Review of Kinder Morgan
Trans Mountain Pipeline Expansion Project
Facilities Expansion Application:
Focus on Air Quality

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Summary and Overall Assessment

This report reviews the application of Kinder Morgan for its Trans Mountain Pipeline Expansion Project ('The Project'), with a focus on documents and questions related to air quality. The documents that were reviewed include portions of the Trans Mountain Facilities Application ('The Application') and Air Quality and Greenhouse Gas Technical Report ('The Report', filed in December 2013), the response of Trans Mountain to first round Information Requests (IRs, filed in June 2014), and additional documents submitted by Trans Mountain (filed after June 2014).

My report in divided into two parts: (1) a peer review of The Application and The Report as they relate to air quality, and (2) an opinion as to air quality impacts likely to arise from fugitive emissions during normal operations and during ruptures or releases along the pipeline route, at the terminal and along the tanker route.

Part 1: Peer review of documents related to air quality

My main comments and concerns related to air quality from the peer-reviewed documents fall into three broad groups: (1) quality of the air quality measurements, (2) quality of the air quality modeling, and (3) transparency. Before presenting each group in sub-sections (1) to (3) below, the statistical terms that are used are briefly defined and explained.

Statistical terms.

- **Precision** – how close repeated measurements are to each other.
- **Accuracy** – how close a measurement is to its true value.
- **Detection limit** – the lowest quantity (concentration) that can be measured.
- **Significant figures** – the number of digits that carry real information about a measurement.
- **Error bar** – a measure of the uncertainty in experimental data.

A precise measurement has a small *standard deviation* (expressed as ± 1σ). As an example, say the true temperature in Vancouver is stable at 15.1 °C. If repeated measurements give an average temperature of 15.1 ± 0.1 °C, this is more precise than if repeated measurements give 15 ± 5 °C. Likewise, a reported temperature of 15 °C is more accurate than 25 °C.

- A reported temperature of 25.1 ± 0.1 °C is precise but not accurate;
- A reported temperature of 15 ± 5 °C is accurate but not precise;
- A reported temperature of 15.1 ± 0.1 °C is both accurate and precise;
- A reported temperature of 25 ± 5 °C is neither accurate nor precise.

Using the correct number of significant figures avoids *false precision*, whereby the number of digits that are presented implies a better precision than actually exists. For example a reported temperature of 15.145 °C has too many significant figures if the precision of the measurement is 0.1 °C, because it incorrectly implies a measurement precision of 0.001 °C; instead 15.1 °C carries the correct number of significant figures.
(1) **The basic quality of the ambient air quality measurements still has not been demonstrated.** The first round Information Requests asked for specific details regarding measurement precision, accuracy, calibration, audits, and so forth. Details were not given for accuracy, calibration and audits, and the referenced documents did not provide specific answers. Therefore the basic quality of the measurements, the calibration scale to which they are traceable, and the results of any third-party audits are still unknown. This is very fundamental information that is needed to assess the air quality data.

**Background levels of several pollutants lie within the noise of the instruments.** In response to an Information Request, precision was given for six pollutants (SO\(_2\), H\(_2\)S, NO\(_x\), O\(_3\), CO and THC). However for some compounds the stated precision was surprisingly high, leading to concern that the measurement quality is not sufficient. For example the carbon monoxide (CO) precision was 2-5 times higher than background concentrations at Vancouver latitudes, meaning that the background CO concentrations, and how they vary with time, cannot actually be measured. Likewise the total hydrocarbon (THC) precision was too coarse to detect even broad signals such as normal seasonal variations in levels of the main component of THC, methane. Therefore it is unclear how elevated concentrations caused by The Project will be distinguished from normal background variations.

**Any instrumentation deployed for routine air quality monitoring or spill assessment must be capable of measuring not only peak (high) concentrations but also background (low) levels.** In the case of routine air quality monitoring, the measurements must be able to detect whether background concentrations are increasing in the long-term because of Project emissions. In the case of a spill, the measurements must be able to determine whether a concentration has returned to background levels following the spill. In other words, the instruments must be able to actually measure the background concentrations in any season. However, as stated above, for some pollutants the stated measurement precision is too coarse to distinguish background concentrations from instrument noise. As well as needing precise measurements, the detection limits of the instruments (which were not provided) must be lower than the background concentration in order for the background to be measurable (rather than falling below a high detection limit).

**Ambient data at the Sumas and Burnaby terminals are not available and could not be verified.** Ambient monitoring data from the Sumas and Burnaby Terminals since 2012 and 2013, respectively, are not available because they are undergoing calibration. Therefore these field data could not be viewed or verified. It is also not known where these fence line monitors are located relative to the emission sources and the prevailing wind direction, in other words whether elevated concentrations can be detected for all wind directions.

**It is unclear whether speciated volatile organic compound (VOC) measurements are available.** The hydrocarbon measurements do not appear to be speciated, in which case spikes in individual components such as n-hexane or benzene cannot be identified. In the case of an emergency event or spill, knowing the precise concentrations of individual hydrocarbon pollutants is critical for understanding both direct human health impacts as well as secondary impacts such as the formation of ground-level ozone (O\(_3\)).
The uncertainties in the model results were not quantified. In order to be meaningful, every calculation or emission estimate that is presented needs an associated uncertainty as well as a range of expected values (i.e., maxima and minima). The Information Requests specifically probed the uncertainty in the CALMET/CALPUFF model, but the responses were general in nature and stated that the potential sources of uncertainty were “managed”. Uncertainties cannot be managed; they need to be quantified. The model’s performance in the specific case of The Project was not quantified and therefore remains unknown.

The impact of running the CALPUFF model over a smaller domain than it was designed for was not addressed. The CALPUFF model is intended for long-range applications (> 50 km) but was applied to a 24 x 24 km² domain in the Metro Vancouver region. Because a response to this specific question was not provided during the Information Requests, it is still not known how appropriate the model is for the shorter transport distances considered here and what impact this may (or may not) have on the results.

The decision to use 90th and 98th percentile data as background values is not realistic and undermines the credibility of the model results. The background concentrations used in the model for short-term concentrations (1-24 hr) were unrealistically high in comparison to average conditions at Vancouver latitudes. In some cases (e.g., toluene, SO₂) the background concentrations that were used were more comparable to those found in polluted urban centers such as Hong Kong or Mexico City. Despite this, the background concentrations did not have error bars.

Unrealistically high backgrounds make The Project’s contribution to ambient concentrations appear smaller than it actually is. As an example, a background SO₂ concentration of 10 parts per billion (ppb or 10⁻⁹) was used in the model, and the model estimated that the Burnaby/Westridge Terminals contribute an additional 18 ppb (8 ppb in an updated scenario for the Westridge Terminal). In the updated case of 8 ppb, background and Project each contribute roughly 1/2 to ambient concentrations. Had a credible background SO₂ value of 1 ppb been used, then the background’s contribution to ambient levels decreases to 1/9 and The Project’s contribution increases to 8/9.

The normal variations of background concentrations with time were not addressed. Air pollutants show known diurnal and seasonal variations. For example, background CO concentrations are typically half as high in summer than in winter. However, rather running the model under different scenarios that captured the full range of these variations over time, a single unchanging background concentration was used for each pollutant. This is not realistic and fails to address the fundamental behaviour of pollutants over time. Likewise, the model did not address the possibility that Project emissions may change with time rather than remaining at a single value.

Modeled concentrations were cited to an unrealistic number of significant figures, giving false precision, but this was not recognized or addressed. Even though the background pollutant concentrations used in the CALMET/CALPUFF model have considerable uncertainty, they carried as many as four significant figures. Similarly, the Application case concentrations carried as many as five significant figures. For example, model-predicted
Project NO\textsubscript{x} concentrations (including background) were given as 2414 \(\mu g\) m\(^{-3}\) in a December 2013 report, and as 1491.0 \(\mu g\) m\(^{-3}\) in an August 2014 update. In other words, changing the model input caused the results to decrease by 40\% yet both values were cited to 1 \(\mu g\) m\(^{-3}\) or less, incorrectly implying that they are known to within < 0.04\%.

**Credible measurements will be needed to determine the actual impact of Project operations on pollutant concentrations relative to background, taking into account variations in background and Project concentrations across all seasons.** Because some of the model input was questionable and the model uncertainties were not quantified, there is no context for assessing how reliable the model results are or how representative they are of actual concentrations that may result from The Project at a given time. Therefore emissions from The Project, and their impact on local and regional air quality, are highly uncertain and will require credible and on-going monitoring.

(3) **A lack of direct answers to fundamental questions about measurement and modeling quality creates a lack of transparency and therefore a lack of confidence in the reliability of these results and the ability of this project to self-monitor.** Although detailed and specific data were requested in the Information Requests, in many cases the questions were insufficiently answered or not answered, or the response led to documents that did not exist or did not contain the requested answers. As a result it is still not known whether air quality instrumentation during normal operations and following a spill will be able to credibly measure the full range of concentrations that may be encountered, from background values (low, for example sub-ppb) to plume concentrations (high, for example tens or hundreds of ppb).

**Following protocols does not guarantee good results.** In several cases the Information Requests sought specific information about the measurement and modeling quality, but the response pointed to Air Quality Monitoring directives that were being followed, or to the approval of a model’s use by relevant authorities. However, even if protocols or guidelines are followed, each result then needs to be critically assessed as to its credibility and uncertainty. In other words once the protocols have been followed, does the result actually make sense? Following protocols does not guarantee this, but this did not seem to be recognized.

**Part 2: Air quality impacts expected during normal operations and a rupture or spill**

I was asked to provide an opinion as to likely air quality impacts during a rupture or release along the pipeline, at the terminal, and along the tanker route.

(1) **The Application did not discuss any potential impacts on humans resulting from a pipeline spill.** While The Application provided a human health risk assessment under a hypothetical spill scenario at the Westridge Marine Terminal, the same was not done in the hypothetical case of a pipeline spill. Even though population densities may be lower along the pipeline route, there is still a need for credible and timely responses to the needs and concerns of local communities immediately following a spill.
(2) Because the effects of oil spills can persist for weeks, it cannot be assumed the evaporation of hydrocarbons following a spill will generally occur within the first 12 hours. While The Application correctly stated that hydrocarbon evaporation will be most acute immediately following the spill and will decrease with time, the statement that “The lighter hydrocarbon components, containing from 1 to 12 carbon atoms (C\textsubscript{1}-C\textsubscript{12}), will generally evaporate within the first 12 hours of exposure.” is overly optimistic as excess concentrations can persist for weeks after a spill (as noted elsewhere in The Application). This also underscores the need for instrumentation that can actually measure when a concentration has returned to background levels, as opposed to falling below a detection limit that is not capable of detecting background.

(3) The Deepwater Horizon oil spill and rig explosion is a rare case where independent scientists had full access to an oil spill at sea. While this spill was more catastrophic than ruptures or releases that would be expected as part of The Project, it is still instructive.

\textbf{C\textsubscript{3}-C\textsubscript{10} hydrocarbons, especially alkanes and aromatics, are likely to be the most abundant VOC components released during a spill.} While the exact composition of compounds emitted following a spill will depend on many factors including the composition and volatility of the specific crude oil blend and so forth, the pollutants emitted following the Deepwater Horizon spill were assessed using direct and credible measurements. In this case, \textit{n}-butane was the most abundant non-methane VOC in air impacted by the spill, followed by \textit{n}-pentane, \textit{i}-pentane, \textit{n}-hexane, methlycyclohexane, \textit{n}-heptane, \textit{n}-octane, methlycyclopentane, cyclohexane, \textit{n}-nonane, toluene, and so forth. In the case of a spill at sea, more soluble compounds such as benzene and propane are expected to dissolve into the water column, as was observed during the Deepwater Horizon oil spill.

The exact composition and concentrations of hydrocarbons released into the atmosphere following a spill can only be determined with actual measurements. For example, it would have been difficult to predict that \textit{n}-butane levels would still be as high as 1 part per million (ppm or \(10^\text{6}\)) two months after the Deepwater Horizon oil spill (37,000 times higher than background), that methlycyclohexane levels would reach 670 ppb (42,000 times higher than background), or that \textit{n}-hexane concentrations exceeding 2 ppb would persist two weeks after the spill was capped (1000 times higher than background).

Monitoring a spill and determining when concentrations have returned to background will most likely require an analytical capability to measure VOC concentrations ranging from parts per trillion (ppt or \(10^{\text{12}}\)) to tens or hundreds of ppb. In the case of the Deepwater Horizon oil spill, VOC concentrations ranged over 5-6 orders of magnitude, from ppt to ppm levels. For example, the maximum concentrations of individual VOC components of the spilled oil ranged over 3-4 orders of magnitude two months into the spill, from peaks of 0.47 ppb for benzene to 1080 ppb for \textit{n}-butane. By comparison, background concentrations were 0.02 ppb for benzene and 0.03 ppb for \textit{n}-butane, so that the overall concentrations (background to peak values) ranged over 5-6 orders of magnitude considering the dozens of compounds that were measured. In the case of a Project spill, instruments will likely need to be able to make VOC measurements ranging
from low background values (ppt) up to tens or hundreds of ppb, depending on the spill and composition, meteorological conditions, effectiveness of the response, etc.

**Oil spill air quality monitoring will need to include both primary emissions from the oil slick (e.g., hydrocarbons) and secondary products (e.g., secondary organic aerosol, ozone, organic nitrates).** Hydrocarbons evaporating from the Deepwater Horizon oil spill were the largest source of primary emissions to the air. Chemical transformations of these primary emissions resulted in secondary products such as secondary organic aerosol (SOA). In addition, the hydrocarbons emitted from the spill reacted with nitrogen oxides (NO\(_x\)) from the clean-up and recovery effort to produce other secondary products such as ozone and organic nitrates. Therefore both primary and secondary impacts of a Project spill will need to be included in any air quality monitoring response.

(4) **It is recommended that independent scientists be given access to spill sites.** During a Project emergency event it appears that access would be limited to those involved in the response effort. By contrast, the air quality monitoring following the Deepwater Horizon oil spill involved dozens of independent scientists from multiple government agencies and academic institutions, and the results were made available to the public via the peer-reviewed literature. Given the concerns described earlier about the basic quality of the measurements and modeling results, it is recommended that independent scientists, working in coordination with Trans Mountain, be allowed access to any spill or event site so that credible and transparent air quality information can be provided to the public in the days and weeks following the event.

**3. Overall assessment**

Overall, much of the material presented in The Report related to air quality was not sufficient. The basic quality of the air quality monitoring equipment was not demonstrated, and some of the cited precisions were too high to distinguish background concentrations from instrument noise or to capture normal variations in background pollutant levels with time. Background concentrations used in The Report often were not realistic, were presented to an unreasonable number of significant figures, and did not have uncertainties (error bars) associated with them. One-hour background values used in The Report—and compared to predicted Existing and Application (Project) concentrations—were unrealistically high, making the contribution of Project emissions appear relatively smaller compared to background than they actually would be. Even though guidelines or protocols were followed to arrive at certain results, it did not appear that the results were then critically assessed to see if they made sense.

Air quality impacts following a rupture or spill are difficult to assess because (1) there is a wide range of possible spill scenarios, (2) specific air quality impacts (composition and concentrations) were not provided, and (3) there is a lack of independent data on oil spill emissions in the scientific literature because of limited site access. While it is possible to reasonably predict which specific compounds will be emitted following a spill, for example based on the composition of crude oil, the exact atmospheric concentrations that occur following a spill—from immediately following the spill to the time at which concentrations have returned to background—can only be determined via credible and timely on-site monitoring.
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1. Introduction

1.1 Scope of work

1.1.1 Overview. I have been retained by the Living Oceans Society (1) to review the Facilities Application (hereafter ‘The Application’) of Kinder Morgan for its Trans Mountain Pipeline Expansion Project (hereafter ‘The Project’), with a focus on documents and questions related to air quality, and (2) to provide an opinion as to the air quality impacts likely to arise from:

(1) Fugitive emissions from normal operations of the pipeline, terminal and tankers, with particular emphasis on Burrard Inlet/Indian Arm;

(2) A pipeline rupture or release occurring along the pipeline route through the Fraser Valley and Metro Vancouver;

(3) A rupture, release or spill occurring at the terminal; and

(4) A release or spill occurring on the tanker route within Burrard Inlet and Juan de Fuca/Haro Straits.

1.1.2 Documents reviewed. The documents that I reviewed are listed in Appendix I.

1.1.3 Acronyms. The acronyms used throughout this report are listed in Appendix II.

1.1.4 Statistical terms. The statistical terms used in this report are outlined in the Summary and Overall Assessment (page 2).

1.2 Statement of qualifications

For the past 18 years I have worked in the Nobel Prize-winning Rowland/Blake group in the Department of Chemistry at the University of California, Irvine (UCI). My expertise focuses on the atmospheric composition and chemistry of methane (CH₄), carbon monoxide (CO), and speciated volatile organic compounds (VOCs) in the world’s major atmospheric environments, ranging from pristine to highly polluted conditions. My expertise also includes general knowledge of other trace gases (CO₂, NOₓ, N₂O, SO₂) and modeling, and limited knowledge of particulate matter (PM), polyaromatic hydrocarbons (PAHs) and hydrogen sulphide (H₂S).

1.2.1 CV. My 2-page CV is provided in Appendix III.

1.2.2 Education. I have a B.Sc. degree in Agriculture from the University of British Columbia (1990), an M.Sc. degree in Micrometeorology from the University of Guelph (1993) and a Ph.D. degree in Micrometeorology from the University of Guelph (1996). My M.Sc. thesis received the 1993 award for the best M.Sc. thesis at the University of Guelph.

1.2.3 Professional appointments. Since 1997 I have worked with the Rowland/Blake group in the Department of Chemistry at the University of California, Irvine (UCI). This group received the 1995 Nobel Prize in Chemistry for discovering the role of chlorofluorocarbons (CFCs) in
stratospheric ozone (O\textsubscript{3}) depletion. This discovery was first published in 1974 and was verified 11 years later when the British Antarctic Survey reported the Antarctic Ozone Hole.

1.2.4 Research experience. My research experience combines micrometeorology and atmospheric chemistry. My graduate research advanced the micrometeorological techniques used to measure emissions (fluxes) from agricultural and forest ecosystems (Simpson et al., 1995, 1997, 1998, 1999). My post-graduate research applies world-class analytical techniques to the measurement of trace gases in the atmosphere, and understanding their impacts on atmospheric chemistry, air quality, global climate change and stratospheric ozone depletion.

(1) Global background concentrations. Our group measures trace gas concentrations in the most pristine to the most polluted environments in the world. Since 1978 we have monitored global background concentrations of greenhouse gases (e.g., CH\textsubscript{4}), ozone depleting compounds (e.g., CFCs), and short-lived hydrocarbons (e.g., ethane, propane). This work is funded by the National Aeronautics and Space Administration (NASA) and we are one of three groups in the world who perform such global trace gas monitoring. This research has allowed us to make fundamental advances in our understanding of what has caused levels of key constituents of the Earth’s atmosphere to change with time (e.g., Simpson et al., 2002, 2004, 2006, 2007, 2012).

(2) Airborne field studies: Since 1988 our research group has been involved in diverse airborne projects sponsored by NASA, the National Oceanic and Atmospheric Administration (NOAA), and the National Science Foundation (NSF). These projects seek to understand atmospheric composition and chemistry on regional scales and have resulted in numerous NASA Group Achievement Awards. As part of a 2008 NASA airborne mission over Canada, our group was the first to independently characterize dozens of trace gases emitted from Alberta’s oil sands mining and upgrading operations north of Fort McMurray (Simpson et al., 2010).

(3) Ground-based field studies: Since the 1990s our group has studied trace gas concentrations in more than 75 cities around the world (e.g., Barletta et al., 2006, 2008; Baker et al., 2008). This work includes pioneering studies in Mexico City (Mexico), Santiago (Chile) and Mecca (Saudi Arabia) that led to key recommendations for improving air quality, which have since been implemented by the relevant governments (Blake and Rowland, 1995; Chen et al., 2001; Simpson et al., 2014). In 2012 I led a survey of air quality in the Industrial Heartland of Alberta, which includes upgrading and refining of Alberta’s oil sands (Simpson et al., 2013).

(4) Ship-based field studies: Our group surveyed VOC emissions from the Deepwater Horizon oil spill and rig explosion by aircraft and by ship one month into the oil spill and again at two and three months (e.g., de Gouw et al., 2012; Middlebrook et al., 2012; Neuman et al., 2012; Ryerson et al., 2011, 2012). We measured extremely high levels of numerous C\textsubscript{3}-C\textsubscript{10} alkanes and aromatics (e.g., n-butane, n-hexane). The total average nonmethane hydrocarbon burden in this area was more than 7 parts per million of carbon (ppmC), equivalent to more than four times the amount of carbon represented by methane. While a disaster of this scale is not anticipated as part of the Trans Mountain Expansion project...
Project, the Deepwater Horizon results provide context for the types of compounds that may be released and chemical transformations that may occur after a spill.

(5) **Auditing capacity:** Our UCI research group is known for its ability to accurately identify and precisely quantify CH₄, CO, and more than 100 speciated VOCs. We have participated in every international hydrocarbon intercomparison experiment, with excellent results (e.g., Apel et al., 2003; Hall et al., 2010). Our data are published in the 2013 *Assessment Report of the Intergovernmental Panel on Climate Change* (Hartmann et al., 2013) and I am a contributor to the World Meteorological Organization’s 2014 *Scientific Assessment of Ozone Depletion* (Carpenter and Reimann, 2014). Because of our group’s strong analytical capability, we are hired to audit VOC measurements performed by other research groups around the world, for example the Hong Kong Environmental Protection Department and an industrial monitoring company in Canada.

1.2.5 **Peer-reviewed publications.** I am lead author or co-author on more than 60 peer reviewed scientific publications, including five publications for which UCI issued press releases:

(1) Extensive regional atmospheric hydrocarbon pollution in the southwestern United States (Katzenstein et al., *Proc. Natl. Acad. Sci.*, 2003);

(2) Influence of biomass burning during recent fluctuations in the slow growth of tropospheric methane (Simpson et al., *Geophys. Res. Lett.*, 2006);

(3) Long-term decline of global atmospheric ethane concentrations and implications for methane (Simpson et al., *Nature*, 2012);

(4) Air quality in the Industrial Heartland of Alberta, Canada and potential impacts on human health (Simpson et al., *Atmos. Environ.*, 2013);


Publication (1) was the first to report the widespread impact of the oil and natural gas industry on regional air quality in the southwestern United States. Publications (2) and (3) address changing concentrations of CH₄, the most important human-augmented greenhouse gas after carbon dioxide (CO₂). Publication (4) reports the impact of heavy industrial activity on air quality and human health in the Industrial Heartland of Alberta, which includes facilities to upgrade and refine Alberta oil sands. Publication (5) presents strategies to improve air quality in polluted cities in Saudi Arabia, which are currently being implemented by the Saudi Arabian government.

1.2.6 **Synergistic activities.** I am an Associate Editor of the peer-reviewed, open-access journal *Elementa*. I have served as peer reviewer for dozens of manuscripts for more than 10 scientific journals. In 2011 I received the Editor’s Citation for Excellence in Refereeing from the *Journal of Geophysical Research, Atmospheres*. I have served as external proposal reviewer for NASA and NSF, and served on a recent NASA review panel. My research collaborations include colleagues from government institutions and universities around the world.
2. Background and context for assessing air quality

2.1 Trans Mountain Facilities Application

2.1.1 Pipeline routing. In December 2013 Trans Mountain filed its Pipeline Expansion Project (‘The Project’) to the National Energy Board. The filings include a Facilities Application (‘The Application’) and an Air Quality and Greenhouse Gas Technical Report (‘The Report’). The Project seeks to expand an existing 1,150 km pipeline between Strathcona County, Alberta and Burnaby, B.C. by 940 km, creating a twinned pipeline with an expanded capacity of 890,000 barrels per day, compared to 300,000 currently (www.transmountain.com/proposed-expansion) (Figure 1).

![Figure 1. Proposed Trans Mountain Expansion Project routing (www.transmountain.com/map).](image)

2.1.2 Dock facilities. In conjunction with the proposed pipeline expansion, the Westridge Marine Terminal would serve an estimated 37 vessels per month (34 tankers and 3 barges), compared to 8 currently (5 tankers and 3 barges) (http://www.transmountain.com/marine-plans). Two new 30-inch, 4 km delivery lines will connect the Burnaby Terminal to the Westridge Marine Terminal, compared to the current 24-inch delivery line.

2.1.3 Air quality impacts. According to the Marine Air Quality and Greenhouse Gas Marine Transportation Technical Report of June 2014, quoted directly here, the Project will result in the following air emissions:

(1) Criteria air contaminants (CACs), including particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO₂), and sulphur dioxide (SO₂):
(2) Volatile organic compounds (VOCs), including benzene, toluene, ethyl benzene (sic), and xylenes, collectively known as BTEX, as well as other compounds with the potential to cause nuisance and odours; and,

(3) Greenhouse gases (GHGs), including carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) with the potential to affect overall climate change.

2.2 Introduction to atmospheric composition

Predicting the potential impact of routine operations or a rupture or spill on air quality requires a robust understanding of pre-existing air quality, including background concentrations of compounds likely to be emitted and their normal variations with time and space. A general introduction to each trace gas listed in Section 2.1.3 is given below. The lifetime of each trace gas and the conversions between units of ppb and μg m⁻³ are given in Table 1 of Section 2.3.

2.2.1 Carbon dioxide (CO₂). Carbon dioxide is a long-lived gas (> 100 yrs) and the most potent greenhouse gas in terms of human impact on climate (‘enhanced radiative forcing’). Its concentration increased from 278 ± 2 ppm in 1750 to 390.5 ± 0.3 ppm in 2011 (Hartmann et al., 2013). Fossil fuel combustion and land use change (deforestation) are the leading causes of this increase, with fossil fuel combustion recognized as the main contributor in recent decades (Tans, 2009). Its concentration varies seasonally, primarily because of plant photosynthesis (CO₂ uptake) in the boreal summer and plant respiration (CO₂ release) in the boreal winter. Its growth rate shows interannual variability linked to changes in the balance between terrestrial photosynthesis and respiration. In 2014 the CO₂ concentration at Vancouver latitudes ranged from 388 ppm in summer to 405 ppb in winter, based on airborne samples collected at 500 m altitude by the National Oceanic and Atmopsheric Administration (NOAA) at Estevan Point, B.C. (http://www.esrl.noaa.gov/gmd/dv/iaidv/graph.php?code=ESP&program=ccgg&type=ts).

2.2.2 Methane (CH₄). Methane is a long-lived hydrocarbon (9 yrs) and a potent greenhouse gas (Hartmann et al., 2013). About two-thirds of methane’s sources are anthropogenic (e.g., fossil fuel extraction, distribution and use; rice agriculture; ruminant animals; landfills) and one third natural (e.g., wetlands, biomass burning). Its main removal mechanism in the atmosphere is reaction with the hydroxyl radical (OH). Methane’s global concentration has more than doubled from 722 ± 25 ppb in 1750 to 1803 ± 2 ppb in 2011 (Hartmann et al., 2013). However methane’s growth rate began to slow in the late 1980s, most likely because of decreased venting and flaring of natural gas in oil fields (Simpson et al., 2012). Methane also shows significant seasonal and interannual variability caused by factors such as variable emissions from biomass burning and tropical wetlands (Simpson et al., 2006; Dlugokencky et al., 2009). Methane has a strong latitudinal gradient, with higher concentrations in the Northern Hemisphere than in the Southern Hemisphere. In 2014 its concentration at Vancouver latitudes ranged from 1850 ppb in summer to 1910 ppb in winter, based on 500 m airborne samples at Estevan Point, B.C. (http://www.esrl.noaa.gov/gmd/dv/iaidv/graph.php?code=ESP&program=ccgg&type=ts).
2.2.3 Nitrous oxide ($N_2O$). Nitrous oxide is a long-lived greenhouse gas (130 yrs). Since the Industrial Revolution its concentration has increased by about 20%, from 270 ± 7 ppb in 1750 to to 324.2 ± 0.2 ppb in 2011 (Hartmann et al., 2013). Its growth since the 1950s is linked to agriculture (application of nitrogen fertilizer). Unlike $CO_2$ and $CH_4$, its growth rate has remained fairly steady over the past 20 years. In 2014 its concentration at Vancouver latitudes ranged from 326.6 to 328.3 ppb, based on 500 m airborne samples at Estevan Point, B.C. (http://www.esrl.noaa.gov/gmd/dv/iadv/graph.php?code=ESP&program=ccgg&type=ts).

2.2.4 Carbon monoxide (CO). Carbon monoxide is a tracer of incomplete combustion (e.g., fossil fuel combustion, biomass burning) and is a precursor to photochemical smog (Yoon and Pozzer, 2014). It is toxic to humans at levels greater than 35 ppm. Compared to the greenhouse gases listed above it is relatively short-lived in the atmosphere (2-3 mo), and as a result shows more spatial and temporal variability. Its concentration is much higher in the Northern Hemisphere than in the Southern Hemisphere, and its concentration is higher in winter than in summer because of slower removal by OH during winter. During the 2000s its global concentration declined by about −1% yr$^{-1}$ (Hartmann et al., 2013). In 2014 its concentration at Vancouver latitudes ranged from 75 ppb in summer to 140 ppb in winter (http://www.esrl.noaa.gov/gmd/dv/iadv/graph.php?code=ESP&program=ccgg&type=ts).

2.2.5 Sulphur dioxide ($SO_2$). Sulphur dioxide is a short-lived trace gas (1 d) that is strongly associated with natural emissions from volcanoes and anthropogenic activities such as fossil fuel combustion, especially coal and residential oil (Benkovitz et al., 1996). $SO_2$ concentrations as high as 38.7 ppb were measured near oil sands mining and upgrading operations north of Fort McMurray, Alberta based on measurements made aboard NASA’s DC-8 research aircraft in summer 2008 at an altitude of 800 m (Simpson et al., 2010). By comparison, background $SO_2$ concentrations were 0.10 ± 0.03 ppb.

2.2.6 Nitrogen dioxide ($NO_2$). The major source of nitrogen oxides ($NO_x = NO_2 + NO$) is fossil fuel combustion (Benkovitz et al., 1996). Virtually all $NO_x$ is emitted as NO, which is rapidly converted to other species including $NO_2$. NO is colourless while $NO_2$ gives smog its characteristic brown/orange colour. Because $NO_x$ are very short-lived species (< 1 d), their concentrations strongly vary with time and space. Typical $NO_x$ concentrations are 0.02-0.08 ppb in remote areas and 10-1000 ppb in suburban/urban areas (Seinfeld and Pandis, 1998). In general $NO_2$ levels are increasing over parts of Asia and decreasing in Europe and North America (Hilboll et al., 2013). For example $NO_2$ levels over the USA decreased by 30-50% from 1996-2010 (Hartmann et al., 2013).

2.2.7 Volatile organic compounds (VOCs). VOCs react together with $NO_x$ in the presence of sunlight to create tropospheric ozone. Many hundreds of VOCs exist at trace levels in the Earth’s atmosphere, and in general their atmospheric lifetimes decrease as their carbon number increases. The most relevant VOCs for this report include light alkanes that make up diluted bitumen, and the BTEX compounds expected to be released by The Project. Of the BTEX compounds, benzene is the longest-lived (1-2 wk), followed by toluene (2-3 d), ethylbenzene (1-2 d) and the xylenes (0.5-1 d). Benzene is a known carcinogen that causes leukemia, and
ethylbenzene is a probably carcinogen (IARC, 2010). Because of their very short atmospheric lifetimes the concentrations of BTEX are highly variable in the atmosphere, for example ranging from < 0.09 ppb in background air in the temperate Northern Hemisphere to 0.6-23 ppb close to sources (Simpson et al., 2013).

2.2.8. Summary. Trace gas concentrations are not constant with time and space, even for long-lived compounds such as CO₂ and CH₄. Understanding the long-term, interannual and seasonal variations in trace gas concentrations at Vancouver latitudes is critical for establishing the correct background concentrations against which to compare any additional impacts caused by The Project.

2.3 Conversions

A compound’s abundance in the atmosphere can be expressed as a concentration (e.g., μg m⁻³), a mixing ratio (e.g., parts per billion or ppb), and a mole fraction (e.g., nmol mol⁻¹). All are used in the literature, and both concentrations and mixing ratios are presented in the Trans Mountain filings. Table 1 provides some basic conversions for the trace gases listed in Section 2.1.3. Throughout the report I use ‘concentration’ to mean either ‘concentration’ or ‘mixing ratio’.

Table 1. Concentration conversions and atmospheric lifetimes for selected trace gases. The conversions are based on 1 ppb = 0.0409 x MW μg m⁻³ (air at 1 atm and 25 °C), where MW = molecular weight (Finlayson-Pitts and Pitts, 2000). Lifetime estimates are as described in Simpson et al. (2010).

<table>
<thead>
<tr>
<th>Compound</th>
<th>Formula</th>
<th>MW (g mol⁻¹)</th>
<th>Conversion (ppb to μg m⁻³)</th>
<th>Atmospheric lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>44.01</td>
<td>1 ppb = 1.800 μg m⁻³</td>
<td>&gt; 100 yr</td>
</tr>
<tr>
<td>Methane</td>
<td>CH₄</td>
<td>16.04</td>
<td>1 ppb = 0.656 μg m⁻³</td>
<td>9 yr</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>CO</td>
<td>28.01</td>
<td>1 ppb = 1.145 μg m⁻³</td>
<td>2 mo</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>NO₂</td>
<td>46.01</td>
<td>1 ppb = 1.882 μg m⁻³</td>
<td>1 d</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>SO₂</td>
<td>64.07</td>
<td>1 ppb = 2.620 μg m⁻³</td>
<td>1 d</td>
</tr>
<tr>
<td>Benzene</td>
<td>C₆H₆</td>
<td>78.11</td>
<td>1 ppb = 3.195 μg m⁻³</td>
<td>1-2 wk</td>
</tr>
<tr>
<td>Toluene</td>
<td>C₇H₈</td>
<td>92.14</td>
<td>1 ppb = 3.769 μg m⁻³</td>
<td>2-3 d</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>C₈H₁₀</td>
<td>106.17</td>
<td>1 ppb = 4.342 μg m⁻³</td>
<td>1-2 d</td>
</tr>
<tr>
<td>Xylenes</td>
<td>C₈H₁₀</td>
<td>106.17</td>
<td>1 ppb = 4.342 μg m⁻³</td>
<td>0.5-1 d</td>
</tr>
</tbody>
</table>
3. Peer review of Trans Mountain Facilities Application

3.1 Air quality technical report

3.1.1 Overview. During the construction and operation phases of The Project, emissions of CACs (PM, CO, NO\textsubscript{2}, SO\textsubscript{2}), VOCs (especially BTEX), and GHGs (CO\textsubscript{2}, CH\textsubscript{4}, N\textsubscript{2}O) are expected (Section 2.1.2). The Air Quality and Greenhouse Gas Technical Report (‘The Report’) seeks to assess emissions of air contaminants and greenhouse gases resulting from The Project, including pipelines, pump stations and storage terminals, both during construction and during normal operations. Emission estimates were made for three scenarios: existing, Project and cumulative. Fugitive and combustive emissions from tankers at the Burnaby/Westridge marine terminals were also included. The following sections discuss the quality of the air quality measurements (Section 3.2), the transparency of the air quality measurements (Section 3.3), and the uncertainty of the air quality modeling products (Section 3.4).

3.1.2 Existing emissions. A theme that runs throughout The Application and The Report is a general failure to recognize and quantify uncertainty. When a measurement is used or a model result is calculated, it always needs an associated error bar to give some indication of its uncertainty. The Information Requests (IRs) provided an opportunity to address this issue, but the opportunity in most cases was not taken. Instead the responses to questions about uncertainty were almost always general in nature rather than quantitative.

As a first example, emission inventories (EIs) were used to establish existing emissions of CAC and VOCs in the air quality local and regional study areas (Section 3.4.1.3 of The Report). However EIs for urban areas and the oil and natural gas industry have many times been shown to underestimate emissions relative to those derived from measurements, often by a factor of 2-3 (e.g., Katzenstein et al., 2002; Karion et al., 2013; Peischl et al., 2013; Pétron et al., 2012, 2014; Wunch et al., 2009) though sometimes much higher. For example, National Pollutant Release Inventory (NPRI) emissions of VOCs including benzene were found to be underestimated by 15 to 18-fold at an unnamed Canadian refinery (Chambers et al., 2008). Because the uncertainties in EIs were not addressed or quantified in The Report, it is not known how these uncertainties impact the overall assessment of emissions. The uncertainty of each measurement or calculation that was used in The Application or Report should have been critically evaluated and quantified. Without this, the presented results have no context as to their reliability or credibility.

3.2 Measurement quality

3.2.1 Ambient air quality data. Ambient air quality data for CACs, BTEX, total reduced sulphur (TRS) and O\textsubscript{3} were collected from the Clean Air Strategic Alliance, the BC Ministry of the Environment, Metro Vancouver, and Environment Canada (Section 3.4.1.2). Also included are real-time ambient fence line monitors at the Sumas Tank Farm and the Burnaby and Westridge Marine Terminals, which measure H\textsubscript{2}S, VOCs, SO\textsubscript{2} and weather parameters. The Information Request asked how these measurement data are calibrated, what their precision and accuracy
are, and whether the quality of the data has been demonstrated by recognized international audits or other intercomparisons. However the response provided few concrete answers, and instead often made reference to Air Monitoring Directives which provided general procedures for data quality, calibration, audits, and so forth, but not the actual results of these calibrations and audits (i.e., real data). *Therefore the basic quality of the ambient air quality data still has not been demonstrated.*

### 3.2.2 Calibration

In order to understand the basic quality of a given measurement, its calibration scale needs to be traceable to a recognized standard. For example, a CO₂ measurement traceable to the World Meteorological Organization (WMO) CO₂ scale is accurate to within 0.07 ppm (http://www.esrl.noaa.gov/gmd/ccgg/about/co2_measurements.html). As a second example, if a CH₄ measurement is traceable to the NOAA calibration scale, then someone using these data knows that the scale changed in 2004 and is now 1.0124 ± 0.0007 times greater than the NOAA scale used since 1983 (*Dlugokencky et al.*, 2005). These are examples of the quantitative answers I was seeking.

The Information Requests asked how the CACs, BTEX, TRS and O₃ are calibrated, but the response was vague rather than specific (e.g., “Instruments are monitored and calibrated on a regular basis.”) References were provided for standard quality assurance and quality control procedures set out by Alberta and B.C. Air Monitoring Directives, but the information in these documents was again general rather than specific. For example the Alberta Air Monitoring Directive (*AAMD*, 2014) states that calibration standards must be “(a) certified as traceable to either: (i) the U.S. National Institute of Standards and Technology (NIST); or (ii) the Dutch Metrology Institute (VSL) primary standard; or (b) derived from local or working standards (e.g., cylinders of compressed or permeation devices)”", but this information does not tell us which specific standards were used for the data cited in The Report. *Therefore we still do not know which specific calibration standards apply to the ambient air quality data used in The Report, and therefore what the reliability and accuracy of the measurements is.*

### 3.2.3 Audits

Similarly, the Information Requests asked whether the quality of the measurements has been demonstrated by international audits or other intercomparisons. Again the reply was general (e.g., “The data is subjected to the internal and Alberta Environment and Sustainable Resource Development audits.”) and the response referred us to details provided in the Air Monitoring Directive (AMD). However, the information in the AMD was also general in nature (e.g., that audits of the calibration system should occur once per year at a minimum) rather than the specific answers I sought, namely the quantitative results from the Audit Summaries and Analyzer Audits. *Therefore the quality of the measurements is still unknown, even if protocols were followed to achieve the measurements.* For example, our UCI group audits VOC measurements of other groups around the world (who follow protocols), and from this first-hand experience we know that following protocols does not guarantee good results, even if the measurement team is putting forward their best effort to make high quality measurements.

### 3.2.4 Measurement precision

Although specific information was not provided for measurement accuracy, calibration and audits, the precision was given for six pollutants (SO₂,
H₂S, NOₓ, O₃, CO and THC) (Table 2). However for some compounds the stated precision was surprisingly high, leading to additional concerns that the measurement quality is not sufficient, as discussed below. Also, in the cases of SO₂ and H₂S, the stated precision was the same as the 1-hr background values that were cited (Figures 5.5 and 5.13 of The Report), which seems not only highly unlikely but also means that the average background value (if correct) lies within the noise of the measurement. In the case of a release or spill, how will it be determined that concentrations have returned to normal if background concentrations cannot be precisely measured?

3.2.4.1 Sulphur dioxide. The SO₂ precision of 10 ppb (26 μg m⁻³) is extremely high compared to concentrations that are likely to be encountered. Because SO₂ is very short-lived (1 d) its concentration can vary over a wide range (Section 2.2.5). For example, background SO₂ levels of 0.10 ± 0.03 ppb (0.27 μg m⁻³) were measured in the Fort McMurray region, with industrial plume values averaging 4.7 ± 11.5 ppb and reaching as high as 38.7 ppb (101 μg m⁻³) (Simpson et al., 2010). SO₂ levels in Mexico City, which is heavily impacted by both volcanic and industrial SO₂ sources, have a diurnal cycle that ranges from 0-5 ppb in the southern part of the city and 5-20 ppb in the north, with peaks up to 225 ppb (de Foy et al., 2009). At the time of writing, SO₂ levels reported at Burnaby Kensington Park are 1.0-1.1 ppb, though the quality of these measurements was not provided (http://gis.metrovancouver.org/airmap/). Therefore the SO₂ precision of 10 ppb is insufficient to measure not only B.C. and Alberta background values, but even baseline levels encountered in heavily polluted urban/industrial areas such as Mexico City.

Table 2. Data reporting precision of pollutant concentrations, as provided in the Information Request. The conversions from ppb to μg m⁻³ are based on the data provided in Table 1.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Precision (ppm)</th>
<th>Precision (ppb)</th>
<th>Precision (μg m⁻³)</th>
<th>Cited background (μg m⁻³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sulphur dioxide</td>
<td>0.01</td>
<td>10</td>
<td>26.2</td>
<td>26.3</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>0.001</td>
<td>1</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>0.01</td>
<td>10</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Ozone</td>
<td>0.001</td>
<td>1</td>
<td>2.0</td>
<td>--</td>
</tr>
<tr>
<td>Carbon monoxide</td>
<td>0.5</td>
<td>500</td>
<td>572</td>
<td>--</td>
</tr>
<tr>
<td>Total hydrocarbons</td>
<td>0.1</td>
<td>100</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

The maximum predicted SO₂ concentration in the Application case (The Project), including ambient background and all marine transportation for the Burnaby and Westridge Marine Terminals, is 73.2 μg m⁻³ or 28 ppb for 1-hr averaging (Figure 5.13 of The Report), 20.2 μg m⁻³ or 7.7 ppb for 24-hrs (Figure 5.14) and 3.0 μg m⁻³ or 1.1 ppb annually (Figure 5.15). Note that the 1-hr value assumes a background value of 26.3 μg m⁻³, or 10 ppb, which is not realistic because it is higher even than baseline levels measured in Mexico City (population of 20 million) in areas impacted by industrial complexes and the Popocatepetl volcano (de Foy et al.,
2009). The unrealistically high SO$_2$ background value will be discussed below in Section 3.3.6.3. *Apart from very high plume levels, the instrumentation will not be able to measure most SO$_2$ levels that are expected as part of the Project.*

3.2.4.2 *Carbon monoxide.* The CO precision of 500 ppb is also extremely high. Clean air background CO concentrations at Vancouver latitudes range from 75 ppb in summer to 140 ppb in winter (Section 2.2.4), so the stated precision of 500 ppb is too high to make meaningful measurements at or even several times higher than background levels. Annual CO concentrations for the Burnaby area range from 120-350 μg m$^{-3}$ (105-305 ppb) based on data shown in Figure 4.3.6 of The Report, though again the quality of these data has not been demonstrated. If correct, they also indicate that the CO precision of 500 ppb is higher than average levels encountered in a year. A rough analogy would be trying to measure the temperature in Vancouver using a thermometer with a precision of 30 °C. While extreme events could be detected, the measurements would miss most of the normal diurnal and seasonal variations in temperature, as well as any long-term changes with time.

Background CO concentrations of 605.0 μg m$^{-3}$ or 528 ppb (1-hr averaging) and 542.6 μg m$^{-3}$ or 461 ppb (8 hr) were cited for the Burnaby and Westridge Marine Terminals (Table 3.30 of the Report). The accuracy of these background CO values, their false precision, and their failure to incorporate uncertainty or to address seasonal variations, will be discussed below in Section 3.3.6.2. However even if these background CO values are accurate, they lie at the precision of the measurements and so *background CO values, especially in summer when they will be at a seasonal minimum, will lie within the noise of the measurement.*

3.2.4.3 *Total hydrocarbons.* Total hydrocarbons (THCs) are understood to mean the sum of CH$_4$ and non-methane hydrocarbons (NMHCs). As with SO$_2$ and CO, the THC precision of 100 ppb is too high to detect even broad signals such as the normal seasonal variations in the main component of THC, methane. Background CH$_4$ concentrations at Vancouver latitudes range from 1860 ppb in summer to 1910 ppb in winter, but it is worth noting that CH$_4$ concentrations are increasing with time (Section 2.2.2). For example concentrations increased by 25 ppb at the Estevan Point station in British Columbia from 2003-2014. Therefore a THC precision of 100 ppb is also very high and insufficient to distinguish even broad background signals—such as long-term trends and seasonality—from excess concentrations caused by Project emissions. As a result it is unclear how Project emissions will be distinguished from normal concentration variations, or how it will be established that concentrations have returned to background after an exceedance or spill.

An additional concern is that the hydrocarbon measurements do not appear to be speciated, so spikes in individual components such as $n$-hexane or benzene would not be identified. *In the case of an emergency event or spill, knowing the concentrations of individual hydrocarbon pollutants is critical for understanding both direct human health impacts as well as secondary impacts such as the formation of ground-level ozone.* For example, while benzene and toluene are both aromatic compounds included in a grouping called BTEX (benzene, toluene, ethylbenzene, xylenes), benzene is a known carcinogen that is less reactive in the atmosphere, whereas ethylbenzene is a possible carcinogen that is more reactive in the atmosphere (*IARC*, 2010; *Table 1*). Therefore each needs to be measured separately in order to
understand its impact on air quality and human health. The ability to make credible measurements of the individual components of BTEX was not demonstrated in The Report.

3.2.5 Sumas and Burnaby Terminals. According to The Report, “Both Sumas and Burnaby terminals currently have continuous ambient stations that report H2S, SO2 and VOC measurements in addition to wind speed and wind direction” based on 1-minute averages. The Information Requests asked for the data recorded by those stations (since 2012 and 2013, respectively), but the response stated, “The units are still going through a calibration process on some of the sensors. For this reason, Kinder Morgan Inc. is not able to commit at this point to providing data from the monitoring units.” While I recognize that calibration is an on-going process, viewing these data would have allowed an assessment of whether the concentrations are reasonable and whether they match those used in the CALMET/CALPUFF model (see Section 3.3.1 below). Instead, we still have no data with which to assess the magnitude and quality of actual concentrations measured at the Sumas and Burnaby terminals.

Following from this, one of the Information Requests inquired about the monitoring of post-construction emissions. It was stated that the Automated Monitoring Systems described above are installed but undergoing calibration. The response then stated, “Since there are no substantial criteria air contaminant (CAC) emissions at Burnaby or Sumas Terminals, monitoring of CACs on-site is not required.” This statement is perplexing as it appears to contradict the modeling results presented in Table 5.21 of The Report, which indicate clear enhancements of CACs (PM2.5, PM10, SO2, NOx) at the Burnaby and Westridge Terminals relative to the background concentrations shown in Table 3.30. In addition, this statement cannot be verified given that the instruments are currently undergoing calibration. It also assumes that emissions are constant with time rather than allowing for the possibility that emissions may change in the future, which requires ongoing monitoring. Further, the location of the monitors relative to the prevailing wind direction was not provided. The only way to determine whether there are CAC emissions at the Terminals is with credible, high-quality monitoring.

3.2.6 Summary. Overall it was not demonstrated that the air quality measurements are sufficient. The accuracy was not shown, the calibration procedures and standards were not described in detail, and the results of audits were not provided. Therefore the basic quality of the measurements, the calibration scale to which they are traceable, and the results of any third-party audits are still unclear. This is very fundamental data that is needed to assess the air quality data, and it still has not been provided. The measurement precisions that were provided are in some cases surprisingly large and are not sufficient to measure the full range of concentrations that are likely to be encountered during Project operations (from low background levels to high plume concentrations).

3.3 Modeling quality

3.3.1 CALMET/CALPUFF modeling. As stated in Section 3.4.4 of The Report, CALMET/CALPUFF modeling was used to estimate ambient concentrations of CACs and VOCs in the Air Quality regional study area, due to both existing and projected future emissions from the Trans Mountain Terminals (CALMET is the California Meteorological Model and CALPUFF is the
California Puff Model). The Information Requests related to the modeling effort were seeking an acknowledgment that the model input and therefore output is subject to uncertainty, which needs to be quantified. However the answers did not attempt to quantify this uncertainty.

3.3.2 Spatial resolution. According to the developers of the CALPUFF model, “The EPA has proposed the use of CALPUFF for applications involving long-range transport, which is typically defined as transport over distances beyond 50 km. Therefore, the use of CALPUFF for EPA regulatory applications involving transport distances of less than 50 km requires approval by the relevant reviewing authorities.” (SRC, 2014). (The EPA is the U.S. Environmental Protection Agency.) The Information Requests sought justification for use of the CALMET/CALPUFF dispersion modeling system for the less than 50 km transport distance considered in The Report, in other words the 24 x 24 km² CALMET and CALPUFF domains (Sections 3.4.4.1 and 3.4.4.2 of The Report).

While a general justification for using the CALMET/CALUFF dispersion modeling system was provided in the response to the Information Request, an answer was not provided as to how appropriate the model is for the shorter transport distances considered here. Further it is unknown whether these smaller modeling domains were known to the relevant authorities (Metro Vancouver and the British Columbia Ministry of Environment) when they provided their approval for the model. Because the question remains unanswered, the quantitative impact of the smaller domain on the modeling results remains unknown.

3.3.3 Sources of uncertainty. Similarly the Information Requests asked that the uncertainty of results from the CALMET/CALPUFF model, which were discussed in Appendix B of The Report, be described. The response listed several potential sources of uncertainty, including:

(1) The accuracy of activity data and emission factors used to estimate emissions;

(2) The accuracy and representativeness of the meteorological data used to initialize the CALMET model;

(3) The representativeness of the ambient data used to represent background concentrations;

(4) The potential error associated with omitting some sources; and so forth.

However, these uncertainties still were not quantified. Instead the response stated, “These uncertainties were managed through the use of a number of conservative assumptions in the emission estimation and dispersion modelling.” The meaning of this statement is unclear. **Uncertainties cannot be “managed”; they need to be quantified.**

By realistically quantifying uncertainties, one can then estimate the accuracy of the CALMET/CALPUFF output and so apply an appropriate uncertainty (error bar) to the model results. The response stated, “Models are reasonable and reliable in estimating the maximum concentrations occurring on an average basis. That is, the maximum predicted concentration that may occur at some time somewhere within the model domain, as opposed to the exact concentration at a point at a given time, will usually be within the ±10% to ±40% range (United States Environmental Protection Agency 2005) of the observed maximum concentration.” The
meaning of this statement, or how it applies to the concentrations cited in The Report, is not clear. What is relevant is how well the model is performing in the particular case of the Trans Mountain Terminals. *The results of the CALMET/CALPUFF model should have been critically assessed to see if they were reasonable and credible, with appropriate error bars included.*

The response also stated, “Typically, a model is viewed as replicating dispersion processes if it can predict within a factor of two, and if it can replicate the temporal and meteorological variations associated with monitoring data. Model predictions at a specific site and for a specific hour, however, may correlate poorly with the associated observations due to the above-indicated uncertainties. For example, an uncertainty of 5 to 10 degrees in the measured wind direction can result in concentration errors of 20% to 70% for an individual event (United States Environmental Protection Agency 2005).” The response did not provide a clear quantitative answer as to the overall uncertainty of the model output. However, the above responses suggest that the overall error is likely to be reasonably large. Given this, it is unclear why no attempt was made to quantify this uncertainty.

### 3.3.4 Speciation profiles

The Report states that emissions of VOCs and other compounds were estimated by applying speciation profiles (for example of Cold Lake Blend) to estimated emissions of total organic compounds (TOCs) (Section 3.4.2.2). The Information Requests asked about the expected uncertainty in these profiles.

While it was recognized that the speciation profiles were based on limited sampling data and their uncertainty cannot readily be quantified, the variation in product composition for Peace River Sour was estimated based on information from Crude Quality Inc. The standard deviation of the VOC content in Peace River Sour ranged from 11.5% to 43% between 2005 and 2014. In general however, because the uncertainty in most of the profiles could not be quantified, it is still not known how this impacts the reliability of emission estimates derived from the speciation profiles. In general very few error bars were presented in The Application. While the existence of uncertainty was sometimes recognized, not enough effort was made to quantify the uncertainties and understand how they impact the reliability of subsequent calculations.

### 3.3.5 Background concentrations

The background concentrations used in the model contain large uncertainties that still have not been quantified. According to Section 3.4.4.4 of The Report, “Typically a single value is chosen as background, which is assumed to apply for every hour of the model period and for every location within the model grid.” Clearly this is not realistic, as shown in Section 2.2 in which the temporal and spatial variations of contaminants of potential concern are outlined. The shorter a compound’s atmospheric lifetime, the greater its variability in the atmosphere, so assuming a single background value for all times and locations introduces a large uncertainty that has not been quantified, and it is unclear how meaningful any of the background concentrations are. *Even though concentrations with high uncertainty were used in the model, the uncertainty associated with this decision and its impact on the model results was not clearly stated and quantified.*

The Information Requests asked for the uncertainties involved in determining background concentrations, but again this was not quantified. The following response was given: “One station was selected to represent overall background in each of the Air Quality
Regional Study Areas (RSAs). Using one station to represent a large area is a limitation of the modelling since in reality there may be spatial variation in ambient air quality concentrations.” The use of the word “may” is concerning since spatial variation in trace gas concentrations is already well established in the atmospheric science literature. Using a single concentration introduces a clear uncertainty, which was not addressed.

3.3.5.1 98th percentile background values. Other statements in Section 3.4.4.4 of The Report and the Information Request responses were very perplexing. For example, Section 3.4.4.4 states, “Background concentrations for short-term averaging periods (1-hour to 24-hour) were based on the 90th percentiles of observations for the Edmonton Terminal RSA and the 98th percentiles of observations for the RSAs in BC. Annual average background concentrations were based on the 50th percentiles of observations.” This does not make sense; the average short-term background is not the same as the maximum or near-maximum value. Effectively, it appears that an unrealistically high background concentration was input into the model, which would explain why many of the modeled background concentrations are too high (Section 3.3.5.3).

The reason for selecting 90th and 98th percentile data to represent background is not clear. The response states, “This methodology is very conservative because it assumes that the maximum predicted concentration and the background concentration will occur at the same time even though, by definition, concentrations equal to or greater than the 98th and 90th percentile occur only 2% and 10% of the time, respectively.” This methodology does not make sense since it effectively equates the background and maximum concentrations, and therefore deliberately inputs an incorrect and artificially high background into the model. In order to understand the uncertainty of this decision, The Report would have needed to show the actual 3-year data sets from the relevant observing stations (Edmonton Terminal, Burnaby Kensington Park, etc.) and show how the 90th and 98th percentile concentrations compare to the 2nd and 10th percentiles, the 50th percentiles, etc. The decision to use 90th and 98th percentile data as background values is not realistic and undermines the credibility of the model results.

A quick search of Burnaby Kensington Park station data shows 1-hr concentrations of Contaminants of Potential Concern (COPCs) varying considerably, even over a 7-day period (Figure 1). For example, ground-level O₃ ranged from 5-43 ppb and PM₁₅ ranged from 0-26 μg m⁻³. The variations of COPCs over longer seasonal timescales were discussed in Section 2.2. For example background CO levels vary by a factor of 2 from winter to summer at Vancouver latitudes. Therefore choosing 90th and 98th percentile data effectively weights the background concentrations towards higher wintertime values that are not representative of an entire year.

One of the concerns with artificially high backgrounds is that it makes The Project’s contribution to ambient concentrations appear relatively smaller than it actually is. As an example, a background SO₂ concentration of 10 ppb was used in the model, and an updated version of the model estimated that the Westridge Terminal will contribute an additional 8 ppb (see Section 3.3.7). In this case, background and Project each contribute roughly 1/2 to total ambient SO₂ concentrations. Had a credible background SO₂ value of 1 ppb been used (Section 3.3.6.3), then the background’s contribution to ambient levels decreases to 1/9 and The Project’s contribution increases to 8/9. For these reasons it is important to correctly evaluate the background concentration and realistically determine its uncertainty, yet this was not done.
Figure 1. Screenshot of 1-hour air quality data at the Burnaby-Kensington Park air quality monitoring station, displayed over a 7-day period. Data were accessed on April 24, 2015 from http://gis.metrovancouver.org/airmap/.

The background concentrations were also cited to an unrealistic number of significant figures, which implies a false level of precision rather than the large uncertainty that these numbers actually carry. For example, an ambient background CO concentration of 605.0 μg m$^{-3}$ (528 ppb) was provided for the Westridge Marine Terminal, or four significant figures (Table 3.30 of The Report or Table 26 of Technical Update No. 2 of The Report). This is discussed further below in Section 3.3.5.5.

3.3.5.2 Historical data. As a second example of a choice that introduces uncertainty into the model, historical data were used to calculate background levels that were applied to the modeled concentrations for the future operations (Section 3.4.4.4 of The Report). Data from 2009-2011 were used to determine background for CACs and H$_2$S, and data from 2007-2011 were used for BTEX. The Information Request response states, “Multiple years of data were considered because there can be seasonal and annual differences in ambient concentrations.”

While using historical data is reasonable, the last sentence is concerning because on the one hand it recognizes the reality of seasonal and annual variations, but on the other hand does not attempt to quantify the uncertainty associated with this type of bulk averaging. Likewise, other statements in The Report recognize long-term improvements in air quality along the pipeline corridor (Section 4.1.1.7) but do not carry this information forward into understanding the impact on model performance. For example, because CO$_2$ concentrations continue to increase with time, data from 2009-2011 will not accurately represent conditions in 2015 or 2016, just on the basis of long-term CO$_2$ growth. Some of these trends, such as the decline in
CO and NO\textsubscript{2} levels, are clearly evident in long-term time series shown in The Report (Figures 4.35 and 4.36). As shown in Section 2.2, \textit{the temporal and spatial variations of many of the contaminants of potential concern are known, yet no attempt was made to quantify the effects of these variations and trends on the model performance.}

\textbf{3.3.5.3 Background variations.} Following from the above, background trace gas concentrations vary with time of day (typically higher at night than in the day) and with season (typically higher in winter than in summer). This is especially the case for shorter-lived compounds such as benzene, toluene and ethylbenzene that have strong diurnal variations as well as seasonal variations (e.g., Ho et al., 2004; Laowagul and Yoshizumi, 2009). Further, some of the compounds being considered have interannual variations and/or long-term trends (Section 2.2). It is unclear why efforts were not made to understand the changes in background concentrations in time and space, and to place appropriate uncertainties on the background measurements to reflect this. \textbf{Table 3} provides a summary of background concentrations used in The Report, but none of these numbers were given an uncertainty or compared with the literature to see if they are reasonable, and some were presented to an unrealistic number of significant figures (4 in some cases, or 0.1 \textmu g/m\textsuperscript{3}). \textit{Overall, assuming a static background concentration is not realistic and the uncertainties associated with this assumption need to be quantified for each pollutant.} Following from this, it is important to accurately monitor background concentrations, including their variations with time, so that they can be correctly separated from additional emissions caused by The Project.

\textbf{3.3.5.4 Averaging.} As stated in Section 3.3.5.2, the background values were based on 3 years of data for CACs and H\textsubscript{2}S, and 5 years in the case of BTEX. Therefore the average of 1-hour values over a 3-year period should be the same as the average of annual averages of over the same 3-year period. However the 1-hr and annual values differ, apparently because the 98\textsuperscript{th} percentile data were used for 1-hr values versus 50\textsuperscript{th} percentile data for annual values. In the case of BTEX, the 1-hr VOC concentrations were calculated as 2.5 times the background 24-hour concentration (Table 3.30 of The Report). This does not make sense. \textit{The average of 24 one-hour values should be the same as one 24-hour average.}

\textbf{3.3.5.5 Significant figures.} The background pollutant concentrations used in the CALMET/CALPUFF model have considerable uncertainty (see above) yet were reported to an unrealistic number of significant figures (Table 3.30 of The Report, summarized in \textbf{Table 3}). For example, if the concentration of CO is known to vary by a factor of two based on seasonality alone, and the data shown in Table 3.30 represent a 3-year average, this concentration cannot realistically be reported to four significant figures (e.g., 605.0 \textmu g m\textsuperscript{-3}).

An analogy is saying that the 1-hr temperature in Vancouver based on 3 years of data is 15.12 °C. While this may be true, it does not reflect that the temperature is closer to say 5 °C in winter and 25 °C in summer. Instead, because 15.12 °C contains too many significant figures and has no error bars, it incorrectly suggests that the temperature in Vancouver varies over a very narrow range on the order of 0.01 °C. In other words, this value is fairly meaningless in comparison to an actual measured temperature on a given day, say 28 °C. By contrast, a value of 15 ± 10 °C would have given a better indication of temperature variations in Vancouver over
a year, and provided some context for a value of 28 °C (i.e., that it is reasonable but relatively high). Likewise, the concentrations in Table 3.30 of The Report fail to indicate the range of background concentrations likely to be encountered over a 3-year period. Instead, time-varying background concentrations should have been presented so that exceedances relative to background can be correctly assessed in any season. Likewise, it is reasonable to assume that Project emissions will also vary with time, which does not appear to have been addressed.

Table 3. Selected background concentrations used in the Air Quality Assessment (μg m⁻³), from Table 3.30 of The Report. ‘Bur./Wes.’ = ‘Burnaby and Westridge Marine Terminals’.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging Period</th>
<th>Sumas (μg m⁻³)</th>
<th>Sumas (ppb)</th>
<th>Bur./Wes. (μg m⁻³)</th>
<th>Bur./Wes. (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1-hr</td>
<td>757.9</td>
<td>662</td>
<td>605.0</td>
<td>528</td>
</tr>
<tr>
<td>NOₓ</td>
<td>1-hr</td>
<td>104.2</td>
<td>--</td>
<td>110.5</td>
<td>--</td>
</tr>
<tr>
<td>SO₂</td>
<td>1-hr</td>
<td>7.0</td>
<td>2.7</td>
<td>26.3</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>1.1</td>
<td>0.4</td>
<td>2.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Benzene</td>
<td>1-hr</td>
<td>2.9</td>
<td>0.9</td>
<td>5.1</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>0.4</td>
<td>0.1</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Toluene</td>
<td>1-hr</td>
<td>15.2</td>
<td>4.0</td>
<td>14.3</td>
<td>3.8</td>
</tr>
<tr>
<td></td>
<td>24-hr</td>
<td>6.1</td>
<td>1.6</td>
<td>5.7</td>
<td>1.5</td>
</tr>
</tbody>
</table>

3.3.6 Literature comparison. As stated above in Section 3.3.5.1, the short-term (1-hr to 24-hr) background values used in the model were based on 98th percentile values in B.C. and as a result are unrealistically high, yet no attempt was made to compare these estimates to values from the literature to verify whether they were reasonable. Four examples are given below. Overall, following protocols or guidelines does not guarantee good results, and each result needs to be critically evaluated to see if it’s realistic, has a reasonable number of significant figures, and is given an appropriate uncertainty. Similar comments apply to Supplemental Report 2.

3.3.6.1 Benzene. The 1-hour background benzene value of 3.2 μg/m³ in Sumas and 5.1 μg/m³ in Burnaby and Westridge is the same as has been reported during 1-hour roadside sampling in a polluted urban environment in Hong Kong (Ho et al., 2004). Therefore from a quick literature check, these concentrations appear to be implausibly high. Our group’s seasonal measurements of background benzene concentrations on the Pacific Coast of the Olympic Peninsula (about 300 km south of Vancouver) from 2009-2012 suggest that the background benzene value is likely closer to 0.05-0.20 μg/m³ in summer and 0.25-0.50 μg/m³ in winter (unpublished data based on 1-minute samples), in other words similar to the annual benzene value of 0.6 μg/m³ that was cited for Burnaby/Westridge based on 50th percentile data (Table 3.30 of The Report). In other words, the 1-hr value of 5.1 μg/m³ is likely a factor of 10–100 too high, depending on
the season, and instead likely should be 0.05-0.50 µg/m$^3$ over the course of a year. **In the case of an exceedance to 10 µg/m$^3$, it is critical to know whether the background is 5 µg/m$^3$ (an excess of 5 µg/m$^3$) or 0.5 µg/m$^3$ (an excess of 9.5 µg/m$^3$).**

3.3.6.2 **Carbon monoxide.** The background CO concentrations in Table 3.30 are given to an implausible number of significant figures and are also too high. As stated above in Section 2.2, clean background CO concentrations at Vancouver latitudes vary from a summer minimum of 75 ppb (86 µg m$^{-3}$) to a winter maximum of 140 ppb (160 µg m$^{-3}$). That is the CO background varies by a factor of 2 based on seasonality alone, and the 1-hr values of 605-758 µg m$^{-3}$ are a factor of 4-10 too high. In other words, instead of the Burnaby/Westridge value of 605.0 µg m$^{-3}$, an appropriate background is likely closer to 100-200 µg/m$^3$, or 3-6 times lower.

3.3.6.3 **Sulphur dioxide.** As a third example, the SO$_2$ background of 26.3 µg m$^{-3}$ (10 ppb) is implausibly high. The stated background of 10 ppb would be high even for a city like Mexico City, which is heavily impacted by both volcanic and industrial SO$_2$ sources (Section 3.2.4.1). Because SO$_2$ is short-lived (and therefore does not accumulate in the atmosphere), its summertime background is likely closer to background levels of 0.27 µg m$^{-3}$ (0.10 ppb) that were measured in Fort McMurray region (Section 3.2.4.1). A quick search of the Burnaby Kensington Park station reported a 1-hr SO$_2$ concentration of 1.0 ppb in April 2015 (10 times lower than the value in Table 3.30), though the accuracy and precision of this measurement is not known.

3.3.6.4 **Toluene.** Toluene is very short-lived in the atmosphere, with a lifetime of about 2 days. Therefore, like SO$_2$, its concentration does not accumulate away from point sources. The reported toluene background of 14.34 µg m$^{-3}$ (3.8 ppb) is half that reported in Kowloon, an urban area of Hong Kong (Ho et al., 2003). This is remarkable because Hong Kong is a toluene-rich city where, surprisingly, toluene is the most abundant non-methane hydrocarbon (Guo et al., 2007). It is extremely unlikely that background levels in Burnaby are approaching those in Hong Kong, a city of 7 million people flanked by Guangdong Province with a population of 106 million. Between 2009-2012 our group measured background toluene concentrations of 0.015-0.42 µg m$^{-3}$ at Ocean Shores, Washington State (lower concentrations in summer, higher concentrations in winter). These values are 34-960 times lower than the background toluene level cited in Table 3.30, though credible measurements in Burnaby/Vancouver would be the best way to determine local toluene levels and how they vary with time. Overall the 1-hr toluene background in Table 3.30 is implausibly high, and also has too many significant figures. **As stated elsewhere, the problem with artificially high background values is that they make it seem as though project emissions are small compared to background,** as discussed below. The same issue applies in Tables throughout Supplemental Report 2.

**3.3.7 Impact of unrealistic background estimates.** The decision to apply artificially high (maximum) background concentrations makes The Project’s contribution to ambient concentrations appear relatively smaller than it actually is. As examples, Tables 4.43 and 5.21 of The Report show The Project’s impact on trace gas concentrations for Existing and Existing +
Project conditions at the Burnaby and Westridge Marine Terminals, with updated results for Westridge Terminal in Table 26 of Filing A4A4E3. Selected results are given below in Table 4.

3.3.7.1 Background, Existing and Project concentrations. Several features stand out in Table 4. First, error bars were not given for any of the scenarios. For example it is not realistic to predict that NO\textsubscript{x} levels will change by 1 μg m\textsuperscript{-3} between the original Existing and Application cases, from 2413 to 2414 μg m\textsuperscript{-3}, or that toluene levels will change by exactly 1.0 μg m\textsuperscript{-3} in the updated case, from 135.0 to 136.0 μg m\textsuperscript{-3}. Clearly the uncertainty in these estimates is much larger than 1 μg m\textsuperscript{-3}. For example, in the case of NO\textsubscript{x}, the updated values for Westridge Terminal have changed from the original values by 40-85%. This underscores the very high uncertainty in these predictions depending on the model input, yet error bars still were not included. In addition, the variations in background, Existing, and Application concentrations with time have not been quantified or addressed, so it is not known how these changing conditions will combine to create different scenarios.

Further, the model predictions were given up to five significant figures, which is not realistic and imparts false precision. In the case of NO\textsubscript{x}, the significant figures on the original estimates suggest a precision of 1 μg m\textsuperscript{-3} (1 in 2414, or 0.04%) and the significant figures on the updates suggest a precision of 0.1 μg m\textsuperscript{-3} (0.1 in 1491.0, or 0.007%). Much larger uncertainties in the model predictions clearly exist, yet no attempt was made to acknowledge or quantify these errors. Therefore the model results cannot reasonably be viewed with confidence.

Table 4. Combined modeled concentrations at Burnaby (‘Bur.’) and Westridge (‘Wes.’) Marine Terminals for Existing and Project (Application) conditions, including background, based on Tables 3.30, 4.43 and 5.21 of The Report (μg m\textsuperscript{-3}). Updated Existing and Application values for Westridge Marine Terminal only were provided in Table 26 of Filing A4A4E3.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Averaging Period</th>
<th>Bur./Wes. Background (Table 3.30) (μg m\textsuperscript{-3})</th>
<th>Bur./Wes. Existing (Table 4.43) (μg m\textsuperscript{-3})</th>
<th>Bur./Wes. Application (Table 5.21) (μg m\textsuperscript{-3})</th>
<th>Wes. Existing (Table 26) (μg m\textsuperscript{-3})</th>
<th>Wes. Application (Table 26) (μg m\textsuperscript{-3})</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1-hr</td>
<td>605.0</td>
<td>780</td>
<td>780</td>
<td>649.0</td>
<td>1076.0</td>
</tr>
<tr>
<td>NO\textsubscript{x}</td>
<td>1-hr</td>
<td>110.5</td>
<td>2413</td>
<td>2414</td>
<td>345.0</td>
<td>1491.0</td>
</tr>
<tr>
<td></td>
<td>Annual</td>
<td>26.7</td>
<td>29.2</td>
<td>39.8</td>
<td>31.1</td>
<td>45.1</td>
</tr>
<tr>
<td>SO\textsubscript{2}</td>
<td>1-hr</td>
<td>26.3</td>
<td>73.2</td>
<td>73.2</td>
<td>51.1</td>
<td>48.5</td>
</tr>
<tr>
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<td>3.0</td>
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<td>3.2</td>
</tr>
<tr>
<td>Benzene</td>
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<td></td>
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<td>40.6</td>
<td>40.7</td>
<td>42.7</td>
</tr>
</tbody>
</table>
3.3.7.2 Case study: SO2. Bearing the above in mind, the cited background values are relevant for understanding the relative impact of The Project. In the case of SO2, the Existing and Project concentrations are about 3× the cited background of 10 ppb in the original case, and 2× in the updated case. However, as stated in Section 3.3.5.1, this background value is implausibly high. At the time of writing, SO2 levels reported at the Burnaby Kensington Park station are 1.0-1.1 ppb, though the accuracy/precision of these measurements is not known (http://gis.metrovancouver.org/airmap/). Notwithstanding, if a credible background SO2 value is 1 ppb rather than 10 ppb, then the contribution of Existing and Project operations to ambient SO2 concentrations in the updated case increases from 2× background to approximately 9× background. This is why it is important to provide both time-varying background concentrations that cover the range of 1-hr values expected in a given year, as well as time-varying Existing and Project concentrations that accurately capture expected variations in Project emissions. It will also be important to credibly monitor these concentrations.

Further, Section 4.3.1.4 of The Report states the following in regards to modeled SO2 concentrations: “The maximum predicted 24-hour concentration is greater than the proposed Metro Vancouver objective of 20 μg m⁻³, (i.e., the WHO guideline), only when background is included. A large fraction of this maximum concentration is from the background.” There are two concerning statements in these sentences. First, the statement “only when background is included” is perplexing, because background concentrations always exist and instead it is the contribution from The Project that pushes the SO2 concentration above the objective in this scenario. Second, the statement that a “large fraction of this maximum concentration is from the background” underscores why it is important to correctly assign the background concentration and understand its full range over time (Section 3.3.5.1). Had a smaller background been assigned, the overall concentration would have been lower but The Project’s contribution to SO2 levels would have been relatively higher. These results show the limitations of modeling that was done to estimate expected impacts caused by Existing and Project conditions. Credible measurements will be needed to determine the actual impact of Project operations on concentrations of SO2 (and other compounds) relative to background, taking into account variations in background and Project concentrations across all seasons.

Similar comments apply to Table 4.4 of Supplemental Report 2, in which background values of benzene, CO and so forth are too high so that too much of the maximum predicted concentrations for Project-related traffic are attributable to background. For example the 1-hour base case for toluene (2.66 μg m⁻³ without background) is small compared to the cited background of 14.34 μg m⁻³, but is large compared to more realistic background values of 0.015-0.42 μg m⁻³ (Section 3.3.6.4).

3.4 Transparency

3.4.1 Overview. Although detailed and specific data were requested in the Information Requests, in many cases the questions were insufficiently answered or else not answered, or the response pointed to documents that did not exist or did not contain the requested answers. Several examples of this were given in Section 3.2. For example, even though the Application was filed in December 2013 and two rounds of Information Requests have now been
completed, and at the time of writing (May 2015) the following basic air quality information still has not been provided:

(1) What is the quality of the air quality measurements? Why were basic measurement specifications such as accuracy, detection limits, calibration scales, and audit results not provided in response to the Information Requests?

(2) When will fence line monitoring data at Sumas Tank Farm (since 2012) and Burnaby Terminal (since 2013) become available? How do these data compare to modeled results?

(3) Will speciated VOC measurements be available during normal operations and during a spill? If so, what is the quality of these measurements, and will they be sufficient to measure the wide range of concentrations that is expected (from low background concentrations to high plume values)?

(4) How will it be determined that concentrations have returned to background levels following a spill, given that the precision of some cited measurements was insufficient to distinguish background concentrations from instrument noise?

(5) Why were modeled results not compared with literature data to check whether they were reasonable?

(6) Why weren’t overall uncertainties provided for the modeled data, as requested in the Information Requests?

(7) Why were modeled data provided to an unrealistic number of significant figures?

(8) What is the impact of citing unrealistically high background values?

The lack of direct answers to fundamental questions creates a lack of transparency in the air quality monitoring plan and oil spill response. Based on the limited information that was provided, it seems unlikely that the basic air quality measurements during normal Project operations and following a spill will be sufficient to provide credible concentrations across the range of values that are likely (ppt to tens or hundreds of ppb). It was also not shown that any further results obtained via models will be critically assessed to determine whether or not they are credible. Additional examples of lack of transparency are given below.

### 3.4.2 Air monitoring plan.

The Application states that, in the event of a spill, a detailed air monitoring plan is applied from the Emergency Response Plan (Section 4.4). The Information Request asked for a copy of the detailed air monitoring plan, and whether independent scientists would be given access to a spill site.

The response stated that air monitoring equipment is dispatched to the area of an incident immediately, although from Section 3.2 the quality of such equipment or its ability to credibly measure trace gases of interest across a range of concentrations still has not been demonstrated. The response also stated that real-time continuous ambient fence line monitors measure H₂S, VOC, SO₂ and weather parameters at both the Sumas Tank Farm and the Burnaby Terminal. However, from Section 3.2, the precision of several measurements was insufficient to resolve even broad features of the air pollutants, including background concentrations.
The response further stated that, “All data, real time and historic, can be viewed and downloaded from a secured website.” and the data from the Sumas Tank Farm and Burnaby Terminal are available from 2012 and 2013, respectively. However, when we asked for these data in a different Information Request, the response was, “The units are still going through a calibration process on some of the sensors. For this reason, Kinder Morgan Inc. is not able to commit at this point to providing data from the monitoring units.” While understanding that calibration is an on-going process, it is noteworthy that no data are available for being able to assess whether the reported concentrations are reasonable or match the modeled data. **Therefore there is still no basis for being able to verify whether the proposed measurements are sufficient to credibly measure background and plume concentrations in the case of a spill.**

### 3.4.3 Oil spill response

Because of this uncertainty, allowing independent scientists access to the site would provide greater transparency and credibility to the spill response. The response to whether independent scientists would be allowed site access following a spill was, “The safety of the responders and the public are very important during an emergency event, and site access is controlled and limited to those that are involved in the response efforts ... KMC maintains a network of response resources which includes scientific professionals from multiple disciplines.” The names of the senior scientific professionals, their affiliations and their accreditations were not provided, and it is still not known who these scientists are.

Further, Kinder Morgan Canada is a shareholder and sits on the Board of Directors of the two main spill response organizations cited in the Application (Western Canada Marine Response Corporation, WCMRC and Western Canada Spill Services, WCSS). The broad mandates of these response organizations are to mitigate the impact when an oil spill occurs via oil spill containment and recovery (wcmrc.com, wcss.ab.ca). However our Information Request was not about oil spill response *per se*, but about the ability of third-party scientists to access the spill site in order to take independent measurements of air quality, water quality, etc. For example following the Deepwater Horizon oil spill, dozens of independent scientists from multiple universities and government agencies accessed the spill site via boat and aircraft, collected air samples, performed transport modeling, and published the results in peer-reviewed journals (e.g., de Gouw *et al.*, 2011; Middlebrook *et al.*, 2011; Neuman *et al.*, 2012; Ryerson *et al.*, 2011; 2012). This multi-agency cooperation was essential for a comprehensive understanding of the air quality implications of the spill. **It is still not clear whether independent scientists will be given access to a spill site so that similarly comprehensive, high-quality and transparent monitoring and analysis can be performed.**

### 3.4.4 Spill scenarios

The spill scenarios in the Ecological Risk Assessment (ERA) consider only Cold Lake Winter Blend, without justifying it as a worst-case or typical product from among the many products that may be carried on the pipeline. The Information Request asked for spill scenarios for each type of product to be carried on the pipeline. Rather than providing a direct reply, the response referred us to the response to Province BC IR No. 1.1.26b for rationale as to why an assessment of potential human health effects associated with other products is not being considered.

In several other questions we were referred to documents that did not provide the answers we were seeking (see Section 3.2). Here we were referred to a document that does not
appear to exist. In the Trans Mountain filings (http://application.transmountain.com/facilities-application) there is a response to Province BC IR No. 1.1.26a (https://docs.neb-one.gc.ca/ll-eng/lisapi.dll?func=ll&objId=2482815&objAction=browse&viewType=1) but not to an IR 1.1.26b. Therefore our question remains unanswered. If 1.1.26b is a typo, and 1.1.26a is the correct filing number, we note that 1.1.26a exists in three files together totaling 374 pages. In other words, rather than providing us with a direct answer it appears that we are being asked to search through 374 pages to find the requested answer. **We cite this as an example of how many of the answers given by Trans Mountain in response to the Information Requests failed to materially respond to the question.** Instead these types of responses sent us to extensive documents, some of which did not exist and some of which did not contain the specific answers that we were seeking.

**3.4.5 Fugitive emissions.** In The Report Cold Lake Blend was used to represent heavy crude product since it “accounted for over 60% of heavy crude throughput in 2011 and 2012 and is expected to be one of the major products transported in the proposed pipeline” (Section 3.4.2.2 of The Report). The Information Request sought to understand the full range in composition of heavy crude, and how emissions will change for the most volatile heavy crude mix, the light and synthetic crudes, as opposed to the typical crude.

The response stated that varieties of crude oil other than Cold Lake Winter Blend are currently being evaluated by Trans Mountain and the results of the updated dispersion modelling will be filed with the NEB as Technical Update No. 1 in Q3 2014. However Section 3.4.1.4 of A3Y1G0, Trans Mountain Pipeline ULC Marine Air Quality Greenhouse Gas Marine Transportation Supplemental Report, filed in June 2014, refers the reader to Volume 5C of the Air Quality and Greenhouse Gas Technical Report for the rationale for selecting Cold Lake Blend to represent heavy crude and Peace River Sour to represent light/synthetic crude. In Section 3.4.2.4 of Supplemental Report 2, Low TAN Dilbit is used to represent a typical heavy crude oil, with rationale given in Filing ID A4A4E3. However Filing A4A4E3 only states, “The air quality assessment now uses six representative products: High TAN¹ Dilbit and Low TAN Dilbit) (sic) to represent super heavy grades, High TAN Synbit/Dilsynbit to represent heavy grades, light sour and synthetic/sweet grades, and ethanol blended gasoline (to represent iso-octane) to represent refined products. These products were selected to be conservatively representative for each listed category based on their high vapor pressure and BTEX, H₂S and mercaptans contents.” In other words there was no quantitative information about the specific VOC content of these products or the volatility of individual components. This is another example of a time-consuming document search, with the original question remaining unanswered.
4. Assessment of oil spill impacts on air quality

4.1 Air quality impacts

The Living Oceans Society requested that I provide an opinion as to the air quality impacts likely to arise from:

(1) Fugitive emissions from normal operations of the pipeline, terminal and tankers, with particular emphasis on Burrard Inlet/Indian Arm;

(2) A pipeline rupture or release occurring along the pipeline route through the Fraser Valley and Metro Vancouver;

(3) A rupture, release or spill occurring at the terminal; and

(4) A release or spill occurring on the tanker route within Burrard Inlet and Juan de Fuca/Haro Straits.

4.2 Normal operations

4.2.1 Effects on air quality. It is difficult to assess fugitive emissions that are expected from normal operations of the pipeline, terminal and tankers, in part because the baseline scenarios that were provided in the Facilities Application were not realistic. For example cited background concentrations were often unrealistically high (Section 3.3.5), which makes impacts from normal operations appear lower than if a realistic (lower) background concentration had been assigned. Further, based on the air quality monitoring instrument specifications that were provided, for many pollutants the existing equipment is not sensitive enough to distinguish background concentrations and normal seasonal variations from additional emissions resulting from the Project (Section 3.2.4).

4.2.2 Third-party monitoring. It is also worth noting that, for better or for worse, local communities are often distrustful of air quality information that is provided by the same organization that is responsible for creating the pollution (i.e., industry self-monitoring). *This underscores the need for credible, transparent monitoring of emissions, both from routine operations and from any ruptures or spills that may occur as a result of The Project.*

4.3 Releases along the pipeline route

4.3.1 Pipeline spills in Canada. The National Energy Board (NEB) has recently released an interactive map of oil spills and other incidents along pipeline routes in Canada (NEB, 2015). Note that this map only includes incidents that occurred on NEB regulated pipelines. For example it does not include the April 29, 2011 oil spill in Little Buffalo, Alberta that resulted from a pipeline rupture, released 28,000 barrels of diluted bitumen, and was Alberta’s largest oil spill in 36 years.
The NEB map cites 692 incidents (spills, fires, etc.) from 2008 to the present, though details such as substance and volume released are not always available in the incident data. The map includes 11 incidents involving Trans Mountain Pipeline in Alberta and British Columbia, including 6 releases of sweet crude oil and one release of waste oil, with reported spill volumes ranging from 1.4 to 305 m³ (8.8 to 1918 barrels). Two of the sweet crude oil releases were classified as “significant”.

4.3.2 Effects on air quality. The emission and fate of compounds released following a spill depend on a number of factors including size and composition of the spill, environmental conditions, effectiveness of the spill response, and so forth. Ground-level hydrocarbon concentrations would be highest in the immediate vicinity of an oil spill and decline with time, but elevated concentrations could continue for days or weeks (Section 6.2.1 of The Application). Hypothetical pipeline spill scenarios were presented in Section 7 of The Application. The Application’s highest Credible Worst Case spill volume was given as 2,700 m³ (Table 7.1.1), or about 17,000 barrels, and three other pipeline spill scenarios were also presented. However, apart from discussing the dissolution of BTEX and other light hydrocarbons into the water column that is assumed in the scenario, The Application did not discuss air quality impacts in terms of the specific composition and concentrations of substances likely to be released. This, together with a lack of third-party literature data collected after pipeline ruptures (Section 4.3.3), makes it difficult to realistically assess the likely air quality impacts in the days and weeks immediately following a pipeline spill.

In addition, while The Application presented an Ecological Risk Assessment addressing the worst case ecological consequences following a pipeline spill, it is noteworthy that it did not discuss any potential impacts on humans resulting from a pipeline spill. Even though population densities may be low along the pipeline route, impacted communities still need an effectively and timely response, the same as would be deployed in an urban center such as Burnaby.

4.3.3 Little Buffalo oil spill. The Little Buffalo oil spill would have provided a good opportunity for independent scientists to make credible measurements of VOCs released in the days and weeks following a major pipeline spill of diluted bitumen. Local residents experienced odours, headaches, dizziness and nausea on the day of the spill as well as several days later. I travelled to Little Buffalo three weeks after the spill (May 24-27, 2011), at which time residents were still reporting odours, especially in the pre-dawn hours. This is consistent with the accumulation of emitted trace gases overnight within the compressed nocturnal boundary layer. Despite being prepared to collect air samples, a film crew and I were not given access to the spill site due to safety concerns.

The events in Little Buffalo also showed a disconnect between the spill response and the experiences of local residents affected by the spill, in terms of accountability to the community and the slow flow of information to the community immediately following the spill. For example in the days following the spill there was disagreement between community leaders, who closed the local school because children were becoming sick from poor air quality, and the Energy Resources Conservation Board (ERCB), who did not believe that the symptoms were related to the spill (CBC, 2011). Relevant air quality monitoring in the community did not take
place when peak exposures were occurring, and the residents of Little Buffalo still do not know the composition and concentrations of gases to which they were exposed in the early days following the spill. This highlights the need for credible and timely responses to the needs and concerns of local communities in the hours and days immediately following a spill, even in remote areas where population densities are low and even if the connection between illness and spill emissions cannot be immediately verified.

4.3.4 Background concentration versus detection limit. The Application discusses the effects of an onshore pipeline spill in 2007, in which oil spilled into Burrard Inlet via storm drains (Section 6.2.4 of The Application). In this case, “Surface water samples were collected at several locations one and two weeks after the incident. All sample results were below detection limits for extractable petroleum hydrocarbons. ... The follow-up monitoring and assessment report concluded that oil concentrations in the water column likely peaked soon after the release, but decreased to background levels within days.” This example is used to make the point that the ability to determine whether a concentration has returned to background levels following a spill requires that the measurement is actually capable of detecting the background concentration. Without knowing what the detection limits on the PAH measurements were, and how this compared to actual background concentrations in the water column, it is not possible to know whether PAH levels actually reached background levels, or were just beyond the instrument’s capacity to measure low concentrations.

As a second example, in the case of the Deepwater Horizon oil spill, our group measured a maximum n-hexane concentration of 670 ppb two months after the rig explosion and 2 ppb three-and-a-half months after the explosion (two weeks after the spill was capped). By comparison the background n-hexane concentration was 0.008 ppb (detection limit of 0.003 ppb). If a less sensitive instrument had been used to measure n-hexane, say with a detection limit of 1 ppb, then the measurement would have fallen below the detection limit long before background concentrations were actually reached. In other words, a measurement below detection limit is not equivalent to a background concentration. This becomes important when the detection limit lies above the background concentration. Any instrumentation deployed for spill assessment must be capable of measuring not only peak (high) concentrations but also background (low) concentrations.

4.4 Release at the terminal

4.4.1 Westridge Marine Terminal. The Application presents a hypothetical scenario in which a spill at Westridge Marine Terminal reaches Burrard Inlet (Section 8 of The Application). In this scenario 160 m$^3$ (or 1006 barrels) is spilled during loading of a tanker, and 20% escapes the containment boom (61 m$^3$ or 384 barrels), which has a capacity of 1500 m$^3$ (Section 8.1). It was recognized that conditions during summer represent a seasonally worse time for a spill, because higher temperatures lead to increased dissolution into water and increased volatilization of hydrocarbons into air. In the hypothetical credible worst case scenario, most of the oil was predicted to appear as sheen after 24 hours, and oil was “totally gone” within 24 hours in some simulations. Elsewhere The Application suggests that, “Evaporation begins immediately upon release of the oil ... The lighter hydrocarbon components, containing from 1
to 12 carbon atoms (C₁-C₁₂), will generally evaporate within the first 12 hours of exposure. Some of the more toxic components of the oil (BTEX) fall into this range and therefore, the toxicity of the vapour plume dramatically reduces within a matter of hours.” (Section 5.2.1).

While we agree that hydrocarbon evaporation will be most acute immediately following the spill and will decrease with time, the above statements appear to be overly optimistic. For example, in the case of the Deepwater Horizon oil spill, to which we had full access, we continued to measure elevated trace gas concentrations (e.g., n-hexane, n-octane, cyclohexane, benzene) from August 1-5, two weeks after the spill was capped (Section 4.5.2). Therefore the statement that C₁-C₁₂ hydrocarbons will “generally evaporate” within the first 12 hours of exposure does not adequately recognize that elevated hydrocarbon levels can persist for weeks after a spill. Indeed, Section 6.2.1 of The Application recognizes that elevated hydrocarbon concentrations in air could continue for days or weeks depending on spill volume, oil characteristics, and spill environment. Because the effects of oil spills can persist for weeks, it cannot be assumed the evaporation of hydrocarbons following a spill will generally occur within the first 12 hours. Further, as noted above in Section 4.3.4, the instrumentation deployed to an oil spill must be able to actually measure background concentrations, and not assume that a measurement that falls below detection is equivalent to reaching background.

4.4.2 Effects on air quality. The Application presents mass balance comparisons for mitigated and unmitigated credible worst case spill scenarios (Table 8.2.1 of The Application). While Table 8.2.1 shows the importance of early mitigation in reducing the impact of the oil spill, specific data were not provided as to the expected composition and concentrations of released hydrocarbons. Therefore, as in the case of a pipeline rupture (Section 4.3 above) it is difficult to evaluate specific impacts on air quality resulting from a spill at the terminal. Crude oil is composed of light hydrocarbons (Tables 5.1.5 and 5.1.6 of The Application), and independent hydrocarbon measurements following the Deepwater Horizon oil spill suggest that dozens of VOCs will be released (Table 5). However, the Deepwater Horizon experience also shows that the exact composition and concentrations of substances emitted following a spill can only be accurately determined based on actual measurements (Section 4.5.2 below).

4.5 Release along the tanker route

4.5.1 Release to water. As noted in The Application, factors that influence the behaviour of oil spilled into water include spill size, air and water temperature, water salinity and flow, wind and wave energy, and so forth (Section 5.3.2 of The Application). Crude oils float on water until the oil densities change, and diluted bitumen may become suspended in the water column or sink.

Expansions to the Westridge Marine Terminal would include serving an estimated 37 vessels per month (34 tankers and 3 barges), compared to 8 currently (5 tankers and 3 barges) (http://www.transmountain.com/marine-plans). The proposed Aframax-class tankers (245 m) are the same as currently loaded at the Westridge terminal, and they have a capacity of about 750,000 barrels (http://maritime-connector.com/wiki/aframax). Therefore a release along the tanker route could range from a small spill to hundreds of thousands of barrels. For perspective, the Exxon Valdez oil spill in 1989 released at least 260,000 barrels of crude oil.

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The Application considers the impact of a hydrocarbon spill at the Westridge Marine Terminal on Burrard Inlet (Section 6.2.4), but does not specifically consider a release along the tanker route. However, the Deepwater Horizon oil spill and rig explosion was thoroughly sampled by third-party scientists, and applicable results from this work are discussed below in relation to possible releases by The Project along the tanker route in Burrard Inlet, Haro Strait, and the Strait of Juan de Fuca (Figure 2).

4.5.2 Deepwater Horizon Oil Spill. The Deepwater Horizon oil spill and rig explosion occurred on April 20, 2010 offshore in the Gulf of Mexico. The spill continued for 87 days (capped on July 15, 2010) and released an estimated 4.9 million barrels of oil. Together with dozens of other scientists, our UCI group sampled the oil spill by aircraft and by ship one month into the oil spill and again at two months (Figure 3). As noted in Section 1.2.4, a disaster of this scale is not anticipated as part of the Trans Mountain Pipeline Expansion Project, and the Deepwater Horizon oil spill (a prolonged release occurring within the deep sea) is not entirely analogous to a spill occurring along The Project’s tanker route (a release at the sea surface) (Gros et al., 2014). However, the Deepwater Horizon disaster is a rare case where independent scientists had full access to an oil spill at sea. Therefore we use the Deepwater Horizon results to provide some context for the types of compounds that may be released and chemical transformations that may occur after a spill along the tanker route, bearing in mind the limitations of this comparison.

![Figure 2. Locations of the Westridge Marine Terminal, Burrard Inlet, Haro Strait, and the Strait of Juan de Fuca.](image-url)
The key features of the assessment of the Deepwater Horizon oil spill by our group and our colleagues are as follows. Our UCI VOC data from the spill are shown in Table 5.

(1) Hydrocarbons evaporating from the oil spill were the largest source of primary emissions to the air (Middlebrook et al., 2011). Extremely high levels of C₅-C₁₂ alkanes and cycloalkanes typical of crude oil were observed by our group in the atmosphere downwind of the spill location. Based on ship-based air samples collected from June 24-25, 2011 (two months after the rig explosion), concentrations of n-butane and n-pentane reached 1080 and 977 ppb, respectively, compared to background values of 0.03 and 0.01 ppb, respectively, or 37,000–89,000 times higher. Background levels of other hydrocarbons such as n-octane were below our detection limit of 0.003 ppb. In other words, monitoring the Deepwater Horizon spill required an analytical capacity to measure concentrations ranging over 5-6 orders of magnitude, from ppt (10⁻¹²) to ppm (10⁻⁶) levels.

(2) The total average atmospheric burden of nonmethane hydrocarbons near the spill site was 7.6 parts per million of Carbon (ppmC). To gain an appreciation for the huge amount of carbon that was being released into the atmosphere two months into the spill, this is equivalent to more than four times the amount of carbon represented by methane.

(3) The extremely high enhancements of alkanes near (and downwind of) the oil spill site were consistent with their water solubilities. The most soluble gases (e.g., ethane, benzene) showed the weakest enhancements in the near-surface atmosphere and instead dissolved in the deep cold water into which they were released (Ryerson et al., 2011). For example, in the sample described above with ppm-levels of n-butane and n-pentane, benzene levels were 0.47 ppb, compared to a background of 0.02 ppb. Again, sensitive measurements are needed to fully characterize the effects of oil spills on the atmospheric environment, even
for catastrophic events such as the Deepwater Horizon spill, and certainly for lesser spills that may be encountered as part of The Project.

(4) Two weeks after the spill was capped, excess concentrations of VOCs were still encountered. For example concentrations of \( n \)-hexane and \( n \)-octane approached 2 ppb compared to a background of 0.01 ppb. This shows the persistence of evaporative emissions following this spill.

(5) Formation of secondary organic aerosol (SOA) was attributed to the chemical transformations of less volatile hydrocarbons (de Gouw et al., 2011). Formation of ozone and organic nitrates was attributed to hydrocarbons evaporating from the oil reacting with \( NO_x \) emissions from the recovery and cleanup effort (Middlebrook et al., 2011; Neuman et al., 2012).

Table 5 shows concentrations that our group measured near the spill site between June 22-25, 2010, or two months after the rig explosion. The Table shows extremely elevated levels of \( C_3-C_{10} \) alkanes and of \( C_7-C_9 \) aromatics. Enhancements of ethane and benzene were less pronounced because of their relatively higher solubilities and therefore greater dissolution into the water column. Propane and \( n \)-butane also dissolved into the water column. It is important to note that the exact composition and concentrations of the hydrocarbons released into the atmosphere could not have been accurately modeled or predicted, and could only be determined by credible on-site measurements. Likewise, the actual impact of any tanker spill resulting from The Project would need to be assessed in the field.

4.5.3 Evaluation of tanker route releases. The impact of releases along the tanker route depends on many factors including the size of the spill, meteorological conditions, spill response, and so forth. The experience from Deepwater Horizon shows that dozens of hydrocarbons are likely to be released following a tanker spill, and that the effect is likely to persist for many weeks, particularly for a large spill. Therefore the instrumentation needed to monitor a Project spill would require a capacity to measure dozens of speciated VOCs. Because many of the VOCs that would be released are present at relatively low concentrations in the background atmosphere (e.g., ppt or tens of ppt), the measurement capacity would need high sensitivity at both high and low concentrations, in order to correctly determine the concentration enhancements downwind of the plume and to assess when these concentrations have returned to background levels.

The Deepwater Horizon research also showed that chemical transformations of primary emissions (i.e., hydrocarbons) will produce secondary products such as secondary organic aerosol, ozone, and organic nitrates. In the case of Deepwater Horizon, VOC concentrations far exceeded \( NO_x \) concentrations, and the presence of additional \( NO_x \) would have formed additional ozone (Neuman et al., 2012). Therefore in the case of a spill close to the Vancouver urban environment, with larger \( NO_x \) sources, the formation of secondary products such as ozone would need to be closely monitored.
Table 5. Concentrations (mixing ratios in units of ppb or $10^{-9}$) measured in air samples collected near the Deepwater Horizon oil spill between June 22-25, 2010. The samples were collected by ship aboard the NOAA Thomas Jefferson, and were analyzed at UCI using high-precision multi-column gas chromatography (the analytical techniques are described in Simpson et al., 2010). ‘<LOD’ = below our detection limit of 0.003 ppb. Error bars represent ± 1 standard error.

<table>
<thead>
<tr>
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<th>“High levels” near site (n = 13)</th>
<th>“Background” (n = 13)</th>
</tr>
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<tbody>
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<td></td>
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<td>CH₄</td>
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### Table 5, continued.

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<td>1,3,5-Trimethylbenzene</td>
<td>11 (± 6)</td>
<td>80</td>
</tr>
</tbody>
</table>
5. References


plumes in Mexico City with surface measurements and OMI SO$_2$ retrievals during the MILAGRO field campaign, *Atmos. Chem. Phys.*, 9, 9599-9617, 2009.


APPENDIX I: Documents reviewed

The documents that were reviewed include the following three groups:

1. Trans Mountain (TM) Facilities Application, filed by TM in December 2013.
2. Response to Living Oceans information requests, filed by TM in June 2014.
3. Additional documents, filed by TM after June 2014.

Filed documents can be accessed at: http://application.transmountain.com/facilities-application. The specific documents are listed below.

A1 Trans Mountain Facilities Application

1. B005 - Volume 5B: Environmental and Socio-Economic Assessment for the Trans Mountain Pipeline ULC – Trans Mountain Expansion Project. Files: A3S1R5 to A3S1T0. Folder: A56004.

A2 Response to information request:

8. B136-2 Trans Mountain Pipeline ULC – Response to information requests from Living Oceans IR No.1.20a1 A3Y2T5. Folder: A61141.
13. B136-7 Trans Mountain Pipeline ULC – Response to information requests from Living Oceans IR No.1.32d1 A3Y2U0. Folder: A61141

A3 Additional documents:
APPENDIX II:  Acronyms

AAAQO  Alberta Ambient Air Quality Objective
AMD    Air Monitoring Directive
BTEX   Benzene, Toluene, Ethylbenzene, Xylenes
CAC    Criteria Air Contaminants
CALMET California Meteorological Model
CALPUFF California Puff Model
CASA   Clean Air Strategic Alliance
CFC    Chlorofluorocarbon
CWC    Credible Worst Case
CH₄    Methane
CO     Carbon monoxide
CO₂    Carbon dioxide
COPC   Contaminant of potential concern
CWC    Credible worst case
ERCB   Energy Resources Conservation Board
EI     Emission inventory
EPA    Environmental Protection Agency
ERA    Ecological Risk Assessment
ERP    Emergency Response Plan
FA     Facilities Application
H₂S    Hydrogen sulfide
HHRA   Human Health Risk Assessment
IARC   International Agency for Research on Cancer
IR     Information Request
ISC    Incident Command System
KMC    Kinder Morgan Canada
LOS    Living Oceans Society
NASA   National Aeronautics and Space Administration
NEB    National Energy Board
NOAA   National Oceanic and Atmospheric Administration
NOₓ    Nitrogen oxides
NPRI   National Pollutant Release Inventory
NSF    National Science Foundation
O₃     Ozone
ppb    Parts per billion ($10^{-9}$)
ppm    Parts per million ($10^{-6}$)
ppt    Parts per trillion ($10^{-12}$)
RCF    Raincoast Conservation Foundation
RSA    Regional Study Area
SLHHRA Screening Level Human Health Risk Assessment
SO₂    Sulfur dioxide
SOA    Secondary organic aerosol
THC  Total hydrocarbons
TM   Trans Mountain
TMP  Trans Mountain Pipeline
TMPEP Trans Mountain Pipeline Expansion Project, or ‘The Project’
TOC  Total organic carbon (= THC)
TRS  Total Reduced Sulfur
VOC  Volatile organic compound
WCMRC Western Canada Marine Response Corporation
WCSS Western Canada Spill Services
APPENDIX III: Dr. Isobel Simpson CV

Isobel J. Simpson, Ph.D.
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EDUCATION

1996  Ph.D. (Micrometeorology)        University of Guelph
Thesis advisor: Prof. George W. Thurtell
NSERC Graduate Research Scholarship; Mary Edmund Williams Scholarship;
W. Brad Drowley Memorial Scholarship Award; Campbell Scientific Student Paper Award;
Air and Waste Management Association Graduate Scholarship; Latornell Travel Grant;
Davidson Travel Grant; NOAA/AMS/DOE Travel Scholarship

1993  M.Sc. (Micrometeorology)        University of Guelph
With distinctions; Thesis advisor: Prof. George W. Thurtell
H. S. Armstrong Excellence in Research Award (Sigma Xi Outstanding M.Sc. Thesis);
NSERC Graduate Research Scholarship; Soden Scholarship in Agriculture

1990  B.Sc. (Agriculture)        University of British Columbia
With honours; Thesis advisor: Prof. T. Andrew Black
C. A. Rowles Alumni Scholarship; Rhona Clare Gillis Scholarship; Dean Blythe Eagles Medal;
D. G. Laird Prize in Soil Science; NSERC Undergraduate Research Grant

1986  International Baccalaureate Diploma        Sir Winston Churchill
B.C. Provincial Scholarship; Federal/Provincial French Scholarship; Churchill Citizenship Award

PROFESSIONAL APPOINTMENTS

2014–present  Research Specialist, Dept. Chemistry        University of California, Irvine
NASA Group Achievement Award (SEAC4RS)

2011 Editor’s Citation for Excellence in Refereeing (JGR-Atmospheres)
NASA Group Achievement Award (ARCTAS)

Comer Foundation Abrupt Climate Change Fellowship

1997–1999  Visiting Postgraduate Researcher        University of California, Irvine
Hosts: Prof. F. Sherwood Rowland and Prof. Donald R. Blake
NSERC Postdoctoral Fellowship; NASA Group Achievement Award (SONEX)

REPRESENTATIVE PEER-REVIEWED PUBLICATIONS


**SYNERGISTIC ACTIVITIES**

1. **Peer review and outreach:**
   Associate Editor: *Elementa*


   External proposal reviewer: NASA, NSF

   Contributor: *WMO Scientific Assessment of Ozone Depletion: 2010, 2014*

   Seminars/conference presentations: *ACS, AGU, CSC, HKPU, GRC (Atm. Chem.), NOAA/ESRL, U Montana*


   AGU Outstanding Student Paper Award judge: *2012, 2013, 2014*

2. **Research collaborations:**

   Eric Apel (NCAR); Elliot Atlas (U Miami); Murat Aydin (UCI); Stuart Batterman (U Michigan); Andreas Beyersdorf (NASA); Philippe Bousquet (U Versailles); Lori Bruhwiler (NOAA); James Crawford (NASA); Joost de Gouw (NOAA); Glenn Diskin (NASA); Ed Dlugokencky (NOAA); Alan Fried (U Colorado); Henry Fuelberg (FSU); Hai Guo (HKPU); Detlev Helmg (U Colorado); Rebecca Hornbrook (NCAR); Greg Huey (GIT); Stefanie Kirschke (U Versailles); Erik Krogh (VIU); Jennifer Logan (Harvard U); Barkley Sive (NPS); Mads Sulbaek Andersen (JPL); Amy Townsend-Small (U Cincinnati); Tao Wang (HKPU); Xinming Wang (GIG); Andrew Weinheimer (NCAR); Paul Wennberg (CIT); Christine Wiedinmyer (NCAR); Oliver Wingenter (NMT); Armin Wisthaler (U Innsbruck); Melissa Yang (NASA); Robert Yokelson (U Montana)

3. **Community service:**

   **Present:** Amnesty International (mentor)

   **Past:** Guelph Correctional Center (literacy tutor); Canadian National Institute for the Blind (volunteer); Victoria Order of Nurses (volunteer); Vancouver General Hospital (volunteer)