



## Analyzing tree cores to detect petroleum hydrocarbon-contaminated groundwater at a former landfill site in the community of Happy Valley-Goose Bay, eastern Canadian subarctic

Fonkwe, Merline L D; Trapp, Stefan

*Published in:*  
Environmental Science and Pollution Research

*Link to article, DOI:*  
[10.1007/s11356-016-6802-2](https://doi.org/10.1007/s11356-016-6802-2)

*Publication date:*  
2016

*Document Version*  
Peer reviewed version

[Link back to DTU Orbit](#)

*Citation (APA):*  
Fonkwe, M. L. D., & Trapp, S. (2016). Analyzing tree cores to detect petroleum hydrocarbon-contaminated groundwater at a former landfill site in the community of Happy Valley-Goose Bay, eastern Canadian subarctic. *Environmental Science and Pollution Research*, 23(16), 16137-16151. <https://doi.org/10.1007/s11356-016-6802-2>

---

### General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

1 Pre-print version. To get the final. printed version please see here:

2 <https://link.springer.com/article/10.1007%2Fs11356-016-6802-2>

3 DOI 10.1007/s11356-016-6802-2

4  
5 **Analyzing tree cores to detect petroleum hydrocarbon-contaminated groundwater at a former**  
6 **landfill site in the community of Happy Valley-Goose Bay, eastern Canadian subarctic**

7 Merline L.D. Fonkwe<sup>a\*</sup>, Stefan Trapp<sup>b</sup>

8 *<sup>a</sup> Labrador Institute, Memorial University of Newfoundland*

9 *219 Hamilton River Road, P.O. Box 490, Station B, Happy Valley-Goose Bay, NL, A0P 1E0,*

10 *Canada*

11 *<sup>b</sup> Department of Environmental Engineering, Technical University of Denmark,*

12 *2800 Kgs. Lyngby, Denmark*

13 *\* Corresponding author: E-mail address: [merline.fonkwe@mun.ca](mailto:merline.fonkwe@mun.ca) (M.L.D. Fonkwe)*

14 *Tel: +001 7098968589; Fax: +001 7098962970*

15

16 **Abstract**

17 This research examines the feasibility of analyzing tree cores to detect BTEX compounds and  
18 MTBE in groundwater in eastern Canada subarctic environments, using a former landfill site in the  
19 remote community of Happy Valley-Goose Bay, Labrador. Petroleum hydrocarbon contamination at  
20 the landfill site is the result of environmentally unsound pre-1990's disposal of households and  
21 industrial solid wastes. Tree cores were taken from trembling aspen, black spruce and white birch  
22 and analyzed by headspace-gas chromatography-mass spectrometry. BTEX compounds were  
23 detected in tree cores, corroborating known groundwater contamination. A zone of anomalously  
24 high concentrations of total BTEX constituents was identified and recommended for monitoring by  
25 groundwater wells. Tree cores collected outside the landfill site at a local control area suggest the  
26 migration of contaminants off-site. Tree species exhibit different concentrations of BTEX  
27 constituents, indicating selective uptake and accumulation. Meanwhile, MTBE was not found in the  
28 tree cores and is considered to be absent in the groundwater. The results demonstrate that tree-core  
29 analysis can be useful for detecting anomalous concentrations of petroleum hydrocarbons, such as  
30 BTEX compounds, in subarctic sites with shallow unconfined aquifers and permeable soils. This  
31 method can therefore aid in the proper management of contamination during landfill operations and  
32 after site closures.

33 **Keywords:** Labrador; solid waste disposal; organic pollutants; phytoscreening; BTEX compounds;  
34 MTBE; preliminary site assessments; remote location

35

## 36 **1. Introduction**

37 Landfilling remains the most prevalent method of organized solid waste disposal in remote  
38 communities of the eastern Canadian subarctic (Ryan 2010; Zagozewski et al. 2011). There has been  
39 and continues to be substantial environmental controversy surrounding landfilling practices (El-  
40 Fadel et al. 1997; Rowe et al. 1997), though solid waste disposal facilities have evolved from  
41 uncovered and unlined landfills or open dumps to modern engineered landfills (e.g. Barrett and  
42 Lawler 1995; Slack et al. 2005; Eggen et al. 2010). However, subsurface pollution may occur at any  
43 time during landfills' active and post-closure phases (Allen 2001; Sawhney and Kozloski 2004).  
44 This represents a human health and environmental hazard, which requires control measures by solid  
45 waste management and pollution control authorities (Christensen et al. 2001; Fatta et al. 1999;  
46 Kjeldsen et al. 2002; Manfredi et al. 2009). In order to better evaluate the pollution risks posed by  
47 leachate emissions from landfills into the underlying soil and groundwater, and to inform corrective  
48 or remedial actions, such sites must be characterized and monitored long-term (Cifrian et al. 2013;  
49 El-Fadel et al. 2001; Laner et al. 2011). The traditional technique of sampling (soil via boreholes  
50 and groundwater via monitoring wells) is extremely costly, technically difficult, and time-  
51 consuming to implement, particularly at remote subarctic sites. Therefore, attention is increasingly  
52 being given to tree-core analysis, as a simple and cost-effective field-screening approach that can  
53 successfully identify and vector borehole and well drilling towards possible zones of subsurface  
54 contamination (Algreen et al. 2015; Burken et al. 2011; Vroblesky et al. 1999).

55 Tree-core analysis (also referred as to phytoscreening) has been used in environmental science  
56 to detect and monitor subsurface contamination by a variety of volatile organic compounds (VOCs)  
57 since the pioneering research by Vroblesky et al. (1999). Trees take up compounds through their  
58 roots, bark, or leaves and can incorporate the compounds into their cells; therefore, the chemistry of  
59 soil, groundwater and atmosphere can be inferred via the analysis of tree tissues (Cutter and Guyette

60 1993; Padilla and Anderson 2002). To date, compared to the attention paid to chlorinated ethenes,  
61 few studies have analyzed tree cores to assess soil and groundwater contamination by petroleum  
62 hydrocarbon constituents, like benzene, toluene, ethylbenzene and m, p, o-xylenes (collectively  
63 referred to as BTEX) or methyl tertiary-butyl ether (MTBE) or both (Algreen 2015; Algreen et al.  
64 2015; Holm 2011; Landmeyer et al. 2000; Rein and Trapp 2009; Sorek et al. 2008; Trapp et al.  
65 2005; Weishaar et al. 2009). The studies undertaken were all located in temperate, subtropical, or  
66 mediterranean regions, and they have met with some success in providing the semi-quantitative data  
67 needed for preliminary site evaluations, especially for BTEX compounds. Besides the practical and  
68 financial convenience, another crucial advantage of tree-core analysis is that because of its root  
69 system, a single tree can take up compounds from a much larger area (many cubic meters of soil and  
70 groundwater) than a single traditional soil or groundwater sample (Dunn 2007). Nonetheless, the  
71 applicability of tree-core analysis must be evaluated site by site, because compound uptakes by trees  
72 depend on site-specific conditions, the physiological characteristics of the tree species used, and the  
73 properties of the contaminants in question (Cutter and Guyette 1993; Trapp 2007).

74 The feasibility of using tree-core analysis to detect subsurface contamination by VOCs has not  
75 been studied in the eastern Canadian subarctic. This study therefore aimed to determine whether the  
76 analysis of tree cores could be useful in this context, using the most common deciduous and  
77 coniferous tree species to assess concentrations of subsurface BTEX compounds and MTBE at a  
78 former landfill site in the remote, subarctic community of Happy Valley-Goose Bay in Labrador. If  
79 substantiated as a valuable approach, tree-core analysis could be integrated into preliminary site  
80 evaluations of possible subsurface contamination at other old or still operational landfills and other  
81 facilities in efforts to minimize negative impacts on the environment and public health. In addition,  
82 this paper compiles and describes the data available in open literature to provide, in conjunction  
83 with the present study, a foundation for the application of tree-core analysis to track subsurface  
84 pollution by petroleum hydrocarbons.

## 85 2. Materials and methods

### 86 2.1. Description of the study area

87 Happy Valley-Goose Bay is a small, remote community in the province of Newfoundland and  
88 Labrador in Canada, at the western extremity of Lake Melville, an inlet of the Labrador Sea (53°30'  
89 N and 60°41' W; Fig. 1). It covers an area of 306 km<sup>2</sup> and has a population of 7552 (Government of  
90 Canada's 2011 census). The climate is subarctic, marked by heavy snowfall from November to  
91 March with snow covering the ground from November to May and high rainfall from June to  
92 September (average annual precipitation of 762 mm). The average daily temperatures remain below  
93 freezing from November to April and vary between -17.6°C and 15.5°C  
94 ([https://weather.gc.ca/canada\\_e.html](https://weather.gc.ca/canada_e.html)). Surficial geology is composed of Quaternary marine and  
95 fluvial sediments to a depth of about 100 m, consisting dominantly of fine- to medium-grained sands  
96 and interbedded marine silts and clay, overlying a conglomerate and sandstone sequence (Liverman  
97 1997; Nunn and van Nosttrand 1996; Wardle and Ash 1986). Bedrock is composed of a  
98 Paleoproterozoic anorthosite-mangerite-charnockite-granite suite and the massif anorthosite of the  
99 Cape Caribou River Allochthon (Valvasori et al. 2015; Wardle and Ash 1986).

100 The community of Happy Valley-Goose Bay is home of the Canadian Force Base (CFB) 5  
101 Wing Goose Bay. This military air force base was constructed in 1941 on a flat-lying terrace, which  
102 has an elevation between 40 to 50 m (a.s.l.) and is bordered by the Terrington Basin to the north and  
103 the Churchill River to the south (Fig. 1). It played an important role as a refuelling base to facilitate  
104 transatlantic flights during World War II and afterwards supported low-level flight training, air-  
105 defence exercises and bombing practices for the North Atlantic Treaty Organization (Wells 2013).  
106 CFB 5 Wing Goose Bay remained a strategic military air base until 1987 and still continues today to  
107 support allied low-level flight training and multinational flying operations. Before 1990, a variety of  
108 residential and industrial wastes generated at CFB 5 Wing Goose Bay were disposed of on-site at

109 several dumping areas making up a poorly-regulated and unlined landfill along the escarpment at the  
110 south-southeast boundary of the military property (AMEC 2009; JWEL 1992; Fig.1).

## 111 2.2. *Landfill site: physiography and hydrogeology*

112 The landfill site covers approximately 6 km<sup>2</sup> of low-lying land at an average elevation of 10 m  
113 (a.s.l.). It has received mainly drums/containers of motor oil, petroleum hydrocarbons, such as  
114 gasoline, jet and diesel fuels, lubricants and pesticides, and also construction and demolition debris  
115 and household wastes from approximately 1941 to 1990 (Figs. 1 and 2; JWEL 1992; BFA 1996).  
116 The refuse was covered at different points of time with sand (JWEL 1992); however, surface  
117 metallic debris is still visible (Fig. 3). The vegetation is dominated by grasses and locally forested  
118 areas, which consist of a mixture of coniferous and deciduous trees. Depth to groundwater averages  
119 2.5 m and in several locations, groundwater intercepts the land surface and forms wetlands (swamps  
120 and marshes) with a number of elongated surface water bodies, collectively named stillwater  
121 (AMEC 2009; Fig. 2). Groundwater is unconfined and flows south to southeast towards the  
122 Churchill River, following low topography (see Fig. 2). The hydraulic conductivity of saturated  
123 subsurface layers at the landfill site ranges from  $3.6 \times 10^{-5}$  m/s to  $1.0 \times 10^{-2}$  m/s (AMEC 2009;  
124 2011). Horizontal hydraulic gradients across the Landfill site averaged to 0.001 m/m. Vertical  
125 hydraulic gradients at the well nest locations ranged from 0.009 m/m to 0.136 m/m (AMEC, 2009).

126 Assessments of the landfill site since 1991 have revealed that it is contaminated by petroleum  
127 products, polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), pesticides,  
128 and heavy metals (AMEC 2011:2009; BFA 1996; JWEL 1992). Clean-up activities have been  
129 undertaken since 1993 with the removal of several thousands of drums/containers, many still with  
130 residual contents; however, an unknown number of drums remains buried at the site (AMEC 2009;  
131 BFA 1996; Curtis and Lammey 1998; Wells 2013). Total BTEX concentrations up to 2744 mg/L  
132 have been obtained from discarded fuel drums (JWEL 1992). Nests of groundwater monitoring

133 wells have been installed at selected parts of the landfill site. Two separate plumes of BTEX  
134 compounds have been identified cross-cutting stillwater #4 (AMEC 2009; FEI 2006; Fig. 2). There,  
135 measured groundwater samples have indicated concentration ranges of 2.0 – 990.0 µg/L for  
136 benzene, 6.5 – 27.9 µg/L for toluene, 0.7 – 27.9 µg/L for ethylbenzene and 2.0 – 17.1 µg/L for total  
137 xylenes; MTBE was not detected (AMEC 2011: 2009; FEI 2006).

### 138 2.3. *Field sampling*

139 Tree-core samples were taken in the eastern portion of the landfill site (Fig. 2). This area is of  
140 concern because initial site investigations found VOCs (including BTEX compounds), PAHs, heavy  
141 metals, and pesticides in both groundwater (from test pits; locations not shown) and surface water  
142 (including samples from the stillwaters); VOCs and PAHs in groundwater exceeded the applicable  
143 Groundwater Quality Standards (AMEC 2009: 2011; FEI 2006). Therefore, continued monitoring is  
144 necessary for risk management and/or mitigation. This area is easy to access and has experienced  
145 only minimally invasive remediation activities, which have preserved mature trees, suitable for use  
146 in tree-core analysis approach (Cutter and Guyette 1993).

147 The site-specific background conditions (i.e. diffuse anthropogenic influences) of the  
148 subsurface environment are unknown, as are those of the study area in general. Moreover, it was  
149 impossible to confidently assign a typical background location within the study area where the  
150 physical and environmental characteristics were representative of the site overall. Nonetheless, a  
151 local control site located outside of the landfill site at about 2 km downstream towards the south-  
152 southeast was selected for the collection of additional tree-core samples (Fig.1), to assess the  
153 possibility of the landfill site contributing to off-site contaminant levels nearby.

### 154 2.4. *Tree-core collection and handling*

155 Tree-core samples were collected on three days, between 18 August 2014 and 2 September  
156 2014, according to the criteria and established procedures by Cutter and Guyette (1993), Holm et al.



157 (2011) and Vroblesky (2008). During sampling, the weather was dry with low wind (6 – 22 km/h)  
158 and daily temperatures ranged between 14°C and 24°C. Mature (stem diameter between 18 and 39  
159 cm) and visibly healthy trees were sampled randomly at the landfill site, including 20 trembling  
160 aspens (*Populus tremuloides*), 15 black spruces (*Picea mariana*) and 9 white birches (*Betula*  
161 *papyrifera*) (Fig. 2). In addition, tree-core samples were taken from 3 trembling aspens and 4 black  
162 spruces at the local control site. Core samples were extracted from the north or northwest side of  
163 each tree (the side facing the direction of groundwater flow), using a 35.5 cm long, 5.15 mm  
164 diameter increment tree-corer (Haglöf®). Tree cores 8 cm in length were taken at a height of about 1  
165 m above the ground surface, the bark was discarded and the wood quickly broken into several  
166 smaller pieces, then placed into 20 mL glass screw-top vials sealed with PTFE-lined septum caps  
167 (Gerstel®). The vials were immediately stored in an iced cooler container in the field and transferred  
168 into a 4°C refrigerator at the end of each day for overnight storage. The following day, the core  
169 samples were freighted by air in an iced cooler box at Memorial University of Newfoundland in St.  
170 John's (Fig. 1) for analysis. Further details are given in the Supplementary Material.

### 171 2.5. *Tree-core analysis*

172 Concentrations of BTEX compounds and MTBE in tree-core samples were determined by  
173 headspace-gas chromatography-mass spectrometry (HS-GC-MS) using an Agilent 6890N gas  
174 chromatograph equipped with a 5975C mass selective detector and a DB-624 capillary column (see  
175 Supplementary Material). Upon receipt in the laboratory the same or next shipping day, the core  
176 samples were either prepared for immediate analysis or stored at 4°C until analysis within 3 to 5  
177 days of sampling. Before analysis, core samples were allowed to equilibrate in the vials for 24 hours  
178 at room temperature (21°C). To generate calibration curves, standard solutions were prepared in  
179 concentration ranges of 0.4 – 10 µg/L for MTBE and all the BTEX constituents, along with 10 – 400  
180 µg/L for toluene from a certified reference material (CRM47505 Supelco®) diluted in deionized

181 water (see Supplementary Material). The vials were heated at 70°C in an incubator for 30 minutes  
182 under gentle shaking and 200 µL volume of headspace was extracted from each vial using a heated  
183 gas-tight syringe and immediately injected into the GC instrument for analysis. The m- and p-  
184 xylenes could not be resolved and were measured together. The calibration curves (peak areas of  
185 quantification ions vs. concentration of standards in aqueous phase) were linear ( $R^2 > 0.996$ ).  
186 Results for the core samples containing the compounds of interest at a concentration below 0.4 µg/L  
187 (lower end of the calibration interval) were reported as such (< 0.4 µg/L) if the signal to noise ratio  
188 was higher than 3; in this case 0.4 µg/L represents the quantification limit (QL). If the signal to  
189 noise ratio was lower than 3, the results were reported as below the detection limit (< DL). The  
190 recovery efficiency of MTBE and BTEX compounds was tested by spiking four core samples from  
191 white birch trees with 1 mL of the prepared standard solution at a concentration of 4.0 µg/L.  
192 Recoveries ranged from 29% to 77% and were related to the octanol-water partition coefficients of  
193 the compounds (see Supplementary Material for details). No correction for recovery was performed  
194 since semi-quantitative data from tree-core analyses are in themselves sufficient for field screening  
195 of groundwater contamination by VOCs (e.g. Algreen et al. 2015; Vrobesky 2008). Contaminant  
196 concentrations in core samples are reported in units of micrograms per liter of headspace. 10 µg/L  
197 corresponds to about 0.288 mg/kg in dry wood. Any resulting values below the QL were assigned to  
198 half QL for representation purpose (see Table 1, 2 and 3).

## 199 2.6. *Data quality assessment*

200 The quality of sampling, sample handling and analytical data was monitored by collecting travel  
201 blanks, field trip blanks, air blanks and field duplicates (details in Supplementary Material). Trace  
202 amounts (almost all values < QL) of toluene, ethylbenzene and xylenes were detected in travel  
203 blanks; BTEX components were also detected in field trip blanks with values also lower than the  
204 laboratory QL. This suggests that the core samples may have been contaminated by the Styrofoam

205 containers used for shipping the core samples (details in Supplementary Material). However, this  
206 was found to have no significant effect on the analytical results of the tree-core samples and  
207 therefore, blanks corrections were not applied. Air samples at the vicinity of the trees contained  
208 trace amounts (all values < QL) of BTEX components with limited presence of benzene. Obtained  
209 results for field duplicate pairs, collected approximately 1 cm vertically apart at selected trees, show  
210 good repeatability with relative standard deviation (RSD) up to 5% for 5 of the 6 field duplicate  
211 pairs (see Table 1 and 2).

### 212 **3. Results and Discussion**

#### 213 *3.1 Concentrations of the BTEX compounds in tree cores*

214 BTEX compounds were identified, in general, in tree-core samples at both the landfill site and  
215 the local control site. At the landfill site (Table 1), benzene concentrations were generally low (0.20  
216  $\mu\text{g/L}$ ) with only two core samples having higher values, of 1.1  $\mu\text{g/L}$  and 2.3  $\mu\text{g/L}$  respectively. In  
217 contrast, toluene content is much higher with the concentrations in the majority of the samples (40  
218 in the range 0.40  $\mu\text{g/L}$  to 137  $\mu\text{g/L}$ ; the remaining samples (16) have a toluene concentration of 0.20  
219  $\mu\text{g/L}$ . Ethylbenzene was identified in small amounts with the majority of the core samples having a  
220 concentration of 0.2  $\mu\text{g/L}$ ; only one sample yielded a concentration of 0.93  $\mu\text{g/L}$ . When detected,  
221 the content of m- and p-xylene was 0.40  $\mu\text{g/L}$  in most of the samples (31), with only one sample  
222 having a concentration of 1.13  $\mu\text{g/L}$ . In comparison with other BTEX constituents, the occurrence of  
223 o-xylene was less frequent and restricted to fewer samples (10) at a concentration of 0.20  $\mu\text{g/L}$ .

224 At the local control site (Table 2), on the other hand, the concentrations were low but similar to  
225 those obtained at the landfill site for benzene (0.20  $\mu\text{g/L}$ ) and ethylbenzene (0.20  $\mu\text{g/L}$ ), and for m-  
226 and p-xylene (0.40  $\mu\text{g/L}$ ), which were detected only in some core samples. As for toluene, it was  
227 found at the highest concentration when compared with the other BTEX constituents. Toluene

228 content in most of the samples ranged between 1.1 µg/L to 40.2 µg/L, whereas low toluene  
229 concentrations of 0.20 µg/L were also measured in aspen core samples.

230 At the landfill site, all tree species contained detectable concentrations of all or selected BTEX  
231 compounds in varied proportions. This is supported by the measurement tests of groundwater and  
232 surface water in the sampling area (Serco 2001; AMEC 2011). In October 2000, elevated BTEX  
233 with maximum concentration of 1180 µg/L for benzene and 13 µg/L for Ethylbenzene, was  
234 observed in the groundwater from test pits (locations not shown) at the head of stillwater #1,  
235 encompassing trees nos. 3, 5, 13, 4, 30 and 31 (Serco 2001; see Figs. 2 and 4). Further sampling  
236 program in February 2010, indicated BTEX contamination in groundwater samples in the area  
237 around stillwater #2, enclosing trees nos. 15, 8, 1, 9 and 7; measured groundwater samples indicated  
238 concentration ranges of 0.5 – 14.0 µg/L for benzene, 0.3 – 31.0 µg/L for toluene, 0.6 – 5.4 µg/L for  
239 ethylbenzene and 0.26 – 37.0 µg/L for total xylenes (AMEC 2011). Moreover, although low, the  
240 concentrations of BTEX in tree-core samples were corroborate groundwater results in the vicinity of  
241 the sampling area (Fig. 2: AMEC 2011: 2009). This is expected because plants such as trees are  
242 passive samplers of subsurface contaminants and they have the ability to sample a much larger area  
243 than that afforded by groundwater samples (Dunn 2007). This suggests that groundwater BTEX  
244 concentration is the primary factor governing the concentrations obtained from tree-core samples at  
245 this site. As for the local control area, the BTEX compounds in tree-core samples indicate the  
246 possible migration of contaminants from the landfill site. Probable contaminant migration off-site  
247 has previously been mentioned by the appropriate authorities (in newspaper archives), who have  
248 urge the abandonment of agricultural lands adjacent to the local control area.

249 These findings demonstrate that tree-core analysis can indeed be used to detect BTEX  
250 contaminated shallow groundwater (~2.5 m deep) in subarctic environments, much as in  
251 mediterranean and temperate environments, as shown by Algreen et al. (2015) and Sorek et al.

252 (2008), who used core samples from eucalyptus (*Eucalyptus camaldulensis*) and rosewood  
253 (*Dalbergia sisso*), and willow (*Salix* sp.) and aspen (*Populus tremula*), respectively. The low content  
254 of BTEX in the tree cores might be due to BTEX degradation (Sorek et al. 2008). Studies on  
255 phytoremediation of petroleum products confirm a relatively rapid break-down of petroleum  
256 hydrocarbons, including BTEX, in the root zones of tree stands and soil profiles under natural  
257 aerobic conditions (Nichols et al. 2014; Wilson et al. 2013).

### 258 3.2 *Spatial distribution of the sum BTEX in tree cores*

259 The normal quantile – quantile (Q – Q) plot was used to identify the background threshold  
260 value (and anomalous values) of the sum BTEX concentrations in tree-core samples (e.g. Reimann  
261 et al. 2005; Papastergios et al. 2011). Two different populations were identified using changes  
262 (breaks) in the slope of a probability plot of sum BTEX concentrations, interpreted as indicating  
263 background (lower) and anomalous (higher) values (Fig. 3). The first bend of the slope on the Q – Q  
264 plot curve occurs at sum BTEX concentrations of 1.7 µg/L; values less than 1.7 µg/L represent  
265 background values, while values above 1.7 µg/L are anomalous. The anomalous values are mostly  
266 dominated by high levels of toluene, with two values dominated by benzene (Fig. 3). To delineate  
267 anomalous zones, core samples from each tree species representing the two populations are shown  
268 with different symbols and colors on a separate sample collection map (Fig. 4). The clustering of  
269 anomalous values of sum BTEX compounds in tree-core samples is observed between stillwater #2  
270 and #3 and at the vicinity of stillwater #4. These delineated zones of elevated sum BTEX  
271 concentrations are optimal for the installation of groundwater monitoring wells for further  
272 investigations of the site.

### 273 3.3 *Comparison of BTEX compounds uptake between tree species*

274 From Table 1 it can be seen that toluene concentrations are clearly higher in black spruce (mean  
275 42.5 µg/L) than in aspen (mean 0.91 µg/L) or birch (mean 0.8 µg/L). Pine trees have been observed

276 to emit elevated levels of toluene under stress (Heiden et al. 1999) and contribute to atmospheric  
277 levels of toluene (White et al. 2009), so an endogenous, natural source in black spruce cannot be  
278 excluded beforehand. However, some arguments support the possibility that measured  
279 concentrations more likely originate from external sources, i.e. groundwater. First, the wide range of  
280 values (5.4 to 146 µg/L) does not indicate production of toluene by black spruce. Second, more  
281 importantly, the highest concentrations of toluene in black spruce (sample 26) are closely  
282 neighbored by the highest concentrations of toluene in aspen (sample 27) (Fig. 4). Moreover, the  
283 next samples in this direction (nos. 28 and 29) have the highest levels of benzene measured in aspen  
284 wood (Fig. 4). Thus, contamination is the most likely explanation for the elevated levels found in the  
285 trees. Although tree uptake of VOCs depends on species-specific physiology, toluene is most likely  
286 to be absorbed and accumulated in larger amounts than other BTEX constituents, or perhaps more  
287 stable, as observed in this study and in previous research (Algreen 2015; Algreen et al. 2015; Sorek  
288 et al. 2008); this finding is independent of climatic environments and other specific site conditions.

### 289 *3.4 Concentrations of MTBE in tree cores*

290 None of the tree-core samples collected at the landfill site or local control area contained a  
291 detectable concentration of MTBE. At the landfill site, MTBE results corroborate with available  
292 groundwater data within or at the vicinity of the sampling area (AMEC 2012; 2011; 2009; Fig. 2).  
293 Although MTBE was not found in monitoring wells, assessment of subsurface MTBE contamination  
294 in this work was prompted by the fact that MTBE and the BTEX compounds are commonly  
295 associated with petroleum hydrocarbon-contaminated groundwater, and by evidence that tree-core  
296 analysis is sometimes able to identify subsurface contamination undetected by traditional  
297 groundwater monitoring (e.g. Larsen et al. 2008). When compared with BTEX compounds, MTBE  
298 is more resistant to biodegradation, has a lower log K<sub>ow</sub>, a greater tendency to move rapidly  
299 through soil and groundwater, and is readily available for tree uptake and translocation (Briggs et al.

300 1982; Borden et al. 1997; Squillace et al. 1997; Vroblesky 2008). The latter characteristic has been  
301 demonstrated in both laboratory and field conditions, using trees from different species.  
302 Experiments conducted by Burken and Schnoor (1998) and Ma et al. (2004), have indicated uptake  
303 of MTBE by poplar (*Populus* spp.) and eucalyptus (*Eucalyptus* spp.) trees. These laboratory findings  
304 were later corroborated by the identification of MTBE in mature oak trees (*Quercus virginiana*)  
305 growing above gasoline-contaminated groundwater <3.9 m bgs (Landmeyer et al. 2000).  
306 Conversely, a more recent investigation has found no MTBE in tree-cores from mature (stem  
307 diameter > 10 cm) willow and aspen trees at a site with known jet fuel-contaminated subsoil and  
308 shallow (2-3 m deep) groundwater (Algreen et al. 2015). Therefore, the absence of MTBE in core  
309 samples is an indication of the absence of groundwater MTBE contamination at this site. Given that  
310 buried drums are still buried at the landfill site and may leak their contents at any time, constituting  
311 a possible source of MTBE in subsurface soil and groundwater, continuous monitoring remain  
312 necessary until cleanup is complete at the landfill site.

#### 313 **4 Compilation and description of available data from open literature: The flops and tops** 314 **in BTEX compounds detection using tree-core analysis**

315 Among the studies using tree-core analysis to detect subsurface contamination by VOCs, many  
316 have successfully investigated chlorinated ethenes, such as tetrachloroethylene (PCE) and  
317 trichloroethylene (TCE) (e.g. Vroblesky et al. 2004, 1999; Larsen et al. 2008; Limmer et al. 2011;  
318 Limmer and Burken 2015).Schumacher et al., 2004; Sorek et al. 2008; Wittlingerova et al. 2013). In  
319 contrast, reports of successful applications for tracking soil and groundwater contamination by  
320 petroleum hydrocarbons, including BTEX compounds, are rare, even though BTEX compounds are  
321 also frequent subsurface pollutants and are similarly soluble in water. It may be that tree-core  
322 analyses for assessing BTEX compounds have encountered some limitations, which in some cases,  
323 lead to less successful applications, most of which remain unpublished. The studies described in this

324 section are summarized together with the present study for comparison in Table 3. The data are from  
325 a number of contaminated sites in a range of ecosystems with tree-core samples from 15 different  
326 tree species and measurement of BTEX compounds performed mostly by headspace extraction, or in  
327 one case study, by headspace solid-phase microextraction followed by gas chromatography-mass  
328 spectrometry.

329 Rein and Trapp (2009) carried out tree-core analysis at a former hydrogenation plant near Zeitz  
330 (Germany), in an area of known very high benzene groundwater contamination (100 to > 1000  
331 mg/L). In May 2009, 14 tree-core samples were taken across the plume. Toluene could not be  
332 detected in any of the tree cores, and benzene was only found in one tree in the source zone at a  
333 rather low concentration of 6.4 µg/kg wood dry weight (dw). Sixteen additional core samples were  
334 taken in July 2009 and no BTEX compounds were detected, except in two trees from the benzene  
335 source zone, with benzene concentrations of 5.5 and 4.2 µg/kg wood dw.

336 At the Hradčany site, a former Soviet military airport in the Czech Republic, a free-phase layer  
337 of jet fuel covered the groundwater at 8 m below ground surface (bgs). Levels of petroleum  
338 hydrocarbons in soil ranged from 10 to 18000 mg/kg soil dw (Machackova et al. 2008). About 20  
339 tree-core samples were collected and BTEX compounds were detected only in those trees growing  
340 on the gas plume of the ventilation outlets of the soil venting system (Trapp et al. 2005).

341 At the former gas works site in Søllerød (Denmark), BTEX compounds are still present in  
342 groundwater at 4 to 5 m bgs (25 to 23000 µg/L; benzene <0.2 to 950 µg/L) and in soil (sum BTEX  
343 100 mg/kg, 1 sample). The corresponding levels in tree-core samples obtained by Algreen (2015)  
344 were maximum 0.1 µg/kg benzene and 0.05 µg/kg xylene (recalculated from µg/L for a wood  
345 density of 1 kg/L), and detects were limited to three samples (benzene) and one sample (xylene)  
346 respectively, out of 52. Toluene and ethylbenzene were not detected in any sample. Moreover, the  
347 anomalous tree-core samples were not near the location of highest groundwater concentrations. At  
348 another Danish site near Gentofte, concentrations of benzene in groundwater were about 1600 µg/L



349 at 4 to 5 m bgs, with sum BTEX up to 13600 µg/L. Tree-core samples (21) were taken and analyzed,  
350 but among the BTEX compounds only xylene was found in a few samples (3 samples, with  
351 maximum 0.3 µg/kg) and the spatial correlation to BTEX compounds in groundwater was weak  
352 (Algreen 2015). In the studies of Algreen (2015), toluene was the most frequently detected  
353 compound (found in 59% of the samples), xylenes and ethylbenzene were measurable in 19% and  
354 16% of the samples and benzene was measured in only 7% of all samples.

355 In the more successful applications of tree-core analysis, the levels of BTEX compounds  
356 detected in tree-core samples, although reflecting the distribution in groundwater, were  
357 comparatively low, corroborating with the findings of this study. At the Szprotawa former military  
358 airport in Poland, concentrations of BTEX compounds of > 1400 µg/L (sum of BTEX  
359 approximately 20:20:500:900 µg/L B:T:E:X, varying with sample) in groundwater (1.5 to 2.2 m  
360 depth) and of 100 to 240 mg/kg soil (dry weight sum of BTEX approximately 2:10:75:150 mg/kg  
361 B:T:E:X, varying with sample) were determined around the abandoned fuel station (Algreen, 2015;  
362 Algreen et al. 2015). Because of the absence of trees growing on the hot spot, cores of nearby trees  
363 were sampled and contained a maximum of 27 µg/kg (sum of BTEX, recalculated from µg/L for a  
364 wood density of 1 kg/L; 4:12:5:6 µg/kg B:T:E:X) (Algreen, 2015; Algreen et al. 2015).

365 Landmeyer et al. (2000) found MTBE, BTEX and trimethylbenzene in tree cores from trees  
366 growing above a gasoline-contaminated shallow aquifer at a gasoline station near Beaufort, South  
367 Carolina (USA). Concentrations of benzene ranged from below detection limit to 7.2 µg/L and were  
368 508 µg/L in an adjacent groundwater well. Toluene had a better tree uptake, with the highest levels  
369 of 26.2 µg/L and 674 µg/L in the tree core and groundwater, respectively. Similarly at a gas station  
370 in Tel Aviv (Israel), Sorek et al. (2008) detected relatively low concentrations of the BTEX  
371 compounds (< 100 µg/kg) in tree cores from trees growing directly above a lens of petroleum  
372 hydrocarbons floating on the groundwater table at 8 m bgs, whereas the concentrations in the nearby  
373 groundwater well were higher: 1100 µg/L for benzene, 2400 µg/L toluene, and 860 µg/L for xylene.

374 Holm (2011) reported the opposite outcome in tree-core samples taken at a former military base  
375 in Potsdam-Krampnitz near Berlin, Germany. Benzene and other BTEX compounds were present in  
376 most samples and in large amounts, but there was an insignificant correlation with groundwater  
377 BTEX concentrations. It is likely that the core samples, measured by HS-SPME, were contaminated  
378 by background benzene in the air or during handling or transportation.

379 All these study sites with non-detectable or low levels of BTEX compounds in tree-core  
380 samples have in common a characteristic, which distinguishes them from the present study: either  
381 they have a high depth to groundwater of  $\geq 8$  m bgs (Zeitz, Hradcany and Tel Aviv sites; Table 3) or  
382 the aquifer is constrained by aquitards such as horizontal clay layers, which act as barriers to the  
383 contact between tree roots and vapour phase of BTEX compounds or the capillary fringe (Zeitz,  
384 Gentofte and Søllerød sites; Table 3). By contrast, successful detections of BTEX compounds have  
385 been reported from contaminated sites with shallow groundwater at 2.5 m bgs or less (Szprotawa  
386 and this study; Table 3). This leads to the conclusion that tree-core analysis can reliably detect  
387 petroleum hydrocarbons such as BTEX compounds only at field sites with shallow unconfined  
388 aquifers and permeable soils. Moreover, there is a risk of sample contamination because benzene or  
389 toluene is widespread used.

## 390 **5. Conclusions**

391 The following conclusions are drawn from this research:

- 392 1. Tree-core sampling is restrained by the presence and distribution of mature trees and further by  
393 the extensive marshes and stillwater bodies at the landfill site.
- 394 2. The detection of BTEX compounds in tree-core samples collected at the landfill site and local  
395 control area indicates contamination of shallow groundwater (~2.5 m deep) by waste disposal at  
396 the landfill site, whereas the local control area is influenced by the migration of contaminant  
397 off-landfill site.

- 398 3. Uptake and accumulation of BTEX constituents vary between tree species: higher  
399 concentrations of toluene dominate in black spruce, whereas concentrations of benzene,  
400 ethylbenzene, m- and p xylenes, and o-xylene fall within similar range in all the examined tree  
401 species.
- 402 4. An anomalous zone of high sum BTEX concentrations has been identified at the landfill site to  
403 guide the drilling of boreholes and wells for further investigations of the site.
- 404 5. While negative results for MTBE in tree-core samples were obtained, suggesting the absence of  
405 MTBE in groundwater, continued site monitoring is recommended.
- 406 6. A shallow unconfined aquifer and permeable soils are important field site characteristics for the  
407 successful application of tree-core analysis for petroleum hydrocarbons, such as BTEX  
408 compounds.
- 409 7. Tree-core analysis is potentially an excellent field-screening tool during preliminary site  
410 assessments for petroleum hydrocarbon-contaminated groundwater in remote subarctic regions.  
411 This method can provide first-hand data to assist solid waste management and pollution control  
412 authorities in minimizing or preventing possible environmental damages.

### 413 **Acknowledgements**

414 The authors are indebted to the Canadian Department of National Defence for its interest and  
415 support and for access to the landfill site, and to the municipality of Happy Valley-Goose Bay for  
416 supporting this research project. Special thanks to C. Cooney, environmental officer Canadian Force  
417 Base 5 Wing Goose Bay, and D. AuCoin, M. Clough and other staff at the environmental office of  
418 Defence Construction Canada Goose Bay for their generous logistical and field support, and for  
419 access to unpublished contract reports on the landfill site assessment and remediation. R. Sparkes  
420 (Labrador Institute) graciously assisted with community consultation at various stages of the project.  
421 M. Mills, D. Frawley and S. Murphy (Labrador Institute) are acknowledged for their assistance

422 during tree-core sampling. We thank G. Van Biesen (Memorial University) for his analytical  
423 assistance. D. Frawley also kindly prepared the figures for this manuscript. M. Mills (Labrador  
424 Institute) and D. Chipley (Queen's University) are thanked for their constructive editorial comments  
425 that greatly improved this manuscript. We appreciate additional insightful comments by  
426 *Environmental Sciences and Pollution Research* and four anonymous reviewers. This research  
427 benefited from financial support by the Harris Centre MMSB Waste Management Applied Research  
428 Fund 2014-2015 and the Memorial Undergraduate Career Experience Program (MUCEP) grant-  
429 Spring 2014 to M. L.D. Fonkwe. This research is also supported by funding from the Atlantic  
430 Canada Opportunities Agencies (ACOA) and the Department of Business, Tourism, Culture and  
431 Rural Development, Newfoundland and Labrador (BTCRD NL).

## 432 **References**

- 433
- 434 Algreen M (2015) The feasibility of tree coring as a screening tool for selected contaminants in the  
435 subsurface. PhD thesis at the Technical University of Denmark, Department of Environmental  
436 Engineering. Available at: [http://orbit.dtu.dk/en/publications/the-feasibility-of-tree-coring-as-a-  
437 screening-tool-for-selected-contaminants-in-the-subsurface%2880785fd4-7426-46b4-9b33-  
438 28883e29ad53%29.html](http://orbit.dtu.dk/en/publications/the-feasibility-of-tree-coring-as-a-screening-tool-for-selected-contaminants-in-the-subsurface%2880785fd4-7426-46b4-9b33-28883e29ad53%29.html). Accessed on 07 October 2015
- 439 Algreen M, Kalisz M, Stalder M, Martac E, Krupanek J, Trapp S, Bartke S (2015) Using pre-  
440 screening methods for an effective and reliable site characterization at megasites. *Environ Sci  
441 Pollut Res* 22(19):14673–14686
- 442 Allen A (2001) Containment landfills: The myth of sustainability. *Journal of Engineering Geology*  
443 (60):3–19
- 444 AMEC Earth and Environmental (2009) TCE plume refinement – South escarpment area, CFB 5  
445 Wing Goose Bay, Newfoundland and Labrador. Contract no: DCC#HQ06010, Commission#75

446 AMEC Earth and Environmental (2011) Site investigation central/Eastern landfill, CFB 5 Wing  
447 Goose Bay, Newfoundland and Labrador. Contract no: DCC#IE090214, Commission #2.3.5.1

448 Barrett A, Lawlor J (1995) The economics of waste management in Ireland. Economic and Social  
449 Research Institute, Dublin

450 BFA Beatty Franz & Associates Limited (1996) Remediation alternatives for South escarpment  
451 drum removal risk assessment, Goose Bay. CFB 5 Wing Goose Bay, Newfoundland and  
452 Labrador, contract reference# 96-5

453 Borden RC, Daniel RA, LeBrun IV LE, Davis CW (1997) Intrinsic biodegradation of MTBE and  
454 BTEX in a gasoline-contaminated aquifer. *Water Resour Res* 33(5):1105–1115

455 Briggs GG, Bromilow RH, Evans AA (1982) Relationships between lipophilicity and root uptake  
456 and translocation of non-ionised chemicals by barley. *Pestic Sci* 13:495–504

457 Burken JG, Schnoor, JL (1998) Predictive relationships for uptake of organic contaminants by  
458 hybrid poplar trees. *Environ Sci Technol* 32:3379–3385

459 Burken JG, Vroblesky DA, Balouet JC (2011) Phytoforensics, dendrochemistry, and  
460 phytoscreening: new green tools for delineating contaminants from past and present. *Environ Sci*  
461 *Technol* 45(15):6218–6226

462 Christensen TH, Kjeldsen P, Bjerg PL, Jensen DL, Christensen JB, Baun A, Albrechtsen HJ, Heron  
463 G (2001) Biogeochemistry of landfill leachate plumes. *Appl Geochem* 16:659–718

464 Cifrian E, Andres A, Viguri, RJ (2013) Estimating monitoring indicators and the carbon footprint of  
465 municipal solid waste management in the region of Cantabria, Northern Spain. *Waste Biomass*  
466 *Valor* 4:271–285

467 Curtis F, Lammey J (1998) Intrinsic remediation of a diesel fuel plume in Goose Bay, Labrador,  
468 Canada. *Environ Pollut* 103: 203–210

469 Cutter BE, Guyette RP (1993) Anatomical, chemical and ecological factors affecting tree species  
470 choice in dendrochemistry studies. *J Environ Quality* 22:611–619

471 Dunn CE (2007) Biogeochemistry in mineral exploration. Hale, M. (ed.) *Handbook of 367*  
472 *exploration and environmental Geochemistry, Series 9*, Elsevier, Amsterdam

473 Eggen T, Moeder M, Arukwe A (2010) Municipal landfill leachates: A significant source for new  
474 and emerging pollutants. *Sci Total Environ* 408(21):5147–5157

475 El-Fadel M, Findikakis A, Leckie J (1997) Environmental impacts of solid waste landfilling. *J*  
476 *Environ Manage* 50 (1):1–25

477 El-Fadel M, Sadek S, Chahine W (2001) Environmental management of quarries as waste disposal  
478 facilities. *J Environ Manage* 4:515–531

479 FEI Franz Environmental Inc. (2006) Hydrogeological Study of the South Escarpment Area, CFB 5  
480 Wing Goose Bay, Newfoundland and Labrador. Contract no: DND Report#06–27

481 Fetta D, Papadopoulos A, Loizidou M (1999) A study on the landfill leachate and its impact on the  
482 groundwater quality of the greater area. *Environ Geochem Health* 21(2):175–190

483 Heiden AC, Kobel K, Komenda M, Koppmann R, Shao M, Wildt J (1999) Toluene Emissions from  
484 Plants. *Geophy Res Lett* 26(9): 1283–1286

485 Holm O (2011) Development and application of a method for investigation and monitoring of  
486 CVOC contaminated sites by taking samples from plants. PhD thesis at the Technical University  
487 of Berlin, faculty III– Prozesswissenschaften (in German). Available at:  
488 <https://opus4.kobv.de/opus4-tuberlin/frontdoor/index/index/docId/3182>. Accessed on 13 October  
489 2015

490 Holm O, Rotard W, Trapp S, Dési R (2011) Guide to Phytoscreening: Using tree core sampling and  
491 chemical analyses to investigate contamination in the groundwater and soil, Federal Ministry of  
492 Education and Research, Germany: 27. Available at:

493 [https://www.ufz.de/export/data/38/34096\\_Guide\\_to\\_Phytoscreening\\_20111121\\_FINAL.pdf](https://www.ufz.de/export/data/38/34096_Guide_to_Phytoscreening_20111121_FINAL.pdf).  
494 Accessed on 16 August 2013.

495 JWEL Jacques Whitford Environment Limited (1992) Environmental Clean-up study, CFB 5 Wing  
496 Goose Bay, Newfoundland and Labrador. Contract no: JWEL Project#7250

497 Kjeldsen P, Barlaz MA, Rooker AP, Baun A, Ledin A, Christensen TH (2002) Present and long-  
498 term composition of MSW landfill leachate: A review. *Crit Rev Env Sci Technol* 32(4):297–336

499 Landmeyer JE, Vroblesky DA, Bradley PM (2000) MTBE and BTEX in trees above gasoline-  
500 contaminated groundwater. In: Wickramanayake, G.B., and others (eds) Case studies in the  
501 remediation of chlorinated and recalcitrant compounds. Proceedings of the 2nd international  
502 conference on remediation of chlorinated and recalcitrant compounds, Monterey, California, May  
503 22–25, 2000, pp 17–24

504 Laner D, Fellner J, Brunner PH (2011) Environmental compatibility of closed landfills - assessing  
505 future pollution hazards. *Waste Manage Res* 29(1):89–98

506 Larsen M, Burken JG, Macháčková J, Karlson UG, Trapp S (2008) Using tree core samples to  
507 monitor natural attenuation and plume distribution after a PCE spill. *Environ. Sci. Technol.*  
508 42:1711–1717

509 Limmer MA, Balouet JC, Karg F, Vroblesky DA, Burken JG (2011) Phytoscreening for chlorinated  
510 solvents using rapid in vitro SPME sampling: Application to urban plume in Verl, Germany.  
511 *Environ Sci Technol*, 45(19):8276–8282

512 Limmer MA, Burken JG (2015) Phytoscreening with SPME: Variability Analysis. *Int J Phytorem*  
513 17(11):1115–1122

514 Liverman DGE (1997) Quaternary Geology of the Goose Bay Area. Current Research, Department  
515 of Mines and Energy, Geological Survey, Newfoundland and Labrador, Report 97-1:173–182

516 Ma X, Richter AR, Albers S, Burken JG (2004) Phytoremediation of MTBE with hybrid poplar  
517 trees. *Int J Phytoremediat* 6(2):157–167

518 Machackova J, Wittlingerova Z, Vlk K, Zima J, Linka A (2008) Comparison of two methods for  
519 assessment of in situ jet-fuel remediation efficiency. *Water Air Soil Poll* (187):181–194

520 Manfredi S, Tonini D, Christensen TH (2009) Landfilling of waste: accounting of greenhouse gases  
521 and global warming contributions. *Waste Manage Res* 27(8):825–836

522 Newman LA, Gordon MP, Heilman P, Cannon DL, Lory E, Miller K, Osgood J, Strand SE (1999)  
523 Phytoremediation of MTBE at a California naval site. *Soil & Groundwater Cleanup*, Feb./March,  
524 1999:42–45

525 Nichols EG, Cook RL, Landmeyer JE, Atkinson B, Malone DR, Shaw G, Woods L (2014)  
526 Phytoremediation of a petroleum-hydrocarbon contaminated shallow aquifer in Elizabeth City,  
527 North Carolina, USA. *Remed J* 24:29–46

528 Nunn GAG, van Nosttrand T (1996) Geology of the Kenemich River map area (NTS 13G/SW),  
529 Labrador. Department of Mines and Energy, Geological Survey, Newfoundland and Labrador,  
530 Report 96-1:73–83

531 Padilla KL, Anderson KA (2002) Trace element concentration in tree-rings biomonitoring centuries  
532 of environmental change. *Chemosphere* 49:575–585

533 Papastergios G, Fernandez-Turiel J-L, Filippidis A, Gimeno DA (2011) Determination of  
534 geochemical background for environmental studies of soils via the use of HNO<sub>3</sub> extraction and  
535 Q–Q plots. *Environ Earth Sci* 64:743–751

536 Reimann C, Filzmoser P, Garrett RG (2005) Background and threshold: critical comparison of  
537 methods of determination. *Sci Total Environ* 346:1–16.



538 Rein A, Trapp S (2009) Model Driven Soil Probing, Site Assessment and Evaluation, EU FP 7  
539 Project Grant Nr. 213161, Activity report 2009. Cited in Holm O, Rotard W, Trapp S, Dési R.  
540 (2011): Guide to Phytoscreening – Using tree core sampling and chemical analyses to investigate  
541 contamination in the groundwater and soil. Available at:  
542 [www.ufz.de/export/data/38/34096\\_Guide\\_to\\_Phytoscreening\\_20111121\\_FINAL.pdf](http://www.ufz.de/export/data/38/34096_Guide_to_Phytoscreening_20111121_FINAL.pdf). Accessed  
543 on 11 August 2015

544 Rowe RK, Quigley RM, Booker JR (1997) Clayey barrier systems for waste disposal facilities.  
545 Chapman and Hall

546 Ryan M (2010): Environmental standards for municipal solid waste landfill sites, Newfoundland and  
547 Labrador. Government of Newfoundland and Labrador. Available at: <http://www.env.gov.nl.ca/>.  
548 Accessed on 09 June 2015.

549 Sawhney LB, Kozloski RP (2004) Organic Pollutants in Leachates from Landfill Sites. J Environ  
550 Qual 13 (3):349–352

551 Schumacher JG, Struckhoff GC, Burken JG (2004) Assessment of subsurface chlorinated solvent  
552 contamination using tree cores at the Front Street site and a former dry cleaning facility at the  
553 Riverfront Superfund Site, NewHaven, Missouri, 1999–2003: U.S. Geological Survey Scientific  
554 Investigations Report 2004-5049, 35 p. Available at: [http://mo.water.usgs.gov/Reports/sir2004-  
555 5049-schu/complete.pdf](http://mo.water.usgs.gov/Reports/sir2004-5049-schu/complete.pdf). Accessed on June 11, 2015.

556 Serco (2001) Remedial options evaluation, stillwater #1. Canadian Department of National Defence,  
557 Goose Bay, Labrador.

558 Slack RJ, Gronow JR, Voulvoulis N (2005) Household hazardous waste in municipal landfills:  
559 contaminants in leachate. Sci Total Environ 337:119–137

560 Sorek A, Atzmon N, Dahan O, Gerstl Z, Kushisin L, Laor Y, Mingelgrin U, Nasser A, Ronen D,  
561 Tsechansky L, Weisbrod N, Graber ER (2008) "Phytoscreening": The use of trees for discovering  
562 subsurface contamination by VOCs. *Environ Sci Technol* 42(2):536–542

563 Squillace PJ, Pankow JF, Korte NE, Zogorski JS (1997) Review of the environmental behavior and  
564 fate of methyl tertiary-butyl ether. *Environ Toxicol Chem* 16:1836–1844

565 Trapp S (2007) Fruit tree model for uptake of organic compounds from soil and air. SAR - QSAR  
566 *Environ. Res.* 18(3-4):367–387

567 Trapp S, Karlson U, Larsen M, Legind C (2005) Correlation between below and above surface  
568 contamination. Biological procedures for diagnosing the status and predicting evolution of  
569 polluted environments BIOTOOL project, deliverable 12.

570 Valvasori A, Fonkwe DLM, Piercey JS, Conliffe J (2015) Orthomagmatic Fe-Ti-V oxide  
571 mineralization hosted in Paleoproterozoic anorthosite in the Cape Caribou River Allochthon,  
572 Grenville Province, Southeast Labrador: Preliminary Results. Current Research, Department of  
573 Natural Resources, Geological Survey of Newfoundland and Labrador, Report 15-1:125–138

574 Vrobley DA (2008) User's guide to the collection and analysis of tree cores to assess the  
575 distribution of subsurface volatile organic compounds: U.S. Geological Survey Scientific  
576 Investigations Report 2008–5088. Available at: <http://pubs.water.usgs.gov/sir2008-5088>.  
577 Accessed on 05 June 2013

578 Vrobley DA, Clinton BD, Vose JM, Casey CC, Harvey GJ, Bradley PM (2004) Ground water  
579 chlorinated ethenes in tree trunks: case studies, influence of recharge, and potential degradation  
580 mechanism. *Ground Water Monit R*, 24(3):124–138

581 Vrobley DA, Nietch CT, Morris JT (1999) Chlorinated ethenes from ground water in tree trunks.  
582 *Environ Sci Technol* 33(3):510–515

583 Wardle RJ, Ash, C (1986) Geology of the Goose Bay-Goose River area. Current Research, Mineral  
584 Department of Mines and Energy, Geological Survey, Newfoundland and Labrador, Report 86-  
585 1:113–123

586 Weishaar JA, Tsao D, Burken J G (2009) Phytoremediation of BTEX hydrocarbons: Potential  
587 impacts of diurnal groundwater fluctuation on microbial degradation. *Int J Phytorem* 11(5):509–  
588 523

589 Wells C (2013) 5 Wing Goose Bay remediation project-A case study in sustainability? RPIC Federal  
590 Contaminated Sited Regional Workshop, Halifax (Nova Scotia), June 19, 2013. Available at:  
591 <http://www.rpic ibic.ca/>. Accessed on 08 October 2013

592 Wilson J, Bartz R, Limmer M, Burken J (2013) Plants as bio-indicators of subsurface conditions:  
593 impact of groundwater level on BTEX Concentrations in trees. *Int J Phytorem* 15(3):257–267

594 White ML, Russo RS, Zhou Y, Ambrose JL, Haase K, Frinak EK, Sive BC (2009) Are biogenic  
595 emissions a significant source of summertime atmospheric toluene in the rural Northeastern  
596 United States? *Atmos Chem Phys* 9(1): 81–92

597 Wittlingerova Z, Machackova J, Petruzelkova A, Trapp S, Vlk K, Zima J (2013) One-year  
598 measurements of chloroethenes in tree cores and groundwater at the SAP Mimoň Site, Northern  
599 Bohemia. *Environ Sci Pollut Res Int* 20(2):834–847

600 Zagozewski R, Judd-Henrey I, Nilson S, Bharadwaj L (2011) Perspectives on Past and Present  
601 Waste Disposal Practices: A Community-Based Participatory Research Project in Three  
602 Saskatchewan First Nations Communities. *Environmental Health Insights* 5:9–20

603

604

## List of figures and tables

605 **Fig. 1** Map (from Google Earth) showing the former landfill site and major dump areas along the  
606 south boundary of Canadian Force Base 5 Wing Goose Bay; the area of tree-core sampling is  
607 outlined. The local control site located outside the landfill site is indicated. An inset map of Canada  
608 shows the location of the study area, the remote community of Happy Valley-Goose Bay and the  
609 city of St. John's where the core samples were freighted for analysis.

610 **Fig. 2** Map of the area of tree-core sampling showing the locations of sampled trees by species; the  
611 numbers represent of the tree-core samples. Locations of major stillwaters, monitoring wells, and  
612 contours of BTEX plumes in groundwater collected in summer 2005 and Sept.-Oct. 2006 (AMEC  
613 2009; FEI 2006), in the vicinity of the sampling area are also shown. The direction of groundwater  
614 flow is indicated.

615 **Fig. 3** Normal quantile - quantile (Q-Q) plot showing the first bend of the slope curve at sum BTEX  
616 concentration of 1.7  $\mu\text{g/L}$ , which separates the sum BTEX concentrations into two populations: (1)  
617 background (lower) values, represented by grey squares; and (2) anomalous (higher) values,  
618 represented by orange circles for core samples containing higher levels of toluene and yellow circles  
619 for core samples containing higher levels of benzene.

620 **Fig. 4** Spatial distribution maps of sum BTEX concentrations in tree-core samples for each tree  
621 species: black spruce (top), trembling aspen (middle) and white birch (bottom). The numbers  
622 represent the sampled trees. Also shown are the nearby stillwaters, monitoring wells and contours of  
623 BTEX plumes in groundwater collected in summer 2005 and September-October 2006 (FEI 2006;  
624 AMEC 2009). Note that the clustering of anomalous values of sum BTEX compounds in tree-core  
625 samples is observed between stillwater #2 and #3 and at the vicinity of stillwater #4.

626 **Table 1** Location, tree characteristics, and concentrations in micrograms per liter ( $\mu\text{g/L}$ ) of the  
627 petroleum hydrocarbon constituents benzene, toluene, ethylbenzene, m-and p-xylene, and o-xylene  
628 in the headspace of vials containing tree cores collected at landfill site in Happy Valley-Goose Bay,  
629 August-September 2014.

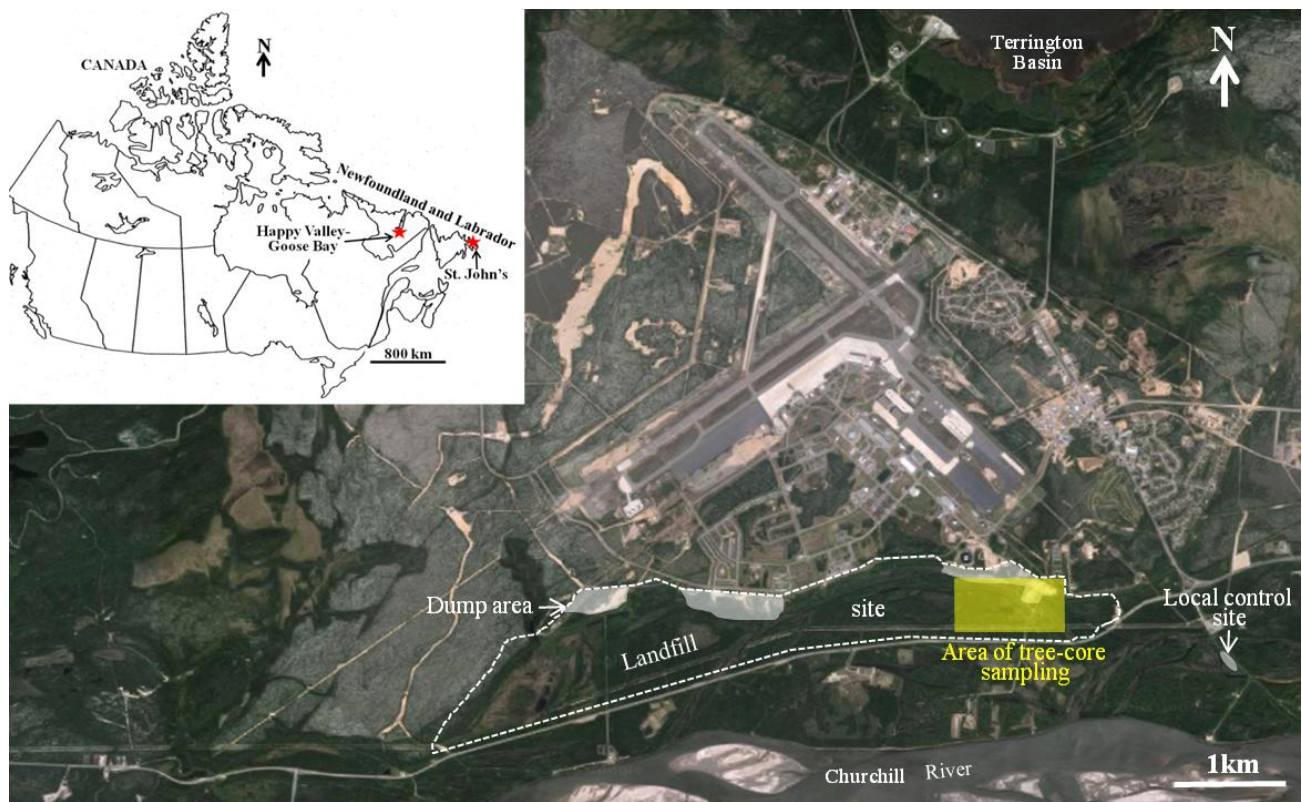
630 Notes: MTBE was not found in tree cores. Resulting values below the QLs of  $0.4 \mu\text{g/L}$  for benzene,  
631 toluene, ethylbenzene and o-xylene, and of  $0.8 \mu\text{g/L}$  for m- and p- xylene were set to half QL values  
632  $0.2 \mu\text{g/L}$  and  $0.8 \mu\text{g/L}$ , respectively for representation. Dup = duplicate sample; a.s.l = above sea  
633 level; <DL = below detection limit; “-” = co-elution, ratios of quantification and confirmatory ions  
634 do not conform to those obtained from a standard.

635 **Table 2** Location, tree characteristics and concentrations in micrograms per liter ( $\mu\text{g/L}$ ) of the  
636 petroleum hydrocarbon constituents benzene, toluene, ethylbenzene, m-and p-xylene, and o-xylene  
637 in the headspace of vials containing tree cores collected at the local control site in Happy Valley-  
638 Goose Bay, August-September 2014.

639 Notes: MTBE was not found in tree cores. Resulting values below the QLs of  $0.4 \mu\text{g/L}$  for benzene,  
640 toluene, ethylbenzene and o-xylene, and of  $0.8 \mu\text{g/L}$  for m- and p- xylene were set to half QL values  
641  $0.2 \mu\text{g/L}$  and  $0.8 \mu\text{g/L}$ , respectively for representation. Dup = duplicate sample; a.s.l = above sea  
642 level; <DL = below detection limit; “-” = co-elution, ratios of quantification and confirmatory ions  
643 do not conform to those obtained from a standard.

644 **Table 3** Overview of field site characteristics and measurement methods of petroleum hydrocarbons  
645 (especially BTEX compounds) in tree-core samples from reports found in open literature and the  
646 present study.

647 Note: HS-GC-MS = headspace-gas chromatography-mass spectrometry; HS-SPME-GC-MS =  
648 headspace solid-phase microextraction-gas chromatography-mass spectrometry; GW =groundwater.

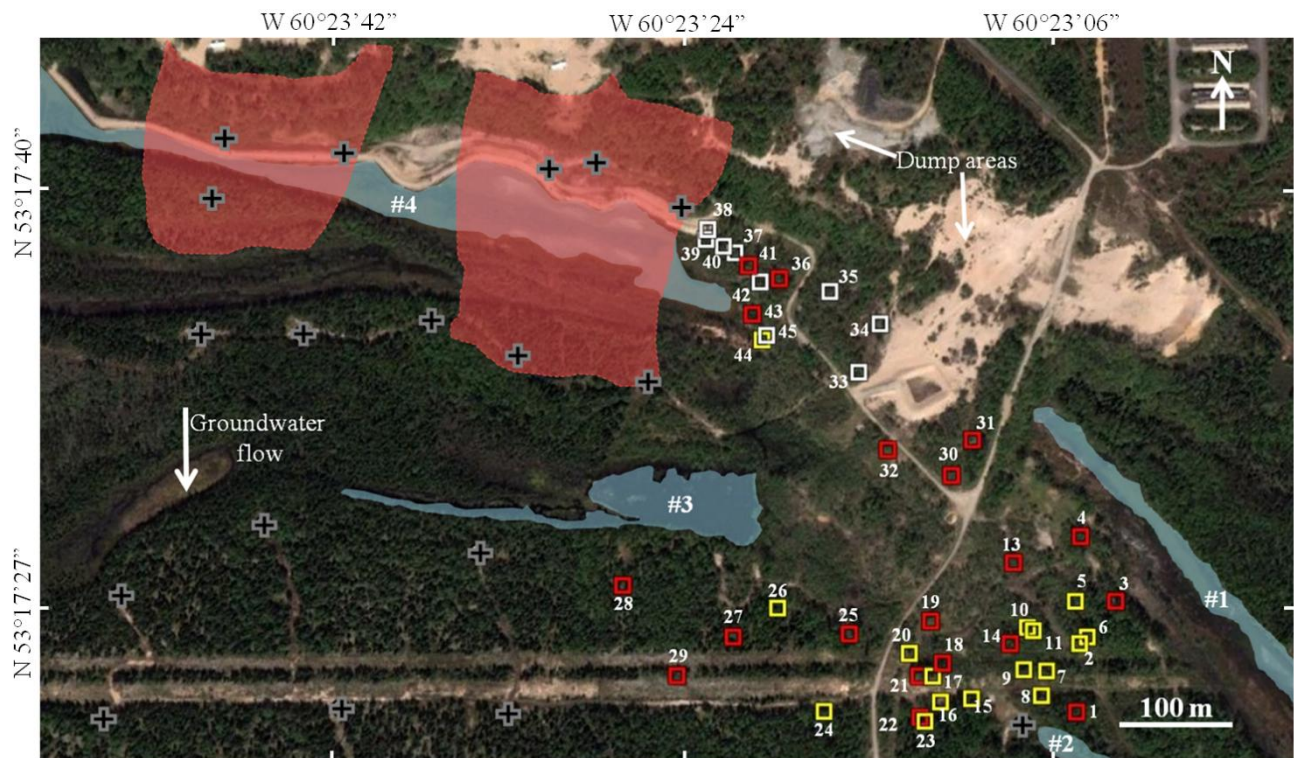


649

650 **Fig. 1** Map (from Google Earth) showing the former landfill site and major dump areas along the  
651 south boundary of Canadian Force Base 5 Wing Goose Bay; the area of tree-core sampling is  
652 outlined. The local control site located outside the landfill site is indicated. An inset map of Canada  
653 shows the location of the study area, the remote community of Happy Valley-Goose Bay and the  
654 city of St. John's where tree-core samples were freighted for analysis.

655





Base map from Google Earth  
 World Geodetic System Datum Projection  
 WGS84

EXPLANATION

- |   |                                  |   |                 |
|---|----------------------------------|---|-----------------|
| + | Nest of monitoring wells         | ■ | Trembling aspen |
| ● | BTEX plume (FEI 2006; AMEC 2009) | ■ | Black spruce    |
| ● | Stillwater                       | ■ | White birch     |

656

657 **Fig. 2** Map of the area of tree-core sampling showing the locations of sampled trees by species; the

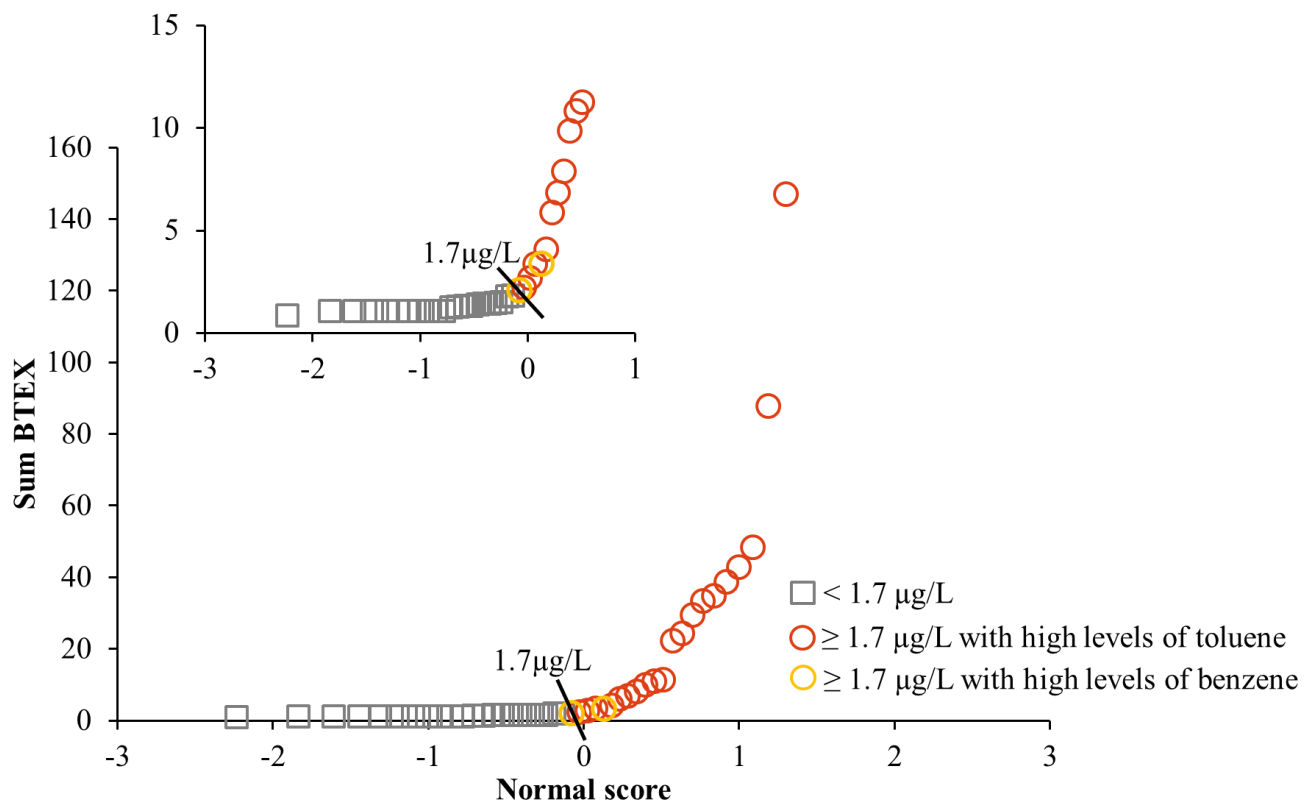
658 numbers represent of the tree-core samples. Locations of major stillwaters, monitoring wells, and

659 contours of BTEX plumes in groundwater collected in summer 2005 and Sept.-Oct. 2006 (AMEC

660 2009; FEI 2006), in the vicinity of the sampling area are also shown. The direction of groundwater

661 flow is indicated.

662



663

664 **Fig. 3** Normal quantile - quantile (Q-Q) plot showing the first bend of the slope curve at sum BTEX

665 concentration of 1.7 μg/L, which separates the sum BTEX concentrations into two populations: (1)

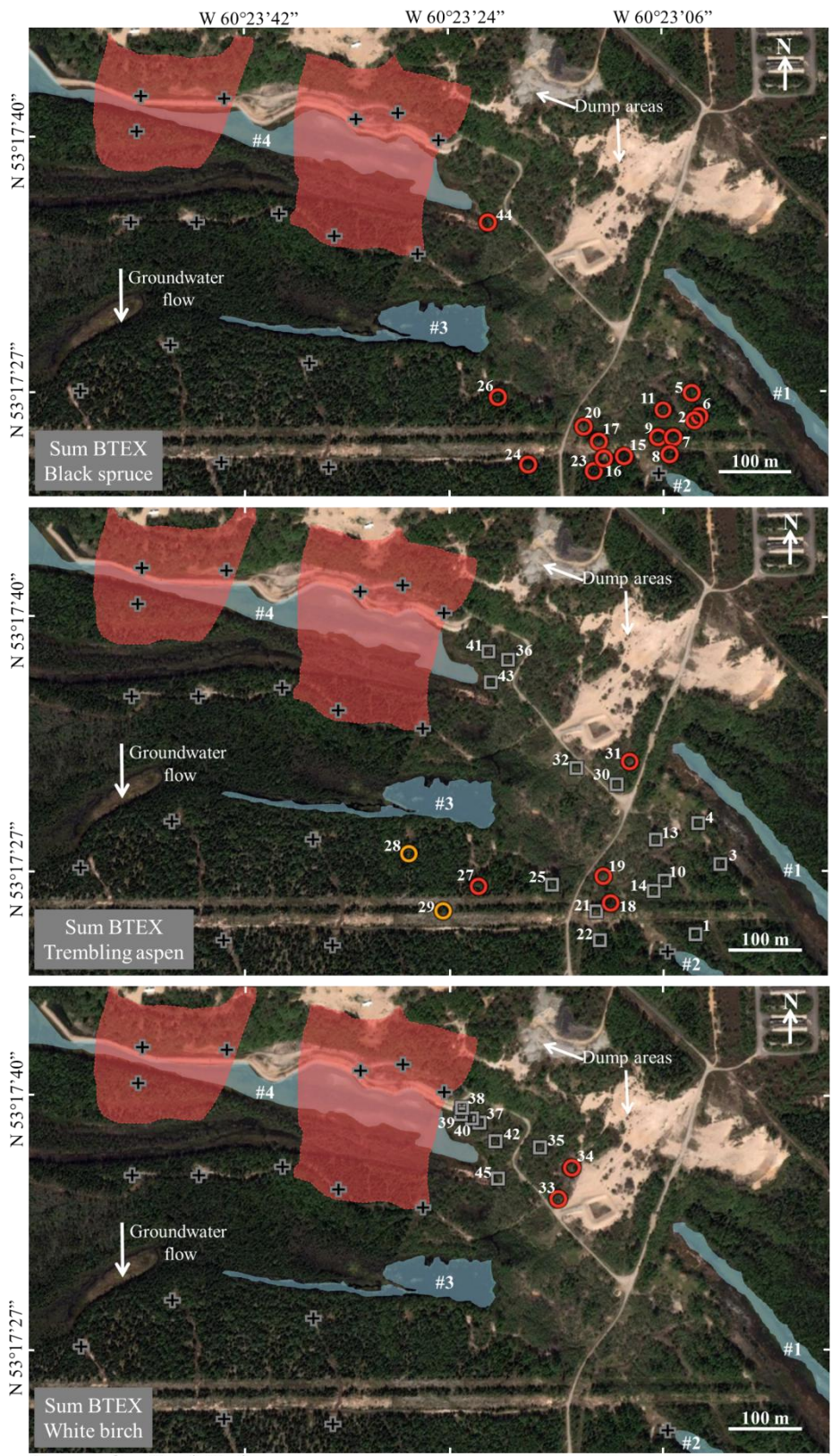
666 background (lower) values, represented by grey squares; and (2) anomalous (higher) values,

667 represented by orange circles for core samples containing higher levels of toluene and yellow circles

668 for core samples containing higher levels of benzene.

669





Base map from Google Earth  
 World Geodetic System Datum Projection  
 WGS84

EXPLANATION

- Nest of monitoring wells
- BTEX plume (FEI 2006; AMEC 2009)
- Stillwater
- < 1.7 µg/L
- ≥ 1.7 µg/L with high levels of toluene
- ≥ 1.7 µg/L with high levels of benzene

671 **Fig. 4** Spatial distribution maps of sum BTEX concentrations in tree-core samples for each tree  
672 species: black spruce (top), trembling aspen (middle) and white birch (bottom). The numbers  
673 represent the sampled trees. Also shown are the nearby stillwaters, monitoring wells and contours of  
674 BTEX plumes in groundwater collected in summer 2005 and September-October 2006 (FEI 2006;  
675 AMEC 2009). Note that the clustering of anomalous values of sum BTEX compounds in tree-core  
676 samples is observed between stillwater #2 and #3 and at the vicinity of stillwater #4.

677

678 **Table 1** Location, tree characteristics, and tree-cores concentrations in micrograms per liter ( $\mu\text{g/L}$ ) of the petroleum hydrocarbon  
 679 constituents benzene, toluene, ethylbenzene, m- and p-xylene, and o-xylene in the headspace of vials containing tree cores collected at  
 680 landfill site in Happy Valley-Goose Bay, August-September 2014.

681 Notes: MTBE was not found in tree cores. Resulting values below the QLs of 0.4  $\mu\text{g/L}$  for benzene, toluene, ethylbenzene and o-xylene, and of 0.8  $\mu\text{g/L}$   
 682 for m- and p- xylene were set to half QL values 0.2  $\mu\text{g/L}$  and 0.8  $\mu\text{g/L}$ , respectively for representation. Dup = duplicate sample; a.s.l = above sea level;  
 683 <DL = below detection limit; “-” = co-elution, ratios of quantification and confirmatory ions do not conform to those obtained from a standard.

Tree Identifier (Fig. 2 and 3)	Latitude	Longitude	Elevation of tree location a.s.l. (m)	Tree species	Tree diameter (cm)	Concentrations ( $\mu\text{g/L}$ )					Sum BTEX
						Benzene	Toluene	Ethyl- benzene	m- and p- xylene	o-xylene	
1	53°17'23.60"	60°23'03.90"	8	Trembling aspen	33	0.20	0.44	0.20	0.40	-	1.2
2	53°17'25.70"	60°23'03.70"	9	Black spruce	31	0.20	7.4	0.20	-	-	7.8
3	53°17'27.00"	60°23'01.80"	10	Trembling aspen	39	0.20	0.63	0.20	0.40	-	1.4
4	53°17'29.00"	60°23'03.60"	11	Trembling aspen	23	0.20	0.2	0.20	0.40	-	1.0
5	53°17'27.00"	60°23'03.90"	12	Black spruce	23	0.20	38.2	0.20	-	-	38.6
6	53°17'25.90"	60°23'03.30"	11	Black spruce	26	0.20	29.0	0.20	-	-	29.4
7	53°17'24.90"	60°23'05.40"	11	Black spruce	21	0.20	10.8	0.20	-	-	11.2
8	53°17'24.10"	60°23'05.70"	11	Black spruce	25	0.20	10.4	0.20	-	-	10.8
9	53°17'24.90"	60°23'06.60"	11	Black spruce	19	0.20	5.4	0.20	-	-	5.8
10	53°17'26.20"	60°23'06.40"	10	Trembling aspen	28	0.20	0.20	0.20	0.40	-	1.0
10Dup	53°17'26.20"	60°23'06.40"	10	Trembling aspen	28	0.20	0.20	0.20	0.40	-	1.0
11	53°17'26.20"	60°23'06.20"	11	Black spruce	27	0.20	87.3	0.20	-	-	87.7
13	53°17'28.20"	60°23'07.10"	11	Trembling aspen	21	0.20	0.55	0.20	0.40	-	1.4
14	53°17'25.70"	60°23'07.30"	11	Trembling aspen	24	0.20	0.47	0.20	0.40	-	1.3
15	53°17'24.00"	60°23'09.30"	9	Black spruce	18	0.20	21.8	0.20	-	-	22.2
16	53°17'23.90"	60°23'10.90"	11	Black spruce	18	0.20	23.7	0.20	-	-	24.1
17	53°17'24.70"	60°23'11.30"	10	Black spruce	18	0.20	32.8	0.20	-	-	33.2
18	53°17'25.10"	60°23'10.80"	1	Trembling aspen	30	0.20	1.4	0.20	0.40	-	2.2
19	53°17'26.40"	60°23'11.40"	5	Trembling aspen	18	0.20	2.5	0.20	1.13	-	4.0
20	53°17'25.40"	60°23'12.50"	4	Black spruce	33	0.20	6.4	0.20	-	-	6.8
21	53°17'24.70"	60°23'12.00"	6	Trembling aspen	25	0.20	0.20	0.20	0.40	-	1.0
22	53°17'23.30"	60°23'11.70"	6	Trembling aspen	23	0.20	0.20	0.20	0.40	-	1.0

684

685 **Table 1** (continued)

Tree Identifier (Fig. 2 and 3)	Latitude	Longitude	Elevation of tree location a.s.l. (m)	Tree species	Tree diameter (cm)	Concentrations ( $\mu\text{g/L}$ )					Sum BTEX
						Benzene	Toluene	Ethyl- benzene	m- and p- xylene	o-xylene	
23	53°17'23.30"	60°23'11.70"	6	Black spruce	31	0.20	47.7	0.20	–	–	48.1
24	53°17'23.60"	60°23'16.90"	6	Black spruce	27	0.20	34.2	0.20	–	–	34.6
25	53°17'26.00"	60°23'15.60"	5	Trembling aspen	29	0.20	0.20	0.20	0.40	–	1.0
25Dup	53°17'26.00"	60°23'15.60"	5	Trembling aspen	29	0.20	0.80	0.20	0.40	–	1.6
26	53°17'26.80"	60°23'19.30"	4	Black spruce	27	0.20	146	0.20	–	–	147
26Dup	53°17'26.80"	60°23'19.30"	4	Black spruce	27	0.20	137	0.20	–	–	137
27	53°17'25.90"	60°23'21.60"	6	Trembling aspen	26	0.20	9.0	0.20	0.40	–	9.8
28	53°17'27.50"	60°23'27.30"	8	Trembling aspen	25	1.1	0.43	0.20	0.40	–	2.1
29	53°17'24.70"	60°23'24.50"	7	Trembling aspen	23	1.5	0.59	0.93	0.40	–	3.4
30	53°17'30.90"	60°23'10.30"	14	Trembling aspen	24	0.20	0.60	0.20	0.40	–	1.4
31	53°17'32.00"	60°23'09.20"	15	Trembling aspen	18	0.20	0.94	0.20	0.40	–	1.7
32	53°17'31.70"	60°23'13.60"	12	Trembling aspen	19	0.20	0.20	0.20	0.40	–	1.0
33	53°17'34.10"	60°23'15.10"	13	White birch	22	0.20	0.91	0.20	0.40	0.20	1.7
34	53°17'35.60"	60°23'14.00"	14	White birch	24	0.20	1.8	0.20	0.40	0.20	2.6
35	53°17'36.60"	60°23'16.60"	13	White birch	32	0.20	0.40	0.20	0.40	0.20	1.2
35Dup	53°17'36.60"	60°23'16.60"	13	White birch	32	0.20	0.44	0.20	0.40	0.20	1.2
36	53°17'37.00"	60°23'19.20"	10	Trembling aspen	25	0.20	0.53	0.20	0.40	–	1.3
37	53°17'37.80"	60°23'21.50"	8	White birch	34	0.20	2.5	0.20	0.40	0.20	3.3
38	53°17'38.50"	60°23'22.90"	9	White birch	26	<DL	0.20	0.20	0.40	0.20	0.80
39	53°17'38.20"	60°23'23.00"	7	White birch	28	0.20	0.20	0.20	0.40	0.20	1.0
40	53°17'38.00"	60°23'22.10"	6	White birch	25	0.20	0.20	0.20	0.40	0.20	1.0
41	53°17'37.40"	60°23'20.80"	6	Trembling aspen	30	0.20	0.20	0.20	0.40	–	1.0
42	53°17'36.90"	60°23'20.20"	8	White birch	26	0.20	0.58	0.20	0.40	0.20	1.4
43	53°17'35.90"	60°23'20.60"	8	Trembling aspen	34	0.20	0.20	0.20	0.40	–	1.0
43Dup	53°17'35.90"	60°23'20.60"	8	Trembling aspen	34	0.20	0.20	0.20	0.40	–	1.0
44	53°17'35.10"	60°23'20.10"	6	Black spruce	34	0.20	42.3	0.20	–	–	42.7
45	53°17'35.10"	60°23'20.00"	6	White birch	34	0.20	0.47	0.20	0.40	0.20	1.3

687 **Table 2** Location, tree characteristics and tree-core concentrations in micrograms per liter ( $\mu\text{g/L}$ ) of the petroleum hydrocarbon constituents  
 688 benzene, toluene, ethylbenzene, m- and p-xylene, and o-xylene in the headspace of vials containing tree cores collected at the local control  
 689 site in Happy Valley-Goose Bay, August-September 2014.

690 Notes: MTBE was not found in tree cores. Resulting values below the QLs of 0.4  $\mu\text{g/L}$  for benzene, toluene, ethylbenzene and o-xylene, and of 0.8  $\mu\text{g/L}$   
 691 for m- and p- xylene were set to half QL values 0.2  $\mu\text{g/L}$  and 0.8  $\mu\text{g/L}$ , respectively for representation. Dup = duplicate sample; a.s.l = above sea level;  
 692 <DL = below detection limit; “-” = co-elution, ratios of quantification and confirmatory ions do not conform to those obtained from a standard.

Tree identifier	Latitude	Longitude	Elevation of tree location a.s.l. (m)	Tree species	Tree diameter (cm)	Concentrations ( $\mu\text{g/L}$ )					Sum BTEX
						Benzene	Toluene	Ethylbenzene	m- and p-xylene	o-xylene	
BK-2	53°17'18.60"	60°21'32.70"	0	Black spruce	20	0.20	6.6	0.20	–	–	7.0
BK-3	53°17'16.40"	60°21'30.90"	3	Black spruce	30	0.20	40.2	0.20	–	–	40.6
BK-5	53°17'13.50"	60°21'29.70"	5	Black spruce	21	0.20	38.0	0.20	–	–	38.4
BK-6	53°17'18.60"	60°21'32.70"	10	Trembling aspen	27	0.20	1.1	0.20	0.40	–	1.9
BK-7	53°17'14.30"	60°21'27.00"	9	Trembling aspen	31	0.20	0.20	0.20	0.40	–	1.0
BK-7Dup	53°17'14.30"	60°21'27.00"	9	Trembling aspen	31	0.20	0.20	0.20	0.40	–	1.0

693

694 **Table 3** Overview of field site characteristics and measurement methods of petroleum hydrocarbons (especially BTEX compounds) in tree-  
 695 core samples from reports found in open literature and the present study.  
 696 Note: HS-GC-MS = headspace-gas chromatography-mass spectrometry; HS-SPME-GC-MS = headspace solid-phase microextraction-gas  
 697 chromatography-mass spectrometry; GW = groundwater.

Study area	Regional climate	Depth to groundwater table (m)	Groundwater aquifer	Compounds measurement method	Tree species	Was tree-core analysis successful?	Sources
Gasoline station near Beaufort, South Carolina, USA	Humid subtropical	0.6 – 3.9	Well-sorted sand	HS-GC-MS	Oak	yes	Landmeyer et al. 2000
Hradčany site, former Soviet military airport, Czech Republic	Continental, warm dry summers	8	Sand and gravel (0 – 3m), fine grained sandstone	HS-GC-MS	Conifers (spruce and pine), birch	no	Trapp et al. 2005
Gas station in Tel Aviv, Israel	Mediterranean	8	Sand and gravel	HS-GC-MS	Rosewood, Eucalyptus	yes (in low concentrations)	Sorek et al. 2008
Former military base Potsdam-Krampnitz near Berlin, Germany	Atlantic to continental	1.3 – 7, and > 9	Fine to medium sized sands intermixed with silt layers	HS-SPME-GC-MS	Birch, willow, poplar, locust, maple, linden	no (due to cross contamination)	Holm 2011
Former hydrogenation plant near Zeitz, Germany	Humid continental with mild summer	8 – 9.4	Silty sand and gravel, with top layer of silt	HS-GC-MS	Sycamore maple, poplar, oak	erratic (detected in 1-2 trees only)	Rein and Trapp 2009
Former gas works site in Søllerød, Denmark	Humid continental with mild summer	4	Varying layers of silt, clay and clay till	HS-GC-MS	Poplar	no (no correlation to GW)	Algreen 2015
Gentofte site, Denmark	Humid continental with mild summer	5	Silt, clay and sand	HS-GC-MS	Willow, poplar	no (no correlation to GW)	Algreen 2015
Szprotawa former military airport, Poland	Continental, warm dry summers	1.5 – 2.2 (0.9 to 3.5)	Thin layer of silt underlain with sand and gravel	HS-GC-MS	mostly willow and poplar	yes	Algreen et al. 2015
Former landfill site at the Canada Force Base 5 Wing Goose Bay in Happy Valley-Goose Bay, Labrador, Canada	Subarctic with cool summer	0 – 2.5	Loose fine to medium-grained sands with scarce interbedded clayey silt	HS-GC-MS	Black spruce, trembling aspen, white birch	yes	This study