2011-2012 Prince George Neighbourhood Volatile Organic Compound (VOC) Sampling Program



March 2013

Executive Summary

In response to odour complaints within the City of Prince George, the BC Ministry of Environment (MOE) has been working in collaboration with residents to identify which compounds may be associated with the odours experienced. Twelve ambient air samples (1-hour) were collected and analyzed for volatile organic compounds (VOCs) from March 2011 to June 2012. This report summarizes VOCs measured and provides recommendations for next steps. Its primary purpose is to communicate the results of the sampling program to the residents of Prince George.

British Columbia does not currently have ambient air quality objectives or screening levels for VOCs monitored in this project. As a result, VOC concentrations were compared to the most stringent short-term ambient air quality objectives, and (more stringent) health-based effects levels set by various North American agencies.

All compounds but one (acrolein) fell well below the short-term ambient screening levels and objectives. Acrolein exceeded the acute Reference Exposure Level (REL) set by the California Protection Agency's Office of Environmental Health and Hazard Assessment (OEHHA) (2.50 µg m^{-3}) in five out the 12 samples collected. The concentrations of these five (1-hour) samples ranged from 2.73-3.98 µg m^{-3}. At concentrations below the acute REL, adverse health effects are not anticipated within the most sensitive populations during intermittent 1-hour exposures. Levels above the REL do not necessarily indicate that health effects will occur but signal the need for a more in-depth review. When reviewing the results it is also important to recognize that acrolein is a highly reactive compound which makes it difficult to accurately measure its concentration.

Primary recommendations include a) acrolein targeted sampling if requested by residents and b) if samples continue to exceed OEHHA's acute REL, a more systematic sampling strategy to be able to assess acrolein concentrations in the airshed overtime. Residents have also expressed interest in comparing the results of this study European Ambient Air Quality Objectives or health-based effects levels.

2011-2012 Prince George Neighbourhood VOC Sampling Program

Background

In response to odour complaints within the City of Prince George, the BC Ministry of Environment (MOE) has been working in collaboration with residents on a series of odour studies since 2008. This report summarizes all air samples collected in residential areas from March 2011 to June 2012 which were analyzed for volatile organic compounds (VOCs).

City residents living within odour affected neighbourhoods have been trained by MOE staff to collect VOC samples as this arrangement increases the opportunity for sampling during odourous periods. Priority testing has been given to locations where residents have reported occurrences of a distinct but unrecognizable odour causing discomfort. The purpose for collecting the samples was to identify which compounds may be associated with the odour experienced.

Due to the large number of VOCs analyzed in each sample (194 compounds), results focus on compounds with the highest concentrations. Specifically,

Volatile Organic Compounds (VOCs)

What are VOCs?

VOCs are a large class of compounds that contain at least one carbon and one hydrogen atom. They are emitted from a wide variety of sources, both natural (e.g. trees, plants and volcanoes) and anthropogenic (e.g. industry, vehicles, paint, and personal products).

Why measure VOCs?

VOCs are most commonly monitored because: (1) they are precursors of the air pollutant ozone (O_3) and (2) several VOCs are associated with odours and/or adverse health effects.

(1) compounds with the highest concentrations relative to their ambient air quality objectives (AAQO) or effects levels (EL) (≥ 5%). *Refer to the information box on page 4 for further information about AAQOs and ELs. Understanding these concepts is important for interpreting results presented in this report.*

(2) compounds with the highest overall concentrations measured within any given sample.

The province of British Columbia does not currently have AAQOs or ELs for VOCs measured in this project therefore samples were compared to 1-hour AAQOs and ELs from other jurisdictions. These include Alberta Environment, Ontario Ministry of Environment, Texas Commission on Environmental Quality (TCEQ) and the California Protection Agency, Office of Environmental Health and Hazard Assessment (OEHHA). When more than one AAQO or EL was available for a given compound, the most stringent was chosen for comparison.

What is the difference between Ambient Air Quality Objectives (AAQO) and Effects Levels (EL)?

In British Columbia, AAQOs are non-statutory limits used for airshed management. They balance information from health and environmental risk assessments as well as cost-benefit analyses. If an air contaminant exceeds its AAQO, adverse outcomes are generally expected in the exposed population and/or environment.

There are a variety of measures that are more stringent than AAQOs and are used to indicate when *potential exists* for adverse effects to occur in an exposed population (or environment). For simplicity, this report refers to these types of measures as Effects Levels (ELs).

This report considers two types of ELs:

(1) Effects Screening Levels (ESLs) of the Texas Commission on Environmental Quality (TCEQ) and,

(2) Reference Exposure Levels (RELs) of the Office of Environmental Health and Hazard Assessment (OEHHA) in California.

Their values are determined from medical, toxicological, and exposure studies. Effects Screening Levels (ESLs) indicate when health, odour, or vegetative impacts may occur. Reference Effects Levels (RELs) are very conservative measures. They are set *below* the level at which adverse health effects have been observed in the most sensitive individuals of an exposed population.

If a contaminant is below its EL, adverse outcomes are not expected. If a contaminant exceeds its EL, it does not necessarily indicate that adverse effects will occur but signals the need for a more in-depth review.

Measurements

From March 2011 to June 2012, a total of twelve 1-hour ambient air samples were collected (Table 1). All sampling took place in the Millar Addition, a neighbourhood located in the eastern section of Prince George. Residents collected samples when they experienced strong odours. Samples were collected at ground level.

Table 1: Millar Addition VOC sample dates, times, and description of odour experienced by the resident during 1-hour sample collection. PST = Pacific Standard Time.

Sample Date	Start Time (PST)	Odour Description
9-Mar-2011	9:15 am	Sharp, pungent, acid
10-Mar -2011	8:25 am	Sharp, pungent, acid
15-Mar-2011	6:33 am	Chemical, sharp pungent, acid
19-May-2011	8:28 am	Burnt, chemical
23-Nov-2011*	7:44 am	Burnt, chemical
5-Dec-2011*	6:40 am	Chemical, sharp pungent, acid
14-Dec-2011	11:22 am	Sulphidic, chemical
15-Feb-2012*	7:40 am	Pungent, gasoline, solvent
28-Feb-2012	9:41 pm	Chemical, sharp pungent, acid
11-Apr-2012	6:55 am	Chemical
1-Jun-2012	6:57 am	Sulphidic, chemical
1-Jun-2012	8:00 am	Sulphidic, chemical

* NAPS VOC sample collected same day.

Additionally, 24-hour VOC samples have been routinely collected (every six days) at the downtown air monitoring station (Plaza 400) since 2005 as part of the National Air Pollution Survey (NAPS) Program operated by Environment Canada. These samples are collected at the top of a six-story building. Annual summaries of the NAPS VOC data are available in the MOE Prince George Annual Air Quality Reports (http://www.env.gov.bc.ca/epd/regions/omineca/air/annual_info.htm).

Both the NAPS and residential samples were collected in evacuated canisters (Figure 1a). To provide portability, the residential samples were collected by passive sampling where a regulator controls the flow of air into the canister over a 1-hour sampling period (Figure 1b). The NAPS program uses pressurized sampling where a pump draws air into the canister over a 24-hour sampling period.

All samples were analyzed using a method recommended by the US Environmental Protection Agency (US EPA), Compendium Method TO-15.[1]

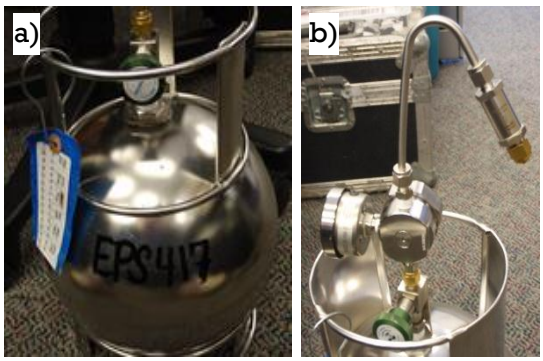


Figure 1. a) VOC sample canister, b) canister with a passive flow regulator.

[1] US EPA (1999). Compendium Method TO-15. Determination of volatile organic compounds (VOCs) in air collected in specially-prepared canisters and analyzed by gas chromatography/mass spectrometry (GC/MS). Available at: http://www.epa.gov/ttnamti1/files/ambient/airtox/to-15r.pdf

Results

Relative Concentrations

Concentrations of all VOCs measured from the residential samples are summarized in Appendix A. Figure 2 identifies VOCs that fell at or above 5% of their respective AAQO or EL. The two compounds with the highest concentrations relative to their EL were acrolein and alpha-pinene. They are described in more detail below. Characteristics of the remaining nine VOCs shown in Figure 2 are summarized in Appendix B.

Acrolein

Acrolein has an intensive acrid odour and is considered a tissue irritant (e.g. eyes, nasal passage, and respiratory tract).[2] It can persist in the atmosphere for short to moderate periods of time (~20 hours – 15 days) and tends to have localized rather than long-range impacts due to atmospheric mixing. Acrolein is released into the air from a large number of sources including vehicles (particularly diesel), aircrafts, oil and gas industries, pulp and paper mills, residential wood burning, forest fires, cigarette smoke, and heated cooking oil.[3,4,5] Acrolein can also form in the atmosphere as product of photo-oxidation (the breakdown of larger compounds such as 1,3-butadiene in the presence of nitrogen oxides, NO_x, and sunlight).[6,7]

Acrolein concentrations measured from the 1-hour residential samples collected in this project ranged from 0.38-3.98 µg m^{-3} (Table 2). Even though trends cannot be discerned from random grab samples, it is interesting to note that acrolein concentrations appear to increase over time.

Table 2. Acrolein concentrations reported for the 12 1-hour VOC canister samples collected in this study. Sample time is reported in PST.

Sample Date	Start Time (PST)	Acrolein (µg m^{-3})	Sample Date	Start Time (PST)	Acrolein (µg m^{-3})
9-Mar-2011	9:15 am	1.69	14-Dec-2011	11:22 am	2.25
10-Mar -2011	8:25 am	1.31	15-Feb-2012	7:40 am	3.98
15-Mar-2011	6:33 am	2.92	28-Feb-2012	9:41 am	2.18
19-May-2011	8:28 am	0.38	11-Apr-2012	6:55 am	3.48
23-Nov-2011	7:44 am	2.09	1-Jun-2012 (1)	6:57 am	2.73
5-Dec-2011	6:40 am	1.70	1-Jun-2012 (2)	8:00 am	3.52

[2] Farroon et al. (2008). Acrolein health effects. *Toxicology and Industrial Health*, 24(7): 447-490.
[3] Environment Canada and Health Canada (2000). Canadian Environmental Protection Act priority substances list assessment report: acrolein. Ottawa, Environment Canada and Health Canada. Available at: http://www.hc-sc.gc.ca/ewh-semt/pubs/contaminants/psl2-lsp2/acrolein/index-eng.php
[4] US EPA (2001). Pulping and bleaching system NESHAP for the pulp and paper industry: A plain English description. EPA-456/R-01-002. North Carolina, US EPA. Available at: http://www.epa.gov/ttnatw01/pulp/guidance.pdf
[5] Amosa et al (2010). Sulphide scavengers in oil and gas industry – a review. *NAFTA* 61(2), 85-92.
[6] International Programme on Chemcial Safety (IPCS) (2002). Acrolein. Concise International Chemical Assessment Document 43. Available at: http://www.inchem.org/documents/cicads/cicads/cicad43.htm
[7] Doyle, M., Sexton, K., Jeffries, H., Bridge, K. and Jaspers, I. (2004). Effects of 1,3-butadiene, isoprene, and their photochemical degradation products. *Environmental health perspectives* 112:1488-1495.

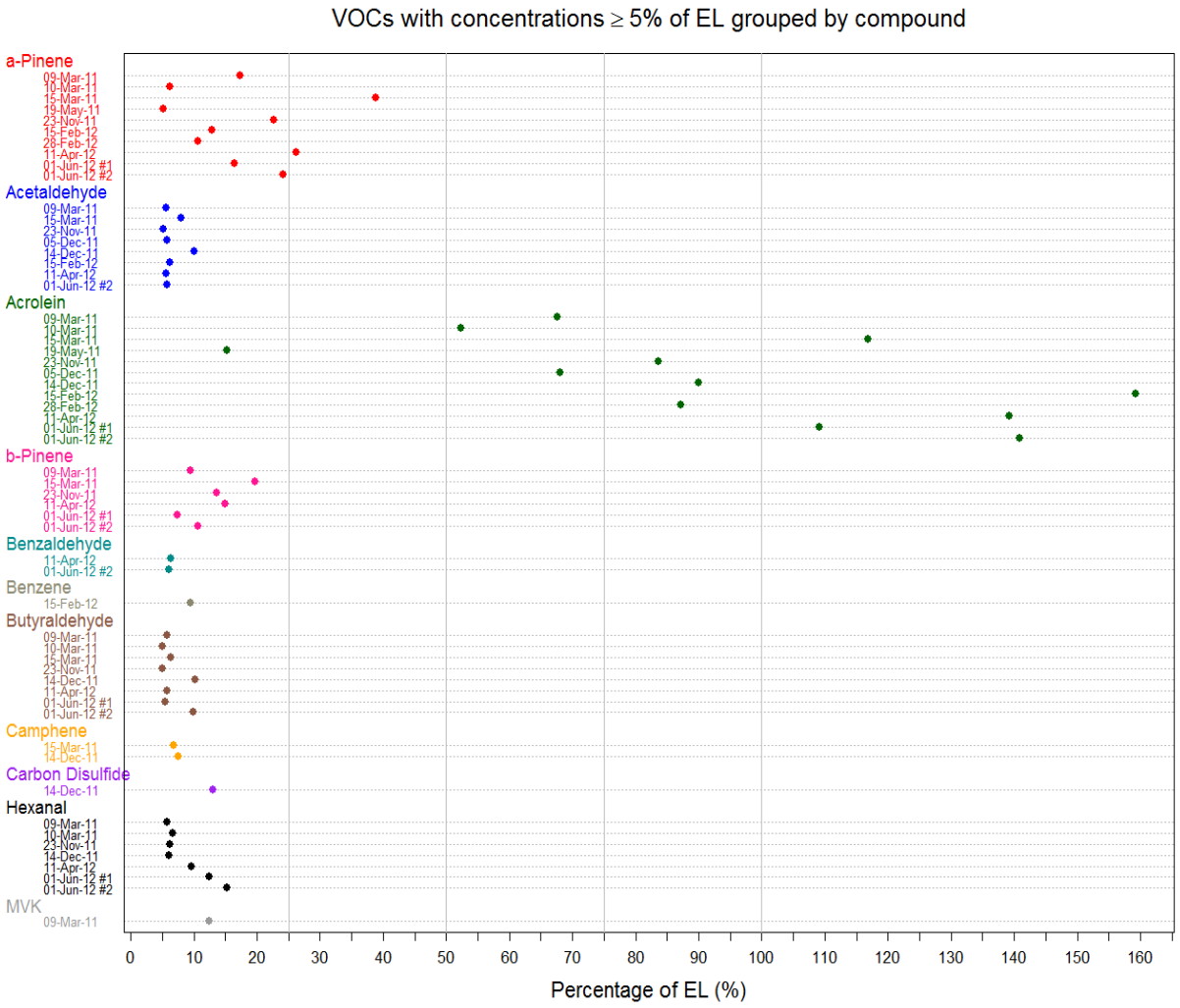


Figure 2. Compounds from all samples with concentrations ≥ 5% of their respective EL/AAQO.

Winds were calm to light around the time of sample collection (Appendix C). Meteorological data collected near the sampled locations (Exploration Place) indicates that winds were most often flowing from the north or northeast. Land use within these sectors is predominantly industrial. Two busy roadways, Highway 16 and Queensway Street, also pass through these sectors.

Acrolein concentrations collected in the residential area were compared to the acute REL set by the OEHHA, 2.50 µg m^{-3} (Box 1).[8] The acute REL is the most appropriate comparison because samples were collected for 1-hour periods during odourous events. Five out of the twelve samples collected exceeded the acute REL: 15 March 2011 (2.92 µg m^{-3}), 15 February 2012 (3.98 µg m^{-3}), 11 April 2012 (3.48 µg m^{-3}), and 1 June 2012 (2.73 µg m^{-3} and 3.52 µg m^{-3}) (Table 2). Note that the NAPS VOC samples collected at

[8] OEHHA (2008). Acrolein Reference Exposure Levels. California Protection Agency, Office of Environmental Health Hazard Assessment.

Plaza 400 do not report acrolein concentrations due to uncertainties associated with accurate measurement of this compound (see page 6).

It should be clarified that previous reports related to this project referenced the TCEQ ESL for acrolein (4.00 µg m^{-3}) (http://www.bcairquality.ca/reports/region_Omineca.html). All ELs were reviewed prior to compiling this report. During this process, the more stringent acute REL from the OEHHA (2.50 µg m^{-3}) was identified and used as a means of comparison for all acrolein data collected to date.

Box 1. Reference Effects Levels (RELs) established by the California Protection Agency, OHEAA.

OEHHA Reference Effects Levels (RELs)

Acute REL: 2.50 µg m^{-3}

Adverse health effects are not anticipated within the most sensitive populations for intermittent 1-hour exposures to concentrations below the acute REL.

8-hour REL: 0.70 µg m^{-3}

Adverse health effects are not anticipated within the most sensitive populations for repeated 8-hour exposures to concentrations below the 8-hour REL.

Chronic REL: 0.35 µg m^{-3}

Adverse health effects are not anticipated within the most sensitive populations for continuous exposure to concentrations below the chronic REL (annual average).

To provide context around the results, the remainder of this section summarizes ambient acrolein concentrations measured in other communities and microenvironments (e.g. indoors, cooking with oil, areas with cigarette smoke).

Before addressing these topics, it is important to state that acrolein is one of the most difficult compounds to quantify from ambient air samples because it is highly reactive.[9,10] Samples collected in evacuated canisters tend to be biased high (i.e. reported concentrations are higher than the true values) but can also be biased low.[9] Errors are largely attributed to sample storage time and canister cleaning methods.

Recommended protocols to reduce error include (1) a maximum sample storage time of 6-14 days[9] (although some protocols indicate up to 30 days is acceptable)[11] and, (2) using heat (steam) to clean the canisters.[12,13]

Even when best practices are carefully followed, error associated with acrolein measured from evacuated canisters has been estimated to be approximately 20-30% although much larger errors can

[9] Environment Canada (2012). Personal communication. Daniel Wang.
[10] US EPA (2010). Data quality evaluation guidelines for ambient air acrolein measurements. Available at: http://www.epa.gov/ttnamti1/files/ambient/airtox/20101217acroleindataqualityeval.pdf
[11] US EPA (2006). Procedure for the determination of acrolein and other volatile organic compounds (VOCs) in air collected in canisters and analyzed by gas chromatography/mass spectrometry (GC/MS) using selective ion monitoring (SIM). North Carolina, Office of Air Quality Planning and Standards, Research Triangle Park. Available at: http://www.epa.gov/ttn/amtic/files/ambient/airtox/sopacrolein.pdf
[12] Shelow et al. (2009). Acrolein measurements. Presented to the 2009 National Ambient Air Monitoring Conference, Nashville, Tennessee, 2-5 November 2009.
[13] Swift et al. (2006). Collection and analysis of acrolein using Compendium Method TO-15. National Environmental Monitoring Conference (August 2006). Available at: http://epa.gov/tnamti1/airtox.html

occur.[14] Refer to the accompanying literature review (*Sampling and Measurement Methods for Volatile Organic Compounds*) for further information about VOC measurement methods, particularly those pertinent to acrolein.

The Environment Canada Air Quality Laboratory uses a heated canister cleaning method. Samples collected in this project were analyzed 6-19 days after collection with two samples exceeding the maximum recommended 14 day storage period (9 March 2011 and 10 March 2011). These two samples fell below the acute OEHHA REL (2.50 µg m^{-3}) (Table 2). Based on the protocols followed and known uncertainties around acrolein quantification, it is assumed that acrolein concentrations reported for this project provide a general representation of the ambient conditions monitored albeit with considerable uncertainty of the exact concentrations.

Studies with the same sample collection method and sample duration could not be found to provide a direct comparison to the results of this project. The closest comparisons used the same sampling and measurement methods but had different sampling durations (i.e. not 1-hour).

Table 3 lists ranges of 24-hour samples collected in evacuated canisters throughout Canada and the US. Samples with elevated concentrations were typically associated with smog events or areas in close proximity to an acrolein emission source such as a busy roadway. The highest acrolein concentrations measured in this project (1-hour sample during an odour event) are similar to concentrations reported for polluted areas in an urban airshed (24-hour sample).

Acrolein concentrations measured in microenvironments that contain an acrolein emission source are illustrated in (Figure 3).[15,16,17,18] Samples included in this figure were collected using various sample methods and sampling collection periods therefore the absolute values should not be directly compared. What the figure is meant to illustrate is that people can be exposed to concentrations much higher than ambient levels during certain personal activities and in some microenvironments. Still, this information does not decrease the merit of investigating ambient concentrations that exceed ELs.

[14] NESCAUM (2012). What's a reasonable expectation from acrolein analysis from Summa canister? MAC Committee briefing notes provided by Roy Heaton. Available at: http://www.nescaum.org/documents/mac/mac-committee-meeting-apr10/acroleinnotes_heaton.pdf/view

[15] Gilbert et al. (2005). Levels and determinants of formaldehyde, acetaldehyde, and acrolein in residential indoor air in Prince Edward Island, Canada. *Environmental Research*, 99(1): 11-17.

[16] Héroux et al. (2010). Predictors of Indoor Air Concentrations in Smoking and Non-Smoking Residence. *International Journal of Environmental Research and Public Health*, 7(8):3080-3099.

[17] Seaman et al. (2009). Indoor acrolein emission and decay rates resulting from domestic cooking events. *Atmospheric Environment*, 43(39): 6199-6204.

[18] Triebig and Zober (1984). Indoor air pollution by smoke constituents – a survey. *Preventative Medicine,*13(6): 570-581.

Table 3. Acrolein concentrations reported by other studies which utilized evacuated canisters for sample collection.

Location	Site Description	Sample Environment	Sample Duration	Concentration Range [µg m^{-3}]
Austin, Texas	ARTS study - City-wide (schools, research centre, near major roadways)	Ambient	24 hours	2.51-4.24*[19]
Austin, Texas	Follow up to ARTS study (above) to investigate high acrolein	Ambient	24 hours	0.60-1.47[20]
California	State-wide during 2011	Ambient	24 hours	0.34-12.90[21]
Ontario, Clarkson	Ambient monitoring stations – urban areas, near major roadways and an industrial complex. Some samples collected during air quality advisories.	Ambient	24 hours	0.58-3.94[22]
Prince George	Residential area during odour event	Ambient	1-hour	0.38-3.98

*Range of mean acrolein concentrations at four sites in Austin, Texas. In this study, mean acrolein concentrations were found to be significantly higher than other US cities.

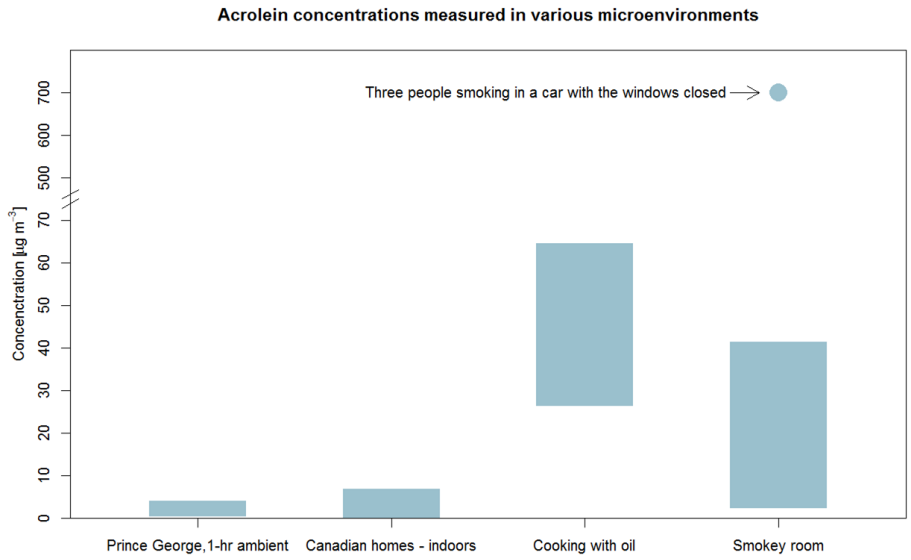


Figure 3. Acrolein concentrations reported for various microenvironments. *"Prince George, 1-hr ambient"* is the range of acrolein concentrations measured from the residential 1-hour samples collected in this project. Note: sampling methods and durations are not consistent between categories.

[19] URS Corporation (2006). Austin – Round Rock Toxics Study (ARTS). Available at: http://www.epa.gov/ttnamti1/files/20032004csatam/ARTS_Final_Report_021607.pdf

[20] URS Corporation (2007). Ambient air measurements of acrolein in Austin, Texas follow up to the Austin-Round Rock Toxics Study. Available at: http://www.capcog.org/documents/airquality/reports/toxics/Acrolein%20Report%20112007.pdf

[21] California Air Resources Board. Annual Toxics Summaries. Available at: http://www.arb.ca.gov/adam/toxics/sitesubstance.html

[22] Ministry of Ontario (2009). Clarkson airshed study. A scientific approach to improving air quality. Available at: http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_080782.pdf

Alpha-Pinene

Besides acrolein, alpha-pinene is the only other compound that exceeded 20% of the most stringent 1-hour EL (TCEQ ESL, 60 µg m^{-3}). The maximum 1-hour alpha-pinene concentration collected in the residential area was sampled on 15 March 2012 (23 µg m^{-3}, Figure 2).

Alpha-pinene is emitted from vegetation and is most abundant in coniferous trees, particularly pine. Naturally occurring emissions increase with temperature and light intensity.[23] Industrial emissions are associated with forest-based industries. Due to its aromatic properties, it is also present in several manufactured products such as deodourizers and cleaners.

In terms of ambient air quality, alpha-pinene emissions are important to consider because they are a precursor to the air pollutant ozone (O_3). Little information is available regarding health effects associated with the compound however some research has indicated that chronic exposure to high concentrations (e.g. 10,000 - 214,000 µg m^{-3}) of terpenes such as alpha-pinene may result in decreased lung function.[24]

A comparison of alpha-pinene and temperature measurements collected at Plaza 400 between 2005 and 2012 suggests that both natural and anthropogenic sources contribute to the presence of the compound in the Prince George airshed (Figure 4). Elevated concentrations during the months of August through September include contributions from natural sources in addition to anthropogenic sources since temperature and vegetative photosynthetic activity is greatest at this time of year. In contrast, concentrations during cold-temperature months are more representative of anthropogenic emissions alone. Atmospheric stability also influences concentrations observed across seasons. Refer to the information box on page 12 for further explanation.

Absolute Concentrations

Compounds that ranked as the top five absolute concentrations within any given sample are shown in Figure 5. Methanol and alpha-pinene consistently had the highest concentrations. Characteristics of methanol are described on page 14. Information about alpha-pinene was provided in the previous section.

All other compounds listed in Figure 5 were less than 20.00 µg m^{-3} with the exception of one sample of butane collected on 19 May 2011 8:28am - 9:27am (22.26 µg m^{-3}, 0.09% of the 1-hour TCEQ ESL). The oil refinery is a nearby industrial source of this compound however field notes indicate that a lawn tractor and trimmer were operating across the street during the time of sample collection (19 May 2011 8:50 am-9:06 am). Characteristics of butane and the remaining compounds shown in Figure 5 are summarized in Appendix B.

[23] Blanch et al. (2011). Instantaneous and historical temperature effects on a-pinene emissions in Pinus halepensis and Quercus ilex, *Journal of Environmental Biology*, 32:1-6.
[24] Eriksson, et al (1996). Terpene exposure and respiratory effects among workers in Swedish joinery shops. *Scandinavian Journal of Work and Environmental Health*, 22(2): 114-120.

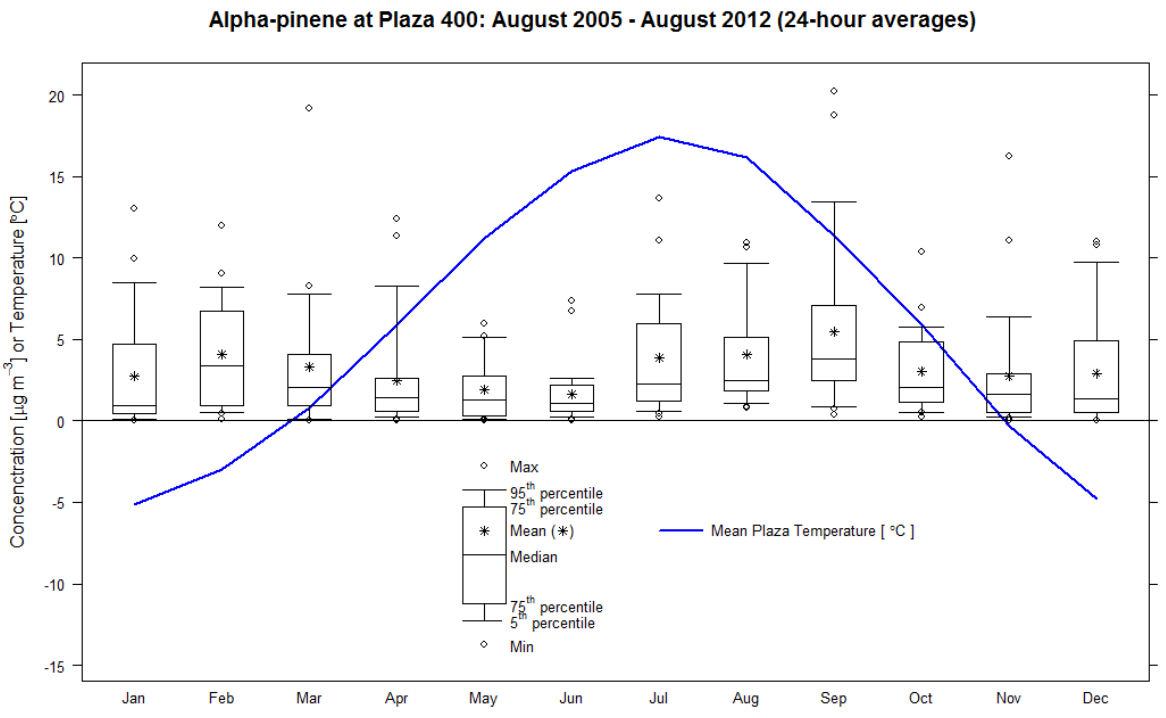


Figure 4: Alpha-pinene concentrations and monthly mean temperatures measured at Plaza 400 (2005-2012).

Seasonal influences of atmospheric stability on air contaminant concentrations

When interpreting Figure 4 it is important to consider how meteorological processes influence air contaminant concentrations seasonally. In general, contaminants emitted into the air tend to have a greater impact on ambient concentrations per unit of pollutant emitted during cold-temperature months relative to warm-temperature months. This phenomenon occurs because the atmosphere is generally more stable when temperatures are cold and daylight hours are short. Under stable conditions, air contaminants released near the ground remain trapped causing concentrations to increase. Conversely, when the atmosphere is unstable, air contaminants can disperse more freely resulting in concentrations near the ground surface.

With this in mind, the total amount of alpha-pinene released during the summer (natural and anthropogenic sources) is likely larger than the winter (mainly anthropogenic sources) even though concentrations during both seasons are similar.

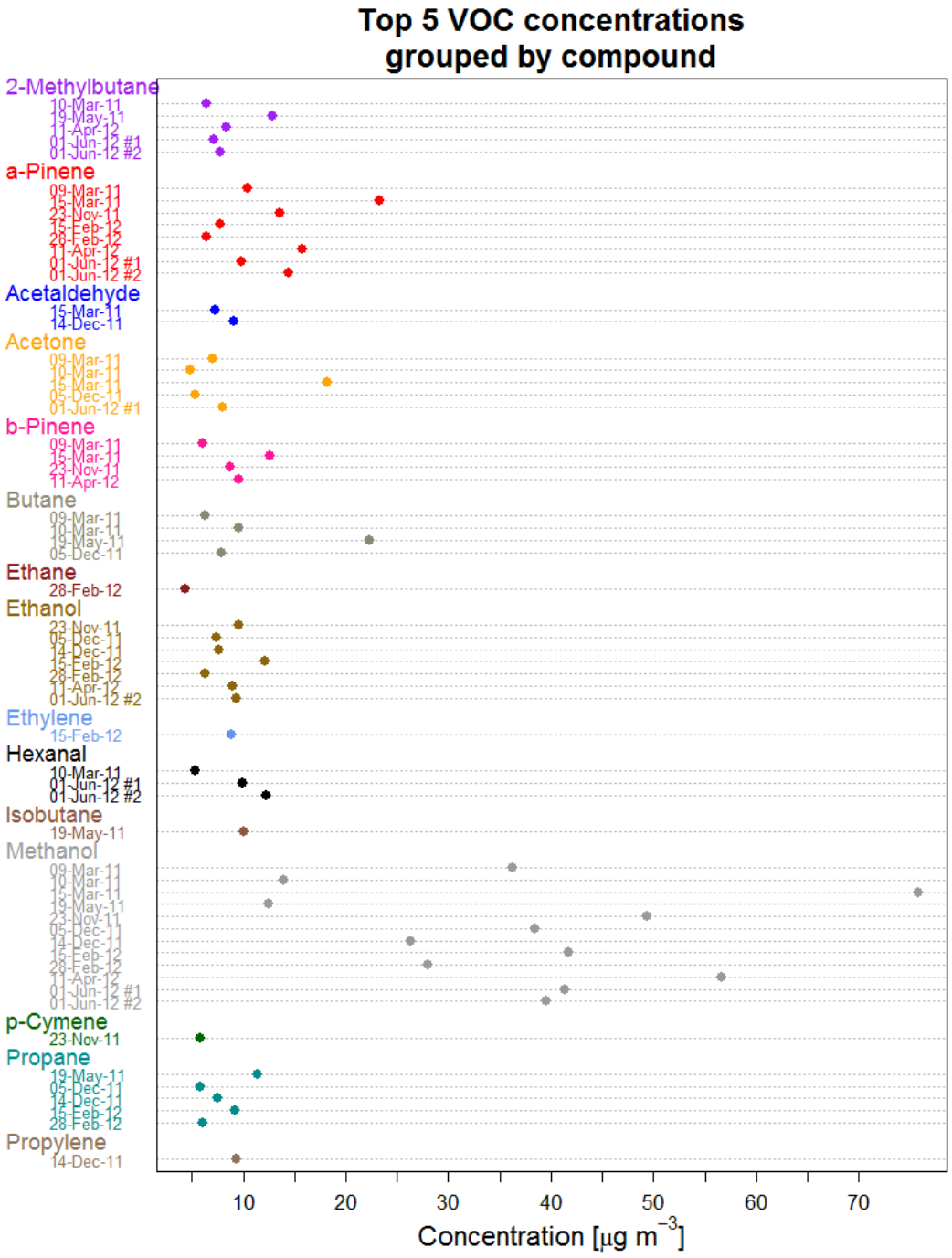


Figure 5. VOC compounds from residential samples (1-hour average) that that ranked as the top five absolute concentrations within any given sample.

Methanol

Methanol is commonly referred to as wood alcohol. It consistently had the highest measured concentrations within the residential VOC samples (12.52 µg m^{-3}-75.75 µg m^{-3}) which represents 0.5 - 2.9% of the 1-hour EL (2,600 µg m^{-3}, TCEQ) (Figure 5).

Crude methanol has a repulsive, pungent odour whereas pure methanol smells similar to drinking alcohol. Methanol odour is not generally detected by humans in the ambient air although the odour threshold is highly variable depending on its purity (13 – 26,600 mg m^{-3}).[25]

Natural sources of methanol pertinent to the Prince George area include vegetation, decaying wood, microbes, and insects. Anthropogenic methanol emissions include biological decomposition (e.g. sewage), pulp mills[26,27], the petrochemical industry, vehicles, paints, solvents, and antifreeze.[25]

Acute exposures to methanol can result in vision impairment, motor dysfunction, and neurological damage. Lower concentrations may lead to various symptoms including headache, dizziness, and nausea. [25,28]

Residential – NAPS sample comparison

Three of the residential samples collected coincided with NAPS sample collection at Plaza 400 (23 November 2011, 5 December 2011, and 15 February 2012). Figure 6 shows between-site comparisons for compounds listed in Figure 2 and Figure 5 that were measured at both sites.

Concentration differences between the two sites were variable but relatively small in magnitude. Alpha-pinene had the largest between-site difference on 23 November 2011 where the 1-hour residential sample was 7.44 µg m^{-3} greater than the 24-hour sample collected at Plaza 400. With the exception of alpha-pinene and beta-pinene, concentrations differences between sites were relatively small which may indicate (1) residential samples were not always collected during peak odour periods for that day (e.g. odours dissipated after sample collection began) or (2) VOC concentrations were consistently elevated throughout the day and the two sites were impacted fairly similarly. It is important to point out that potential explanations made here are only based on three samples and for this reason should be considered anecdotal.

[25] US EPA 1994. Chemical summary for methanol. Office of Pollution Prevention and Toxics. Available at: http://www.epa.gov/chemfact/s_methan.txt

[26] Environment Canada (2012). Pulp and paper. Available at: http://www.ec.gc.ca/air/default.asp?lang=En&n=CB1E071C-1

[27] Zhu et al. (1998). The formation of volatile organic compounds (VOCs) during pulping. A progress report to the member companies of the Institute of Paper Science and Technology. Project F01708, Report 4. Available at: http://smartech.gatech.edu/jspui/bitstream/1853/773/1/F01708-4--1998-11.pdf

[28] Givens et al. (2008). Comparison of methanol exposure routes reported to Texas poison control centers. *The Western Journal of Emergency Medicine*, 9(3):150-153.

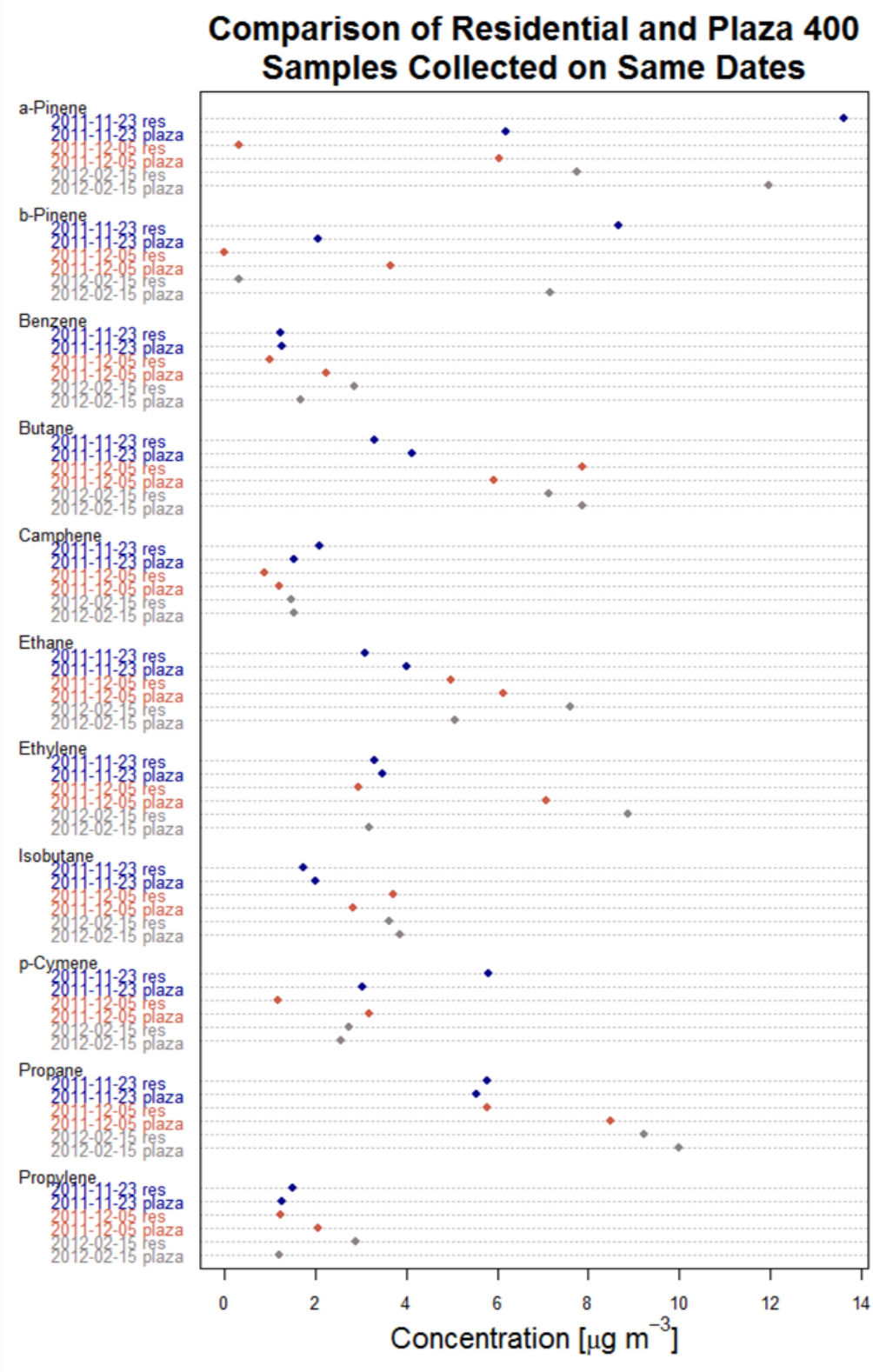


Figure 6. Comparison of residential (1-hour) and Plaza 400 (24-hour average) samples collected on the same dates.

Conclusions and Recommendations

It is important to recognize that conclusions and recommendations made in this report take a precautionary approach.

(1) The most stringent AAQOs and ELs found within North America were used as the basis of comparison.
(2) Acrolein concentrations are assumed to be correct even though,
    a) there is reduced confidence associated with acrolein measurements due to the reactive nature of the compound and,
    b) errors associated with acrolein samples measured from evacuated canisters using the Compendium TO-15 method are in the range of 20-30%, can be much larger, and tend to be biased high.

With the exception of acrolein, all measured compounds within samples collected as part of the Prince George Neighbourhood VOC Program fell well below their respective 1-hour AAQO or EL.

Acrolein exceeded the acute (1-hour) REL developed by the OEHHA (2.50 µg m^{-3}) for five out of the twelve samples collected. Elevated 1-hour average concentrations during odour events collected in this study were comparable to 24-hour average concentrations reported for high-traffic areas or during smog events.[22,21] Exceedence of the acute REL indicates that acrolein may have contributed to the odour and discomfort experienced by the residents in the Millar Addition.

Other compounds listed in Figure 2 and Figure 5 such as acetaldehyde, butane, and butyraldehyde, have similar odours to those described by the residents which raises the consideration of synergistic or additive effects. Unfortunately, very little is known about these types of effects for VOCs.[29] There are thousands of potential combinations to evaluate and identifying exposure-response associations between hundreds of pollutants with low concentrations in the ambient environment is problematic and continues to elude researchers.

Based on the results of the samples collected to date, information provided in the supporting literature review (*Sampling and Measurement Methods for Volatile Organic Compounds*), and information gathered during consultation with the residents who submitted samples for analysis, recommendations going forward include:

(1) Additional sampling should be made available if requested by residents. If acrolein is of specific interest, samples should be collected in duplicate, field blanks should be collected periodically, and canister cleaning methods, sample collection, and GC/MS analysis should be conducted using protocols that are specific to acrolein detection. Shorter sampling times should also be

[29] California OHEAA (2000). Air Toxics Hot Spots Program Risk Assessment Guidelines Part III. Technical Support Document for the Determination of Noncancer Chronic Reference Exposure Levels. Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment California Environmental Protection Agency. Oakland, California.

considered as residents indicated some of the intense odour events were short in duration (10-15 minutes). As a result, one-hour samples may not be sufficient to characterize the intensity of the events.

(2) If further (duplicate, acrolein targeted) samples indicate the continuance of acute REL exceedences,
    a) a more systematic sampling strategy may be warranted to (i) identify the frequency that the acute REL is exceeded, (ii) gain a better understanding of the spatial distribution of acrolein throughout the airshed, (iii) track how acrolein concentrations vary diurnally, and (iii) provide a means to evaluate acrolein concentrations against the 8-hour and chronic RELs.
    b) it may useful to compile an emissions inventory for the compound in the Prince George airshed although practically, this may be a difficult task to accomplish given the measurement uncertainties of the compound, and the large number of potential emission sources.

(3) Based on the results of this report and interest expressed in understanding potential cumulative and/or synergistic impacts of pollutant mixtures, it may be beneficial to invite an expert (e.g. epidemiologist or other medical professional) who specializes in VOCs to review the data and provide further recommendations for the Prince George airshed.

(4) Compare data collected in this project to studies conducted in Europe and investigate if any Ambient Air Quality Objectives or Effects Levels in other countries (e.g. Europe) are more stringent than those in North America.

Appendix A

Summary of VOC compounds measured from the 1-hour residential samples collected from 9-March-2011 to 1-June-2012. The full dataset is available upon request. Concentrations recorded below detection limit are reported as zero.

	Concentration [µg m^{-3}]			
VOC	Mean	Median	Max.	Date of Max.
1-Butanol (Butyl Alcohol)	0.19	0.24	0.35	11-Apr-12
2-Butanol	0.02	0	0.07	1-Jun-12
2-Butenal (Crotonaldehdye)	0	0	0	--
2-Heptanone	0.04	0.04	0.07	23-Nov-11
2-Hexanone	0.04	0	0.15	11-Apr-12
2-Methyl-Propanal (Isobutylaldehyde)	1.52	1.22	3.17	23-Nov-11
2-Methylbutanal (Isovaleraldehyde)	0.24	0.25	0.4	11-Apr-12
2-Methylfuran	0.64	0.44	2.21	15-Feb-12
2-Pentanone	0	0	0	--
3-Methyl-1-Butanol	0	0	0	--
3-Methylfuran	0	0	0	--
Acetaldehyde	5.09	5.05	9.07	14-Dec-11
Acetone	7.21	6.44	18.18	15-Mar-11
Acetonitrile	0.21	0.16	0.5	1-Jun-12
Acrolein (2-Propenal)	2.35	2.21	3.98	15-Feb-12
Acrylonitrile (2-Propennitrile)	0	0	0	--
Benzaldehyde	0.71	0.59	1.4	11-Apr-12
Butylacetate	0.43	0.16	2.2	28-Feb-12
Butylaldehyde (Butanal)	0.77	0.74	1.43	14-Dec-11
Carbon Disulfide	0.71	0.4	3.89	14-Dec-11
Cyclohexanone	0.04	0.03	0.12	23-Nov-11
Cyclopentanone	0	0	0.05	9-Mar-11
Ethanol	7.26	6.96	12.16	15-Feb-12
Ethylacetate	0.42	0.3	1.97	28-Feb-12
Ethylene Oxide	0	0	0	--
Hexanal	4.82	4.7	12.2	1-Jun-12
Isobutylacetate	0	0	0	--
Isobutylalcohol	0	0	0	--
Isopropyl Alcohol	0.41	0.44	1.01	23-Nov-11
Isopropylacetate	0	0	0	1-Jun-12
MAC (2-Methyl-2-Propenal)	0.15	0.15	0.23	15-Mar-11
MEK (Methyl Ethyl Ketone)	0.82	0.87	1.11	15-Mar-11
Methanol	38.31	38.97	75.75	15-Mar-11
Methyl Acetate	0.21	0.21	0.52	1-Jun-12
MIBK (Methyl Isobutal Ketone)	0.08	0.08	0.13	1-Jun-12
MVK (Methyl Vinyl Ketone)	0.06	0	0.75	9-Mar-11
Propionaldehyde	0	0	0	--

VOC	Concentration [µg m^{-3}]			
	Mean	Median	Max.	Date of Max.
Propyl Alcohol (1-Propanol)	0.11	0.12	0.19	14-Dec-11
Propylene Oxide	0	0	0	--
Valeraldehyde (Pentanal)	0	0	0	--
1-Butene (Isobutene, 2-Methylpropene)	1.13	1.08	2.16	9-Mar-11
1-Butyne	0.01	0	0.02	15-Feb-12
1-Decene	0.01	0	0.04	10-Mar-11
1-Heptene	0	0	0.04	10-Mar-11
1-Hexene (2-Methyl-1-Pentene)	0.12	0.12	0.22	11-Apr-12
1-Methylcyclohexene	0.01	0.01	0.02	11-Apr-12
1-Methylcyclopentene	0.04	0.04	0.11	15-Feb-12
1-Nonene	0.02	0	0.07	23-Nov-11
1-Octene	0.05	0.04	0.1	15-Mar-11
1-Pentene	0.14	0.14	0.23	11-Apr-12
1-Propyne	0.16	0.13	0.51	14-Dec-11
1-Undecene	0	0	0.03	9-Mar-11
1,1-Dichloroethane	0.01	0.01	0.01	1-Jun-12
1,1-Dichloroethene	0	0	0	--
1,1,1-Trichloroethane	0.04	0.03	0.06	1-Jun-12
1,1,2-Trichloroethane	0	0	0.01	5-Dec-11
1,1,2,2-Tetrachloroethane	0	0	0.01	5-Dec-11
1,2-Dibromoethane (EDB)	0	0	0.01	28-Feb-12
1,2-Dichlorobenzene	0.01	0.01	0.03	11-Apr-12
1,2-Dichloroethane	0.07	0.06	0.1	11-Apr-12
1,2-Dichloropropane	0.02	0.02	0.04	11-Apr-12
1,2-Diethylbenzene	0.02	0.02	0.05	1-Jun-12
1,2,3-Trimethylbenzene	0.2	0.18	0.36	1-Jun-12
1,2,4-Trichlorobenzene	0.03	0.02	0.08	1-Jun-12
1,2,4-Trimethylbenzene	0.38	0.32	0.76	15-Feb-12
1,3-Butadiene	0.14	0.14	0.5	15-Feb-12
1,3-Dichlorobenzene	0.01	0.01	0.03	11-Apr-12
1,3-Diethylbenzene	0.02	0.02	0.04	1-Jun-12
1,3,5-Trimethylbenzene	0.11	0.1	0.25	15-Feb-12
1,4-Dichlorobenzene	0.02	0.02	0.04	15-Feb-12
1,4-Dichlorobutane	0	0	0.01	5-Dec-11
1,4-Diethylbenzene	0.12	0.09	0.37	1-Jun-12
2-Ethyl-1-Butene	0	0	0	--
2-Ethyltoluene	0.08	0.06	0.17	15-Feb-12
2-Methyl-1-Butene	0.25	0.22	0.51	11-Apr-12
2-Methyl-2-Butene	0.35	0.33	0.68	15-Feb-12
2-Methylbutane	5.97	5.75	12.85	19-May-11
2-Methylheptane	0.21	0.19	0.38	15-Feb-12

VOC	Concentration [µg m^{-3}]			
	Mean	Median	Max.	Date of Max.
2-Methylhexane	0.71	0.59	1.54	15-Feb-12
2-Methylpentane	1.63	1.44	2.67	19-May-11
2,2-Dimethylbutane	0.54	0.57	0.87	19-May-11
2,2-Dimethylhexane	0	0	0	--
2,2-Dimethylpentane	0.06	0.06	0.11	28-Feb-12
2,2-Dimethylpropane	0.03	0.03	0.09	19-May-11
2,2,3-Trimethylbutane	0.01	0.01	0.02	11-Apr-12
2,2,4-Trimethylpentane	0.82	0.58	2.25	15-Mar-11
2,2,5-Trimethylhexane	0.02	0.02	0.09	5-Dec-11
2,3-Dimethylbutane	0.37	0.34	0.61	19-May-11
2,3-Dimethylpentane	0.45	0.45	0.97	15-Feb-12
2,3,4-Trimethylpentane	0.09	0.06	0.29	5-Dec-11
2,4-Dimethylhexane	0.09	0.1	0.18	15-Feb-12
2,4-Dimethylpentane	0.2	0.2	0.39	15-Feb-12
2,5-Dimethylhexane	0.07	0.06	0.14	15-Feb-12
3-Ethyltoluene	0.22	0.18	0.49	15-Feb-12
3-Methyl-1-Butene	0.13	0.12	0.22	1-Jun-12
3-Methyl-1-Pentene	0.02	0.02	0.04	11-Apr-12
3-Methylheptane	0.2	0.17	0.4	15-Feb-12
3-Methylhexane	0.8	0.65	1.7	15-Feb-12
3-Methylpentane	1.06	0.96	1.64	15-Feb-12
3,6-Dimethyloctane	0.01	0	0.05	9-Mar-11
4-Ethyltoluene	0.11	0.09	0.24	15-Feb-12
4-Methyl-1-Pentene	0.01	0	0.02	23-Nov-11
4-Methylheptane	0.08	0.07	0.17	15-Feb-12
a-Pinene	9.15	8.8	23.33	15-Mar-11
Acetylene	1.45	1.24	NA	15-Mar-11
b-Pinene	4.51	3.62	12.62	15-Mar-11
Benzene	1.04	0.98	2.85	15-Feb-12
Benzylchloride	0	0	0	--
Bromodichloromethane	0	0	0	--
Bromoform	0.01	0.01	0.02	1-Jun-12
Bromomethane	0.05	0.05	0.05	1-Jun-12
Bromotrichloromethane	0	0	0	--
Butane	7.53	6.62	22.26	19-May-11
c-1,2-Dichloroethene	0	0	0	--
c-1,2-Dimethylcyclohexane	0.02	0.02	0.04	15-Feb-12
c-1,3-Dichloropropene	0	0	0	--
c-1,3-Dimethylcyclohexane	0.07	0.06	0.13	11-Apr-12
c-1,4/t-1,3-Dimethylcyclohexane	0.03	0.02	0.05	15-Feb-12
c-2-Butene	0.38	0.38	0.7	15-Feb-12

VOC	Concentration [µg m^{-3}]			
	Mean	Median	Max.	Date of Max.
c-2-Heptene	0	0	0	--
c-2-Hexene	0.03	0.03	0.05	15-Feb-12
c-2-Pentene	0.13	0.12	0.27	11-Apr-12
c-3-Heptene	0	0	0	--
c-3-Methyl-2-Pentene	0.07	0.06	0.13	15-Feb-12
c-4-Methyl-2-Pentene	0.05	0.04	0.1	11-Apr-12
Camphene	1.68	1.46	3.78	14-Dec-11
Carbontetrachloride	0.43	0.43	0.54	19-May-11
Chlorobenzene	0	0	0.01	1-Jun-12
Chloroethane	0.02	0.02	0.03	1-Jun-12
Chloroform	0.22	0.19	0.34	5-Dec-11
Chloromethane	1.21	1.2	1.38	11-Apr-12
Cyclohexane	0.46	0.44	0.83	15-Feb-12
Cyclohexene	0.02	0.02	0.04	15-Feb-12
Cyclopentane	0.23	0.23	0.48	19-May-11
Cyclopentene	0.03	0.03	0.08	15-Feb-12
Decane	0.23	0.2	0.59	9-Mar-11
Dibromochloromethane	0	0	0.01	5-Dec-11
Dibromomethane	0.03	0.03	0.04	1-Jun-12
Dichloromethane	0.74	0.64	2.5	5-Dec-11
Dodecane	0.22	0.24	NA	19-May-11
Ethane	5.03	4.98	NA	15-Mar-11
Ethylbenzene	0.34	0.34	0.74	15-Feb-12
Ethylbromide	0	0	0	--
Ethylene	2.93	2.41	NA	15-Mar-11
Freon 11 (Trichlorofluoromethane)	1.39	1.4	1.56	15-Feb-12
Freon 113 (1,1,2-Trichlorotrifluoroethane)	0.54	0.54	0.58	1-Jun-12
Freon 114 (1,2-Dichlorotetrafluoroethane)	0.12	0.12	0.14	1-Jun-12
Freon 12 (Dichlorodifluoromethane)	2.44	2.49	2.66	28-Feb-12
Freon 134a	0.46	0.46	NA	19-May-11
Freon 22 (Chlorodifluoromethane)	0.69	0.7	0.78	15-Feb-12
Heptane	0.69	0.59	1.82	9-Mar-11
Hexachlorobutadiene	0	0	0.01	1-Jun-12
Hexane	1.21	1.13	1.98	19-May-11
Hexylbenzene	0.01	0.01	0.02	1-Jun-12
Indane (2,3-Dihydroindene)	0.2	0.1	0.57	23-Nov-11
iso-Butylbenzene	0.03	0.02	0.15	23-Nov-11
iso-Propylbenzene	0.02	0.02	0.04	15-Feb-12
Isobutane (2-Methylpropane)	3.97	3.66	10.06	19-May-11
Isoprene (2-Methyl-1,3-Butadiene)	0.14	0.12	0.31	11-Apr-12
Limonene	2.36	1.87	5.46	23-Nov-11

VOC	Concentration [µg m^{-3}]			
	Mean	Median	Max.	Date of Max.
m and p-Xylene	1.41	1.35	3.28	15-Feb-12
Methyl-t-Butyl Ether (MTBE)	0	0	0	--
Methylcyclohexane	0.31	0.29	0.57	11-Apr-12
Methylcyclopentane	0.62	0.58	0.99	15-Feb-12
n-Butylbenzene	0.01	0.01	0.04	9-Mar-11
n-Propylbenzene	0.06	0.05	0.12	15-Feb-12
Naphthalene	0.11	0.12	0.17	11-Apr-12
Nonane	0.21	0.15	0.65	9-Mar-11
o-Xylene	0.46	0.42	1.03	15-Feb-12
Octane	0.26	0.22	0.68	9-Mar-11
p-Cymene (1-Methyl-4-Isopropylbenzene)	2.91	2.71	6.2	15-Mar-11
Pentane	2.57	2.36	6.13	19-May-11
Propane	5.82	5.78	11.36	19-May-11
Propylene	2.09	1.28	9.37	14-Dec-11
sec-Butylbenzene	0.01	0.01	0.02	15-Feb-12
Styrene	0.08	0.08	0.15	23-Nov-11
t-1,2-Dichloroethene	0	0	0	--
t-1,2-Dimethylcyclohexane	0.05	0.04	0.1	11-Apr-12
t-1,3-Dichloropropene	0	0	0	--
t-1,4-Dimethylcyclohexane	0.03	0.03	0.06	11-Apr-12
t-2-Butene	0.52	0.52	0.91	15-Feb-12
t-2-Heptene	0.01	0.01	0.02	11-Apr-12
t-2-Hexene	0.05	0.05	0.1	15-Feb-12
t-2-Octene	0	0	0	--
t-2-Pentene	0.29	0.24	0.59	11-Apr-12
t-3-Heptene	0.01	0.01	0.02	1-Jun-12
t-3-Methyl-2-Pentene	0.03	0.02	0.06	15-Feb-12
t-4-Methyl-2-Pentene	0.01	0	0.02	1-Jun-12
tert-Butylbenzene	0	0	0	--
Tetrachloroethene	0.09	0.06	0.27	15-Feb-12
Toluene	2.85	2.8	6.54	15-Feb-12
Trichloroethene	0.12	0.04	0.72	15-Mar-11
Undecane	0.24	0.22	0.53	9-Mar-11
Vinylchloride (Chloroethene)	0	0	0.01	15-Feb-12

Appendix B

Characteristics of VOCs listed in Figure 2 and Figure 5. Note: the AAQOs/ELs reported in this table are those that were used for comparative purposes in the evaluation of the 1-hour residential VOC samples.

VOC	Sources and Characteristics
Acetaldehyde[30]	• **Odour:** pungent and suffocating, fruity at low concentrations • **Sources:** food, pulp and paper production, lumber mills, oil and gas production, refining, vehicle emissions, wood burning, photochemical oxidation, cement kilns • **AAQO/EL:** 1-hour TCEQ EL, 90 µg m^{-3}
Acetone[27,31]	• **Odour:** sweet, fruity, mint-like • **Sources:** chemical and manufacturing industries, vehicle exhaust, biomass and plastics burning • **AAQO/EL:** 1-hour TCEQ EL, 5,900 µg m^{-3}
Acrolein	• **Odour:** intensive, acrid • **Sources:** gasoline and diesel, photo-oxidation of 1,3-butadiene, pulp mills, oil refineries, vehicle emissions, residential wood combustion, forest fires, cooking • **AAQO/EL:** 1-hour OEHHA EL, 2.5 µg m^{-3}
Alpha-pinene[32]	• **Odour:** woody, pine • **Sources:** vegetation, forest-based industries, manufactured products • **AAQO/EL:** 1-hour TCEQ EL, 60 µg m^{-3}
Benzaldehyde[33,34]	• **Odour:** almond-like • **Sources:** gasoline and diesel combustion, wood burning, forms in atmosphere (oxidation product of Styrene), manufactured products (detergents, perfume, carpet) • **AAQO/EL:** 1-hour TCEQ EL, 22 µg m^{-3}
Benzene[35,36]	• **Odour:** aromatic • **Sources:** vehicle emissions, petroleum/crude oil, natural gas condensates, coal, pulp and paper production, solvents, forest fires • **AAQO/EL:** 1-hour Alberta Environment AAQO, 30 µg m^{-3}

[30] HEI Air Toxics Review Panel (2007). Mobile-source air toxics: A critical review of the literature on exposure and health effects. HEI Special Report 16. Health Effects Institute, Boston , MA.
[31] Alberta Environment (2004). Assessment report on acetone for developing ambient air quality objectives.
[32] Stromvall and Petersson (1992). Terpenes emitted to air from TMP and Sulfite pulp mills. H*olzforschung*, 46(2):99-102.
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[34] NCBI (2009). Pubchem Compound Summary: Benzaldehyde. Available at: http://pubchem.ncbi.nlm.nih.gov/summary/summary.cgi?cid=240#x27
[35] Environment Canada and Health and Welfare Canada (1993). Canadian Environmental Protection Act. Priority Substances List Assessment Report: Benzene. ISBN 0-662-20434-4, Canada. 45pp.
[36] Alberta Environment (2012). Environment and Sustainable Resource Development. Webpage: http://environment.alberta.ca/01711.html

VOC	Sources and Characteristics
Beta-pinene	• **Odour:** see alpha-pinene • **Sources:** see alpha-pinene • **AAQO/EL:** 1-hour TCEQ EL, 64 µg m^{-3}
Butane[37]	• **Odour:** petroleum-like • **Sources:** natural gas/petroleum industry, activities involving gasoline combustion, manufactured products (propellant) • **AAQO/EL:** 1-hour TCEQ EL, 23,750 µg m^{-3}
Butyraldehyde (Butanal)[38]	• **Odour:** pungent • **Sources:** biogenic emissions, food, wood combustion, diesel exhaust, solvent, sewage treatment • **AAQO/EL:** 1-hour TCEQ EL, 14 µg m^{-3}
Camphene[39]	• **Odour:** aromatic, woody • **Sources:** pulp and paper production (by-product of alpha-pinene), fragrances, food additive • **AAQO/EL:** 1-hour TCEQ EL, 50 µg m^{-3}
Carbon Disulphide[40,41]	• **Odour:** rotting radishes (impure form), sweet (pure form) • **Sources:** oceans, soil, vegetation, used as a solvent in chemical and tire manufacturing, oil refineries, forest-related industries, gas plants, oil sands • **AAQO/EL:** 1-hour TCEQ EL, 30 µg m^{-3}
Ethane	• **Odour:** mild, gasoline-like • **Sources:** oil refineries, coal carbonization, vehicle emissions • **AAQO/EL:** <NA>
Ethanol (grain alcohol)[42]	• **Odour:** agreeable ethereal odour • **Sources:** vehicle emissions, ethanol and oil refineries, (gasoline additive), industrial applications (e.g. solvents and paints), manufactured goods (e.g. cleaners and polishes), microbes • **AAQO/EL:** 1-hour TCEQ EL, 18,800 µg m^{-3}
Ethylene[43]	• **Odour:** sweet • **Sources:** forest fires, fossil fuel combustion, natural gas processing, petroleum processing • **AAQO/EL:** 1-hour Alberta Environment AAQO, 1,200 µg m^{-3}

[37] Texas Commission on Environmental Quality (2012). n-Butane and Isobutane. Available at: http://www.tceq.state.tx.us/assests/public/implemntation/tox/dsd/proposed/jan12/butane.pdf

[38] US EPA (1994). Butyraldehyde Fact Sheet (CAS No. 123-72-8). Available at: http://www.epa.gov/chemfact/butyr-sd.txt

[39] Toxnet (2004). Camphene (CASRN: 79-92-5). Available at: http://toxnet.nlm.nih.gov/cgi-bin/sis/search/a?dbs+hsdb:@term+@DOCNO+900

[40] Environment Canada, Health Canada, 2000, Priority Substance List Assessment Report: Carbon Disulphide. ISBN 0-662-28496-8, Canada. 62 pp.

[41] Alberta Environment (2005). Ambient Air Quality Objectives, Carbon Disulphide.

[42] Australian Government (2010). National Pollutant Inventory. Fact sheets: ethanol. Available at: http://www.npi.gov.au/substances/factsheets.html

[43] Alberta Environment (2004). Ambient air quality objectives. Ethylene. Available at: http://environment.gov.ab.ca/info/library/6691.pdf

VOC	Sources and Characteristics
Hexanal[44]	• **Odour:** sharp, fruity, or green grass odour • **Sources:** vegetation, wood, pulp and paper mills • **AAQO/EL:** 1-hour TCEQ EL, 80 µg m^{-3}
Isobutane[45]	• **Odour:** faint petroleum-like odour • **Sources:** fuel, vehicle emissions, oil and gas production and refining, manufactured products (propellant) • **AAQO/EL:** 1-hour TCEQ EL, 4,800 µg m^{-3}
Methanol[46] **(Wood Alcohol)**	• **Odour:** pungent (crude form), alcohol (pure form) • **Sources:** vegetation, decaying wood, microbes, insects, sewage, pulp mills, petrochemical industry, vehicle emissions, manufactured products • **AAQO/EL:** 1-hour TCEQ EL, 2,600 µg m^{-3}
2-Methylbutane (Isopentane)[47]	• **Odour:** mild gasoline • **Sources:** petroleum refining, motor vehicle exhaust, trees and vegetation • **AAQO/EL:** 1-hour TCEQ EL, 3,500 µg m^{-3}
Methyl Vinyl Ketone (MVK)[48]	• **Odour:** pungent • **Sources:** photo-oxidation product of isoprene • **AAQO/EL:** 1-hour TCEQ EL, 6 µg m^{-3}
p-Cymene[32]	• **Odour:** turpentine-like • **Sources:** vegetation, pulp mills • **AAQO/EL:** 1-hour TCEQ EL, 2,750 µg m^{-3}
Propane	• **Odour:** odourless (common odour additive, ethyl mercaptan has odour of rotten eggs, cabbage) • **Sources:** natural gas processing, petroleum refining, fuel, manufactured products (fuel, propellant) • **AAQO/EL:** <NA>
Propylene[49]	• **Odour:** virtually odourless • **Sources:** petroleum refining, vegetation, forest fires, residential wood burning, cigarette smoke, vehicle exhaust • **AAQO/EL:** 1-hour OEHHA EL, 3,000 µg m^{-3}

[44] Hämäläinen et al. (2005). On the management of odour in chemical pulps: Formation and removal of hexanal. 59th Appita Conference, Auckland, New Zealand, 16-19 May 2005.
[45] Wu et al. (2006). Determination and impact of volatile organics emitted during rush hours in the ambient air around gasoline stations. *Journal of the Air & Waste Management Association*, 56(9): 1342-1348.
[46] US EPA (2000). Technology Transfer Network Air Toxics Web Site. Methanol. Available at: http://www.epa.gov/ttnatw01/hlthef/methanol.html
[47] Galvin et al 1999. 2-Methybutane (Isopentane). *Journal of Toxicology and Environmental Health, Part A: Current Issues*, 58(1-2): 23-33.
[48] Park et al 2011. Characteristics of the flux of isoprene and its oxidation products in an urban area. *Journal of Geophysical Research-Atmospheres*, 116:D21303.
[49] OEHHA (n.d.). Chronic Toxicity Summary. Propylene. Available at: http://oehha.ca.gov/air/chronic_rels/pdf/115071.pdf

Appendix C

Wind roses for periods prior to and during residential 1-hour sample collection.

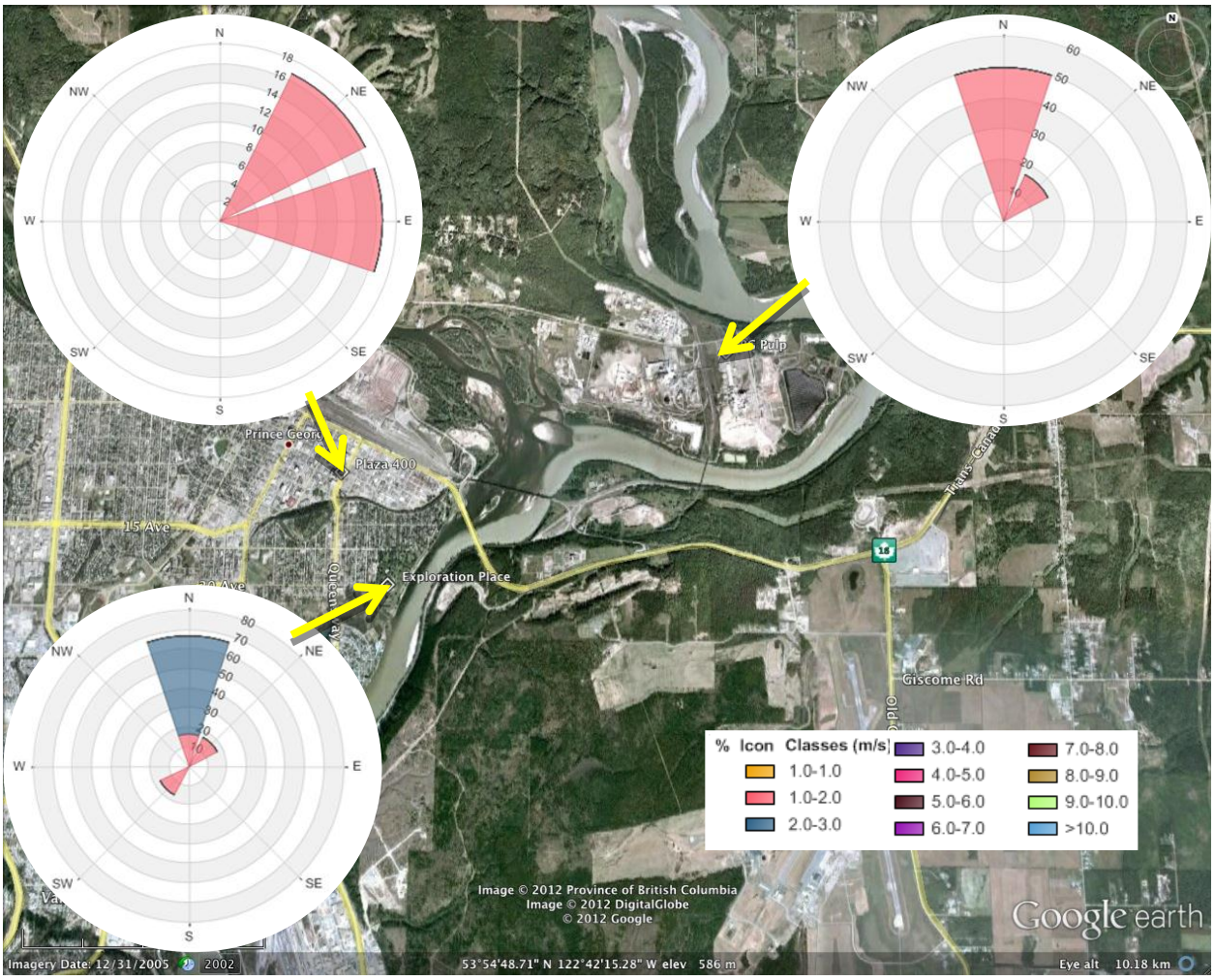


Figure A 1. Windroses at Plaza 400, Exploration Place, and PG Pulp. 9 March 2011, 0500-1000 PST. Calms (< 1 m s^{-1}), 67%, 17% and 33%, respectively. Sample collected 09:15-10:15 PST, acrolein concentration 1.69 µg m^{-3}. Yellow arrows point to actual station location.

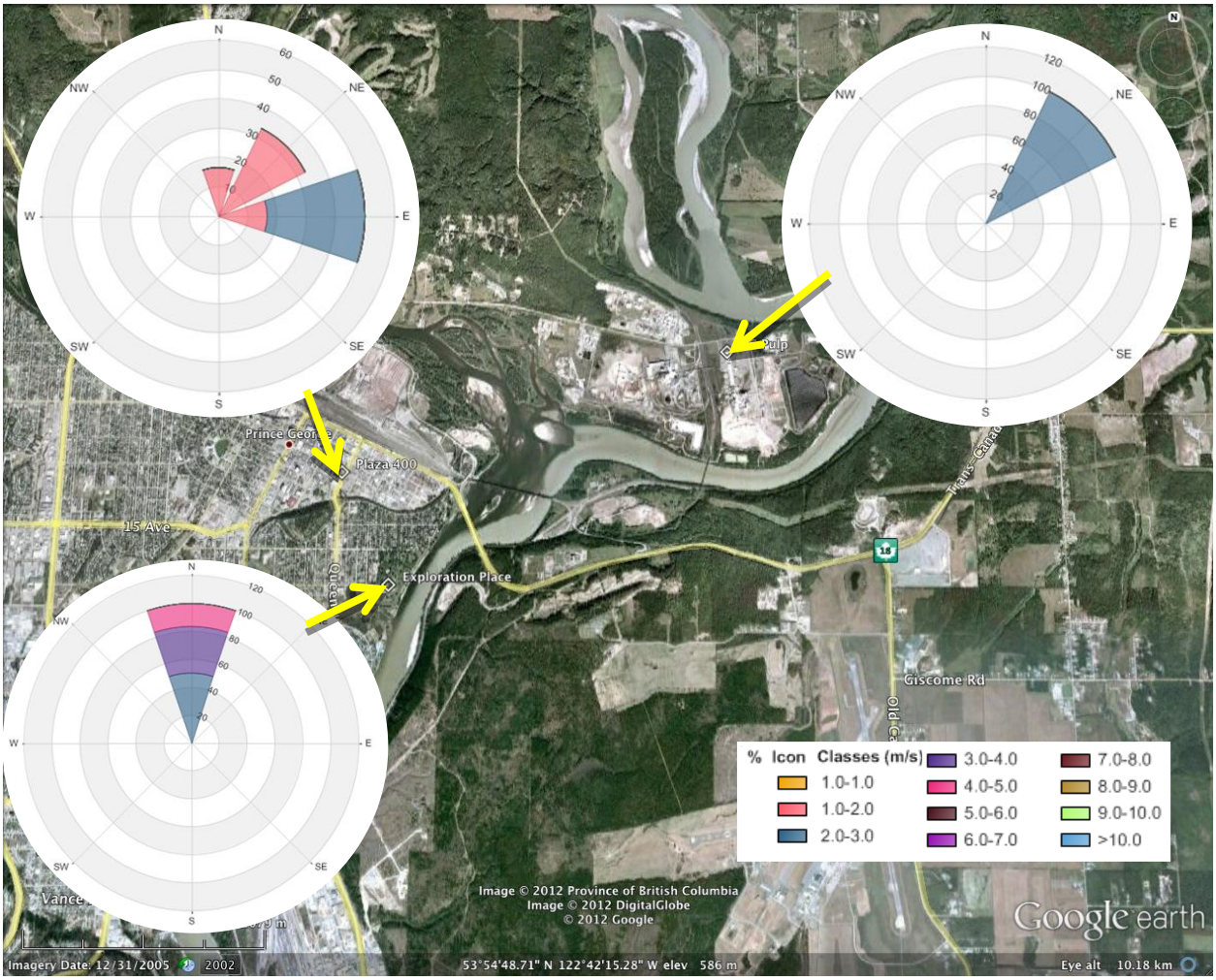


Figure A 2. Windroses at Plaza 400, Exploration Place, and PG Pulp. 10 March 2011, 0500-1000 PST. Calms (< 1 m s^{-1}) 0%, 0% and 0%, respectively. Sample collected 0825-0925 PST, acrolein concentration 1.31 µg m^{-3}. Yellow arrows point to actual station location.

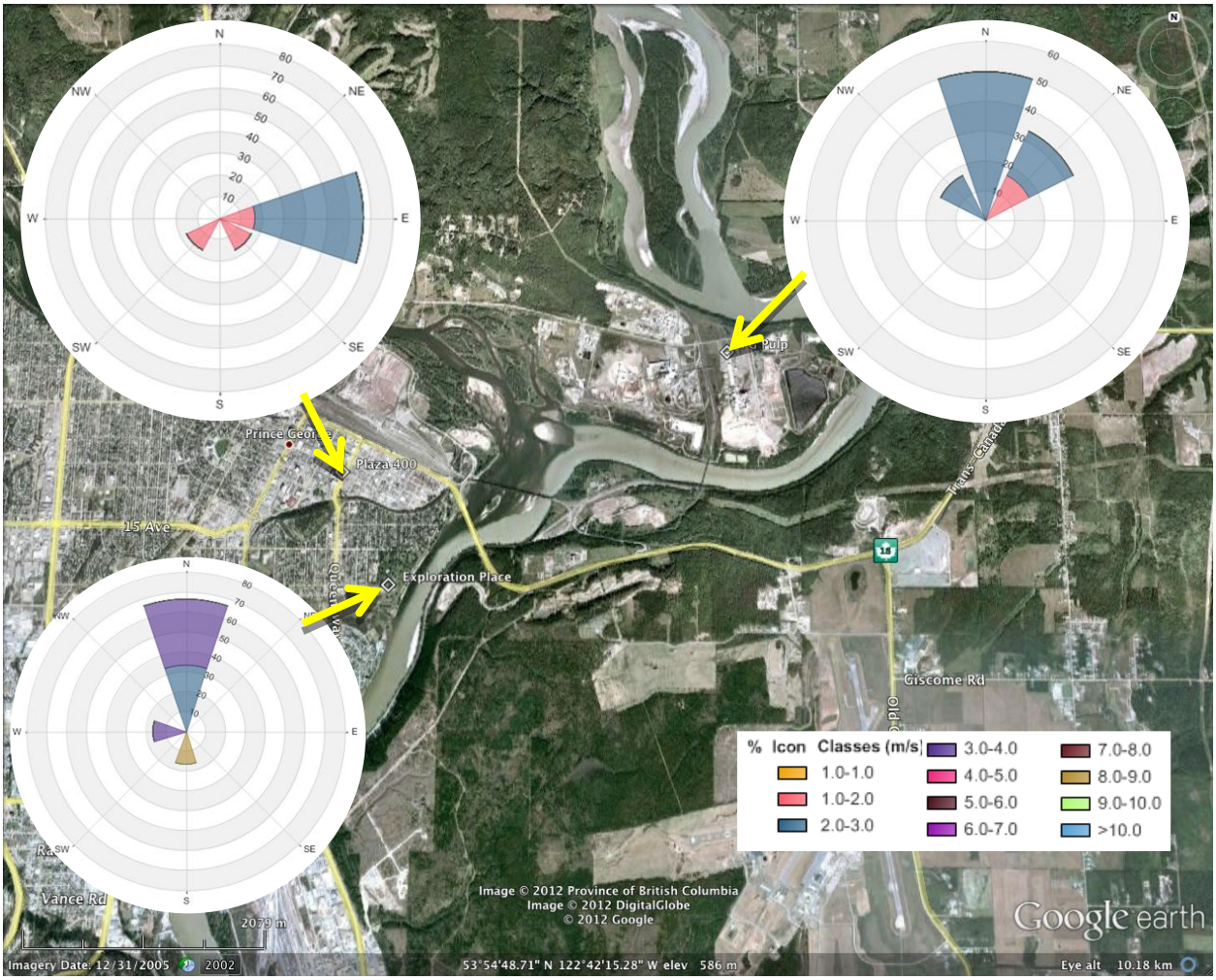


Figure A 3. Windroses at Plaza 400, Exploration Place, and PG Pulp. 15 March 2011, 0300-0800 PST. Calms (< 1 m s^{-1}) 0%, 0% and 0%, respectively. Sample collected 0633-0733 PST, acrolein concentration 2.92 µg m^{-3}. Yellow arrows point to actual station location.

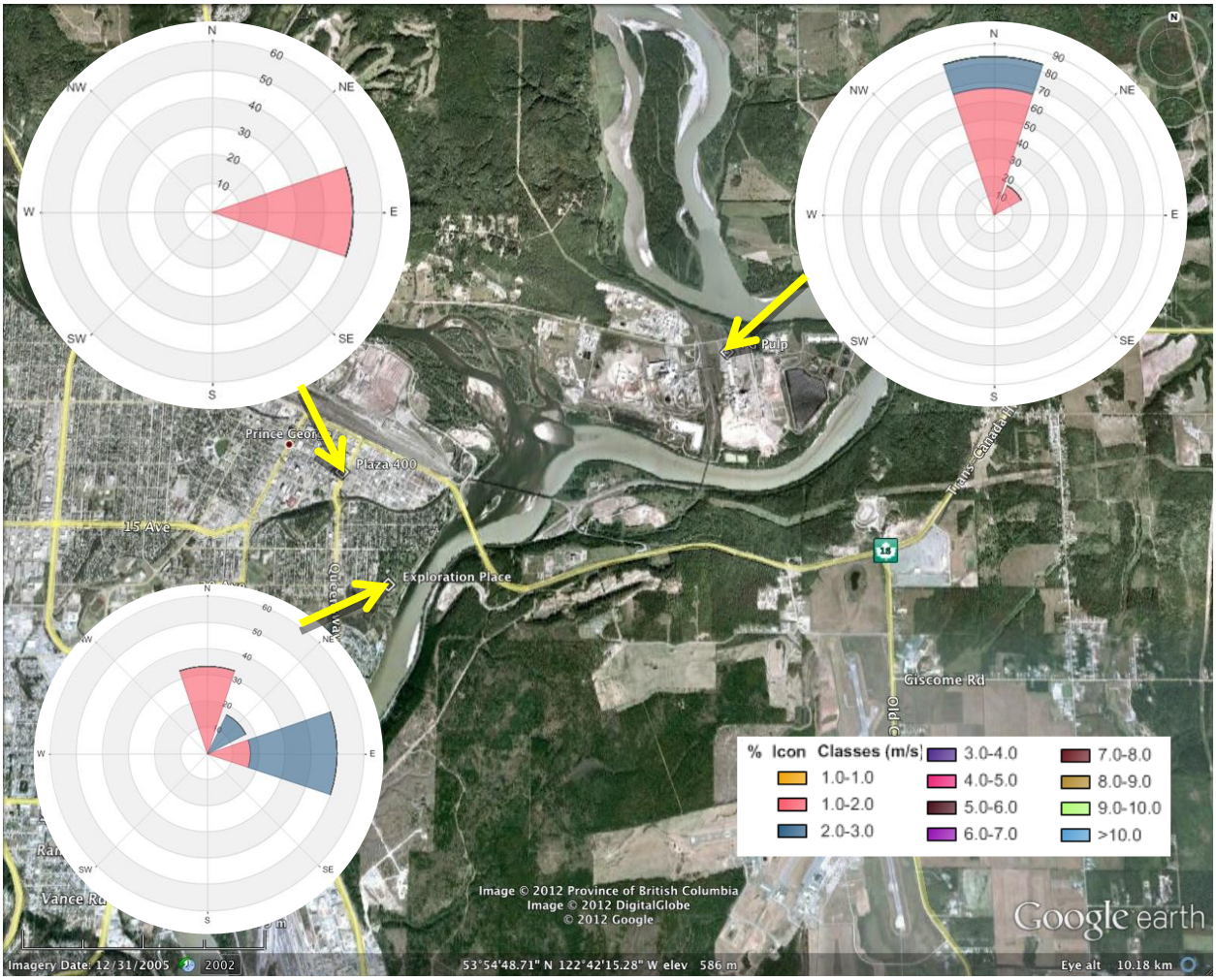


Figure A 4. Windroses at Plaza 400, Exploration Place, and PG Pulp. 19 May 2011, 0500-1000 PST. Calms (< 1 m s^{-1}) 50%, 0% and 0%, respectively. Sample collected 0828-0928 PST, acrolein concentration 0.38 µg m^{-3}. Yellow arrows point to actual station location.

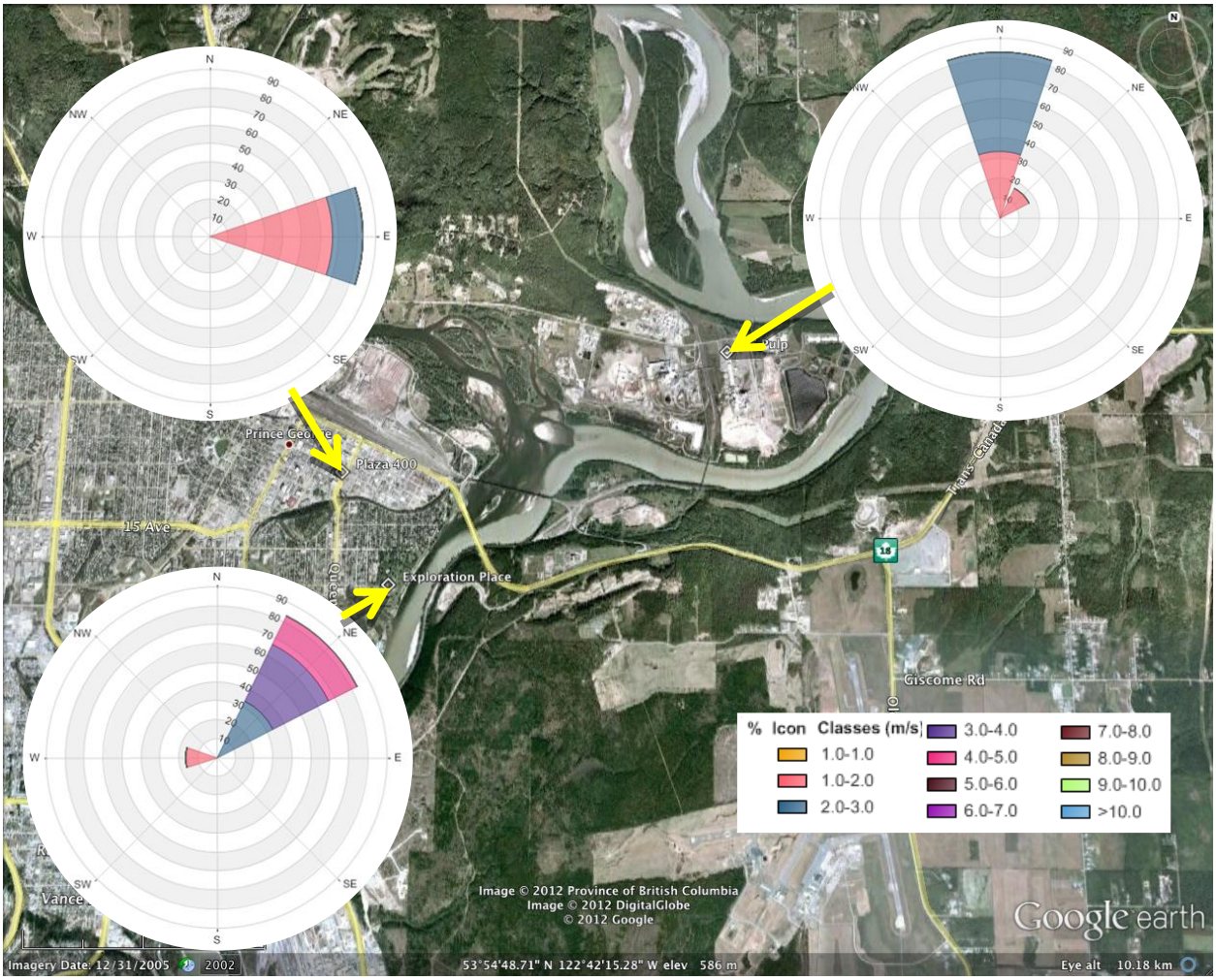


Figure A 5. Windroses at Plaza 400, Exploration Place, and PG Pulp. 23 November 2011, 0400-0900 PST. Calms (< 1 m s^{-1}) 17%, 0% and 0%, respectively. Sample collected 0744-0844 PST, acrolein concentration 2.09 µg m^{-3}. Yellow arrows point to actual station location.

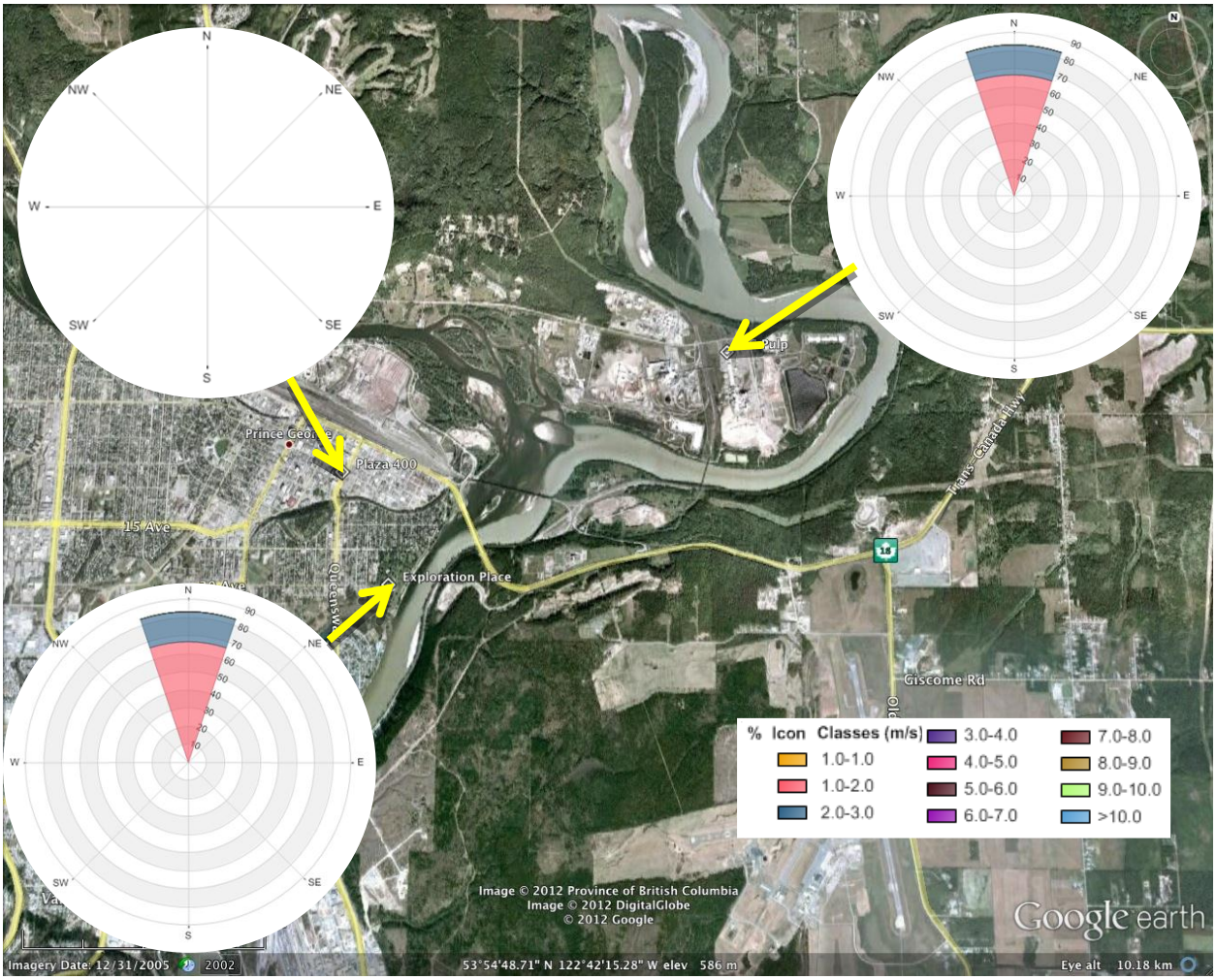


Figure A 6. Windroses at Plaza 400, Exploration Place, and PG Pulp. 5 December 2011, 0300-0800 PST. Calms (< 1 m s^{-1}) 100%, 17% and 17%, respectively. Sample collected, 0640-0740 PST, acrolein concentration 1.70 µg m^{-3}. Yellow arrows point to actual station location.

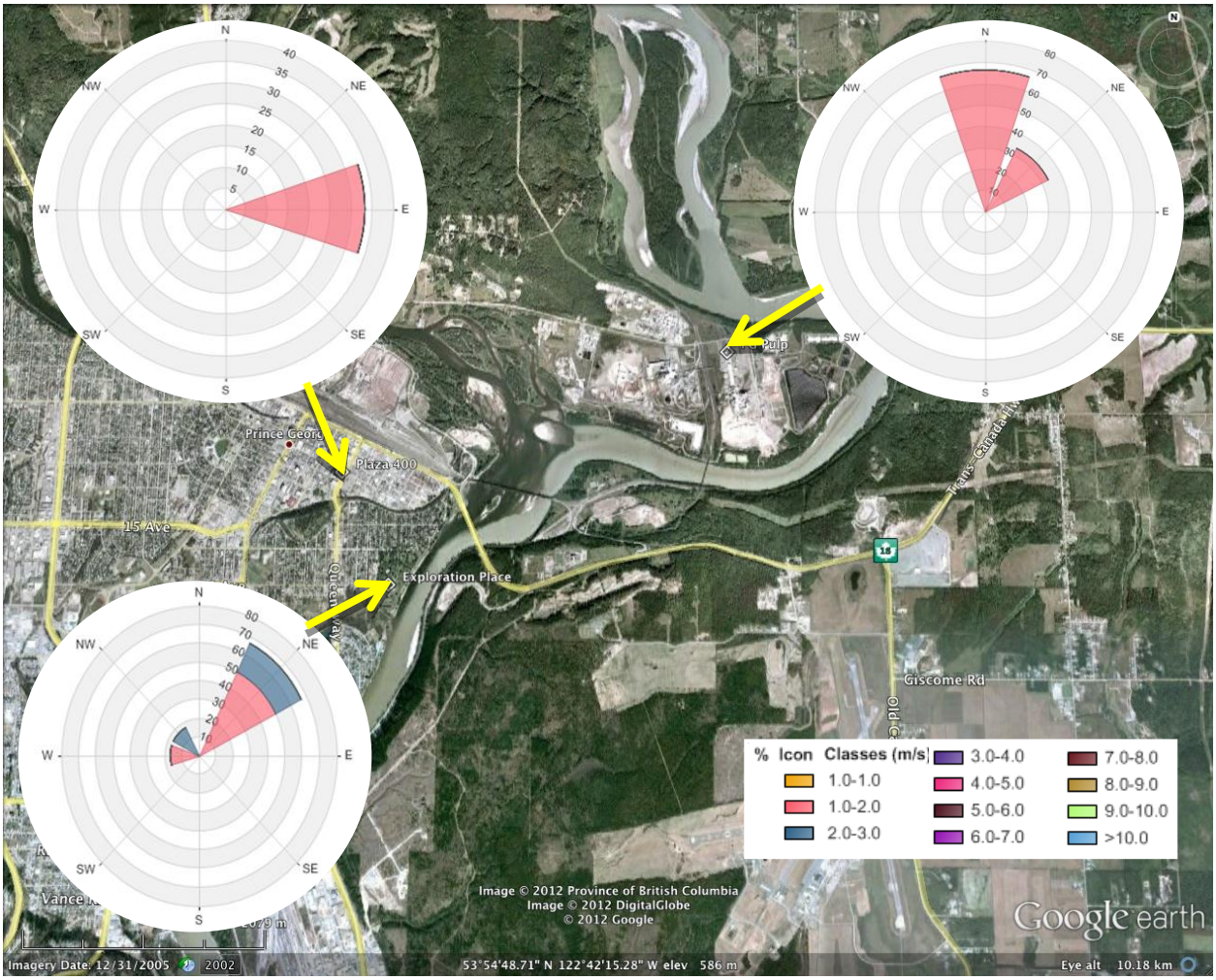


Figure A 7. Windroses at Plaza 400, Exploration Place, and PG Pulp. 14 December 2011, 0800-1300 PST. Calms (< 1 m s^{-1}) 67%, 0% and 0%, respectively. Sample collected, 1122-1222 PST, acrolein concentration 2.25 µg m^{-3}. Yellow arrows point to actual station location.

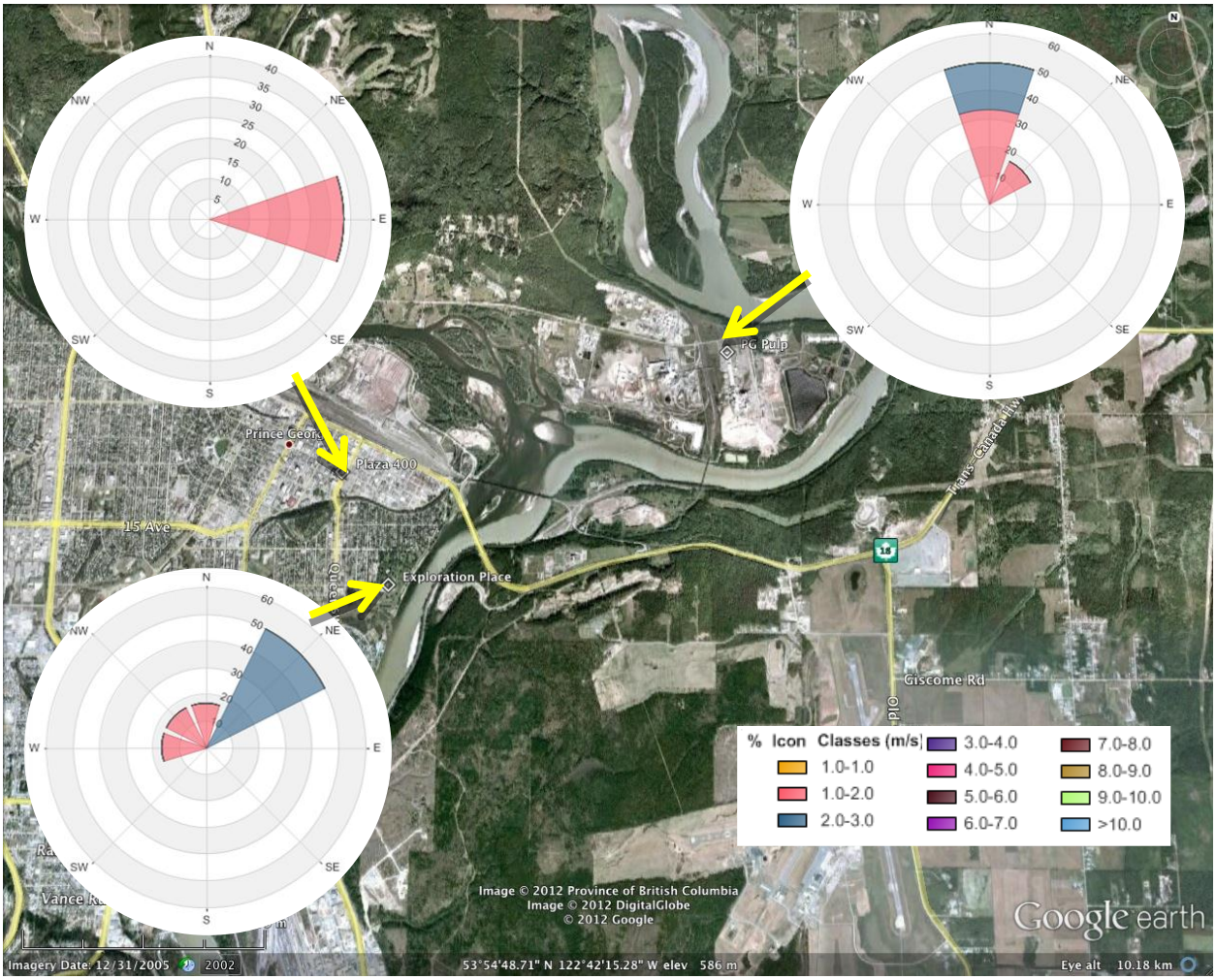


Figure A 8. Windroses at Plaza 400, Exploration Place, and PG Pulp. 15 February 2012, 0400-0900 PST. Calms (< 1 m s^{-1}) 67%, 0% and 33%, respectively. Sample collected, 1122-1222 PST, acrolein concentration 3.98 µg m^{-3}. Yellow arrows point to actual station location.

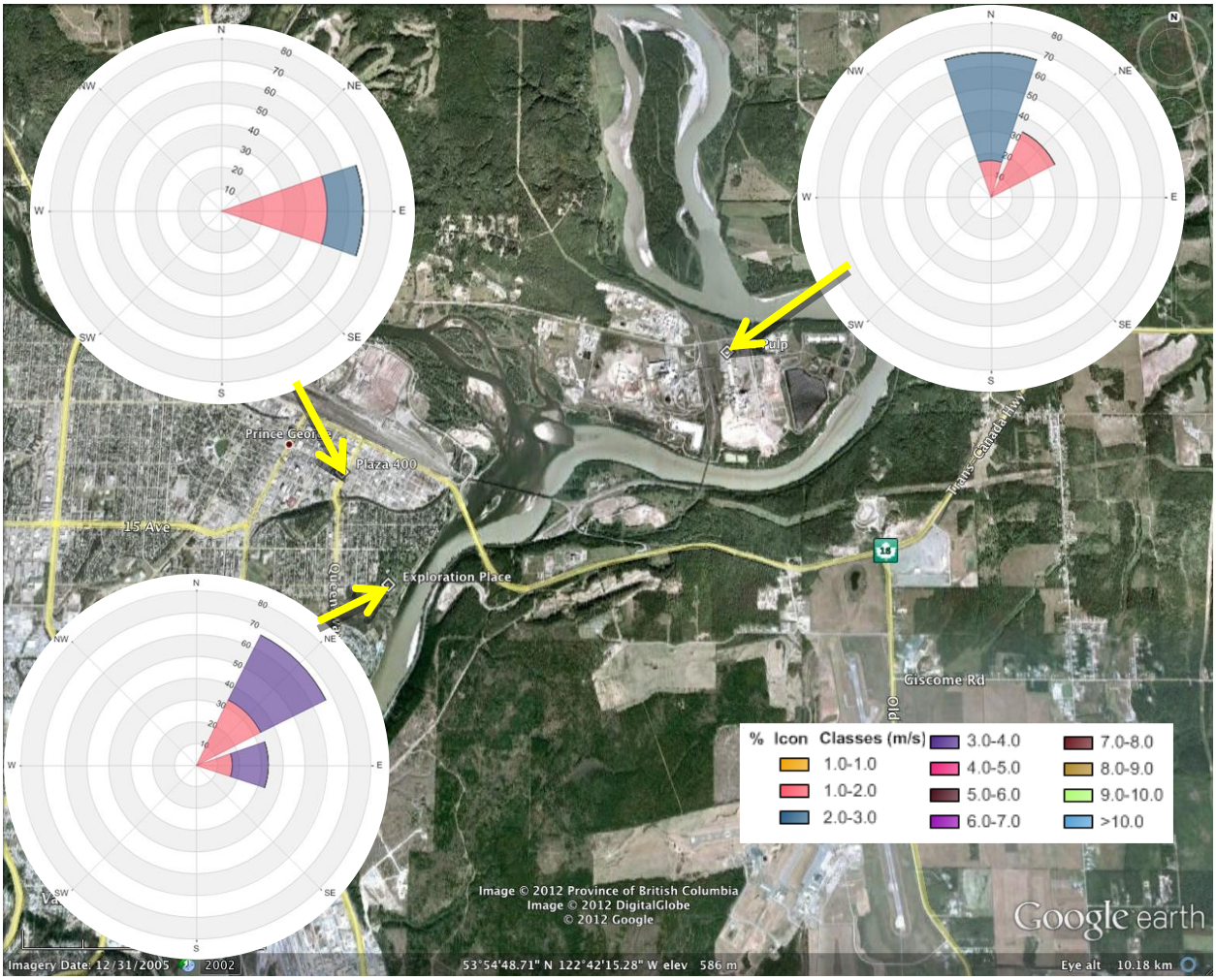


Figure A 9. Windroses at Plaza 400, Exploration Place, and PG Pulp. 28 February 2012, 1800-2300 PST. Calms (< 1 m s^{-1}) 33%, 0% and 0%, respectively. Sample collected, 2141-2241 PST, acrolein concentration 2.18 µg m^{-3}. Yellow arrows point to actual station location.

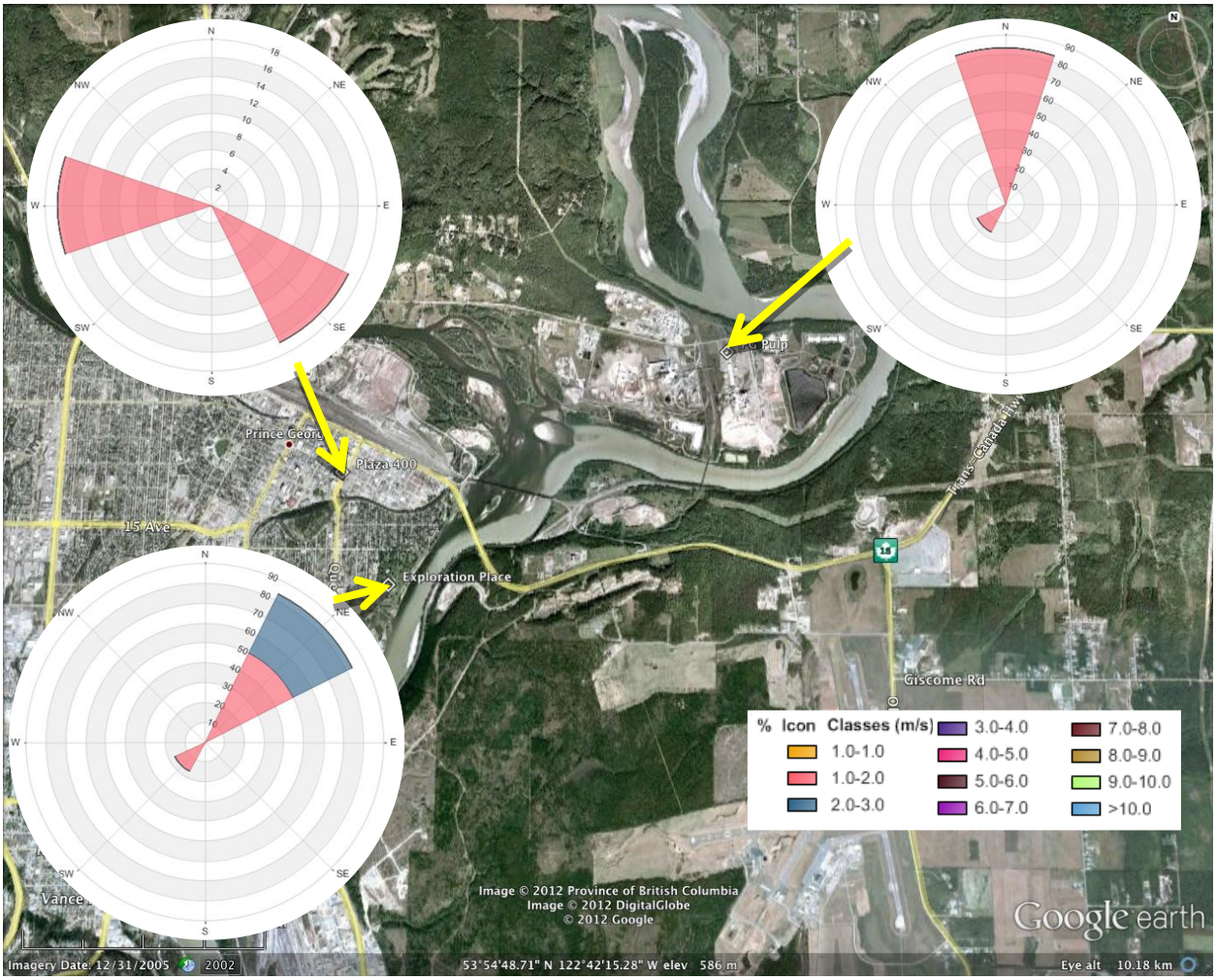


Figure A 10. Windroses at Plaza 400, Exploration Place, and PG Pulp. 11 April 2012, 0300-0800 PST. Calms (< 1 m s^{-1}) 67%, 0% and 0%, respectively. Sample collected, 0655-0755 PST, acrolein concentration 3.48 µg m^{-3}. Yellow arrows point to actual station location.

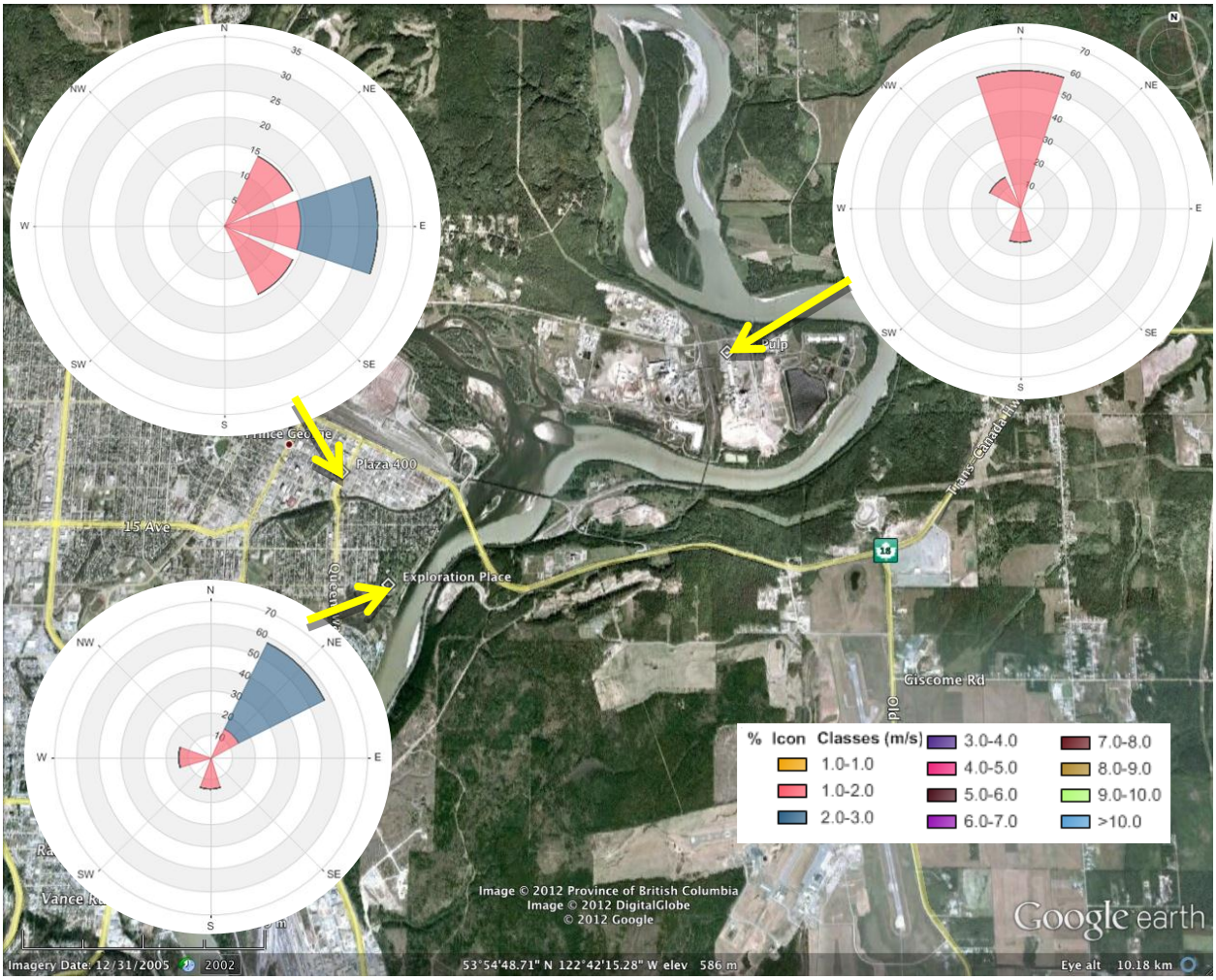


Figure A 11. Windroses at Plaza 400, Exploration Place, and PG Pulp. 1 June 2012, 0300-0900 PST. Calms (< 1 m s^{-1}) 43%, 14% and 14%, respectively. Samples collected, 0757-0857 PST and 0800-0900 PST, acrolein concentration 2.73 and 3.52 µg m^{-3}. Yellow arrows point to actual station location.