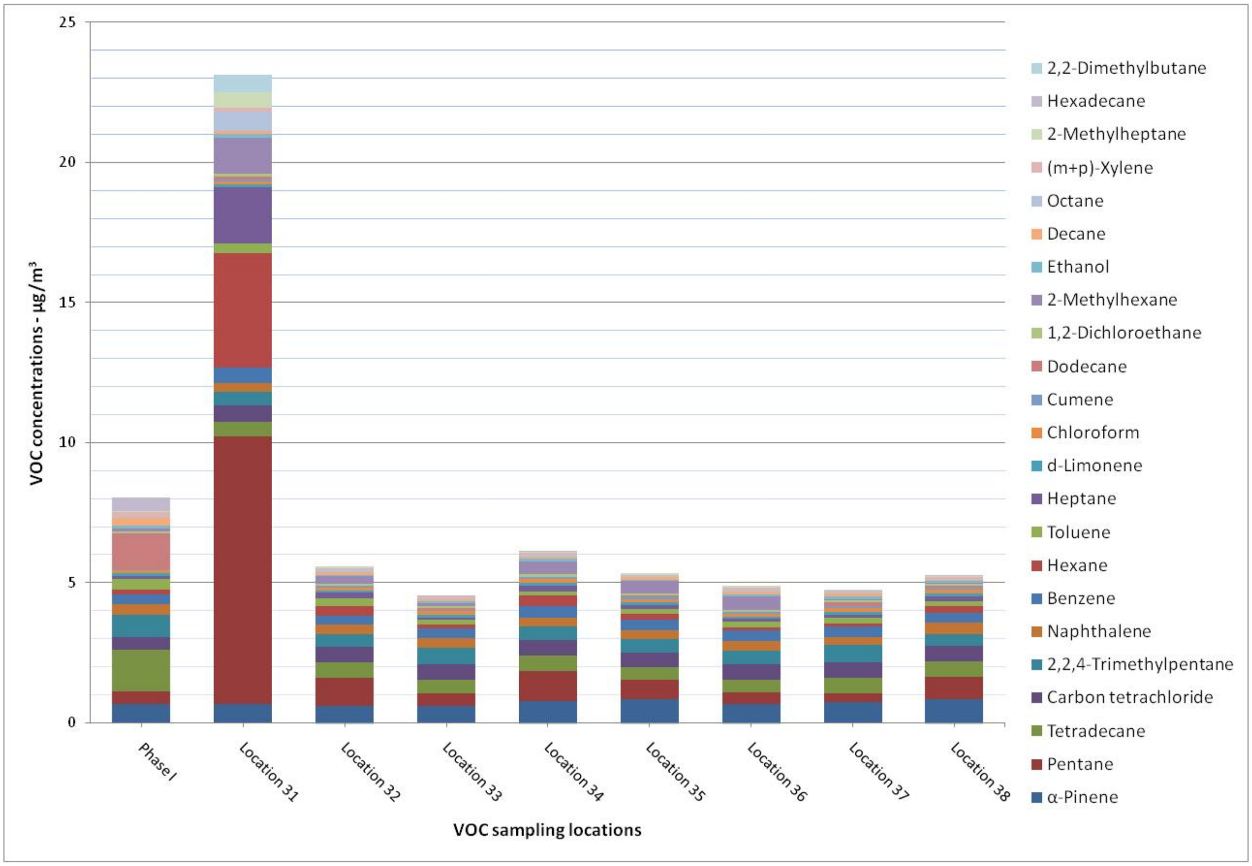

Figure 6. Stacked mean concentrations for VOCs measured at Phase I and Phase III locations based on OVM badges

In order to identify VOC species that varied the most spatially in comparison with location 31 (located on the fence line of the facility and directly downwind), ratios for mean VOC concentrations between different locations of Phase III were estimated (Table 1). Owing to the limited number of samples (i.e., six samples at each location) and the very low concentrations that were measured,

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[23] The columns do not represent a measure of "total" VOCs. They reflect the sum of the 24 selected VOCs.

concentrations for compounds linked to ratios of 0.5–2.0 were not considered different from one site to another.

Table 1. Ratios among mean VOC concentrations measured at different sampling locations based on OVM badge samples collected during Phase III

Ratio descriptor		Fence line	Upwind	Downwind	Downwind versus upwind
Numerator (locations)		31	31	31	35 and 38
Denominator (locations)		32 and 34	33, 36 and 37	35 and 38	33, 36 and 37
Code	Parameter	Ratios			
V7	1,2,4-Trichlorobenzene	-	-	-	-
V8	1,2,4-Trimethylbenzene	0.9	0.8	0.7	-
V34	2,2,4-Trimethylpentane	1.0	0.9	1.1	1.2
V55	2-Methylheptane	**8.7**	**14.7**	**14.1**	1.0
V56	2-Methylhexane	1.9	**6.1**	**5.4**	0.8
V76	α-Pinene	1.0	1.0	0.8	1.1
V78	Benzene	1.3	1.4	1.5	1.38
V102	Carbon tetrachloride	1.0	1.0	1.1	1.0
V117	Dichloromethane	-	-	-	1.0
V122	Ethylbenzene	1.2	1.3	1.4	**0.2**
V131	Heptane	**2.5**	**22.9**	**14.2**	0.9
V135	Hexane	**2.6**	**37.9**	**17.4**	1.6
V147	(m+p) Xylene	1.7	1.9	**2.3**	**2.2**
V157	Naphthalene	0.9	1.0	0.9	0.8
V162	Octane	**8.3**	**13.3**	**17.1**	0.8
V163	o-Xylene	1.3	1.3	1.4	1.1
V166	Pentane	**2.5**	**24.1**	**13.0**	0.9
V173	Styrene	**0.3**	**0.3**	**0.2**	1.9
V188	Toluene	1.4	1.7	**2.0**	1.8
V212	Tetradecane	1.0	1.1	1.1	0.9
V213	1,2,3-Trichlorobenzene	**10.0**	1.6	0.5	**3.0**

Notes: To calculate the ratios, the mean concentration for the “numerator” location(s) was divided by the mean concentration for the “denominator” locations. Refer to Figure 5 to visualize the distribution of sampling locations around the gas treatment facility. Estimates rounded to one decimal point. Estimates that included values below detection limits are marked as “-”. Values in bold indicate ratios of 0.5 and lower or 2.0 and higher.

The results suggested that VOC concentrations were generally higher at location 31 for heptane, hexane, 2-methylheptane, 2-methylhexane, octane and pentane. These alkane compounds are generally associated with the petroleum industry. Xylenes, toluene and 1,2,3-trichlorobenzene were also associated with higher concentrations at location 31. In contrast, styrene levels were lower at location 31. It is uncertain why the styrene levels were higher at locations 32 and 34 than at location

31. However, several samples were associated with values below detection limits for styrene at all locations, which would increase the uncertainty associated with ratio estimates. In comparison, heptane, hexane and pentane values were available for all samples.

The ratio between the downwind locations and the upwind locations were generally close to 1.0, suggesting that most ground-level VOC concentrations returned to background level within 300 m of the fence line. Downwind locations were notably associated with higher (m+p) xylene and 1,2,3-trichlorobenzene concentrations, with respective ratios of 2.2 and 3.0 compared with upwind locations. Downwind 1,2,3-trichlorobenzene concentrations were even higher (ratio of 0.54) than levels recorded at location 31.

3.2.6.2 Summa canister samples

Table B6 in Appendix B shows the Summa canister results for a limited list of VOCs that were detected and measured at Phase III. Data were available for two sampling locations, location 31 (downwind fence line) and location 37 (open field, upwind of the gas plant). The VOCs that are listed in Table B6 include those that are commonly reported near oil and gas operation, as well as species that were associated with the highest concentrations. The highest mean concentrations were reported for butane (8.32 µg/m^3), ethane (5.40 µg/m^3) and pentane (4.12 µg/m^3). In comparison, the 24 h air quality standard for pentane is 240 µg/m^3, as adopted in Quebec (MDDEFP 2013), which is much higher than the levels reported for Phase III. Air quality standards were not available for butane and ethane.

Among the other VOCs that were measured at higher concentrations for Summa canisters collected at location 31, air quality standards were available for hexane. The OMOE has defined a 24 h air quality standard of 2500 µg/m^3 for hexane (OMOE 2012) while Quebec has an annual standard of 140 µg/m^3 (MDDEFP 2013). Hexane was associated with a mean concentration of 1.8 µg/m^3 during Phase III, well below the Ontario and Quebec standards. Although it is not possible to directly compare a 24 h measurement with an annual standard, the fact that the hexane concentrations were almost a 100 times lower than an annual standard indicates that ambient concentrations were very low.

Figure 7 shows the cumulative concentrations for VOCs measured from Summa canisters collected during Phase I and Phase III. The 15 VOCs with the highest concentrations at each sampling location were retained to generate the stacked columns, resulting in a total of 22 species per column.[24] The results clearly show that location 31 was associated with higher VOC levels than location 37 and Phase I. The increase in VOC concentrations at location 31 was associated mainly with butane, ethane, isobutene, 2-methylhexane, pentane and propane. These compounds are generally linked to natural gas production or vehicle use. In the current study, facility emissions are the most likely source of the increases in VOC levels. The composition and concentration VOC data at location 37 were very similar to those for Phase I. Propane levels were actually higher during Phase I, whereas

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[24] The columns do not represent a measure of “total” VOCs. They reflect the sum of the 24 selected VOCs.

α-pinene and β-pinene concentrations (i.e., naturally occurring VOCs emitted from vegetation) were higher at location 37.

Summa canister data for Phase I were generally similar to or higher than those reported for Phase III–location 37 (upwind of the gas treatment facility). VOC concentrations at location 37 were higher than those at Phase I for bromodichloromethane, chlorobenzene, 1,1-dichloroethane, tert-butylbenzene and trichloroethene. 24 h air quality standards were not available for these VOCs.[25]

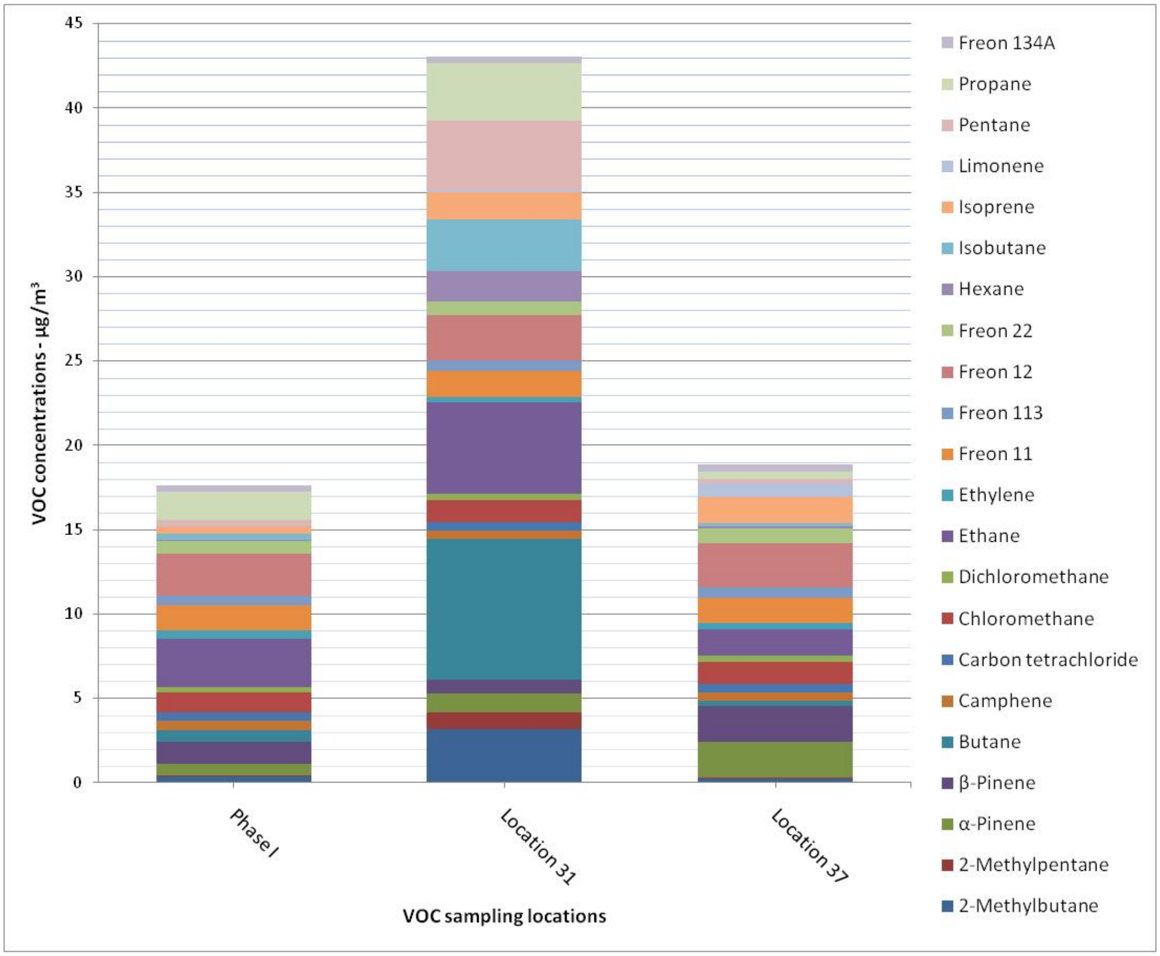

Figure 7. Stacked mean concentrations for VOCs measured at Phase I and Phase III locations based on Summa canisters

Stacked columns were generated from the NAPS 2012 VOC data for the Champlain Heights and Forest Hills monitoring stations in Saint John (not shown). VOC measurements were based on Summa canister samples. Despite the fact that direct comparisons were not possible because the NAPS VOC data were not blank and recovery corrected, the analysis did show that mean

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[25] Although not directly comparable, mean concentrations of bromodichloromethane (0.004 µg/m^3), chlorobenzene (0.64 g/m^3) and 1,1-dichloroethane (0.004 µg/m^3) were lower than their respective air quality criteria of 0.08 µg/m^3 (annual; MDDEFP 2013), 8.5 µg/m^3 (annual; MDDEFP 2013) and 165 µg/m^3 (1 h; OMOE 2012). This is a general indication that ambient levels of these VOCs were low.

concentrations for the VOCs included in Figure 7 added to approximately 35 µg/m^3 in Forest Hills and 70 µg/m^3 in Champlain Heights. This suggests that VOCs in ambient air downwind from the gas treatment facility were present at concentrations similar to or lower than levels typically found in medium population centres (i.e., 10 000–49 999 population within 4 km) of New Brunswick. Note that the Champlain Heights site and the Forest Hills site are located within 400 m of a major industrial source.[26]

Some of the compounds that were detected are ubiquitous in the atmosphere and they are expected to be measured in stable amounts. For example, Freon 11, Freon 12, Freon 113 and chloromethane were once used as refrigerants and propellants (PADEP 2011). Some of the highest VOC concentrations measured at the Phase I and Phase III sites during this study were associated with Freon 11, Freon 12, Freon 22 and chloromethane. Carbon tetrachloride, which was detected at most sampling sites, was used to produce these refrigerants.[27] Although the production and use of these compounds has been banned and/or has decreased in the last decades (e.g., Montreal Protocol for ozone-depleting substances in 1989), they persist at measurable levels in the atmosphere (PADEP 2011). In fact, these compounds have been detected and measured elsewhere in New Brunswick (see NAPS 2012; NB DELG 2013b). Concentrations of these compounds were similar across sampling locations, as would be expected for globally mixed persistent pollutants (McCarthy et al. 2007).

The ratios between the mean concentration for each VOC measured at location 31 and location 37 were determined by dividing the location 31 concentrations by the location 37 concentrations (see Table 2 for a partial list). Owing to the limited number of samples and the very low values that were measured, concentrations were not considered different from one site to another for compounds linked to ratios of 0.5–2.0. The results for all VOCs (not shown) suggested that 34% of the VOCs at location 31 had concentrations that were at least two times higher than those reported at location 37. Only 2% of VOCs were associated with higher concentrations at location 37. The remaining 64% of VOCs had similar levels at both locations – that is, the concentration ratios varied between 0.5–2.0.

Table 2 shows some of the ratios calculated for mean VOC concentrations based on Summa canisters. The results indicated that the lowest ratios (i.e., higher concentrations at location 37 than location 31) were associated with VOCs emitted from vegetation, such as α-pinene, β-pinene, limonene and p-cymene. It is unknown why tert-butylbenzene and cis-4-methyl-2-pentene levels were higher at the upwind site. However, it must be noted that concentrations of these two compounds were below detection limits in half of the samples, which affected the ratio estimates.

The highest ratios were estimated for compounds associated with the manufacture, use or treatment of petroleum products, such as butane, 2,2-dimethylpropane (a structural isomer of

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[26] Refer to NAPS Network Information at http://maps-cartes.ec.gc.ca/rnspa-naps/data.aspx?lang=en (accessed February 2015)

[27] www.ec.gc.ca/toxiques-toxics/Default.asp?lang=En&n=98E80CC6-1&xml=08B000FD-9EC1-49CC-8302-E5F6E47C6F5F (accessed October 21, 2014)

pentane), heptanes and pentane. These compounds were generally measured in all samples (i.e., no or only a few values below detection limits). McCarthy et al. (2013) have observed associations between butane, cyclohexane, hexane, pentane and 2,2-dimethylbutane concentrations and fuel-related industrial activities in Edmonton, Alberta (although these authors estimated much higher levels).

Table 2. Ratios between mean VOC concentrations measured at location 31 and location 37 based on Summa canister samples collected during Phase III (partial list)

Code	Parameter	Concentration ratio	Code	Parameter	Concentration ratio
V36	2,2-Dimethylbutane	23.1	V129	Freon 12	1.0
V39	2,2-Dimethylpropane	58.5	V131	Heptanes	14.7
V53	2-Methylbutane	12.9	V135	Hexane	15.7
V55	2-Methylheptane	12.4	V138	Isobutane	16.5
V57	2-Methylpentane	22.3	V142	Isoprene	1.0
V76	α-Pinene	0.54	V146	Limonene	0.17
V78	Benzene	1.0	V152	Methylcyclohexane	10.0
V80	β-Pinene	0.38	V164	p-Cymene	0.74
V85	Butane	25.6	V166	Pentane	17.5
V119	Ethane	3.4	V167	Propane	7.7
V126	Freon 11	1.0	V186	Tert-butylbenzene	0.01

Notes: Data were available for 14 samples (seven samples per site); ratios estimated by dividing the mean concentration for location 31 by the mean concentration for location 37.

Overall, the results suggested that emissions from the gas treatment facility affected VOC concentrations at downwind locations, particularly by increasing the concentrations of alkane species associated with oil and gas production compared with background or upwind conditions. Nonetheless, preliminary analyses showed that the VOCs that were detected and measured with OVM badges and Summa canisters during Phase III were below levels that would be considered of concern to human health.

3.2.7 Polycyclic aromatic hydrocarbons

Table B7 in Appendix B shows descriptive statistics of PAH data for URG pesticide personal samplers collected during Phase III at location 31. Data were available for six samples. The highest mean concentrations were reported for phenanthrene (6.09 ng/m^3), naphthalene (2.11 ng/m^3) and fluorene (1.94 ng/m^3). The highest maximum values were associated with phenanthrene (12.46 ng/m^3), naphthalene (3.25 ng/m^3) and acenaphthene (3.13 ng/m^3).

Air quality objectives for the measured PAHs have not been adopted in New Brunswick. Air quality standards based on a 24 h average were available from other Canadian jurisdictions for benzo(a)pyrene and naphthalene. The OMOE (2012) has determined a 24 h air quality criterion of 0.05 ng/m^3 for benzo(a)pyrene and a 24 h criterion of 22.5 mg/m^3 for naphthalene. The Government of Alberta has adopted a 24 h air quality objective of 0.30 ng/m^3 for benzo(a)pyrene (Alberta

Government 2013). The benzo(a)pyrene concentrations measured at the Phase III site (0.0588 ng/m^3), which were based on 24 h samples, were above the OMOE 24 h criterion but lower than the 24 h Alberta standard. Even so, benzo(a)pyrene concentrations at Phase III were comparable to or lower than historical values collected at NAPS stations across Canada (Environment Canada 2013). The mean benzo(a)pyrene concentration measured from URG samples during Phase I (0.15 ng/m^3; see Table A9 in Appendix A) was also above the OMOE criterion. More importantly, the mass of benzo(a)pyrene measured from the filters was below the method detection limit values, increasing the uncertainty of the estimated concentrations.[28] Thus, comparing the results for the current study with the OMOE criterion may not be very informative or relevant in this case. Naphthalene levels at Phase III (mean of 2.11 ng/m^3; see Table A9 in Appendix A) were considerably below the air quality criteria adopted in Ontario (OMOE 2012).

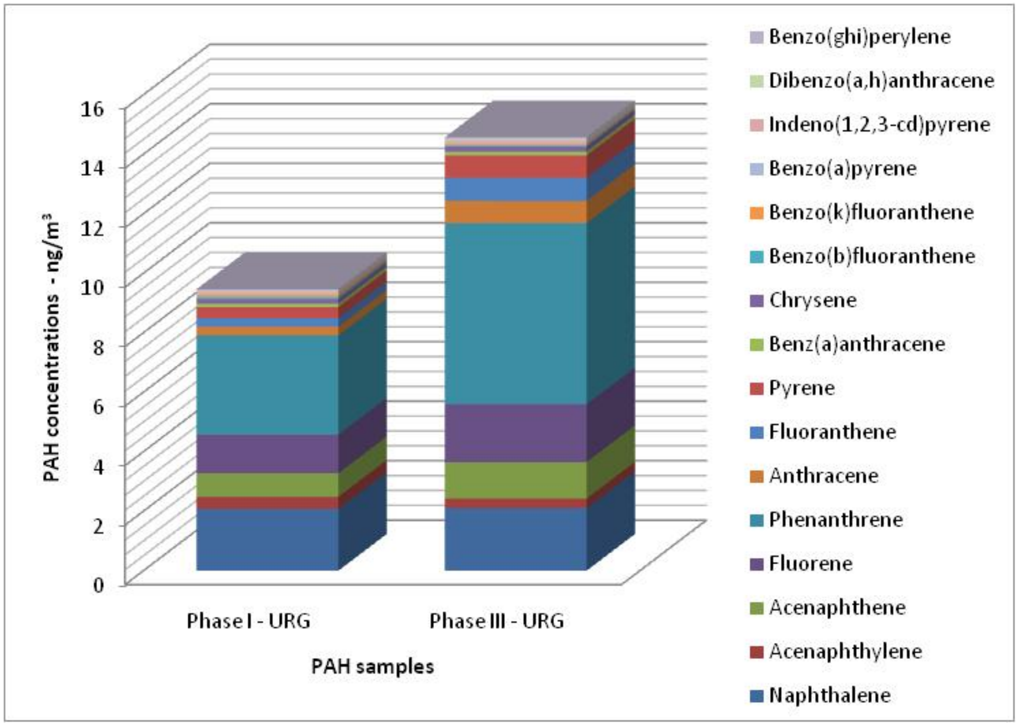

Figure 8. Stacked mean concentrations for 16 PAHs measured during Phase I and Phase III based on URG pesticide personal samplers

Figure 8 shows the cumulative concentrations of the 16 PAHs measured from URG pesticide personal samples collected from June 9 to July 15, 2013, at the Phase I and Phase III locations.[29] Notwithstanding the limitations of this preliminary analysis, the results suggested that PAH levels were higher during Phase III. Higher phenanthrene levels during Phase III (6.09 ng/m^3) than Phase I

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[28] The mass values for benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, indeno(1,2,3-c,d)pyrene, benzo(g,h,i)perylene and dibenzo(a,h)anthracene were below the method detection limits for these compounds.

[29] The columns do not represent a measure of "total" PAHs. They reflect the sum of the 16 measured PAHs.

($3.34\ ng/m^3$) were responsible for most of the difference. Otherwise, the composition and concentration of PAHs were fairly similar between Phase I and Phase III.

3.2.8 Methane

Air bag samples were collected at location 31. An average methane concentration of 2.03 ppb was measured (see Table B8 in Appendix B). Methane concentrations at the Phase III site were very similar to the methane levels measured at the background site (see Table A10 in Appendix A).

3.2.9 Meteorological data

Wind speed and direction data are shown in a wind rose in Figure B8 in Appendix B. The dominant vector indicated that winds were blowing predominantly from the southwest. Based on knowledge of the area and satellite photography (e.g., Google Earth; see Figures 2 and 4), the most significant sources of emissions upwind of the gas treatment facility were the Town of Sussex (12 km southwest) and the PotashCorp mine (5 km southwest). Wind speeds averaged approximately 2.1 m/s (7.6 km/h) and rarely exceeded 5.7 m/s (20.5 km/h). Less than 1.1% of wind data were characterized as calm wind conditions.

The average temperature was 18.1°C during Phase III, with minimum and maximum measurements of 4.2°C and 34.3°C.

3.3 Limitations and uncertainties

Several incidents and issues were noted during Phase III that may have affected the air pollutant measurements. These included potential outliers in the data set (unexplained high or low readings) that needed to be reviewed, unforeseen events (e.g., forest fires) as well as equipment failures.

For example, as part of the Canada Day celebrations, the Town of Sussex organized fireworks at approximately 22h00 on July 1, 2013.[30] The time of the fireworks concurred with a spike in $PM_{2.5}$ concentrations ($30–40\ \mu g/m^3$) over several hours at the gas plant, which was located only a few kilometres from Sussex (see Figure B4 in Appendix B). Based on wind data for July 1, 2013, the wind was blowing from the southwest – that is, from Sussex towards the gas treatment plant – and it is likely that particulates from the fireworks were transported and affected the measurements. The winds did shift on July 2, and blew from the northeast, when $PM_{2.5}$ decreased to typical levels ($10–15\ \mu g/m^3$).

An air quality advisory was also issued by the Government of New Brunswick on July 1, 2013.[31] The poor air quality resulted from the transport of smoke from forest fires in northern Quebec. Although the smoke was projected to affect air quality in northern New Brunswick, air pollutant levels in Sussex may have been influenced via long-range transport of forest fire emissions. Unfortunately, $PM_{2.5}$ filter samples for the analysis of biomass burning markers (e.g., levoglucosan) were not scheduled for July 1, 2013, at the Phase I or Phase III sites.

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[30] www.sussex.ca/content/250775 (accessed December 5, 2014)

[31] www2.gnb.ca/content/gnb/en/news/news_release.2013.06.0619.html (accessed December 5, 2014)

The gas treatment plant was active throughout the Phase III monitoring period. Air pollutant concentrations measured around the gas plant reflected emissions from the various activities being conducted in and around the facility. However, it was difficult to associate specific activities with ambient concentrations as precise data on emissions were not available. Between June and August, 2013, the volume of gas combusted by the flare was considered normal and no outstanding flaring was recorded. Temperatures were also within seasonal averages and excessive flashing (i.e., fugitive emissions) from the tanks was not suspected.[32]

Some of the activities around the gas plant, while they were not necessarily associated with natural gas treatment processes, may have affected air pollutant concentrations. For example, regular maintenance activities involved cutting the grass in and around the gas treatment facility every two weeks. This was done using gasoline or diesel powered equipment. In addition, manure was spread on some of the adjoining agricultural fields on August 1, 2013, when the ambient temperature was around 28°C.[33] This agricultural activity was correlated on the same day with the higher H_2S readings at the Airpointer location. Manure handling is a known source of H_2S (e.g., ATSDR 2006). It is likely that the spreading contributed to the elevated H_2S concentrations on August 1, 2013.

Corridor also mentioned the shipment of condensate products from the facility on August 8, 2013.[34] A methane reboiler was also dismantled on August 12, 2013. This unit is a distillation column used to recover methanol from liquid mixtures (essentially water and methanol mixtures). The methanol reboiler remained opened until August 21, 2013. Further, downhole work was conducted on a natural gas well located on the gas plant property (well D-48) on August 2 and 7, 2013. These activities were potential sources of VOCs and methane. However, they occurred during the second half of Phase III, when VOC samples were no longer being collected. Hence, it was not possible to evaluate if these activities affected the ambient concentration of VOCs around the gas treatment facility. The continuous data for CO and NOx in August were slightly higher than previous weeks, but several other factors may have contributed to these increases in concentrations.

Lastly, motor vehicle activities and agricultural operations near the gas treatment facility (except for manure spreading on adjacent fields) were not monitored during the study period. Vehicle exhaust can be a considerable source of air pollutants, such as NOx, $PM_{2.5}$ and VOCs.

The Airpointer CO module was found to be dysfunctional during the initial set-up and calibration of the Airpointer on June 6, 2013. On June 24, fluctuations in O_3 concentration readings were also observed. New CO and O_3 modules were installed on July 17 and calibrated on July 18. Installation of the new equipment coincided with the start of the second six-week segment (July 18 to August 26, 2013).

The Airpointer was positioned at ground level and may not have picked up pollutant plume(s) originating from the gas plant. However, aside from the flare stack, sources of emissions were

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[32] David Graves, Corridor Resources Inc. Personal communications. November 12, 2014.

[33] *Ibid.*

[34] *Ibid.*

relatively low-lying equipment (e.g., well head, storage tanks, dehydrators). Further, the Airpointer was located on the fence line and relatively close to on-site equipment. Hence, there was a reasonable chance that emissions were being captured by the sampling equipment.

The analysis of VOCs, metals, PAHs and PM speciation was limited by the small number of samples (3–6). However, most samples were valid and several pollutants were detected and measured in all samples.

Concentrations reflecting "total" VOCs were not available. In fact, the ability to determine total VOC concentrations was limited by the analytical method used (e.g., number of detectable species), the number of samples and non-detected species.

Air quality standards for individual VOCs and PAHs have not been adopted in New Brunswick, and very few of the VOCs detected at higher concentrations were covered by air quality objectives adopted in other Canadian jurisdictions (e.g., Alberta Government 2013; OMOE 2012). As a result of these limitations, a health-based comparative evaluation was limited for most VOCs or PAHs.

4. Phase IV – Well closure

4.1 Overview of site location and data collection

Phase IV of the study was conducted to characterize potential emissions from a decommissioned well – that is, after the active or operational life of a well. It was not possible to identify a natural gas well near Sussex that had been hydraulically fractured, put into production and then decommissioned. The best alternative was a site with two wells, one horizontal (B-41; water used as fracking fluid) and one vertical (G-41; liquid propane used as fracking fluid), that had been hydraulically fractured but never put into production.

The Phase IV site, also referred to as the Green Road site, is located north of Elgin, New Brunswick, and is owned by Corridor Resources Inc. The surrounding area was mainly forested and undeveloped. The well heads were still present (see Photo 3), but they were inactive.[35]

As there were no sources of combustion on site, emissions of pollutants such as PM, NOx and CO were not expected. Fugitive emissions from the well heads and adjacent areas were the focus for the monitoring at this site. VOCs (including carbonyl compounds and methane) were monitored using passive 3M OVM VOC badges, Summa canisters and air bag samples. Samples were collected for six weeks between April 23 and June 6, 2013. Continuous data were not collected. Seasonal variations in air quality associated with emissions from the well heads were not expected at this site.

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[35] In summer 2014, Corridor Resources Inc. conducted additional well stimulation activities in well G-41.

Photo 3. Inactive well heads at the Corridor Resources Inc. Green Road site near Elgin, New Brunswick
(Note: Large vertical steel tanks were located on site and are visible in the right-hand part of the photograph. The tanks were empty during the sampling period.)

Figure 9 shows the general sampling approach during Phase IV. The area covered by the sampling locations corresponded to the surface cleared during the well development stage of the existing wells. Passive OVM badges were deployed at five locations (41–45), and Summa canisters were deployed at locations 41 (well heads) and 43 (expected downwind based on prevailing winds). In relation to the well heads (i.e., location 41), locations 42, 43, 44 and 45 were approximately 50, 74, 71 and 55 m away, respectively.

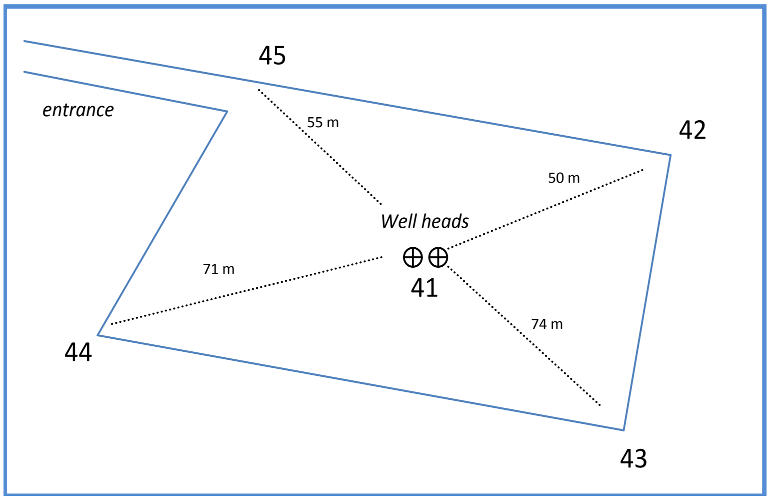

Figure 9. Schematic of monitoring locations at the Phase IV sampling site (not to scale)

OVM badges were exposed for 6–7 days and then replaced. They represented an integrated sample of approximately one week. Field blanks were collected each week. OVM badges were installed on tripods, at approximately 1.2–1.5 m above ground level. The Summa canisters were activated by timers and collected a 24 h integrated sample. The Summa canisters were stabilized on concrete blocks, at approximately 0.3 m above ground level.

Sampling for methane was also conducted weekly and/or when personnel were on site. Air bag samples were collected directly beside the well heads using the lung sampling method (the exact location changed according to wind conditions during the visit). Uncertainties and limitations for Phase IV are addressed in Section 4.3.

4.2 Results and analyses

Samples were collected at this site between April 23 and June 6, 2013. The following sections provide information regarding the measured VOC and methane concentrations. Tables C1–C3 in Appendix C present the data from OVM badge samples, Summa canisters and air bag samples. Data collected during Phase IV were compared with data from Phase I, air monitoring data from nearby provincial monitoring sites (NAPS 2012; NB DELG 2012, 2013a, 2013b), and air quality standards for New Brunswick or other Canadian jurisdictions.

4.2.1 Volatile organic compounds

OVM badge samples were analyzed for 41 VOCs and Summa canister samples were analyzed for 154 compounds.

4.2.1.1 Organic vapour monitoring badge samples

Table C1 shows the mean VOC concentrations for the five sampling locations during Phase IV based on measurements for OVM samples. The samples for locations 42, 43, 44 and 45 were also combined for comparison with VOC concentrations measured near the well heads (i.e., location 41). The list was limited to VOCs that are generally associated with oil and gas activities, species that were measured at higher concentrations and species for which concentrations varied between locations.

Overall, the results for each sampling location showed that α-pinene, benzene, carbon tetrachloride, decane, dodecane, 2-Methylhexane, styrene, tetradecane and 2,2,4-trimethylpentane were associated with the highest concentrations. These VOCs represent a mixture of compounds that are generally associated with the manufacture, treatment, use or disposal of petroleum products (e.g., benzene and 2,2,4-trimethylpentane), vegetation (e.g., α-pinene) or ubiquitous and environmentally persistent pollutants (e.g., carbon tetrachloride).

Dodecane and tetradecane had mean concentrations of 18.12 µg/m^3 (location 45) and 13.88 µg/m^3 (location 42), which were considerably higher than concentrations for other VOCs during Phase IV. They were also higher than dodecane and tetradecane concentrations reported for other monitoring sites in this study and for Saint John (refer to NB DELG 2013b). These two alkanes are found in kerosene and diesel-type fuels and are also used as solvents. No air quality standard was available for these compounds. Upon investigation, the high dodecane and tetradecane values were related to samples exposed from May 1 to May 7, 2013, at locations 42 (122.60 µg/m^3 for dodecane and 92.69 µg/m^3 for tetradecane) and 45 (124.96 µg/m^3 for dodecane and 70.83 µg/m^3 for tetradecane). In fact, when the May 1–7 samples for locations 42 and 45 were removed from the data set, the mean concentrations decreased to 0.39 µg/m^3 and 0.31 µg/m^3, respectively, which were comparable to the mean concentrations estimated at the other locations during Phase IV (Table C4 in Appendix C).

Several pollutants other than dodecane and tetradecane, such as ethanol, heptane, hexane, styrene, toluene and xylenes, also showed considerably higher concentrations in the May 1–7 samples. Currently, there is no reason to invalidate the May 1–7 samples but the high concentrations are questionable (see Section 4.3).

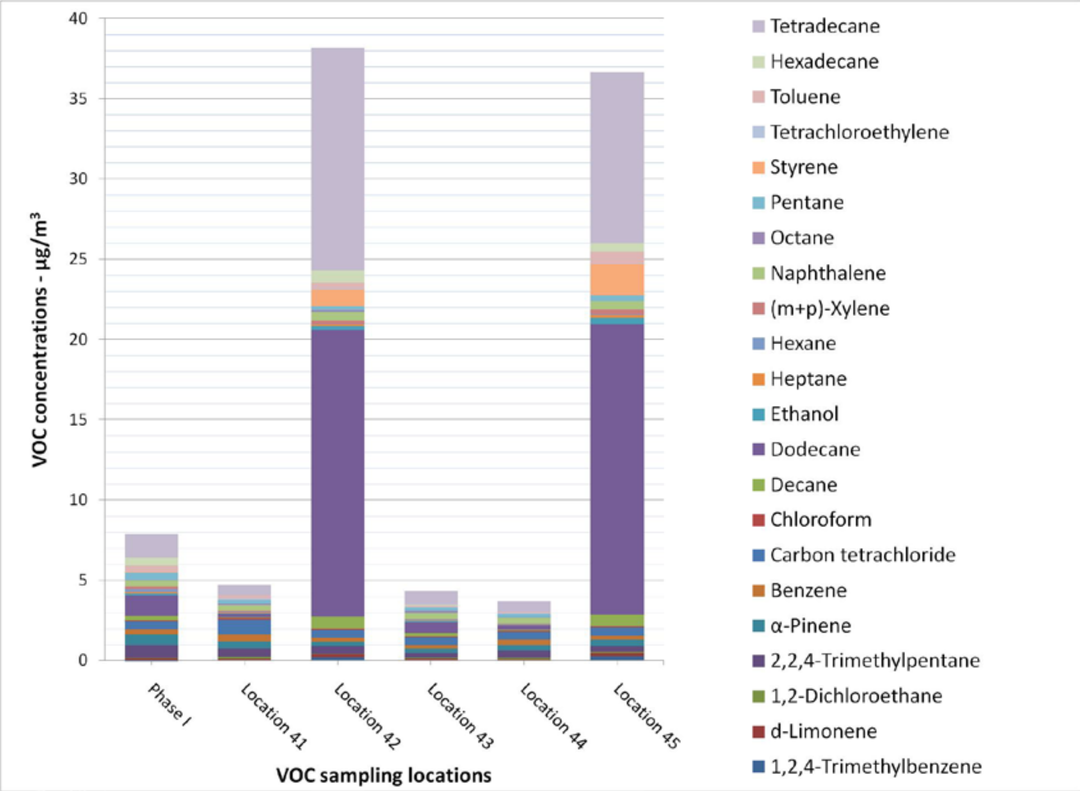

Figure 10. Stacked mean concentrations for VOCs measured at Phase I and Phase IV locations based on OVM badges

Figure 10 shows the cumulative concentrations for VOCs measured from OVM badge samples collected during Phase I and Phase IV. The 15 VOCs with the highest concentrations at each sampling location were retained to generate the stacked columns, resulting in a total of 22 species per column.[36] The VOC data for locations 41, 43 and 44 were very similar to those for Phase I. In contrast, the results clearly showed that locations 42 and 45 were associated with higher VOC levels than Phase I and other Phase IV locations. The increases in VOC concentrations at locations 42 and

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[36] The columns do not represent a measure of “total” VOCs. They reflect the sum of the 22 selected VOCs.

45 were due mainly to dodecane, styrene and tetradecane. These compounds are not necessarily linked to natural gas production, although they could be indicators or petroleum fuels, such as diesel or kerosene.

4.2.1.2 Summa canister samples

Table C2 shows the Summa canister data for samples collected during Phase IV. Seven Summa canisters were collected at location 41 while six canisters were collected at location 43 (one invalid sample owing to automatic timer malfunction). Overall, the Summa canister data indicated that α-pinene, β-pinene, carbon tetrachloride, chloromethane, dichloromethane, dodecane, ethane, Freon 11, Freon 12, Freon 22, propane and undecane were associated with the highest concentrations. These VOCs represent a mixture of compounds that are generally linked to vegetation (e.g., α-pinene), ubiquitous and environmentally persistent pollutants (e.g., carbon tetrachloride and Freon compounds), solvents (e.g., dichloromethane and dodecane) and the manufacture, treatment, use or disposal of petroleum products (e.g., ethane and pentane).

Figure 11 shows the cumulative concentrations for VOCs measured from Summa canisters collected during Phase I and Phase IV. The 15 VOCs with the highest concentrations at each sampling location were retained to generate the stacked columns, resulting in a total of 19 species per column.[37] The results suggest that VOC concentrations and compositions were generally similar among sampling locations.

Concentrations measured from canisters collected at locations 41 and 43 were generally similar. Nonetheless, based on an analysis of ratios between concentrations (not shown), styrene, decene and undecene levels were found to be higher near the well heads (i.e., location 41), whereas concentrations for dodecane, ethylbenzene, toluene, undecane, xylene and several other VOCs (mostly alkanes) were higher at location 43. Preliminary analyses also indicated that concentrations were considerably higher for the sample collected at location 43 on May 21, 2013. The field technician did not report anything particular for this sample and, based on available information, there is no reason to invalidate the sample. Further investigations are necessary to understand why the concentrations for specific VOCs differed markedly from other samples. Nonetheless, all detected VOCs were measured at concentrations below air quality standards available for Canadian jurisdictions (Alberta Government 2013; MDDEFP 2013; OMOE 2012).

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[37] The columns do not represent a measure of “total” VOCs. They reflect the sum of the 19 selected VOCs.

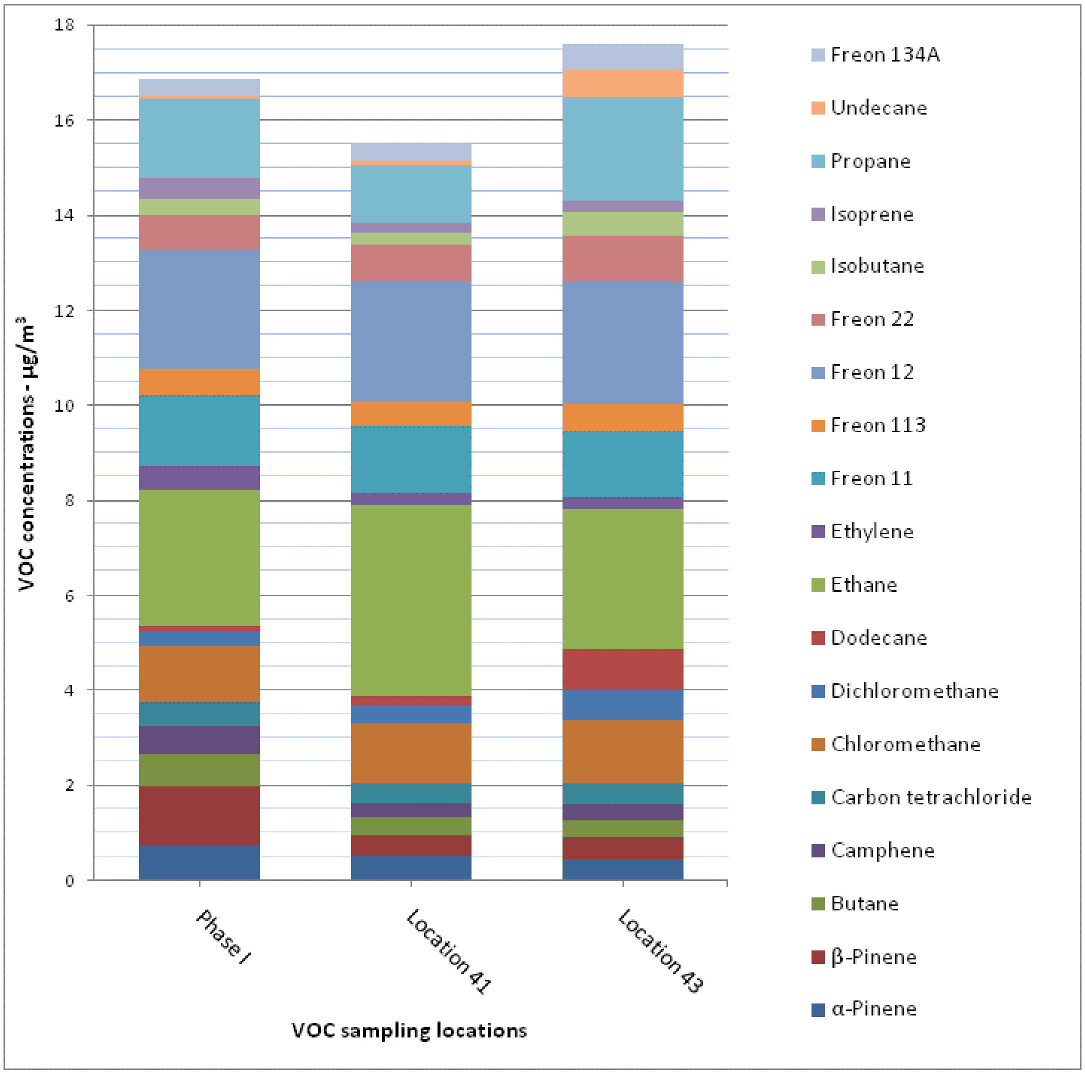

Figure 11. Stacked mean concentrations for VOCs measured at Phase I and Phase IV locations based on Summa canister samples

4.2.2 Methane

Air bag samples were collected weekly during Phase IV, and analyzed for methane and ethane concentrations (Table C3 in Appendix C). The data show a mean methane concentration of 2.03 ppm and 2.11 ppm at locations 41 and 43, respectively (overall average of 2.05 ppm). All ethane measurements were below the method detection limit. Methane concentrations at the Phase IV site were very similar to the methane levels measured at the background site and during Phase III.

4.3 Limitations and uncertainties

Some limitations and uncertainties should be considered regarding the air pollutant data collected during Phase IV. These include potential outliers in the data set (unexplained high or low readings) that need to be reviewed, unforeseen events (e.g., forest fires) as well as equipment failures.

Forest fires were active during Phase IV in the area of Petitcodiac, New Brunswick, located approximately 20 km north of the Phase IV site. One fire was reported on May 7, 2013, near Sanitorium and Middlesex roads.[38] Meteorological data were not being collected at the monitoring site and local wind condition data were not available. Southerly winds were blowing when a technician visited the site on the day the fire was called in. Further, southwesterly winds were reported at the Phase I site on May 7, 2013. Nonetheless, it was uncertain whether or not forest fires affected the air quality at the Phase IV site.

Unusually high VOC values were reported in some of the OVM badge (May 1–7) and Summa canister (May 21) samples. Although there is no reason to invalidate the May 1–7 OVM samples, the high concentrations at locations 42 and 45 needed to be investigated. As mentioned previously, forest fires were reported near the Phase IV site on May 7. However, if forest fire emissions had reached the Phase IV site, it is more probable that samples from all locations would have been affected instead of only those deployed at locations 42 and 45. Also, the field technician who visited the site on that day did not report any particular activities in proximity to the site. Location 45 was located nearest to the Green Road, whereas location 42 was in line with the access road leading to Green Road, but farther away than location 45 (see Figure 9). Contributions from vehicle traffic on Green Road could possibly explain some of the VOC concentrations at locations 45 and 42, but evidence to that effect was lacking. For example, analysis of VOC concentrations without the May 1–7 samples suggested that concentrations at location 45 were mostly equivalent to concentrations measured at other locations (not shown).

Mean concentrations with and without the May 1–7 samples were estimated for locations 42 and 45, and they are shown in Table C4 in Appendix C. VOC concentrations for OVM samples collected at the other locations during the same week did not show such a marked difference (not shown). Table C4 also includes concentration ratios to highlight compounds that were affected the most by the May 1–7 samples. It is interesting to note that the compounds associated with higher ratios are not typically associated with natural gas operations, nor are they the most volatile alkane species. They would not be expected to be released from the well heads. More importantly, they were not reported in high concentrations near the well heads (location 41). Preliminary analyses also indicated that concentrations for many VOCs were considerably higher for the Summa canister sample collected on May 21, 2013.

Possible hypotheses to explain the markedly different concentrations for specific VOCs in some of the samples include sample manipulation errors, sample tampering or volatilization of VOCs from contaminated soil. As mentioned previously, the field technician did not report anything particular for these samples and the sampling log sheets did not contain notes to that effect. Also, there is no reason to suspect that any tampering occurred during Phase IV. The site is located in a fairly remote area and vehicle access is restricted.

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[38] www.cbc.ca/news/canada/new-brunswick/petitcodiac-n-b-forest-fir E-only-25-contained-1.1350704 (accessed May 7, 2014)

Corridor Resources Inc. did report spills on the well pad in 2009 and 2012.[39] These involved 20 litres of 50/50 heavy-duty antifreeze or coolant and 10 litres of glycol water mixed with five litres of chain oil. They occurred in the vicinity of the well heads and were cleaned up immediately. No spills were reported between the drilling in 2011 and the air monitoring in 2013.

50/50 antifreeze or coolant solutions are composed mainly of water (50%) and ethylene glycol (45–47%). Additional compounds (e.g., diethylene glycol, corrosion inhibitors and aversive agents) may vary based on product or usage specifications, but they generally make up less than 5% of the liquid. Glycol water presumably includes a glycol component, such as ethylene or diethylene, mixed with water. Exact composition is not known. Naphthenic and paraffinic petroleum compounds comprise chain oil. Overall, the products that were spilled near the well heads are not characterized as being very volatile. Further, they were quickly recovered following the spills. As such, the spills in 2009 and 2011 are not expected to have affected the samples collected during Phase IV. In fact, samples collected near the well heads, where the spills occurred, were not associated with higher levels of VOCs compared with other locations.

It is likely that smaller unnoticed spills may have occurred, notably during the drilling phase and other activities, when contractors to Corridor Resources Inc. were operating on the site. An environmental site assessment of the well pad area was conducted in 2011, which involved the collection and analysis of soil samples (AMEC 2012). Samples were collected at depths ranging from approximately 0.15–5 m below ground surface to assess impacts associated with exploration activities at this site (e.g., well pad construction, drilling, hydraulic fracturing and storage tanks), notably the use of petroleum products and fracking fluids. Analyses for benzene, toluene, ethylbenzene and xylenes (BTEX) and total petroleum hydrocarbons (TPH) showed that soil samples met the regulatory levels for a commercial site with a potable groundwater source, coarse-grained soil and diesel-type fuel.[40] The report also mentioned the absence of objectionable odours associated with the soil and the absence of visual signs of contamination during the collection of soil samples. Some of the samples from boreholes located near locations 42 and 45 showed traces of extractable petroleum hydrocarbons, although levels met existing criteria for commercial sites. It must be underlined that the results presented in the AMEC report (2012) reflected site conditions in October 2011 when field investigations were conducted.

5. Discussion

The results from the different phases are discussed in this section to highlight similarities and differences in air pollutant concentrations, and to identify the likely basis for these associations. O_3 concentrations were measured at Phase I and Phase III. The data suggested that O_3 levels were similar at these sites (see Table 3). In fact, local emissions generally have a limited influence on O_3

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[39] David Graves, Corridor Resources Inc. Personal communications. November 18, 2014.

[40] Refer to the Atlantic Risk Based Corrective Active Action standards (www.atlanticrbca.com/about-atlantic-rbca/) and the Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health (http://ceqg-rcqe.ccme.ca/en/index.html) (accessed December 1, 2014)

levels. Farrell (2006) determined that transboundary transport of O_3 and its precursors was the dominant contributor to O_3 concentrations in New Brunswick, especially on days or episodes of poor air quality. For example, through air quality modelling simulations, the contribution from anthropogenic emissions in New Brunswick to daily maximum 8 h average O_3 concentration in Saint John was estimated at 3% on average on high pollution days, and estimated at 8% on average under normal (i.e., below the CWS) air quality conditions (Farrell 2006). Modelling for the Norton monitoring site that was located south of the study area suggested that natural background conditions and transboundary sources contributed 39% and 38%, respectively, to O_3 levels, whereas sources within New Brunswick accounted for 16% of the O_3 concentrations (Farrell 2006). As such, the similarity between O_3 concentrations at the Phase I and Phase III sites was not unexpected. The reported O_3 concentrations also concurred with previous observations and estimates in New Brunswick (NB DELG 2012, 2013a, 2013b). Reports for specific regions of the United States, such as Wyoming and Utah, have associated oil and gas development with high O_3 levels. However, it is important to consider the major differences in terms of geography, meteorology and the extent of oil and gas development among regions. For example, oil and gas regions in Utah (e.g., Uintah Basin) are characterized as valleys with thousands of operational oil and gas wells. The surrounding mountains limit air circulation during winter atmospheric inversion episodes, trapping air pollutants in the lower valleys (e.g., Helmig et al. 2014; Utah State University 2013). This is not characteristic of Sussex, New Brunswick, where the topography is relatively low and where oil and gas development is limited.

$PM_{2.5}$ is also described as a regional pollutant. Ambient $PM_{2.5}$ concentrations are influenced by regional atmospheric conditions, both natural (e.g., meteorology and geography) and anthropogenic (e.g., land use and emission sources). Local sources also contribute to ambient $PM_{2.5}$ concentrations. The data from Phase I and Phase III showed that $PM_{2.5}$ concentrations were similar, albeit slightly higher at Phase III (Table 3). Considering that the gas treatment facility was operational throughout the study period (e.g., flaring, light-duty and heavy-duty truck traffic, maintenance activities) and that the PotashCorp mine and the Town of Sussex were located upwind of the Phase III site, the slightly higher $PM_{2.5}$ concentrations are not surprising. Nonetheless, the variations in pollutant concentrations must be interpreted diligently as they may not reflect local disturbances as much as regional phenomena.

Local emissions can affect ambient concentrations of several pollutants, such as CO, NOx and SO_2 that are emitted during fuel combustion (e.g., flaring, diesel engines). Nevertheless, the data showed that NOx concentrations were similar at Phase I and Phase III, thus suggesting that emissions from the gas treatment facility did not affect NOx concentrations at the fence line location (Table 3). CO and SO_2 concentrations were also similar at both sites.

Table 3. Mean and median estimates for air pollutant concentrations based on continuous measurements during Phase I and Phase III, for measurements collected between June 7 and August 26, 2013

Pollutant	Unit	Time	Phase I		Phase III	
			Mean	Median	Mean	Median
$PM_{2.5}$	$\mu g/m^3$	Daily avg	7.1	5.9	7.3	6.9
O_3	ppb	8 h daily max	31.6	30.5	29.1	28.7
O_3	ppb	Hourly	21.3	21.8	19.6	20.2
SO_2	ppb	Hourly	0.1	< 0.1[a]	0.1	0.1
NO	ppb	Hourly	0.2	0.1	0.4	0.1
NO_2	ppb	Hourly	1.1	0.8	1.2	0.9
NOx	ppb	Hourly	1.4	0.9	1.6	0.9
CO	ppm	Hourly	0.2	0.2	0.2	0.2

[a] Median SO_2 value for Phase I between June 7 and August 26, 2013, was 0.004

Gas separation and treatment operations have been identified as a potential source of VOC emissions, both from combustion (e.g., flaring) and evaporative (e.g., petroleum distillate storage tanks) processes. Both of these activities occurred during Phase III. The data from OVM samples showed that, for 50% of the VOC species, concentrations were similar between Phase I and Phase III (location 31). Several VOCs were found at higher concentrations at the Phase I site (e.g., dodecane, hexadecane, tetradecane), whereas heptane, hexane, pentane and 2-methylhexane were higher at the Phase III site.

The data showed that VOC concentrations were higher for Summa canisters at Phase III (location 31) than during Phase I for approximately 25% of the VOCs detected and measured. The latter included a variety of VOCs, such as alkanes and alkenes that could be associated with emissions from oil and gas activity or emissions from fuel combustion (e.g., butane, heptanes, hexane, octane, pentane and propane). Only 5% of the VOCs showed higher concentrations at Phase I, and no apparent trend for these VOCs was identified – that is, the VOCs were not associated with natural sources or specific industrial sources.

Overall, the results suggested that emissions from the gas treatment facility were possibly affecting VOC concentrations, notably increasing the concentrations of alkane species associated with oil and gas production compared with upwind conditions. However, VOC concentrations at all sites appeared to be the considerably lower than ambient levels considered to be of concern to human health.

Concentrations of VOCs identified by Bunch et al. (2014) as being associated with shale gas operations, such as benzene, ethylbenzene, toluene and xylenes did not differ considerably between sites.

A comparative analysis of PAH samples collected during Phase I and Phase III between June 7 and July 15, 2013, was completed (Figure 8 in Section 3.2.7). The results showed that PAH concentrations were higher during Phase III. The difference was mainly driven by higher concentrations of anthracene, fluoranthene, phenanthrene and pyrene during Phase III compared with Phase I. Owing to the greater level of activity at the gas treatment facility (e.g., vehicle traffic, flaring), these results were not unexpected. The data suggested that PAH concentrations at the Phase I and Phase III sites were lower than ambient levels considered to be of concern to human health.

Based on an analysis of OVM samples at Phase I and Phase IV collected between April 23 and June 6, 2013, it was shown that VOC concentrations were higher at Phase IV for approximately 25% of the measured compounds. Values were noticeably higher (by a factor of 2 or more at most locations) at Phase IV for cumene, decane, octane and trichlorotethylene. In contrast, six of the 41 measured compounds had lower concentrations during Phase IV compared with Phase I, including dichloromethane, hexane, xylenes and 2-methylhexane. Comparisons between Phase I and Phase IV locations were inconclusive for dodecane and ethanol. The OVM sample data suggested that VOC concentrations at the Phase IV site were lower than ambient levels considered to be of concern to human health.

Phase IV VOC data from Summa samples were compared with those for Phase I. Average VOC concentrations for Phase I were determined for the period corresponding with Phase IV (April 23 to June 6, 2013). The comparison showed that VOC concentrations were higher during Phase IV for approximately 18% of the compounds (i.e., 27 VOCs for comparisons over the same period), including decane, limonene, nonane, styrene, trichloroethene and undecane. In contrast, five VOCs were associated with higher concentrations during Phase I, such as ethylbromide, propyne and 2,2,5-trimethylhexane. However, it was not possible to identify the exact causes or sources responsible for higher VOCs levels and further investigations are necessary. Nonetheless, the Summa canister data suggested that VOC concentrations at the Phase IV site were lower than ambient levels considered to be of concern to human health.

Methane concentrations measured from air bag samples were found to be similar at all monitoring sites.

6. Conclusions and next steps

This interim report summarizes the first 12 months of activity for the New Brunswick Shale Gas Air Monitoring Study, from October 2012 to October 2013. It covers three phases of the project. The data available included continuous measurements and integrated samples collected during Phase I – baseline conditions prior to any development, Phase III – natural gas processing and distribution and Phase IV – well closure. Preliminary data analyses and comparisons with historical air quality trends across the southern part of the province of New Brunswick (including Fredericton, Saint John and Moncton) showed that the concentrations of air pollutants at the Phase I or baseline site in Apohaqui were similar to or lower than those at other provincial monitoring sites (rural and/or urban). The wind data also indicated that no significant sources of pollution, especially oil and gas activities, were located upwind of the site. As such, the baseline data provided an appropriate data set against which to compare air quality data collected from the latter phases of well development, gas treatment and well closure in the study.

Data from Phase III suggested that criteria air contaminants such as CO, O_3 and $PM_{2.5}$ were not greatly affected, but higher concentrations compared with background locations were noticed for some VOCs, including species generally associated with oil and gas operations. These included several alkanes, such as decane, heptanes, hexane, octane, pentane and propane. The analysis indicated that gas treatment facilities could have a measurable but possibly minimal impact on air quality. However, the monitoring for this study was based around a single gas treatment facility and did not evaluate the potential cumulative impacts of multiple gas plants that would be necessary under a scenario of expanding natural gas production in Kings County, New Brunswick.

Data from Phase IV indicated that VOC concentrations were higher than those at Phase I for several compounds associated with the use, manufacture or disposal or petroleum products, but not necessarily associated with natural gas production. The results suggested that fugitive VOC emissions were occurring near the sampling locations, or close to the well pad area. Spills during previous operations at this site (e.g., during drilling, hydraulic fracturing or site preparation) were suspected as likely causes, but the results of the investigations are inconclusive. Based on available information, it was not possible to identify the exact origin(s) of the measured VOCs.

The background data collected during Phase I, as well as historical air quality data available from monitoring stations across New Brunswick, suggested that the gas treatment facility and the suspended wells had a minimal impact on air quality at nearby receptor points. In fact, air pollutant measurements showed that concentrations during these phases were lower than ambient levels considered to be of concern to human health.

Considerations must be given to the fact that integrated samples and continuous measurements did not explicitly capture local activities, in this case natural gas operations, but reflected community-wide exposures to all likely sources of pollutants. In fact, beyond the local effects of individual wells or facilities, the regional scale needs to be considered. Larger spatial considerations will integrate emissions from multiple sources and reflect the cumulative air quality impacts. However, sorting out sources and allocating effects to individual sources is challenging and was beyond the scope of the current report.

Further, measured concentrations were generally low at all sites. Although relative differences between sampling locations were sometimes high, they reflected very small variations in absolute terms. This was exemplified by the several pollutants measured at higher concentrations at the background site compared with the gas plant site, although the latter was a much more active site in terms of vehicle traffic and industrial operations.

It must also be noted that the data analysis in the Interim report 02 are subject to additional analyses and, as such, they should not be considered final.

Finally, the scope of the study design was geographically limited. Additional data analysis and potentially air monitoring would support extrapolating the results from this study to other shale gas plays. Nonetheless, the study was conducted in a geographic range not covered in previous air quality reports. As such, the study has the potential to indicate possible health-related concerns associated with air quality that could be transferable to other jurisdictions.

6.1 Next steps: Phase II and final report

Air quality monitoring was conducted at an existing well site in Penobsquis from June 2014 to March 2015. This monitoring period included a hydraulic fracturing event that occurred in early September 2014. The monitoring was initiated approximately one month prior to any activity – that is, one month of site-specific baseline data was collected. Eight sampling locations were operational before, during and after the hydraulic fracturing event. Two of the sampling locations, one located upwind and the other downwind of the well site, had continuous monitors for several air pollutants, including CO, NOx and $PM_{2.5}$. Monitoring was scaled down in early November 2014, with only one active sampling location remaining. Monitoring at this location continued until March 2015, which also marked the end of monitoring activities under the New Brunswick Shale Gas Air Monitoring Study. In addition to monitors and samplers used to measure pollutants during the previous phases, continuous real-time monitoring of organics, including BTEX, was conducted during Phase II. Measurements were done using a gas chromatograph coupled to a flame ionization detector provided by Environment Canada.

Standard delays of several weeks to months are expected before all laboratory analyses of samples are available. Data collected at this site will then need to go through all quality assurance and quality check procedures. Final data compilation for Phase II is projected for the fall of 2015. Preliminary data analyses will be completed as the data become available, and results will be presented in a subsequent report tentatively planned for release in 2016.

Lastly, data for carbonyl compound samples collected during Phase I and Phase II, which include measurements for some potentially relevant pollutants, such as acetaldehyde, acrolein and formaldehyde, will also be addressed in the subsequent report.

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Appendix A: Phase I data

Table A1. Descriptive statistics for continuous data collected from October 1, 2012, to October 17, 2013, at the Phase I site

	CO (ppm)	NO (ppb)	NO_2 (ppb)	NO_X (ppb)	O_3 (ppb)	$PM_{2.5}$ ($\mu g/m^3$)	SO_2 (ppb)	TRS (ppb)	TSP ($\mu g/m^3$)
Air quality standard	13/30 ppm		210 ppb		82 ppb (63 ppb)	28 $\mu g/m^3$	169.5 ppb	11 ppb[b]	120 $\mu g/m^3$
AQS avg period	1 h avg		1 h avg		1 h avg (Max 8 h avg)	24 h avg	1 h avg	1 h avg	24 h avg
Reference	NAAQO		NBAAQO		NAAQO (CAAQS)	CAAQS	NBAAQO	NBAAQO	NBAAQO
Sampling frequency	5 min avg	5 min avg	5 min avg	5 min avg	5 min avg	1 h avg	5 min avg	5 min avg	1 h avg
Avg period for stats	1 h avg	1 h avg	1 h avg	1 h avg	1 h avg (Max 8 h avg)	24 h avg	1 h avg	1 h avg	24 h avg
Mean	0.2	0.3	1.2	1.5	25.9 (34.4)	5.0	0.1	0.2	7.8
Median	0.2	0.1	0.8	0.9	27.1 (34.1)	4.3	0.01	0.2	6.5
Minimum / maximum	0.01 / 1.2	0 / 11.9	0 / 14.9	0 / 23.2	[a] / 57.3 (11.9 / 55.0)	0.4 / 35.5	0 / 4.7	0 / 1.9	0.8 / 39.3
5th / 95th percentiles	0.1 / 0.3	< 0.01 / 1.4	0.2 / 3.6	0.2 / 4.7	2.8 / 45.4 (21.0 / 48.2)	1.7 / 10.4	0 / 0.4	0 / 0.4	2.2 / 17.4
98th percentile	0.3	2.5	4.9	6.3	48.2 (50.8)	14.3	0.7	0.6	22.7
No. of AQS exceedances	0	n.a.	0	n.a	0	1	0	0	0
No. of sampling days	382	382	382	382	382	382	382	382	382
No. of measurements	109 740	109 740	109 740	109 740	109 740	9146	109 740	109 740	9146
No. of valid measurements	103 591	105 093	103 921	105 087	102 817	8594	104 444	100 557	4925
% valid measurements	94.4	95.8	94.7	95.8	93.7	94.0	95.2	91.6	53.8

AQS: air quality standards; avg: averaging/average; CAAQS: Canadian Ambient Air Quality Standards; n.a.: not applicable; NAAQO: National Ambient Air Quality Objective; NBAAQO: New Brunswick Ambient Air Quality Objective; ppb: parts per billion; ppm: parts per million

Notes: Values are based on the duration indicated in the *Avg period for stats* row; averaging periods are fixed, except for O_3, which is based on an 8 h rolling average for comparison with the CAAQS. For CO, 13 ppm is the maximum desirable level and 30 ppm is the maximum acceptable level. Mean, median, minimum/maximum and percentile values are in the same units as the AQS. Non-zero values less than 0.01 are shown as < 0.01.

[a] Zero and very low values were recorded, but such low levels are unlikely based on normal regional O_3 levels.

[b] The NBAAQO of 11 ppb was adopted for H_2S. For comparative purposes, the TRS value was considered equivalent to H_2S.

Table A2. Concentration of $PM_{2.5}$ determined gravimetrically from Teflon filters collected using a Partisol 2300 Chemcomb sampling system during Phase I

Parameter – unit	Minimum	5th percentile	Median	95th percentile	Maximum	Mean
$PM_{2.5}$ – µg/m^3	0.14	0.32	3.76	8.66	15.0	3.99

Notes: 24 h samples; 109 samples (105 valid; 4 invalid: 3 owing to possible sample contamination and 1 owing to miscellaneous problems); data available for 105 samples; data were blank corrected; $PM_{2.5}$ mass values below the detection limit (i.e., 4 µg) were substituted by a value equivalent to half the detection limit to calculate concentrations, from which descriptive statistics were calculated.

Table A3. Concentration of galactosan, levoglucosan and mannitol based on Teflon filters collected during Phase I

Parameter – unit	Minimum	5th percentile	Median	Mean	95th percentile	Maximum
$PM_{2.5}$ – µg/m^3	0.14	0.14	3.79	4.02	8.80	15.01
Galactosan – ng/m^3	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Levoglucosan – ng/m^3	< 0.01	< 0.01	11.91	32.80	153.98	190.72
Mannitol – ng/m^3	< 0.01	< 0.01	< 0.01	2.30	8.60	11.84

Notes: 24 h samples; 49 samples (48 valid; 1 invalid: measured concentration did not make sense); data available for 48 samples; data were blank corrected; $PM_{2.5}$ mass values below the detection limit (i.e., 4 µg) were substituted by a value equivalent to half the detection limit to calculate concentrations, from which descriptive statistics were calculated; for galactosan, levoglucosan and mannitol, negative mass values and data below detection limits were included as such and were not substituted with below detection limit indicators when estimating the descriptive statistics; concentrations below 0.01 ng/m^3 are expressed as < 0.01 ng/m^3.

Table A4. Concentration of $PM_{2.5}$–bound metals based on ICPMS analysis of Teflon filters collected during Phase I

Parameter	Concentration – ng/m^3			
	Minimum	Median	Mean	Maximum
$PM_{2.5}$ ($\mu g/m^3$)	0.14	3.60	3.99	14.3
Ag	< 0.01	0.01	0.01	0.02
Al	< 0.01	129	103	234
As	< 0.01	0.13	0.15	0.50
B	0.14	0.97	1.58	8.19
Ba	0.05	0.41	0.48	1.60
Be	< 0.01	< 0.01	< 0.01	0.01
Bi	< 0.01	0.01	0.01	0.05
Ca	< 0.01	28	31	73
Cd	< 0.01	0.03	0.03	0.10
Co	< 0.01	< 0.01	< 0.01	0.24
Cr	< 0.01	0.72	1.06	6.34
Cu	< 0.01	1.12	2.09	14
Fe	1.44	15	18	50
Hg	< 0.01	< 0.01	< 0.01	0.02
K	2.08	18	22	86
Li	< 0.01	< 0.01	< 0.01	0.20
Mg	2.32	12	16	105
Mn	0.01	0.44	0.56	2.67
Mo	0.01	0.04	0.08	0.68
Na	10	84	174	1328
Ni	0.01	0.48	1.14	17
Pb	0.01	0.72	1.09	4.67
Sb	< 0.01	0.11	0.14	0.47
Sn	< 0.01	< 0.01	< 0.01	0.48
Sr	0.03	0.16	0.18	0.67
Th	< 0.01	< 0.01	< 0.01	0.01
Ti	< 0.01	0.69	0.68	3.19
Tl	< 0.01	< 0.01	< 0.01	0.03
U	< 0.01	< 0.01	< 0.01	< 0.01
V	< 0.01	0.15	0.20	0.73
Zn	< 0.01	1.67	2.04	7.39

Notes: 24 h samples; 54 samples (52 valid; 2 invalid: possibly contaminated); data available for 52 samples; data were blank corrected; on average, metals measured via ICPMS accounted for approximately 9.4% of $PM_{2.5}$ concentration; $PM_{2.5}$ mass values below the detection limit (i.e., 4 μg) were substituted by a value equivalent to half the detection limit to calculate concentrations, from which descriptive statistics were calculated; metal mass values below their respective detection limits were substituted by a value equivalent to half the detection limit to calculate concentrations, from which descriptive statistics were calculated; concentrations in ng/m^3 rounded to two decimal points, except for values of 10 ng/m^3 or higher that are rounded to unity; negative concentrations and those below 0.01 ng/m^3 are expressed as < 0.01 ng/m^3.

Table A5. Elemental and organic carbon measurements from quartz filter samples collected during Phase I

Parameter	Minimum	5th percentile	Median	Mean	95th percentile	Maximum
Elemental carbon – µg/m^3	0.01	0.07	0.24	0.32	1.08	1.14
Organic carbon – µg/m^3	0.71	0.73	1.60	1.97	4.51	7.34
Total carbon – µg/m^3	0.73	0.81	1.86	2.30	5.48	8.28
EC/TC concentration ratio	0.01	0.06	0.12	0.13	0.24	0.28
OC/EC concentration ratio	2.53	3.16	7.35	10.0	20.1	116
OC/TC concentration ratio	0.72	0.76	0.88	0.87	0.94	0.99

EC: elemental carbon; OC: organic carbon; TC: total carbon

Notes: 24 h samples; 54 samples (all valid); data available for 54 samples; data were blank corrected; values in µg/m^3 rounded to two decimal points; mass values below detection limits were included as such and were not substituted with below detection limit indicators when calculating concentrations and descriptive statistics.

Table A6. Concentration of volatile organic compounds based on OVM badge samples collected during Phase I

Code	Parameter	No of samples		Concentration in µg/m^3			
		Valid	Invalid or missing	Minimum	Median	Mean	Maximum
V10	d-Limonene	25	22	0.03	0.09	0.11	0.35
V34	2,2,4-Trimethylpentane	25	22	0.04	0.62	0.79	5.03
V76	α-Pinene	25	22	0.12	0.69	0.65	1.39
V78	Benzene	25	22	0.01	0.34	0.34	0.65
V102	Carbon tetrachloride	25	22	0.17	0.47	0.46	0.70
V114	Decane	25	22	< 0.01	0.25	0.26	0.66
V118	Dodecane	25	22	< 0.01	1.13	1.28	3.27
V120	Ethanol	25	22	< 0.01	0.05	0.11	0.42
V135	Hexane	25	22	< 0.01	0.19	0.17	0.40
V147	(m+p)-xylene	25	22	0.04	0.17	0.17	0.42
V157	Naphthalene	25	22	< 0.01	0.36	0.39	1.20
V166	Pentane	25	22	< 0.01	0.45	0.45	0.93
V188	Toluene	25	22	0.08	0.33	0.39	0.93
V211	Hexadecane	25	22	< 0.01	0.23	0.49	2.18
V212	Tetradecane	25	22	0.03	1.73	1.49	3.76

Notes: 6–7 day samples; 47 samples (25 valid; 22 invalid: owing to missing diffuser cap); data available for 25 samples; data were blank corrected; negative values and data below detection limits were included as such and were not substituted with below detection limit indicators when estimating the descriptive statistics; concentrations in µg/m^3 rounded to two decimal points; concentrations below 0.01 µg/m^3 are expressed as < 0.01 µg/m^3.

Table A7. Concentration of volatile organic compounds based on Summa canister samples collected during Phase I

Code	Parameter	No valid	No invalid	Concentration in µg/m^3			
				Minimum	Median	Mean	Maximum
V7	1,2,4-Trichlorobenzene	57	5	0.01	0.02	0.02	0.07
V8	1,2,4-Trimethylbenzene	57	5	< 0.01	0.02	0.03	0.17
V15	1,3-butadiene	57	5	< 0.01	0.01	0.01	0.04
V78	Benzene	57	5	0.07	0.26	0.27	0.57
V80	beta-pinene	51	11	< 0.01	0.39	1.26	8.23
V85	Butane	57	5	0.12	0.61	0.67	2.02
V102	Carbon tetrachloride	57	5	0.39	0.51	0.49	0.56
V117	Dichloromethane	57	5	0.20	0.30	0.33	0.96
V119	Ethane	57	5	1.18	2.95	2.87	5.80
V122	Ethylbenzene	57	5	0.01	0.03	0.03	0.17
V129	Freon 12	57	5	2.20	2.51	2.50	2.71
V131	Heptane	57	5	0.01	0.05	0.06	0.36
V135	Hexane	57	5	0.02	0.08	0.09	0.58
V138	Isobutane	57	5	0.05	0.29	0.36	1.41
V142	Isoprene	57	5	< 0.01	0.04	0.42	6.32
V147	(m+p) xylene	57	5	0.02	0.07	0.08	0.49
V157	Naphthalene	52	10	0.01	0.04	0.05	0.25
V158	n-butylbenzene	57	5	< 0.01	< 0.01	< 0.01	0.01
V163	o-xylene	57	5	0.01	0.03	0.03	0.19
V166	Pentane	57	5	0.06	0.23	0.29	1.74
V167	Propane	43	19	0.45	1.70	1.70	4.47
V168	Propene	57	5	0.05	0.15	0.16	0.51
V173	Styrene	57	5	< 0.01	0.02	0.02	0.10
V188	Toluene	57	5	0.06	0.18	0.21	0.92

No invalid: number of invalid samples; No valid: number of valid samples

Notes: 24 h samples; 62 samples (43–57 valid; 5–19 invalid: owing to laboratory preparation errors and miscellaneous problems); data available for 43–57 samples; data were blank corrected; concentrations in µg/m^3 rounded to two decimal points; concentrations below 0.01 µg/m^3 are expressed as <0.01 µg/m^3.

Table A8. Concentration of polycyclic aromatic hydrocarbons based on modified high-volume sampler samples collected during Phase I

Code	Parameter	Concentration in ng/m^3			
		Minimum	Median	Mean	Maximum
PAH1	**Naphthalene**	< 0.01	< 0.01	< 0.01	4.92
PAH2	**Acenaphthylene**	< 0.01	0.02	0.30	2.70
PAH3	**Acenaphthene**	< 0.01	0.09	0.15	0.69
PAH4	**Fluorene**	< 0.01	0.26	0.44	1.62
PAH5	**Phenanthrene**	0.27	0.81	1.36	5.28
PAH6	**Anthracene**	< 0.01	0.02	0.10	0.77
PAH7	**Fluoranthene**	0.04	0.16	0.36	1.61
PAH8	**Pyrene**	< 0.01	0.04	0.22	1.20
PAH11	**Benzo(b)fluoranthene**	< 0.01	0.02	0.11	0.56
PAH12	**Benzo(k)fluoranthene**	< 0.01	< 0.01	0.03	0.15
PAH13	**Benzo(a)pyrene**	< 0.01	< 0.01	0.02	0.12
PAH14	**Indeno(1.2.3-cd)pyrene**	< 0.01	0.01	0.05	0.24
PAH15	**Dibenzo(ah)anthracene**	< 0.01	< 0.01	0.01	0.03
PAH16	**Benzo(ghi)perylene**	< 0.01	0.01	0.04	0.20
PAH21	**Benzo(a)anthracene**	< 0.01	0.01	0.03	0.14
PAH24	Benzo(b)chrysene	< 0.01	< 0.01	< 0.01	0.01
PAH27	Benzo(e)pyrene	< 0.01	0.01	0.05	0.25
PAH28	Benzo(ghi)fluoranthene	< 0.01	0.01	0.05	0.24
PAH44	Perylene	< 0.01	< 0.01	< 0.01	0.02
PAH46	Retene	< 0.01	0.01	0.08	0.38
PAH50	2-Methylfluorene	< 0.01	0.02	0.04	0.22
PAH51	Benzo(a)fluorene	< 0.01	0.01	0.02	0.08
PAH52	Benzo(b)fluorene	< 0.01	0.01	0.01	0.04
PAH53	1-Methylpyrene	< 0.01	< 0.01	0.01	0.05
PAH54	7-Methylbenz(a)anthracene	< 0.01	< 0.01	< 0.01	< 0.01
PAH55	3-Methylcholanthrene	< 0.01	< 0.01	< 0.01	< 0.01
PAH56	Indeno(1,2,3-cd)fluoranthene	< 0.01	< 0.01	0.01	0.02
PAH57	Anthanthrene	< 0.01	< 0.01	<0.01	0.01
PAH58	Triphenylene	< 0.01	0.01	0.03	0.15
PAH59	**Chrysene**	0.01	0.02	0.09	0.45

Notes: parameters in bold have been identified as priority substances in Canada and/or the United States (e.g., Government of Canada et al. 1994; National Toxicology Program 2014); 24 h samples; 50 samples (33 valid; 17 invalid: 6 owing to laboratory preparation errors and 11 owing to miscellaneous problems); data available for 28 samples; data were blank corrected; negative values and data below detection limits were included as such and were not substituted with below detection limit indicators when estimating the descriptive statistics; concentrations in ng/m^3 rounded to two decimal points; concentrations below 0.01 ng/m^3 are expressed as < 0.01 ng/m^3.

Table A9. Concentration of polycyclic aromatic hydrocarbons based on URG personal pesticide sampler samples collected during Phase I

Code	Parameter	Concentration in ng/m^3			
		Minimum	Median	Mean	Maximum
PAH1	**Naphthalene**	0.04	2.58	3.51	20.17
PAH2	**Acenaphthylene**	< 0.01	0.29	0.39	1.91
PAH3	**Acenaphthene**	0.12	0.54	0.80	3.13
PAH4	**Fluorene**	0.05	0.94	1.49	7.85
PAH5	**Phenanthrene**	0.13	2.86	3.25	6.98
PAH6	**Anthracene**	0.02	0.35	0.39	1.00
PAH7	**Fluoranthene**	0.03	0.41	0.58	2.07
PAH8	**Pyrene**	0.05	0.60	0.68	1.95
PAH9	**Benzo(a)anthracene**	0.02	0.34	0.40	2.13
PAH10	**Chrysene**	0.02	0.26	0.34	1.87
PAH11	**Benzo(b)fluoranthene**	0.03	0.10	0.19	2.20
PAH12	**Benzo(k)fluoranthene**	0.02	0.12	0.20	2.27
PAH13	**Benzo(a)pyrene**	0.03	0.10	0.15	0.58
PAH14	**Indeno(1,2,3-cd)pyrene**	< 0.01	0.07	0.11	0.60
PAH15	**Dibenzo(a,h)anthracene**	0.01	0.06	0.14	1.29
PAH16	**Benzo(ghi)perylene**	0.02	0.06	0.08	0.32

Notes: parameters in bold have been identified as priority substances in Canada and/or the United States (e.g. Environment Canada 2013; Government of Canada et al. 1994; National Toxicology Program 2014); 24 h samples; 50 samples (45 valid; 5 invalid: 3 owing to sample duration and 2 owing to field operator error); data available for 45 samples; data were blank corrected; values below detection limits were included as such and were not substituted with below detection limit indicators when estimating the descriptive statistics; concentrations in ng/m^3 rounded to two decimal points; concentrations below 0.01 ng/m^3 are expressed as < 0.01 ng/m^3.

Table A10. Methane and ethane measurements from air bag samples collected during Phase I

Date (dd/mm/yy)	Concentration, in ppm	
	Methane	Ethane
30/05/14	1.98	< 0.01
30/05/14	1.96	< 0.01
10/07/14	2.05	< 0.01
17/07/14	1.98	< 0.01

dd/mm/yy: day/month/year; ppm: parts per million
Notes: 4 samples during Phase I (all valid); data available for 4 samples; concentrations in ppm rounded to two decimal points; concentrations below 0.01 ppm are expressed as < 0.01 ppm

Figure A1. Hourly ozone concentrations recorded between October 2012 and October 2013 at the Phase I site

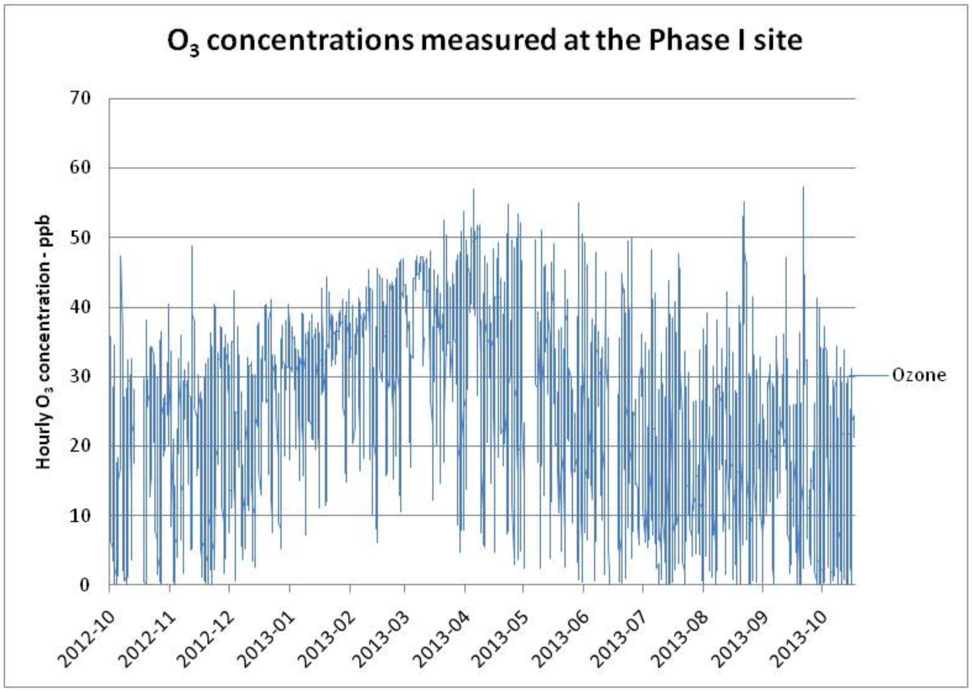


Figure A2. Daily fine particulate matter concentrations recorded between October 2012 and October 2013 at the Phase I site

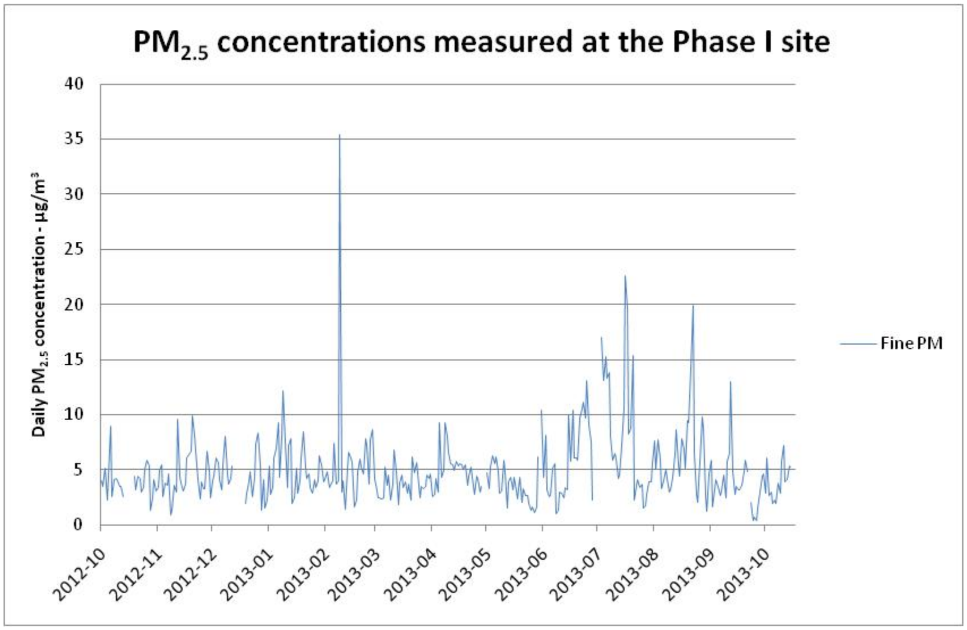
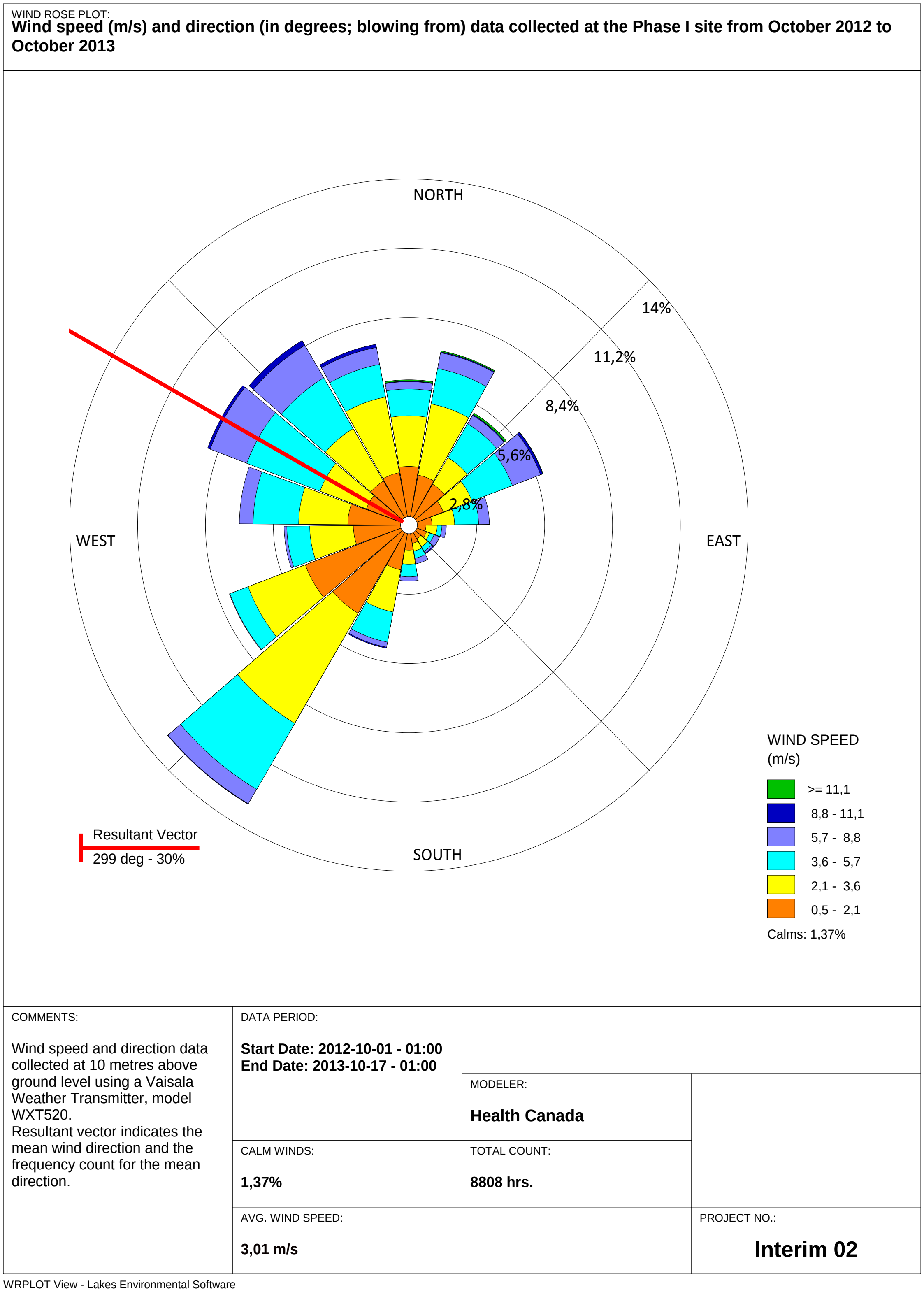


Figure A3. Wind direction and speed data collected during Phase I



WIND ROSE PLOT:
Wind speed (m/s) and direction (in degrees; blowing from) data collected at the Phase I site from October 2012 to October 2013

Resultant Vector
299 deg - 30%

WIND SPEED
(m/s)

- 🟩 >= 11,1
- 🟦 8,8 - 11,1
- 🟪 5,7 - 8,8
- 🟦 3,6 - 5,7
- 🟨 2,1 - 3,6
- 🟧 0,5 - 2,1

Calms: 1,37%

COMMENTS:

Wind speed and direction data collected at 10 metres above ground level using a Vaisala Weather Transmitter, model WXT520.
Resultant vector indicates the mean wind direction and the frequency count for the mean direction.

DATA PERIOD:

Start Date: 2012-10-01 - 01:00
End Date: 2013-10-17 - 01:00

MODELER:

Health Canada

CALM WINDS:

1,37%

TOTAL COUNT:

8808 hrs.

AVG. WIND SPEED:

3,01 m/s

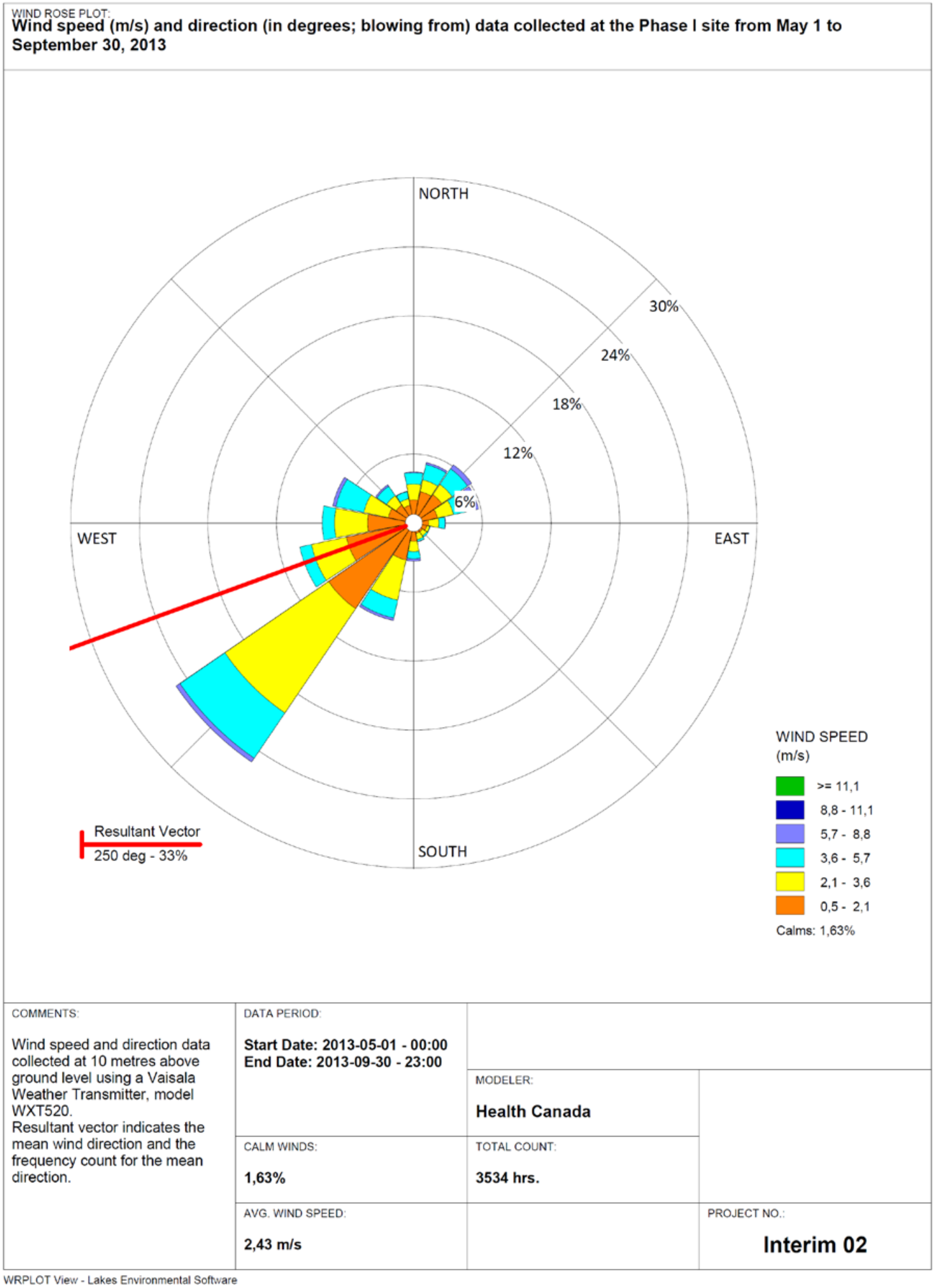
PROJECT NO.:

Interim 02

WRPLOT View - Lakes Environmental Software

Note: Image was generated using Lakes Environmental WRPLOT View Freeware 7.0.0

Figure A4. Wind direction and speed data collected during summer at Phase I



WIND ROSE PLOT:

Wind speed (m/s) and direction (in degrees; blowing from) data collected at the Phase I site from May 1 to September 30, 2013

COMMENTS:

Wind speed and direction data collected at 10 metres above ground level using a Vaisala Weather Transmitter, model WXT520.
Resultant vector indicates the mean wind direction and the frequency count for the mean direction.

DATA PERIOD:

Start Date: 2013-05-01 - 00:00
End Date: 2013-09-30 - 23:00

MODELER:

Health Canada

CALM WINDS:

1,63%

TOTAL COUNT:

3534 hrs.

AVG. WIND SPEED:

2,43 m/s

PROJECT NO.:

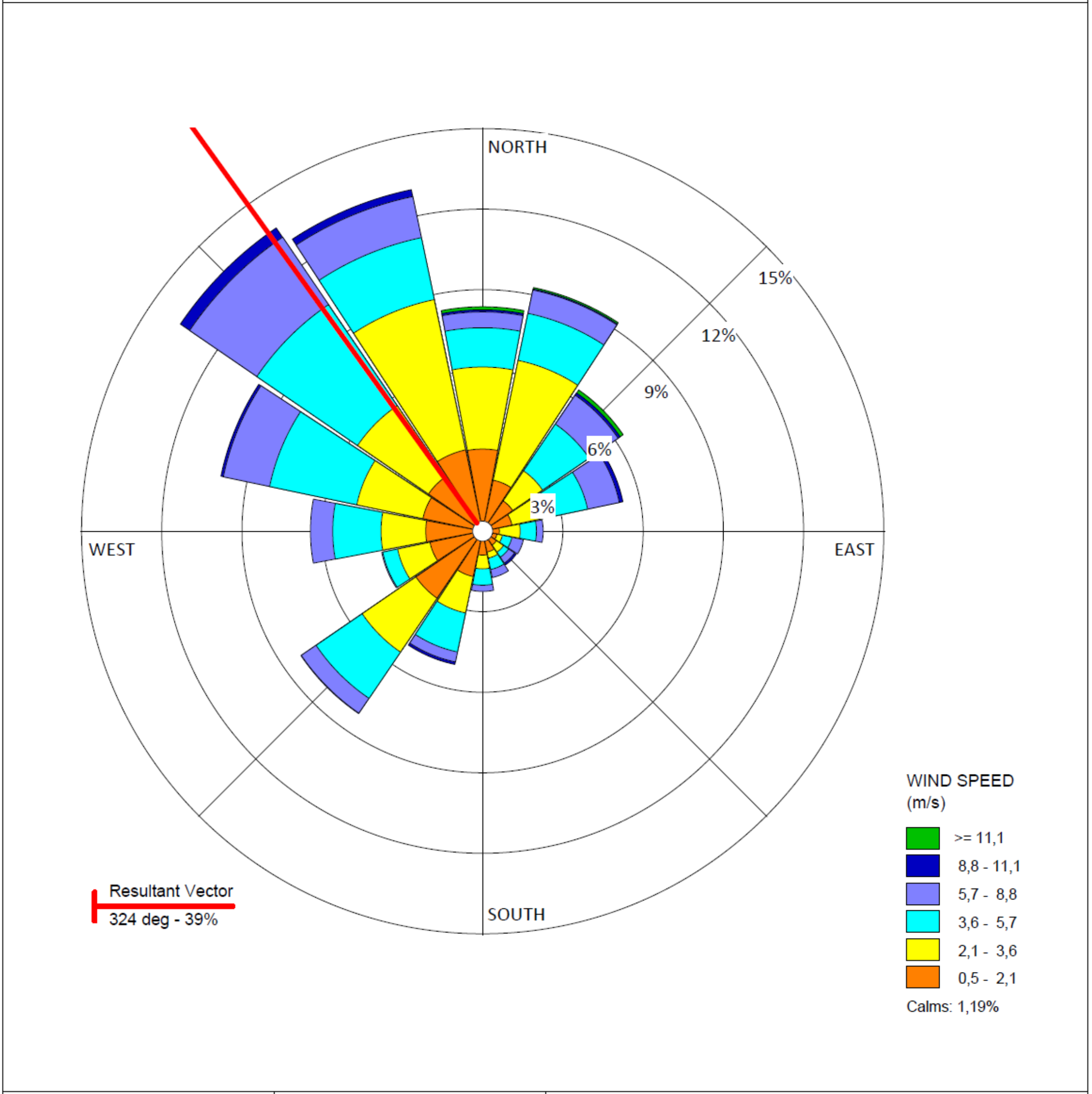
Interim 02

Note: Image was generated using Lakes Environmental WRPLOT View Freeware 7.0.0; summer defined as May to September.

Figure A5. Wind direction and speed data collected during winter at Phase I

WIND ROSE PLOT:

Wind speed (m/s) and direction (in degrees; blowing from) data collected at the Phase I site from October 1, 2012, to April 30, 2013 and from October 1 to 17, 2013



COMMENTS:

Wind speed and direction data collected at 10 metres above ground level using a Vaisala Weather Transmitter, model WXT520.
Resultant vector indicates the mean wind direction and the frequency count for the mean direction.

DATA PERIOD:

Start Date: 2012-10-01 - 01:00
End Date: 2013-10-17 - 01:00

MODELER:

Health Canada

CALM WINDS:

1,19%

TOTAL COUNT:

5274 hrs.

AVG. WIND SPEED:

3,40 m/s

PROJECT NO.:

Interim 02

WRPLOT View - Lakes Environmental Software

Note: Image was generated using Lakes Environmental WRPLOT View Freeware 7.0.0; winter defined as October to April.

Appendix B: Phase III data

Table B1. Descriptive statistics for continuous data collected from June 7, 2013, to August 26, 2013, at the Phase III site

	CO (ppm)	NO (ppb)	NO_2 (ppb)	NO_X (ppb)	O_3 (ppb)	$PM_{2.5}$ ($\mu g/m^3$)	SO_2 (ppb)	H_2S (ppb)
Air quality standard	13/30 ppm		210 ppb		82 ppb (63 ppb)	28 $\mu g/m^3$	169.5 ppb	11 ppb (3.5 ppb)
AQS avg period	1 h avg		1 h avg		1 h avg (max 8 h avg)	24 h avg	1 h avg	1 h avg (24 h avg)
Reference	NAAQO		NBAAQO		NAAQO (CAAQS)	CAAQS	NBAAQO	NBAAQO
Sampling frequency	5 min avg	5 min avg	5 min avg	5 min avg	5 min avg	1 h avg	5 min avg	5 min avg
Avg period for stats	1 h avg	1 h avg	1 h avg	1 h avg	1 h avg (max 8 h avg)	24 h avg	1 h avg	1 h avg (24 h avg)
Mean	0.2	0.4	1.2	1.6	19.6 (29.1)	7.3	0.1	0.2 (0.2)
Median	0.2	0.1	0.9	0.9	20.2 (28.7)	7.3	0.1	0.1 (0.1)
Minimum / maximum	0.1 / 0.5	0 / 21.3	0.2 / 7.8	0.1 / 24.4	0.1 / 55.0 (8.1 / 53.1)	0 / 21.9	0 / 2.0	0 / 32.2 (0 / 2.8)
5th / 95th percentiles	0.1 / 0.4	0 / 2.0	0.3 / 3.2	0.3 / 5.0	1.2 / 38.5 (17.2 / 40.2)	1.5 / 14.6	0 / 0.5	0 / 0.6 (0 / 0.3)
98th percentile	0.5	4.6	3.8	7.3	44.4 (47.8)	16.6	0.6	0.9 (0.4)
No. of AQS exceedances	0	n.a.	0	n.a.	0 (0)	0	0	2 (0)
No. of sampling days	39	80	80	80	80	80	80	80
No. of hourly measurements	930	1930	1930	1930	1930	1930	1930	1930
No. of valid hourly measurements	813	1819	1819	1819	1515	1903	1795	1817
% valid measurements	87.4	94.2	94.2	94.2	78.5	98.6	93.0	94.1

AQS: air quality standard; avg: averaging/average; CAAQS: Canadian Ambient Air Quality Standards; n.a.: not applicable; NAAQO: National Ambient Air Quality Objective; NBAAQO: New Brunswick Ambient Air Quality Objective; ppb: parts per billion; ppm: parts per million

Notes: Values are based on the duration indicated in the *Avg period for stats* row; averaging periods are fixed, except for O_3, which is based on an 8-hour rolling average for comparison with the CAAQS. For CO, 13 ppm is the maximum desirable level, and 30 ppm is the maximum acceptable level. Mean, Median, Minimum/Maximum and percentile values are in the same units as the Air Quality Standard. Concentration values rounded to one decimal point.

Table B2. Concentration of $PM_{2.5}$ determined gravimetrically from Teflon filters collected using a Chemcomb cartridge and BGI pump sampling system during Phase III

Sampling date (dd/mm/yy)	$PM_{2.5}$ – ug/m^3
15/06/13	8.30
21/06/13	8.44
27/06/13	5.10
03/06/13	13.65
09/07/13	6.23
15/07/13	8.46
Mean	**8.37**
Median	**8.37**

Notes: 24 h samples; 7 samples (6 valid; 1 invalid: miscellaneous problems); data available for 6 samples; data were blank corrected; values in µg/m^3 rounded to two decimal points

Table B3. Concentration of galactosan, levoglucosan and mannitol based on Teflon filters of $PM_{2.5}$ collected during Phase III

Parameter	Unit	Minimum	Median	Mean	Maximum
$PM_{2.5}$	µg/m^3	5.10	8.30	7.28	8.44
Galactosan	ng/m^3	< 0.01	< 0.01	< 0.01	< 0.01
Levoglucosan	ng/m^3	6.79	18.77	55.53	141.04
Mannitol	ng/m^3	< 0.01	5.97	5.97	11.95

Notes: 24 h samples; 3 samples (all valid); data available for 3 samples; data were blank corrected; $PM_{2.5}$ concentrations in µg/m^3 rounded to two decimal points; for galactosan, levoglucosan and mannitol, negative mass values and data below detection limits were included as such and were not substituted with below detection limit indicators when estimating the descriptive statistics; galactosan, levoglucosan and mannitol concentrations in ng/m^3 rounded to two decimal points; concentrations below 0.01 ng/m^3 are expressed as < 0.01 ng/m^3.

Table B4. Concentration of $PM_{2.5}$–bound metals based on ICPMS analysis of Teflon filters collected during Phase III

Parameter	Concentration – ng/m^3			
	Minimum	Median	Mean	Maximum
$PM_{2.5}$ ($\mu g/m^3$)	6.23	8.46	9.45	13.65
Ag	0.01	0.01	0.02	0.06
Al	183.90	197.36	200.24	219.47
As	0.14	0.22	0.25	0.39
B	4.34	4.51	5.27	6.96
Ba	0.35	0.81	0.74	1.07
Be	< 0.01	< 0.01	0.01	0.01
Bi	0.01	0.01	0.01	0.02
Ca	11.81	27.76	35.42	66.67
Cd	0.02	0.03	0.03	0.06
Co	< 0.01	< 0.01	0.01	0.04
Cr	< 0.01	0.77	0.50	0.82
Cu	< 0.01	0.78	0.53	1.08
Fe	22.21	61.05	50.93	69.54
Hg	< 0.01	< 0.01	0.01	0.02
K	36.00	47.81	53.03	75.29
Li	< 0.01	< 0.01	< 0.01	0.03
Mg	9.06	19.91	16.40	20.23
Mn	0.51	1.57	1.24	1.63
Mo	0.01	0.04	0.06	0.13
Na	27.80	51.35	48.14	65.28
Ni	0.01	0.37	1.05	2.76
Pb	0.36	0.82	0.78	1.17
Sb	0.03	0.09	0.08	0.14
Sn	< 0.01	< 0.01	< 0.01	0.04
Sr	0.14	0.16	0.18	0.25
Th	< 0.01	0.01	0.01	0.02
Ti	1.25	3.71	2.89	3.71
Tl	< 0.01	0.01	0.01	0.01
U	< 0.01	< 0.01	< 0.01	< 0.01
V	0.13	0.20	0.21	0.28
Zn	< 0.01	4.90	5.46	12.47

Notes: 24 h samples; 3 samples (all valid); data available for 3 samples; data were blank corrected; on average, metals measured via ICPMS accounted for approximately 4.5% of $PM_{2.5}$ concentration; $PM_{2.5}$ concentrations in $\mu g/m^3$ rounded to two decimal points; metal mass values below their respective detection limits were substituted by a value equivalent to half the detection limit to calculate concentrations, from which descriptive statistics were calculated; metal concentrations in ng/m^3 rounded to two decimal points, except for values of 10 ng/m^3 or higher that are rounded to unity; negative values and values below 0.01 ng/m^3 are expressed as < 0.01 ng/m^3.

Table B5. Mean concentration of volatile organic compounds based on OVM samples collected at eight sampling locations during Phase III (partial list)

Code	Parameter	Sampling location							
		31	32	33	34	35	36	37	38
		Mean concentration – µg/m^3							
V7	1,2,4-Trichlorobenzene	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
V8	1,2,4-Trimethylbenzene	0.03	0.03	0.03	0.04	0.04	0.04	0.03	0.05
V34	2,2,4-Trimethylpentane	0.51	0.46	0.60	0.49	0.48	0.50	0.62	0.43
V56	2-Methylhexane	1.30	0.26	0.12	0.48	0.42	0.48	0.04	0.06
V76	α-pinene	0.68	0.59	0.58	0.76	0.84	0.67	0.73	0.85
V78	Benzene	0.53	0.30	0.35	0.41	0.37	0.36	0.40	0.35
V102	Carbon tetrachloride	0.57	0.57	0.54	0.55	0.52	0.55	0.56	0.54
V117	Dichloromethane	< 0.01	0.01	0.01	0.03	< 0.01	0.02	0.03	0.01
V122	Ethylbenzene	0.06	0.04	0.04	0.05	0.05	0.05	0.06	0.04
V131	Heptane	2.00	0.22	0.07	0.20	0.13	0.09	0.10	0.15
V135	Hexane	4.10	0.36	0.12	0.36	0.21	0.10	0.10	0.26
V147	(m+p) xylene	0.11	0.04	0.04	0.05	0.05	0.09	0.05	0.04
V157	Naphthalene	0.31	0.35	0.34	0.33	0.31	0.35	0.26	0.39
V162	Octane	0.72	0.10	0.04	0.08	0.04	0.07	0.05	0.05
V163	o-xylene	0.03	0.02	0.02	0.02	0.03	0.03	0.02	0.02
V166	Pentane	9.53	0.99	0.45	1.08	0.67	0.41	0.33	0.80
V173	Styrene	< 0.01	< 0.01	< 0.01	< 0.01	0.01	< 0.01	< 0.01	< 0.01
V188	Toluene	0.36	0.25	0.19	0.16	0.18	0.23	0.20	0.18
V212	Tetradecane	0.54	0.55	0.50	0.55	0.48	0.44	0.56	0.55

Notes: 6–7 day samples; 48 samples (6 samples per site) (47 valid; 1 invalid for location 34 owing to broken sampler); data available for 47 samples; data were blank corrected; concentrations in µg/m^3 rounded to two decimal points; concentrations below 0.01 µg/m^3 are expressed as < 0.01 µg/m^3.

Table B6. Concentration of volatile organic compounds based on Summa canister samples collected at two locations during Phase III (partial list)

Code	Parameter	Concentration in µg/m^3						Ratio of means
		Location 31			Location 37			
		Minimum	Mean	Maximum	Minimum	Mean	Maximum	31/37
V53	2-Methylbutane	0.07	3.17	12.44	0.03	0.25	0.72	**12.9**
V76	α-pinene	0.22	1.14	2.18	0.13	2.10	4.09	0.5
V78	Benzene	0.08	0.17	0.29	0.08	0.17	0.26	1.0
V80	β-pinene	0.26	0.81	1.81	0.47	2.14	3.81	**0.4**
V85	Butane	0.19	8.32	33.59	0.08	0.32	0.71	**25.6**
V100	Camphene	0.11	0.52	1.04	0.06	0.49	1.12	1.1
V106	Chloromethane	1.19	1.33	1.53	1.17	1.33	1.50	1.0
V119	Ethane	1.34	5.40	16.14	1.13	1.57	2.36	**3.4**
V126	Freon 11	1.42	1.52	1.67	1.44	1.49	1.65	1.0
V127	Freon 113	0.56	0.62	0.69	0.55	0.61	0.68	1.0
V129	Freon 12	2.51	2.70	3.03	2.50	2.67	2.97	1.0
V130	Freon 22	0.72	0.78	0.90	0.73	0.84	1.12	0.9
V135	Hexane	0.04	1.81	7.31	0.02	0.12	0.41	**15.7**
V138	Isobutane	0.07	3.05	12.59	0.03	0.19	0.47	**16.5**
V142	Isoprene	0.20	1.61	4.52	0.20	1.55	5.00	1.0
V146	Limonene	< 0.01	0.14	0.32	< 0.01	0.81	1.82	**0.2**
V166	Pentane	0.10	4.12	15.68	0.04	0.24	0.44	**17.5**
V167	Propane	0.45	3.40	6.36	0.38	0.44	0.50	**7.7**

Notes: 24 h samples; 14 samples (7 samples per site) (all valid); data available for 14 samples; data were blank corrected; 4 missing values for β-pinene at location 31, 5 missing at location 37; 5 missing values for Propane at locations 31 and 37; concentrations in µg/m^3 rounded to two decimal points; concentrations below 0.01 µg/m^3 are expressed as < 0.01 µg/m^3; ratio estimates rounded to one decimal points; bolded ratio values are lower than 0.5 or higher than 2.0.

Table B7. Concentration of polycyclic aromatic hydrocarbons based on URG personal pesticide samples collected during Phase III

Code	Parameter	Concentration in ng/m^3			
		Minimum	Median	Mean	Maximum
PAH1	**Naphthalene**	0.83	2.29	2.11	3.25
PAH2	**Acenaphthylene**	0.09	0.38	0.32	0.40
PAH3	**Acenaphthene**	0.36	0.86	1.23	3.13
PAH4	**Fluorene**	0.77	1.84	1.94	3.13
PAH5	**Phenanthrene**	1.59	6.17	6.09	12.46
PAH6	**Anthracene**	0.19	0.75	0.75	1.44
PAH7	**Fluoranthene**	0.24	0.58	0.78	1.91
PAH8	**Pyrene**	0.30	0.59	0.75	1.53
PAH9	**Benzo(a)anthracene**	0.03	0.15	0.13	0.20
PAH10	**Chrysene**	0.04	0.19	0.16	0.25
PAH11	**Benzo(b)fluoranthene**	0.01	0.04	0.04	0.09
PAH12	**Benzo(k)fluoranthene**	0.01	0.04	0.05	0.10
PAH13	**Benzo(a)pyrene**	0.02	0.06	0.06	0.09
PAH14	**Indeno(1,2,3-cd)pyrene**	0.04	0.05	0.06	0.09
PAH15	**Dibenzo(a,h)anthracene**	0.03	0.05	0.05	0.06
PAH16	**Benzo(ghi)perylene**	0.02	0.05	0.05	0.09

Notes: All parameters have been identified as priority substances in Canada and/or the United States (e.g., Government of Canada et al. 1994; National Toxicology Program 2014); 24 h samples; 6 samples (all valid); data available for 6 samples; data were blank corrected; values below detection limits were included as such and were not substituted with below detection limit indicators when estimating the descriptive statistics; concentrations in ng/m^3 rounded to two decimal points.

Table B8. Methane and ethane measurements from air bag samples collected during Phase III

Date (dd/mm/yy)	Location	Concentration, in ppm	
		Methane	Ethane
10/06/14	31	1.96	< 0.01
04/07/14	31	2.24	< 0.01
10/07/14	31	1.98	< 0.01
17/07/14	31	1.93	< 0.01

dd/mm/yy: day/month/year; ppm: parts per million

Notes: 4 samples for location 31 (all valid); data available for 4 samples; concentrations in ppm rounded to two decimal points; concentrations below 0.01 ppm are expressed as < 0.01 ppm

Figure B1. Hourly ozone concentrations recorded between June 7 and August 26 2013 at the Phase III site

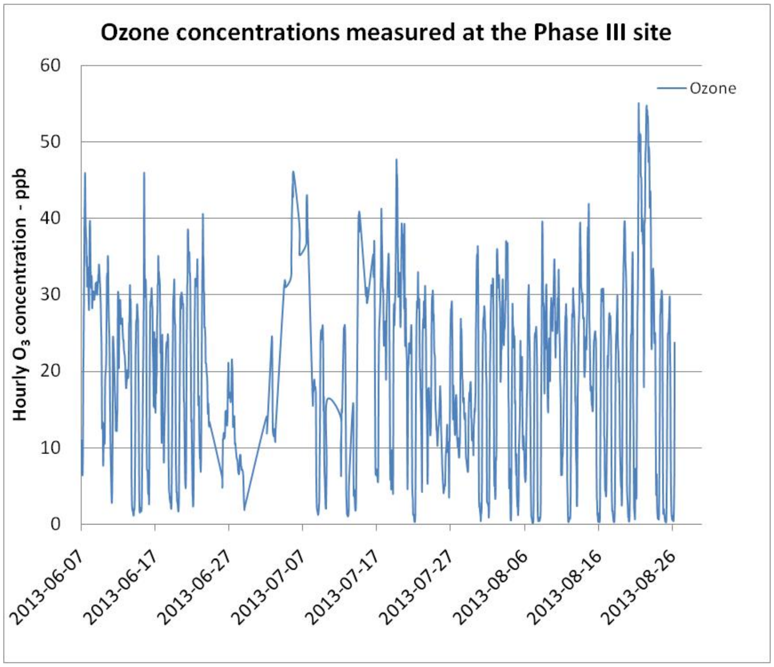


Figure B2. 8 h daily maximum ozone concentrations recorded between June 7 and August 26 2013 at the Phase I and Phase III sites

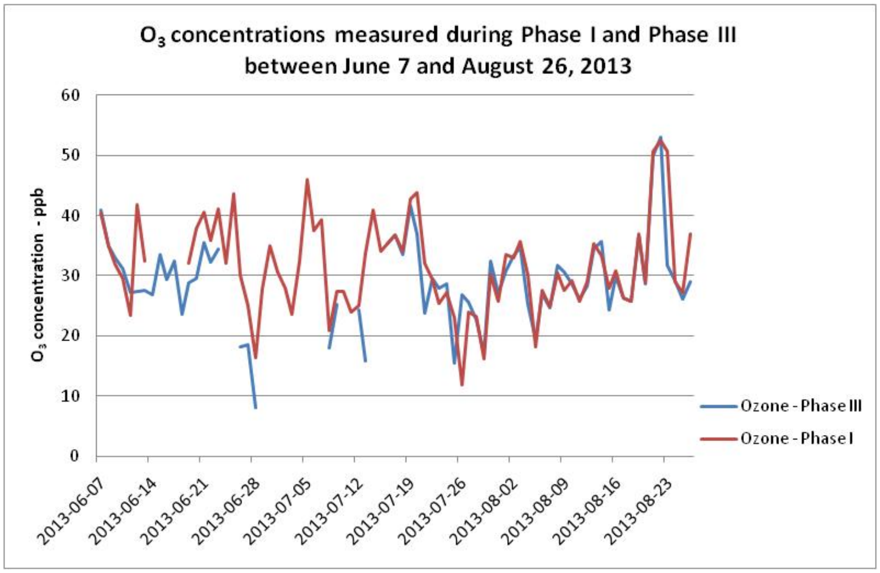


Figure B3. Daily fine particulate matter concentrations recorded between June 7 and August 26 2013 at the Phase I and Phase III sites

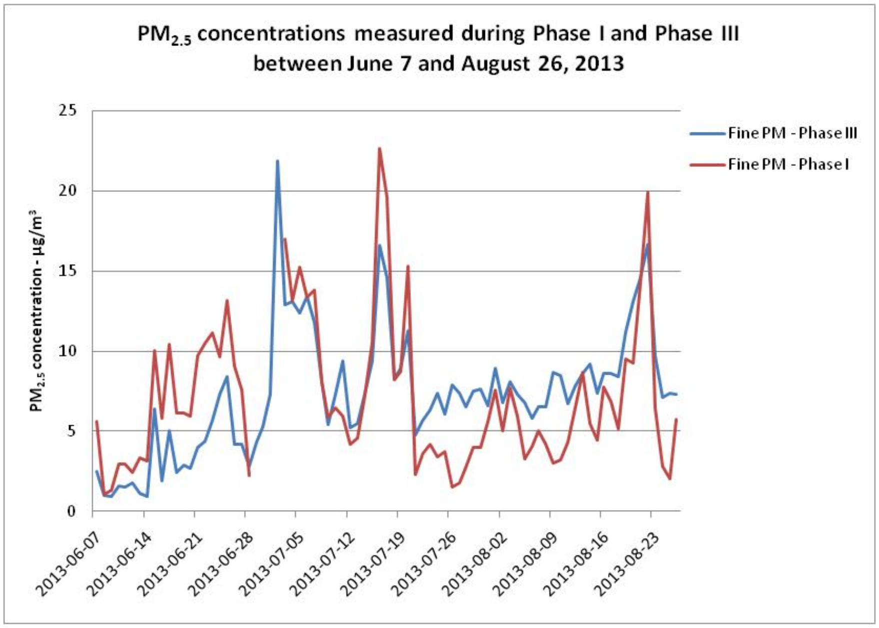


Figure B4. Hourly carbon monoxide concentrations recorded between July 18 and August 26, 2013, at the Phase I and Phase III sites

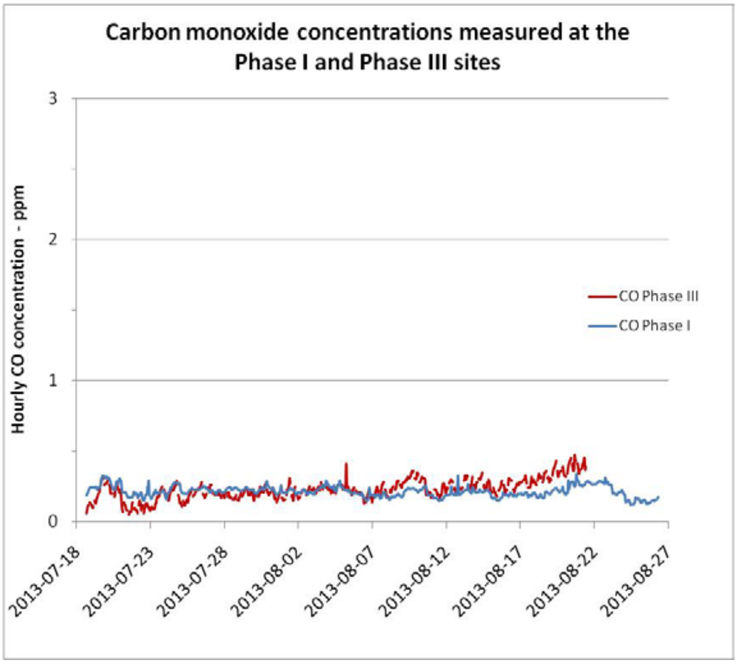
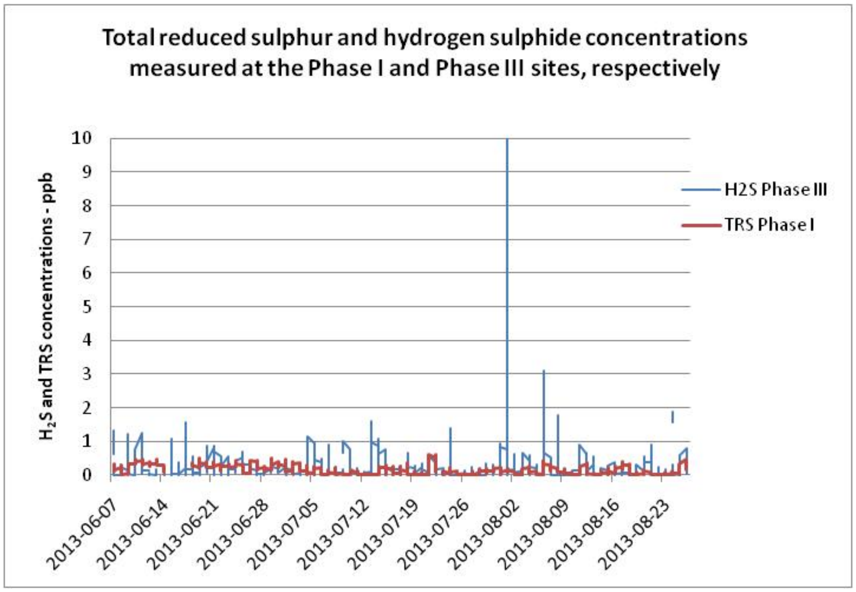


Figure B5. Hourly concentrations of total reduced sulphur and hydrogen sulphide recorded at the Phase I and Phase III sites, respectively, between June 7 and August 26, 2013



Note: Hydrogen sulphide (H_2S) reached 32.2 ppb on August 1, 2013. The vertical axis was cut to better visualize the variability in the data.

Figure B6. Hourly concentrations of nitrogen oxides recorded between June 7 and August 26, 2013, at the Phase III site

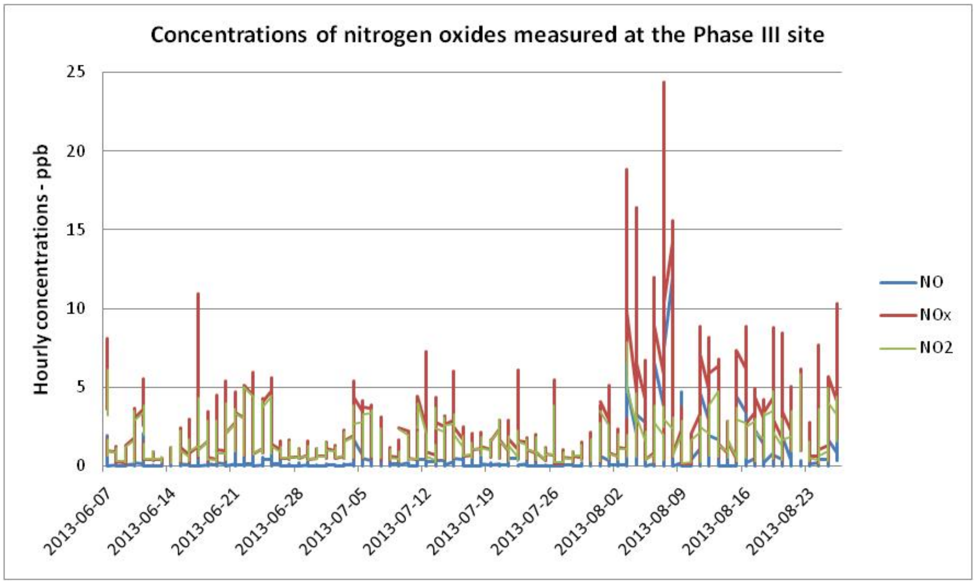


Figure B7. Hourly concentrations of nitrogen oxides recorded between June 7 and August 26, 2013, at the Phase I and Phase III sites

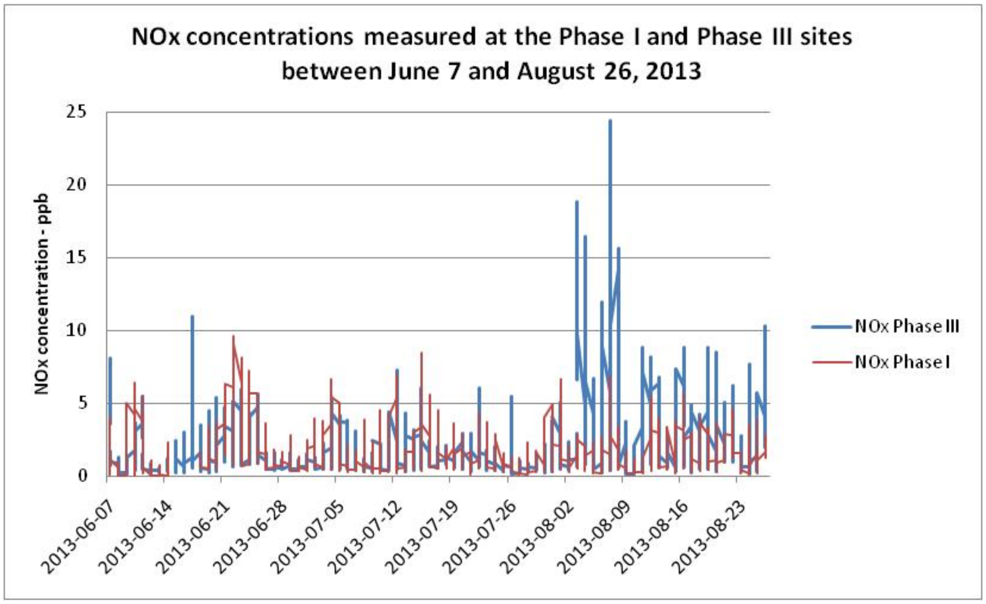
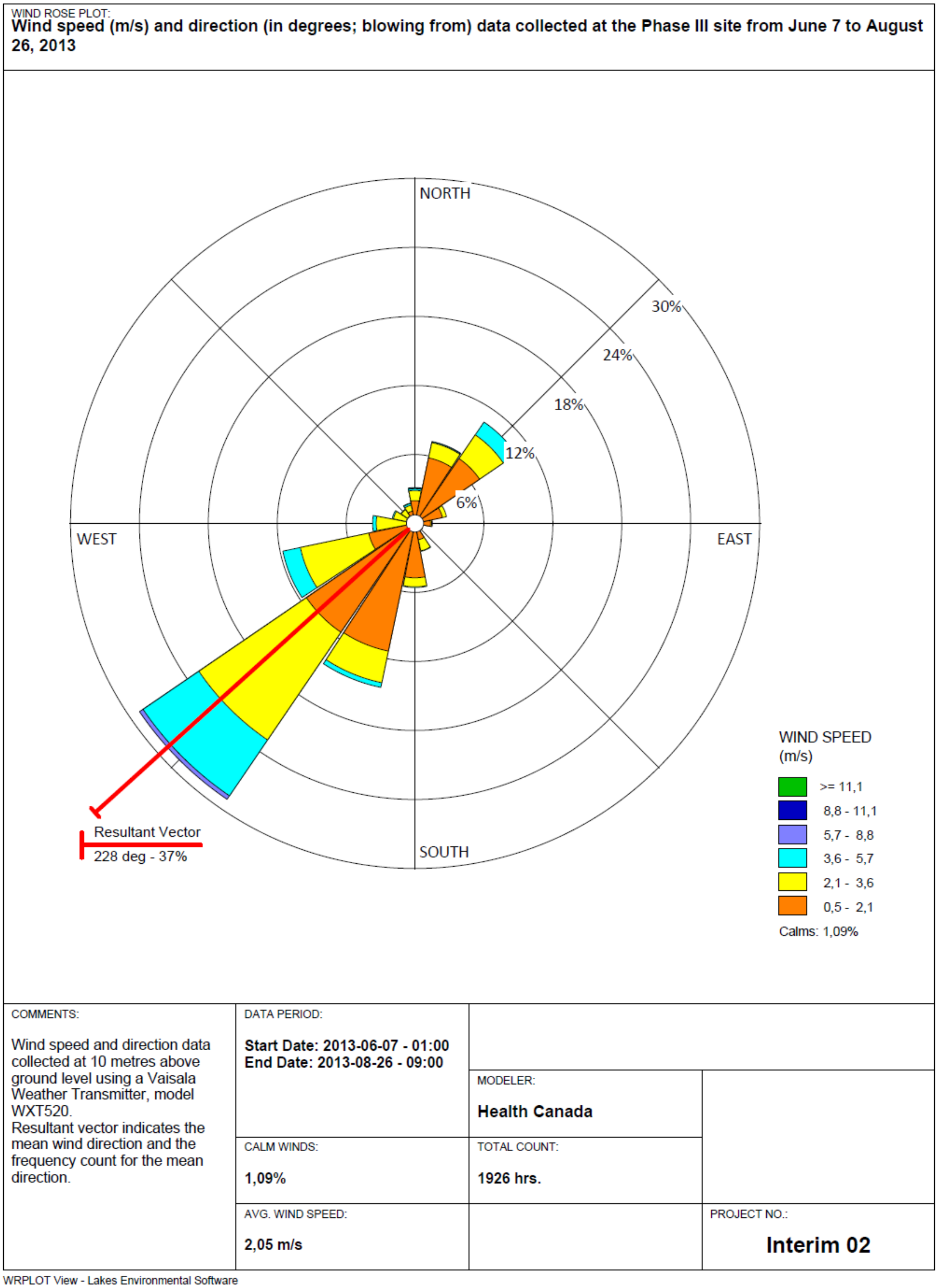


Figure B8. Wind direction and speed data collected during Phase III



WIND ROSE PLOT:

Wind speed (m/s) and direction (in degrees; blowing from) data collected at the Phase III site from June 7 to August 26, 2013

COMMENTS:

Wind speed and direction data collected at 10 metres above ground level using a Vaisala Weather Transmitter, model WXT520.
Resultant vector indicates the mean wind direction and the frequency count for the mean direction.

DATA PERIOD:

Start Date: 2013-06-07 - 01:00
End Date: 2013-08-26 - 09:00

MODELER:

Health Canada

CALM WINDS:

1,09%

TOTAL COUNT:

1926 hrs.

AVG. WIND SPEED:

2,05 m/s

PROJECT NO.:

Interim 02

Note: Image was generated using Lakes Environmental WRPLOT View Freeware 7.0.0.

Appendix C: Phase IV data

Table C1. Concentration of volatile organic compounds based on OVM samples collected during Phase IV (partial list)

Code	Parameter	Mean concentration in µg/m^3					
		41	42	43	44	45	42 43 44 45
V7	1,2,4-trichlorobenzene	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
V8	1,2,4-trimethylbenzene	0.02	0.19	0.02	0.02	0.25	0.12
V11	1,2-dichloromethane	0.13	0.06	0.07	0.08	0.07	0.07
V18	1,4-dichlorobenzene	< 0.01	0.01	< 0.01	0.01	0.02	0.01
V34	2,2,4-trimethylpentane	0.51	0.47	0.31	0.47	0.33	0.40
V56	2-methyylhexane	0.03	0.05	0.01	0.01	0.18	0.06
V76	α-pinene	0.46	0.29	0.29	0.34	0.41	0.33
V78	Benzene	0.42	0.25	0.20	0.34	0.27	0.26
V102	Carbon tetrachloride	0.91	0.48	0.47	0.48	0.49	0.48
V114	Decane	0.08	0.77	0.21	0.06	0.73	0.44
V117	Dichloromethane	0.03	0.02	0.02	0.01	0.04	0.02
V118	Dodecane	0.16	17.84	0.66	0.26	18.12	9.22
V120	Ethanol	0.05	0.24	0.08	0.03	0.36	0.18
V122	Ethylbenzene	0.04	0.08	0.03	0.04	0.12	0.07
V131	Heptane	0.07	0.11	0.05	0.04	0.18	0.09
V135	Hexane	0.04	0.03	0.02	0.02	0.05	0.03
V147	(m+p) xylene	0.05	0.19	0.06	0.04	0.29	0.14
V157	Naphthalene	0.34	0.55	0.37	0.32	0.52	0.44
V162	Octane	0.09	0.10	0.13	0.05	0.01	0.07
V163	o-xylene	0.03	0.08	0.02	0.02	0.13	0.06
V166	Pentane	0.26	0.24	0.20	0.19	0.36	0.25
V173	Styrene	0.01	1.05	< 0.01	0.01	1.92	0.75
V187	Tetrachloroethylene	0.07	0.02	0.02	0.02	0.04	0.03
V188	Toluene	0.18	0.43	0.09	0.10	0.76	0.35
V212	Tetradecane	0.65	13.88	0.88	0.67	10.68	6.53

Notes: 6–7 day samples; 7 samples per location (all valid); data available for 35 samples; data were blank corrected; negative values and data below detection limits were included as such and were not substituted with below detection limit indicators; concentrations in µg/m^3 rounded to two decimal points; concentrations below 0.01 µg/m^3 are expressed as < 0.01 µg/m^3.

Table C2. Concentration of volatile organic compounds based on Summa canister samples collected during Phase IV (partial list)

Code	Parameter	Concentration in µg/m^3 at location 41			Concentration in µg/m^3 at location 43		
		Minimum	Mean	Maximum	Minimum	Mean	Maximum
V7	1,2,4-trichlorobenzene	0.01	0.02	0.03	0.01	0.02	0.05
V8	1,2,4-trimethylbenzene	0.01	0.02	0.04	< 0.01	0.04	0.15
V15	1,3-butadiene	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.03
V76	α-pinene	< 0.01	0.50	1.82	< 0.01	0.45	1.53
V78	Benzene	0.06	0.11	0.15	0.05	0.11	0.21
V80	β-pinene	0.15	0.45	1.48	< 0.01	0.45	1.24
V85	Butane	0.14	0.37	0.68	0.05	0.36	1.30
V102	Carbon tetrachloride	0.38	0.43	0.47	0.39	0.43	0.49
V106	Chloromethane	1.14	1.26	1.44	1.11	1.33	1.44
V117	Dichloromethane	0.25	0.38	0.62	0.22	0.65	2.30
V118	Dodecane	0.02	0.19	0.61	0.01	0.84	4.16
V119	Ethane	2.40	4.02	6.51	1.25	2.96	9.00
V122	Ethylbenzene	0.01	0.02	0.06	0.02	0.09	0.36
V126	Freon 11	1.30	1.41	1.49	1.31	1.41	1.52
V129	Freon 12	2.36	2.50	2.61	2.29	2.59	3.11
V130	Freon 22	0.72	0.77	0.88	0.64	0.96	1.87
V131	Heptane	0.02	0.05	0.12	0.01	0.06	0.17
V135	Hexane	0.02	0.08	0.13	0.01	0.16	0.70
V138	Isobutane	0.06	0.25	0.53	0.03	0.51	2.63
V147	(m+p) xylene	0.01	0.06	0.15	0.03	0.22	0.99
V157	Naphthalene	0.01	0.05	0.14	< 0.01	0.05	0.10
V158	n-butylbenzene	< 0.01	< 0.01	0.01	< 0.01	0.01	0.02
V163	o-xylene	0.01	0.02	0.06	0.01	0.07	0.34
V166	Pentane	0.06	0.18	0.34	0.05	0.22	0.64
V167	Propane	0.74	1.20	2.16	0.31	2.17	5.52
V168	Propene	0.05	0.13	0.29	0.05	0.15	0.49
V173	Styrene	< 0.01	0.21	0.60	< 0.01	0.06	0.21
V188	Toluene	0.03	0.12	0.25	0.05	0.25	0.91
V190	Undecane	0.02	0.09	0.38	0.01	0.59	2.95

Notes: 24 h samples; 7 samples for location 41 (all valid; 3 values missing for propane only); 6 samples for location 43 (all valid; 3 values missing for propane only); data were blank corrected; concentrations in µg/m^3 rounded to two decimal points; concentrations below 0.01 µg/m^3 are expressed as < 0.01 µg/m^3.

Table C3. Methane and ethane concentrations from the air bag samples collected during Phase IV

Date (dd/mm/yy)	Location	Concentration, in ppm	
		Methane	Ethane
6/05/14	41	2.30	< 0.01
	43	2.25	< 0.01
14/05/14	41	2.02	< 0.01
	43	1.96	< 0.01
21/05/14	41	2.02	< 0.01
27/05/14	41	1.97	< 0.01
30/05/14	41	1.98	< 0.01
4/06/14	41	2.00	< 0.01
6/06/14	41	1.91	< 0.01

dd/mm/yy: day/month/year; ppm: parts per million

Notes: 7 samples for location 41 (all valid); 2 samples for location 43 (all valid); data available for 9 samples; concentrations in ppm rounded to two decimal points; concentrations below 0.01 ppm are expressed as < 0.01 ppm.

Table C4. Concentration of volatile organic compounds at locations 42 and 45 based on OVM samples collected during Phase IV, with and without the May 1–7 samples

Code	Parameter	Mean concentration in µg/m^3					
		42	42 rev[a]	Ratio 42[b]	45	45 rev[a]	Ratio 45[b]
V7	1.2.4-trichlorobenzene	< 0.01	< 0.01	-	< 0.01	< 0.01	0.9
V8	1.2.4-trimethylbenzene	0.19	0.01	12.9	0.25	0.01	27.9
V11	1.2-dichloromethane	0.06	0.06	1.0	0.07	0.06	1.1
V18	1.4-dichlorobenzene	0.01	< 0.01	5.0	0.02	< 0.01	6.2
V34	2.2.4-trimethylpentane	0.47	0.49	1.0	0.33	0.30	1.1
V56	2-methyylhexane	0.05	0.01	4.5	0.18	0.14	1.3
V76	α-pinene	0.29	0.29	1.0	0.41	0.40	1.0
V78	Benzene	0.25	0.23	1.1	0.27	0.20	1.3
V102	Carbon tetrachloride	0.48	0.47	1.0	0.49	0.46	1.1
V114	Decane	0.77	0.09	8.8	0.73	0.07	9.8
V117	Dichloromethane	0.02	< 0.01	5.0	0.04	0.01	4.9
V118	Dodecane	17.84	0.38	47.1	18.12	0.31	58.2
V120	Ethanol	0.24	0.05	5.1	0.36	0.04	9.3
V122	Ethylbenzene	0.08	0.03	2.8	0.12	0.03	4.0
V131	Heptane	0.11	0.03	3.8	0.18	0.03	6.2
V135	Hexane	0.03	0.01	3.5	0.05	0.01	5.5
V147	(m+p) xylene	0.19	0.03	6.8	0.29	0.03	11.1
V157	Naphthalene	0.55	0.33	1.7	0.52	0.37	1.4
V162	Octane	0.10	0.02	5.8	0.01	0.01	0.9
V163	o-xylene	0.08	0.02	3.9	0.13	0.02	5.7
V166	Pentane	0.24	0.16	1.5	0.36	0.18	2.0
V173	Styrene	1.05	< 0.01	314	1.92	< 0.01	449[c]
V187	Tetrachloroethylene	0.02	0.02	1.1	0.04	0.03	1.4
V188	Toluene	0.43	0.15	2.8	0.76	0.14	5.3
V212	Tetradecane	13.88	0.75	18.6	10.68	0.65	16.3

Notes: 6–7 day samples; 7 samples per location (all valid); data available for 14 samples; data were blank corrected; negative values and data below detection limits were included as such and were not substituted with below detection limit indicators; concentrations in µg/m^3 rounded to two decimal points; concentrations less than 0.01 µg/m^3 are expressed as < 0.01 µg/m^3.

[a] Revised mean concentrations estimated without the May 1–7 OVM sample for locations 42 and 45.

[b] Ratios estimated by dividing the original mean value by the revised mean value.

[c] The very high variations in mean styrene concentrations result from elevated measurements for the May 1–7 samples, combined with values below detection limits for four samples at location 42 and three samples at location 45 during Phase IV.

Appendix D: Monitoring equipment and laboratory analysis

Table D1. Air pollutants monitored during Phases I, III and IV

Parameter	Sampling type	Notes	Phase		
			I	III	IV
Wind speed / direction	Continuous	Measurements at 10 m above ground	X	X	
Temperature, relative humidity and barometric pressure	Continuous	Measurements at 10 m above ground	X	X	
Sulphur dioxide	Continuous		X	X	
Total reduced sulphur – Hydrogen sulphide	Continuous		X	X	
Carbon monoxide	Continuous		X	X	
Nitrogen oxides	Continuous		X	X	
Fine particulate matter ($PM_{2.5}$)	Continuous		X	X	
Total suspended particulates	Continuous		X		
Ozone	Continuous		X	X	
Volatile organic compounds	Integrated; 24 h and 6–8 days	Sampling every 6 days with Summa canisters; weekly samples with passive badges	X	X	X
Carbonyl compounds	Integrated; 24 h	Sampling every 6 days with Summa canisters	X		
$PM_{2.5}$ speciation - gravimetric - metals - Elemental and organic carbon - levoglucosan	Integrated; 24 h	Sampling every 6 days	X	X	
Polycyclic aromatic hydrocarbons	Integrated; 24 h	Sampling every 6 days; particle-bound and gaseous	X	X	
Methane	Continuous; grab	Grab samples every 1–3 weeks	X	X	X

Table D2. Sampling and laboratory analysis methods for integrated samples

Methane and ethane

Air grab samples were collected for methane and ethane analysis. SKC Tedlar bags were used to collect air samples. The SKC bags were initially purged in the NB DELG laboratory using nitrogen. They were then purged three times on site using the lung sampler method prior to the actual sampling using the same method.[a] Samples were delivered to RPC laboratory for analysis using a gas chromatograph system with a flame ionization detector (GC/FID model 450, Bruker Daltonics Inc. Billerica, MA, USA).

Continuous ambient methane measurements were also collected with a Thermo Scientific IRIS 5500 methane analyser. This stationary device was only used during Phase I.

Polycyclic aromatic hydrocarbons

Polycyclic aromatic hydrocarbon (PAH) samples were collected using the URG personal pesticide sampler (Chapel Hill, NC, USA), within which a glass fibre filter collects PM$_{2.5}$-bound PAHs and a 5-cm plug of polyurethane foam (PUF) collects gaseous PAHs. A BGI pump set to 4 litres (L) per minute was used to collect air samples. The flow was checked and recorded when the filter was installed. The stop flow was assumed to be the same unless the operator included a comment stating that the pump needed adjustment. A value of 4.000 L per minute was presumed for all the flow rates.

Samples were sent to Airzone One laboratories (AirZOne, Mississauga, ON) for analysis with a Gas chromatography–Mass Spectrometry (GC/MS) according to a Canadian Association for Laboratory Accreditation Inc. approved method. Measured PAHs are listed in Table D4 in Appendix D.

PAH samples were also collected over a 24-hour period using a modified high-volume sampler equipped with a Roots meter (model 8C175-CTR-NPDL-MTC-SA). Air was drawn through a Teflon-coated glass fibre filter that was followed by a PUF plug, allowing for the collection of both gaseous and TPM-bound PAHs. The sampling flow rate was set to approximately 500 L per minute. Samples were volume corrected (see below) to adjust for variable sampling volumes. Samples were analyzed by Environment Canada using GC/MS (Method No. 3.03/5.1/M). Measured PAHs are listed in Table D4 in Appendix D.

Volume correction method for PAH concentrations estimates:

The sample volumes were corrected for 25°C (or 298.15°K) and a pressure of 1 atmosphere (or 101.325 kPa). The site specific meteorological data – that is, sampling day temperatures (high and low) and pressure – were provided by the field operators and were used for the correction. This approach is the same as that used for PAH samples collected at National Air Pollution Surveillance stations across Canada.[41]

The method was as follows:

(i) Final Gas Meter Volume (m^3) – Initial Gas Meter Volume(m^3) = **Volume (m^3)** [as recorded on the data sheet]
(ii) (Final Gas Meter Vacuum (inches of H$_2$O) + Initial Gas Meter Vacuum (inches of H$_2$O)) / 2 × 0.249 = **Average Gas Meter Vacuum (kPa)** [0.249 is a constant expressing the kPa in 1 inch of H$_2$0 at 4°C]
(iii) (Sampling Day High Temp (°C) + Sampling Day Low Temp (°C)) / 2 + 273.15 = **Average Temp (°K)**
(iv) Sampling Day pressure (in mm of Hg) [from sampling data sheet] × 0.133324 = **Sampling Day pressure in kPa**
(v) ((Sampling Day pressure (kPa) – Average Gas Meter Vacuum (kPa)) / 101.325 kPa) × (298.15°K / Average Temp (°K)) × Volume (m^3) = **Corrected Volume (m^3)**

Field sample acceptance criteria were 500–1200 m^3 for corrected sample volume and 24 ± 1 h for sample time.

PM$_{2.5}$ gravimetric analysis and speciation – Phase I

The Partisol 2300 speciation sampling system (ThermoScientific) consisted of four independent sampling cartridges. Three ChemComb cartridges (Model 3500, ThermoScientific, Waltham, MA, USA) were connected to separate PM$_{2.5}$ impactor inlets and dedicated mass flow controllers that maintained a constant flow rate of

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[41] May Siu, Environment Canada. Personal communications. 2014-07-15

10 L per minute. A fourth cartridge was used for field blanks.

One Chemcomb cartridge contained a pre-fired quartz fibre filter for collecting $PM_{2.5}$ for analysis of organic carbon and elemental carbon. The quartz filters were analyzed by thermal optical reflectance (TOR) combustion for organic carbon and elemental carbon using a DRI Model 2001 Thermal/Optical Carbon Analyzer (Atmoslytic Inc Calabasas, CA).

One 47 mm Teflon filter was analyzed for $PM_{2.5}$ mass and used for metals analysis via Inductively Coupled Plasma Mass Spectrometry (ICPMS). ICPMS analysis was done using a Perkin Elmer Elan DRC-II Inductively Coupled Plasma Mass Spectrometer following US EPA method 6020A (US EPA 2007a) (samples identified by DC in the log sheet database were sent for metals analysis). A second 47 mm Teflon filter was analyzed for $PM_{2.5}$ mass and used for levoglucosan analysis via ion chromatography by Environment Canada (adapted from Jeong et al. 2013).

Another cartridge was an active blank containing a Teflon filter and a pre-fired quartz backing filter in series. The blank quartz filters were analyzed for positive carbonaceous sampling artefacts arising from trapping of vapour phase carbon species. The carbon content of the quartz backing filter was subtracted from the organic carbon of the organic carbon and elemental carbon cartridge to give the corrected organic carbon content of the aerosol.

Gravimetric analysis was conducted by the Alberta Research Council using the method outlined in the US EPA Quality Assurance Guidance Document 2.12 (US EPA 1998).

Summary statistics for all species were calculated as follows: mass values reported below the detection limit were replaced by one half of the detection limit for each species and all missing data values were excluded from the calculation. Outliers were identified based on a visual analysis of results and removed from the calculation.

$PM_{2.5}$ gravimetric analysis and speciation – Phase III

$PM_{2.5}$ 24 h integrated samples were collected at location 31 using ChemComb Speciation Cartridges (ThermoScientific, Waltham, MA, USA) with a BGI pump (10 LPM Model 40010s, BGI Inc., Waltham, MA, USA).

Samples were sent to Alberta Innovates for gravimetric analysis, followed by analyses for galactosan, levoglucosan and mannitol, or metals (as per methods outlined for Phase I samples).

Volatile organic compounds – 3M organic vapour monitoring badges (OVM)

Volatile organic compounds (VOCs) were collected using 3M Model 3500 organic vapour monitoring (OVM; Guillevan, Montreal) badges. This passive air monitoring device uses a charcoal sorbent to collect organics in ambient air via diffusion. OVM badges were installed under a protective cover at approximately 1.2–1.6 m above ground level and they were exposed for 7 days (target duration). OVM badges were analyzed by Airzone One (AirZOne, Mississauga, ON) using gas chromatography with a mass selective detector (GC/MSD).

Volatile organic compounds – Summa canisters

VOC samples were actively collected using clean evacuated 6 L Summa™ canisters. Summa canisters were equipped with pre-calibrated flow controllers that operated at a flow rate of 3.5 ml per minute and automatic timers to allow the collection of 24 h samples on specific days of the week.

Summa canisters in the New Brunswick mobile laboratory were collected with a pump.

The air samples were analyzed for a suite of VOCs using GC/MS, according to US EPA method TO-15, at Environment Canada laboratories.

GC/FID: gas chromatography/flame ionization detector; GC/MS: gas chromatography/mass spectrometry; GC/MSD: gas chromatography/mass selective detector; ICPMS: Inductively Coupled Plasma Mass Spectrometry; NB DELG: New Brunswick Department of Environment and Local Government; PUF: polyurethane foam; VOC: volatile organic compound

[a] Lung sampling technique: Instructions available online at www.caslab.com/Forms-Downloads/Flyers/Lung_Sampler_Instructions.pdf (accessed October 14, 2014)

Table D3. Volatile organic compounds measured for Summa VOC canisters and OVM badges

Code	Name	Summa canisters	OVM badges	Code	Name	Summa canisters	OVM badges
V1	1,1,1-Trichloroethane	x		V96	c-2-Pentene	x	
V2	1,1,2,2-Tetrachloroethane	x	x	V97	c-3-Heptene	x	
V3	1,1,2-Trichloroethane	x		V98	c-3-Methyl-2-Pentene	x	
V4	1,1-Dichloroethane	x		V99	c-4-Methyl-2-Pentene	x	
V5	1,1-Dichloroethene	x		V100	Camphene	x	
V6	1,2,3-Trimethylbenzene	x		V102	Carbon tetrachloride	x	x
V7	1,2,4-Trichlorobenzene	x	x	V103	Chlorobenzene	x	
V8	1,2,4-Trimethylbenzene	x	x	V104	Chloroethane	x	
V9	1,2-Dibromoethane	x		V105	Chloroform	x	x
V10	1,2-Dichlorobenzene	x	x	V106	Chloromethane	x	
V11	1,2-Dichloroethane	x	x	V108	Cyclohexane	x	
V12	1,2-Dichloropropane	x		V110	Cyclohexene	x	
V13	1,2-Diethylbenzene	x		V111	Cyclopentane	x	
V14	1,3,5-Trimethylbenzene	x	x	V113	Cyclopentene	x	
V15	1,3-Butadiene	x		V114	Decane	x	x
V16	1,3-Dichlorobenzene	x	x	V115	Dibromochloromethane	x	
V17	1,3-Diethylbenzene	x	x	V116	Dibromomethane	x	
V18	1,4-Dichlorobenzene	x	x	V117	Dichloromethane	x	x
V19	1,4-Dichlorobutane	x		V118	Dodecane	x	x
V20	1,4-Diethylbenzene	x		V119	Ethane	x	
V22	1-Butene / 2-Methylpropene	x		V120	Ethanol		x
V23	1-Butyne	x		V122	Ethylbenzene	x	x
V24	1-Decene	x		V123	Ethylbromide	x	
V25	1-Heptene	x		V124	Ethylene	x	
V26	1-Hexene / 2-Methyl-1,Pentene	x		V126	Freon 11	x	
V27	1-Methylcyclohexene	x		V127	Freon 113	x	
V28	1-Methylcyclopentene	x		V128	Freon 114	x	
V29	1-Nonene	x		V129	Freon 12	x	
V30	1-Octene	x		V130	Freon 22	x	
V31	1-Pentene	x		V131	Heptane	x	x
V32	1-Undecene	x		V132	Hexachlorobutadiene	x	
V33	2,2,3-Trimethylbutane	x		V133	Hexachloroethane		x
V34	2,2,4-Trimethylpentane	x	x	V135	Hexane	x	x
V35	2,2,5-Trimethylhexane	x		V136	Hexylbenzene	x	
V36	2,2-Dimethylbutane	x	x	V137	Indane	x	
V37	2,2-Dimethylhexane	x		V138	Isobutane	x	
V38	2,2-Dimethylpentane	x		V141	iso-Butylbenzene	x	
V39	2,2-Dimethylpropane	x		V142	Isoprene	x	

Code	Name	Summa canisters	OVM badges	Code	Name	Summa canisters	OVM badges
V40	2,3,4-Trimethylpentane	x		V145	Cumene	x	x
V41	2,3-Dimethylbutane	x		V146	Limonene	x	
V42	2,3-Dimethylpentane	x		V147	m-p-Xylene	x	x
V43	2,4-Dimethylhexane	x		V152	Methylcyclohexane	x	
V44	2,4-Dimethylpentane	x		V153	Methylcyclopentane	x	
V45	2,5-Dimethylhexane	x		V154	Methyl-t-butyl ether	x	x
V48	2-Ethyl-1,Butene	x		V157	Naphthalene	x	x
V49	2-Ethyltoluene	x		V158	n-Butylbenzene	x	
V50	2-Methyl-1,Butene	x		V159	Nonane	x	
V51	2-Methyl-2-Butene	x		V160	Pentachloroethane		x
V53	2-Methylbutane	x		V161	n-Propylbenzene	x	
V55	2-Methylheptane	x	x	V162	Octane	x	x
V56	2-Methylhexane	x	x	V163	o-Xylene	x	x
V57	2-Methylpentane	x		V164	p-Cymene	x	x
V60	3,6-Dimethyloctane	x		V166	Pentane	x	x
V61	3-Ethyltoluene	x		V167	Propane	x	
V62	3-Methyl-1,Butene	x		V168	Propene	x	
V63	3-Methyl-1,Pentene	x		V171	Propyne	x	
V64	3-Methylheptane	x		V172	sec-Butylbenzene	x	
V65	3-Methylhexane	x		V173	Styrene	x	x
V66	3-Methylpentane	x		V174	t-1,2-Dichloroethene	x	
V67	4-Ethyltoluene	x		V175	t-1,2-Dimethylcyclohexane	x	
V68	4-Methyl-1,Pentene	x		V176	t-1,3-Dichloropropene	x	
V69	4-Methylheptane	x		V177	t-1,4-Dimethylcyclohexane	x	
V73	Acetylene	x		V178	t-2-Butene	x	
V76	α-Pinene	x	x	V179	t-2-Heptene	x	
V78	Benzene	x	x	V180	t-2-Hexene	x	
V79	Benzyl Chloride	x		V181	t-2-Octene	x	
V80	β-Pinene	x		V182	t-2-Pentene	x	
V81	Bromodichloromethane	x		V183	t-3-Heptene	x	
V82	Bromoform	x		V184	t-3-Methyl-2-Pentene	x	
V83	Bromomethane	x		V185	t-4-Methyl-2-Pentene	x	
V84	Bromotrichloromethane	x		V186	tert-Butylbenzene	x	
V85	Butane	x		V187	Tetrachloroethene	x	x
V88	c-1,2-Dichloroethene	x		V188	Toluene	x	x
V89	c-1,2-Dimethylcyclohexane	x		V189	Trichloroethene	x	x
V90	c-1,3-Dichloropropene	x		V190	Undecane	x	
V91	c-1,3-Dimethylcyclohexane	x		V191	Vinylchloride	x	
V92	c-1,4 / t-1,3-Dimethylcyclohexane	x		V209	Freon 134A	x	
V93	c-2-Butene	x		V211	Hexadecane (C16)		x

Code	Name	Summa canisters	OVM badges	Code	Name	Summa canisters	OVM badges
V94	c-2-Heptene	x		V212	Tetradecane (C14)		x
V95	c-2-Hexene	x		V213	1,2,3-Trichlorobenzene		x

Table D4. Detectable PAHs based on selected sampling and laboratory analysis methods

Code	Name	HV	URG	Code	Name	HV	URG
PAH1	Naphthalene	x	x	PAH21	Benzo(a)anthracene	x	
PAH2	Acenaphthylene	x	x	PAH24	Benzo(b)chrysene	x	
PAH3	Acenaphthene	x	x	PAH27	Benzo(e)pyrene	x	
PAH4	Fluorene	x	x	PAH28	Benzo(ghi)fluoranthene	x	
PAH5	Phenanthrene	x	x	PAH44	Perylene	x	
PAH6	Anthracene	x	x	PAH46	Retene	x	
PAH7	Fluoranthene	x	x	PAH50	2-Methylfluorene	x	
PAH8	Pyrene	x	x	PAH51	Benzo(a)fluorene	x	
PAH9	Benz(a)anthracene		x	PAH52	Benzo(b)fluorene	x	
PAH10	Chrysene		x	PAH53	1-Methylpyrene	x	
PAH11	Benzo(b)fluoranthene	x	x	PAH54	7-Methylbenz(a)anthracene	x	
PAH12	Benzo(k)fluoranthene	x	x	PAH55	3-Methylcholanthrene	x	
PAH13	Benzo(a)pyrene	x	x	PAH56	Indeno(1,2,3-cd)fluoranthene	x	
PAH14	Indeno(1,2,3-cd)pyrene	x	x	PAH57	Anthanthrene	x	
PAH15	Dibenzo(ah)anthracene	x	x	PAH58	Triphenylene	x	
PAH16	Benzo(ghi)perylene	x	x	PAH59	Chrysene	x	

HV: modified high-volume sampling

Table D5. Detectable elements based on ICPMS analysis of fine particulate matter samples

Ag	Ba	Cd	Cu	Li	Na	Sb	Th	V
Al	Be	Cl	Fe	Mg	Ni	Se	Ti	Zn
As	Bi	Co	Hg	Mn	Pb	Sn	Tl	
B	Ca	Cr	K	Mo	S	Sr	U	

Appendix E: New Brunswick air quality objectives and Canadian air quality objectives

New Brunswick recognizes a number of air quality objectives and standards, some of which are regulated or voluntary in nature. New Brunswick ambient air quality objectives (NBAAQOs) for CO, H_2S, NO_2, SO_2 and TSP are included in Table E1. These objectives are established under the province's *Clean Air Act*, which also includes a provision for required annual reporting to the province's Legislative Assembly on achievement of the objectives. No NBAAQO exists for ground-level O_3.

New Brunswick is also a signatory to the Canada-wide standards (CWS) for $PM_{2.5}$ and O_3. The Canadian Council of Ministers of the Environment endorsed standards for $PM_{2.5}$ and O_3 in June 2000, which came into force for the 2010 reporting year. These standards are slightly different from AQOs, as they apply to long-term trends. The CWS for O_3 is 65 ppb, calculated as a 3-year rolling average of the 4th highest daily average in each year. The CWS for $PM_{2.5}$ is 30 µg/m^3, calculated as a 3-year rolling average of the 98th percentile (i.e., nearly the highest) daily average value in each year. The national objectives for O_3 and $PM_{2.5}$ are the reference, although they are not legally binding.

Table E1 also includes National Ambient Air Quality Objectives (NAAQOs), which are set by the federal government based on recommendations from a National Advisory Committee and Working Group on Air Quality Objectives and Guidelines. Provincial governments have the option of adopting these either as objectives or as enforceable standards, according to their legislation. NAAQOs must be consistent with the philosophy of the *Canadian Environmental Protection Act, 1999* and must be based on recognized scientific principles that include risk assessment and risk management. The Canadian Ambient Air Quality Standards (CAAQS) under Canada's Air Quality Management System were established as objectives on May 25, 2013. Provinces and territories will implement actions to meet these new objectives as of 2015. CAAQS provide a new approach for managing O_3 and fine PM pollution via different objective levels.

The monitoring results from the current study are compared with applicable values from Table E1 to verify if any exceedances are recorded during the different phases of the study. The values in Table E1 also provide some perspective for the analysis of recorded levels at the different sampling sites. As the monitoring at each site is limited to a maximum of 1 year, it does not seem appropriate to compare the air monitoring data for $PM_{2.5}$ with the $PM_{2.5}$ CAAQS or CWS, which are based on long-term monitoring data (i.e., 3-year average of the 98th percentile). As there are no daily limits for $PM_{2.5}$ under the Canadian or New Brunswick objectives and standards, the World Health Organization 24-hour average $PM_{2.5}$ air quality standard of 25 µg/m^3 was also considered.

Table E1. National and New Brunswick air quality objectives

Air contaminant		Concentrations			
National Ambient Air Quality Objectives (not to be exceeded)[a]					
		Maximum desirable level		Maximum acceptable level	
SO_2	1 h average	450 µg/m^3	0.17 ppm	900 µg/m^3	0.34 ppm
SO_2	24 h average	150 µg/m^3	0.06 ppm	300 µg/m^3	0.11 ppm
SO_2	Annual arithmetic mean	30 µg/m^3	0.01 ppm	60 µg/m^3	0.02 ppm
PM (TSP)	24 h average			120 µg/m^3	
PM (TSP)	Annual geometric mean	60 µg/m^3		70 µg/m^3	
CO	1 h average	15 mg/m^3	13 ppm	35 mg/m^3	30 ppm
CO	8 h average	6 mg/m^3	5 ppm	15 mg/m^3	13 ppm
O_3	1 h average	100 µg/m^3	51 ppb	160 µg/m^3	82 ppb
O_3	24 h average	30 µg/m^3	15 ppb	50 µg/m^3	25 ppb
O_3	Annual arithmetic mean			30 µg/m^3	15 ppb
NO_2	Annual arithmetic mean	60 µg/m^3	0.03 ppm	100 µg/m^3	0.05 ppm
NO_2	1 h average			400 µg/m^3	0.21 ppm
NO_2	24 h average			200 µg/m^3	
Canada-wide Standards[b]					
O_3	Maximum 8 h average	65 ppb			
$PM_{2.5}$	Daily average	30 µg/m^3			
Canadian Ambient Air Quality Standards (management levels; 2015)[b,c]					
		Achieve	Prevent exceedance	Prevent air quality deterioration	Keep clean areas clean
O_3	Maximum 8 h average	63 ppb	56 ≤ 63 ppb	50 ≤ 56 ppb	≤ 50 ppb
$PM_{2.5}$	Daily average	28 µg/m^3	19 ≤ 28 µg/m^3	10 ≤ 19 µg/m^3	≤ 10 µg/m^3
$PM_{2.5}$	Annual average	10 µg/m^3	6.4 ≤ 10 µg/m^3	4.0 ≤ 6.4 µg/m^3	≤ 4.0 µg/m^3
New Brunswick Ambient Air Quality Objectives					
CO	1 h average	30 ppm			
CO	8 h average	13 ppm			
H_2S	1 h average	11 ppb			
H_2S	24 h average	3.5 ppb			
NO_2	1 h average	210 ppb			
NO_2	24 h average	105 ppb			
NO_2	Annual average	52 ppb			
SO_2[d]	1 h average	339 ppb			
SO_2	24 h average	113 ppb			
SO_2	Annual average	23 ppb			
TSP	24 h average	120 µg/m^3			
TSP	Annual average	70 µg/m^3			

[a] Conditions of 25°C and 101 kPa are used as the basis for conversion from µg/m^3 to ppm.

[b] For O_3 maximum 8 hour average, 3-year rolling average of the 4th highest daily average in each year; for $PM_{2.5}$ daily average, 3-year rolling average of the 98th percentile daily average value in each year.

[c] Canadian Ambient Air Quality Standards for SO_2 and NO_2 currently under development.

[d] The standards for SO_2 are 50% lower in Saint John, Charlotte and Kings counties.

Sources: NB DELG (2012); www.ec.gc.ca/rnspa-naps/