Methane in Well Water in Nova Scotia

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Introduction

Methane (CH_4) is a naturally occurring hydrocarbon gas that is colourless, odourless and tasteless. It is commonly present at low levels in groundwater and is reported to be detectable in up to 60% of all water wells in the U.S.A. (National Ground Water Association, 2013). When methane is present at high concentrations in well water, it can cause flammable and explosive conditions. Although it is not considered to be a widespread problem in groundwater in Nova Scotia, its presence is occasionally reported by well owners and well drillers throughout the province.

Regional surveys of methane in well water have recently been carried out in several North American jurisdictions as part of monitoring activities associated with on-shore petroleum exploration, including Quebec (Moritz and Gélinas, 2013), New Brunswick (Al *et al*., 2013), New York (U.S. Geological Survey, 2012) and Pennsylvania (Molofsky *et al*., 2013). In 2013, the Nova Scotia Department of Natural Resources carried out a survey of methane levels in well water in the on-shore sedimentary basin areas of Nova Scotia. The study was funded by Natural Resources Canada, through the Program of Energy Research and Development (PERD), as part of a project titled *Unconventional gas potential from Paleozoic shales of eastern Canada—addressing knowledge gaps for sustainable development*.

The objective of the 2013 Nova Scotia methane survey was to determine the background levels of dissolved methane in well water in the on-shore sedimentary basin areas of the province. These sedimentary basin areas are considered to have the highest potential for elevated methane levels in groundwater. They include both Carboniferous and Triassic basins that have historically been the focus of on-shore petroleum exploration, and they include the Cumberland and Horton groups, where rocks with high carbon content are most likely to be found. At locations where elevated levels of methane were identified, a second objective was to investigate the source of the methane, either biogenic (i.e. methane produced from biological activity at shallow depths and low temperatures, such as occurs in swamps) or thermogenic (i.e. methane produced from organic matter buried for millions of years at great depths and temperatures). The survey involved the testing of 103 water wells for dissolved methane. Follow-up testing for ethane, propane, and hydrogen and carbon isotopes of methane was completed to assess whether the methane originated from biogenic or thermogenic sources.

Previous Methane Sampling in Nova Scotia

A regional survey of methane in groundwater in the Carboniferous basins of eastern Canada was completed in 1975 by the Geological Survey of Canada (GSC) and provincial partners (Dyck *et al*., 1976). The survey included the testing of 714 private water wells in Nova Scotia for dissolved methane and other parameters, including uranium, radon, helium, pH and selected trace metals. The results of the study showed that approximately 15% of water wells had detectable levels of dissolved methane. The maximum detected concentration was 9.2 mg/L.

Guidelines for Methane in Drinking Water

Methane in drinking water is non-toxic; however, it can cause spurting from taps and ‘water hammer’ (i.e. sudden pipe vibration that occurs when a water valve is closed). Furthermore, if it is allowed to accumulate in enclosed spaces, it can cause oxygen-deficient atmospheres, flammable conditions and explosions. There is no Canadian

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drinking water quality guideline (Health Canada, 2012) for dissolved methane. The Ontario drinking water standards (Ontario Ministry of Environment, 2003) provide an aesthetic objective for methane of 3 L/m^3 (i.e. 2 mg/L) to limit problems with gas bubble release and spurting from taps. The U.S. Department of the Interior, Office of Surface Mining (Eltschlager *et al*., 2001) recommends the following action levels for dissolved methane:

- Less than 10 mg/L—no action required, other than periodic monitoring;
- 10 mg/L to 28 mg/L—well owners should consider removing potential ignition sources from the immediate area; and
- Greater than 28 mg/L—take immediate action to reduce methane levels.

Methods

Selection of Water Wells

The approach used for the 2013 Nova Scotia methane survey was to sample water wells that were owned and operated by the Government of Nova Scotia. These included water wells at public schools, provincial parks, museums, visitor information centres, and other government offices and maintenance facilities. All of the wells that were sampled were active water supply wells that are routinely monitored for chemical and biological water quality parameters in accordance with the monitoring requirements for public drinking water supplies in Nova Scotia.

Field Methods

The sampling program was carried out in September, October and December of 2013. An initial sampling event was carried out in September 2013 to collect samples for dissolved methane analysis at 103 water wells. Based on the initial results, 12 water wells with elevated methane concentrations were selected for additional analyses, including ethane, propane, and carbon and hydrogen isotopes of dissolved methane. The ethane and propane analyses were completed using the samples from the initial sampling event. The isotope analyses were completed by collecting additional water samples during a second sampling event in October 2013. A third sampling event was carried out in December 2013 to re-sample the wells with the highest methane results from the September 2013 sampling event, and to collect quality assurance and quality control (QA/QC) samples (see the section below on quality assurance and quality control).

The well water samples were collected from a raw-water source (i.e. before water treatment) as close to the wellhead as possible. Generally, this was achieved by collecting samples from a tap located at the pressure tank. The samples were collected in accordance with the method described by the U.S. Geological Survey (2005) for sampling dissolved gases. The method involves collecting the water sample with the sample bottle submerged under water so that the sample never contacts the air and the potential for methane volatilization is minimized. The following sample collection steps were used:

- The water system was flushed by running the water for at least 5 minutes;
- A Tygon tube was connected to the tap, and air was allowed to flush from the tube by running the water;
- A bucket was filled half-full with water;
- The sample bottle was submerged under water in the bucket, and the sample tube was inserted to the bottom of the sample bottle;
- The sample bottle was allowed to flush with new water for one minute; and
- Once the sample bottled was full, the sampling tube was removed and the bottle was capped while the bottle remained under water, ensuring zero headspace in the bottle.

Samples for dissolved methane were collected into 40 mL clear-glass bottles with open-top caps and chlorobutyl septa. Samples for carbon and hydrogen isotopes of dissolved methane were collected into 500 mL Wheaton clear-glass bottles with open-top caps and chlorobutyl septa. After the samples were collected, they were labelled, stored in a cooler with ice packs, and shipped with a chain-of-custody record to the laboratory.

Laboratory Methods

Analyses for dissolved methane, ethane and propane were submitted to Maxxam Laboratories

in Bedford, Nova Scotia and were performed using the modified method 6211B (Rice *et al*., 2012). The reportable detection limit for dissolved methane was 0.003 mg/L. Carbon ($\delta^{13}C$-CH_4) and hydrogen ($\delta^{2}H$-CH_4) isotope ratios of dissolved methane were analyzed at the G. G. Hatch Stable Isotope Laboratory at the University of Ottawa, Ottawa, Ontario, using the method described by Hilkert (2012).

Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) for the project was achieved by submitting approximately 5% of the dissolved methane samples as field duplicates. The field duplicates were collected during a third sampling event in December 2013. During the QA/QC sampling event, the five locations with the highest methane concentrations were resampled. Two samples were collected at each location: a primary sample and a field duplicate. This allowed a comparison of methane results for samples collected at the same location at two different times (i.e. September and December) and a comparison of the results for two samples collected at the same location and same time.

Results

The methane results from the 2013 sampling program are summarized in Table 1, and a complete list of individual sample results is provided in Appendix A. Twenty-one percent of the wells had detectable levels of methane, and the maximum concentration detected was 6.0 mg/L. The results from the 1975 GSC sampling program are also presented in Table 1 for comparison. The 1975 results are similar to the 2013 results, with detectable levels of methane in 15% of the wells and a maximum detected concentration of 9.2 mg/L. The combined results from both surveys are summarized in Table 1 and plotted on the map in Figure 1.

Table 2 presents the ethane, propane and isotope results from the 2013 survey. The locations of these samples are shown on the map in Figure 1. These 12 samples had the highest dissolved methane results of the 103 wells tested. Appendix B provides additional information on these water wells, including well locations, well construction details, geological formation information and available water-chemistry data (i.e. major ions and trace elements). Only one sample in Table 2 had detectable concentrations of ethane, and propane was not detected in any of the samples. With respect to the methane isotope results, sufficient methane was present to determine $\delta^{13}C$-CH_4 for eight samples and $\delta^{2}H$-CH_4 for seven samples. In general, isotope analyses were obtained for samples with methane concentrations above approximately 0.1 mg/L, but could not be obtained for many of the samples that had methane levels below 0.1 mg/L. An interpretation of the ethane, propane and isotope results are provided in the discussion section below.

The results from the QA/QC sampling event are presented in Appendix C. The results show significant variation in dissolved methane concentrations between the September 2013 and December 2013 sampling events. The percent difference in methane concentration between these two sampling events ranged from 8% to 78% and averaged 33% for the five sites that were re-sampled. The results for the field duplicate samples collected in December 2013 also showed significant variation, although the difference was not as great as that observed between the September and December sampling events. The percent difference in methane concentration for the duplicate samples ranged from 14% to 24% and averaged 21%.

Discussion

The dissolved methane levels identified in the 2013 survey were relatively low compared to the recommended action levels discussed in the above section on methane guidelines for drinking water. All of the results were below the lowest recommended action level of 10 mg/L. However, 2 of the 103 wells tested had methane concentrations that exceeded the Ontario aesthetic guideline for methane, indicating that these wells may have problems with water spurting or water hammer. These two wells, which are listed as sites 1 and 2 in Table 2, had methane concentrations of 6.0 mg/L and 4.4 mg/L and were located in McLellans Brook

Table 1. Summary of dissolved methane results. Statistics were calculated using one half the detection limit for non-detect samples. For sites where duplicate samples were collected, statistics were calculated using the highest sample result.

	2013 NSDNR[1] Survey	1975 GSC[2] Survey	2013 & 1975 Combined Results
No. of samples	103	714	817
Detection limit (mg/L)	0.003	0.007	0.003 & 0.007
No. of samples below detection limit	81	610	691
No. of samples above detection limit	22	104	126
Percent of samples above detection limit	21.4%	14.6%	15.4%
Minimum (mg/L)	<0.003	<0.007	<0.003
Maximum (mg/L)	6.0	9.2	9.2
Arithmetic Mean (mg/L)	0.12	0.044	0.053
Standard deviation (mg/L)	0.73	0.43	0.48
Median (mg/L)	<0.003	<0.007	0.0036
95th Percentile (mg/L)	0.15	0.043	0.043

[1]Nova Scotia Department of Natural Resources.
[2]Geological Survey of Canada (see Dyck *et al*., 1976).

(Pictou County) and Terre Noire (Inverness County), respectively.

Table 3 compares methane survey results from several North American jurisdictions. The data in Table 3 show a large range (i.e. 12% to 90%) in the number of wells reported to have detectable methane concentrations. The results from the current Nova Scotia methane survey are within this range (i.e. 21% of wells had detectable methane), although most other jurisdictions reported a higher percentage of methane detections. The only jurisdiction that reported a lower percentage of methane detections in well water was New Brunswick (i.e. 12% of wells had detectable methane).

The ethane and propane results in Table 2 can be used to assess methane sources. These compounds are usually not produced in significant quantities during microbial methanogenesis, and therefore their presence at low methane-to-ethane ratios (i.e. ratios of less than approximately 100) is often used as an indicator of deep thermogenic gas (Osborn *et al*., 2011). Only one sample in Table 2 (identified as site 2 in Table 2) had detectable levels of ethane or propane, and this sample had a methane-to-ethane ratio of 107. This suggests that the methane in this well, which is located in Terre Noire (Inverness County), is from a thermogenic source. However, there is some uncertainty in this conclusion because there are no isotope data available for this sample to confirm the methane source. The remainder of samples in Table 2 had non-detectable ethane and propane concentrations, indicating that they either have biogenic sources or the ethane and propane concentrations were too low to be detected.

The isotope results in Table 2 can be used to assess methane sources. Whiticar (1999) has reported that biogenic methane typically has $\delta^{13}C\text{-}CH_4$ values ranging between -50‰ and -110‰ and $\delta^{2}H\text{-}CH_4$ values ranging between -150‰ and -400‰. Thermogenic methane typically has $\delta^{13}C\text{-}CH_4$ values ranging between -20‰ and -50‰ and δ^{2} H-CH_4 values ranging between -100‰ and -275‰ (Whiticar, 1999). Other authors report slightly different ranges; for example, Jackson *et al*. (2013) report that $\delta^{13}C\text{-}CH_4$ values for thermogenic methane often range between -25‰ and -55‰.

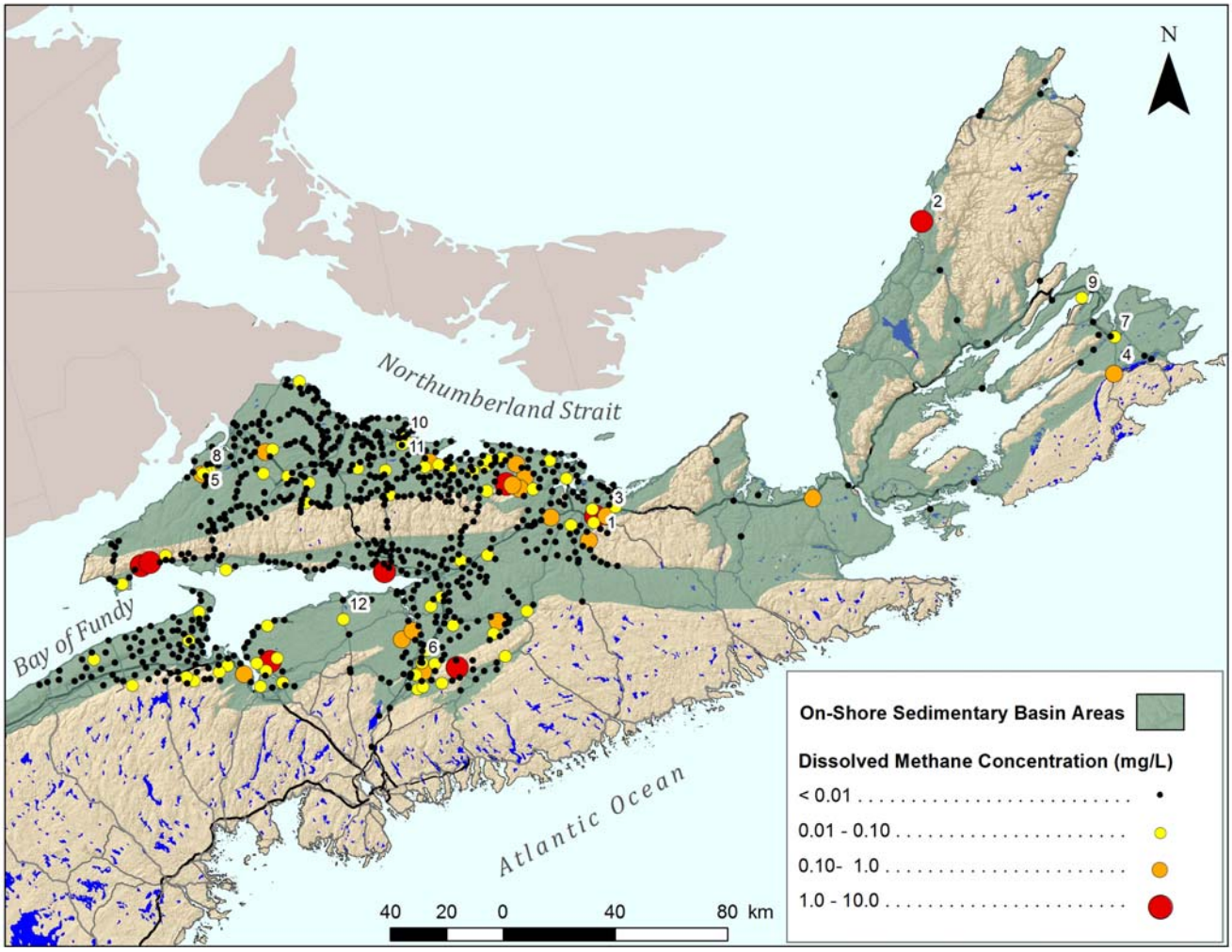

Figure 1. Map of dissolved methane in well water in Nova Scotia. Numbered locations as indicated in Table 2. Data from current study and Dyck *et al*. (1976).

Figures 2 and 3 show two types of graphs that are commonly used to interpret methane-source types. These graphs make use of dissolved methane concentrations and ^{13}C and ^{2}H isotopes of methane. Based on the results in these two graphs, four of the samples were interpreted to be of biogenic origin (sites 1, 3, 5 and 7), three were interpreted to be of thermogenic origin (sites 4, 8 and 11) and one was interpreted to be of mixed biogenic/thermogenic origin (site 10). The three samples interpreted to be of thermogenic origin were collected from water wells located in Marion Bridge (Cape Breton County), River Hebert (Cumberland County) and Wallace (Cumberland County). Note that two of the samples shown in Figure 3 (i.e. site 3 and site 7) fall outside the range of the biogenic, thermogenic or mixed fields. These samples may have been oxidized, resulting in the enrichment of both ^{13}C and ^{2}H. Methane oxidation in groundwater has been reported to be linked to bacterial sulphate reduction (Van Stempvoort *et al*., 2005).

Summary of Findings

Results from the current and previous methane surveys in the on-shore sedimentary basin areas of Nova Scotia indicate that dissolved methane was detected in approximately 15% of water wells, but that concentrations were relatively low (i.e. less than 9.2 mg/L) compared to the recommended action levels established in other jurisdictions. Based on the observed methane-to-ethane ratios and the isotope results from the current study, it appears that water wells in Nova Scotia can have methane originating from a range of possible

Table 2. Methane, ethane, propane and isotope results. Site locations indicated in Figure 1.

Site	Community	County	Well Type	Methane (mg/L)	Ethane (mg/L)	Propane (mg/L)	δ^{13}C-CH_4 (‰, VPDB[1])	δ^{2}H-CH_4 (‰, VSMOW[2])	Methane Source
1	McLellans Brook	Pictou	Drilled	6.0	<0.002	<0.004	-60	-211	Biogenic
2	Terre Noire	Inverness	Drilled	4.4	0.041	<0.004	--	--	Thermogenic?
3	Thorburn	Pictou	Drilled	0.38	<0.002	<0.004	-61	-148	Biogenic (oxidized)?
4	Marion Bridge	Cape Breton	Drilled	0.31	<0.002	<0.004	-53	-215	Thermogenic
5	River Hebert	Cumberland	Drilled	0.27	<0.002	<0.004	-63	-170	Biogenic
6	Shubenacadie East	Colchester	Dug	0.059	<0.002	<0.004	--	--	
7	Sydney	Cape Breton	Drilled	0.056	<0.002	<0.004	-57	-69	Biogenic (oxidized)?
8	River Hebert	Cumberland	Drilled	0.045	<0.002	<0.004	-41	--	Thermogenic?
9	Groves Point	Cape Breton	Dug	0.020	<0.002	<0.004	--	--	
10	Wallace	Cumberland	Drilled	0.020	<0.002	<0.004	-57	-197	Mixed
11	Wallace	Cumberland	Drilled	0.015	<0.002	<0.004	-49	-162	Thermogenic
12	North Noel Road	Hants	Drilled	0.014	<0.002	<0.004	--	--	

[1]Vienna Pee Dee Belemnite
[2]Vienna Standard Mean Ocean Water
-- Isotope data not presented due to low signal strength or other sample problems.

Table 3. Methane survey results from various North American jurisdictions.

Jurisdiction	Area Surveyed	Percent of Wells With Detectable Dissolved Methane	Number of Wells Sampled	Reference
New Brunswick	Sussex	12%	26	Al *et al.*, 2013
Nova Scotia	Northeastern Nova Scotia	15%	714	Dyck *et al*., 1976
Nova Scotia	Northeastern Nova Scotia	21%	103	(current study)
Quebec	Lowlands of the St. Lawrence Estuary & Appalachia	90%	130	Moritz and Gélinas, 2013
Saskatchewan	Cypress Hills	27%	864	Dyck and Campbell, 1986
Maryland	Appalachian Plateau	41%	49	Pham and Bolton, 2012
New York	Statewide	53%	239	U.S. Geological Survey, 2012
Pennsylvania	Northeast Pennsylvania	78%	1701	Molofsky *et al*., 2013
Pennsylvania/New York	Northeast Pennsylvania & Upstate New York	85%	60	Osborn *et al*., 2011
West Virginia	Statewide	77%	170	U.S. Geological Survey, 2006

sources, including biogenic, thermogenic and mixtures of these two. Recommendations for future work include additional methane testing in areas with data gaps (e.g. Cape Breton and northeastern mainland Nova Scotia), additional isotope testing to confirm methane sources, and an evaluation of possible correlations between methane concentrations and water well construction or geospatial criteria.

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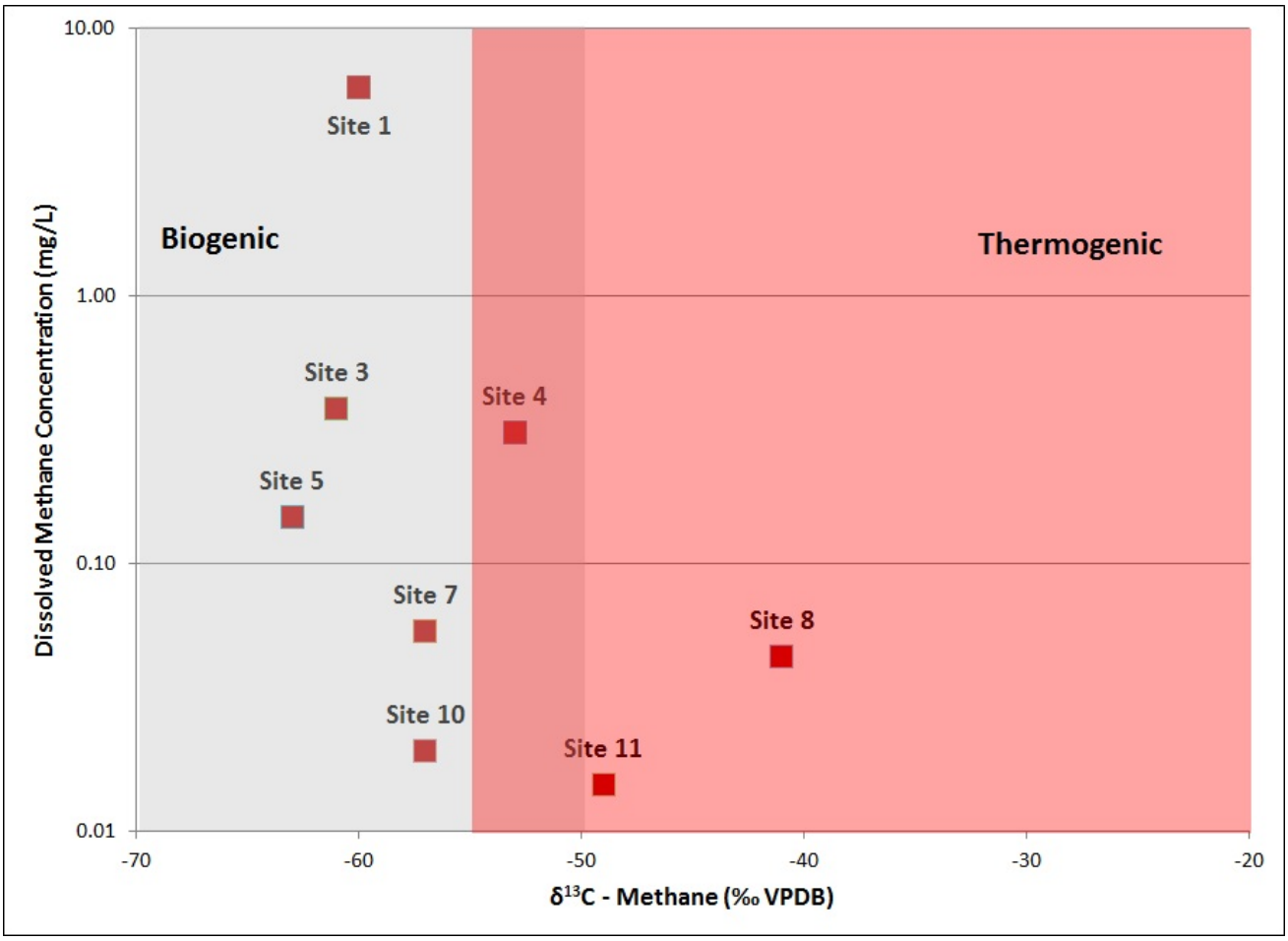

Figure 2. Plot of $\delta^{13}C\text{-}CH_4$ versus dissolved methane.

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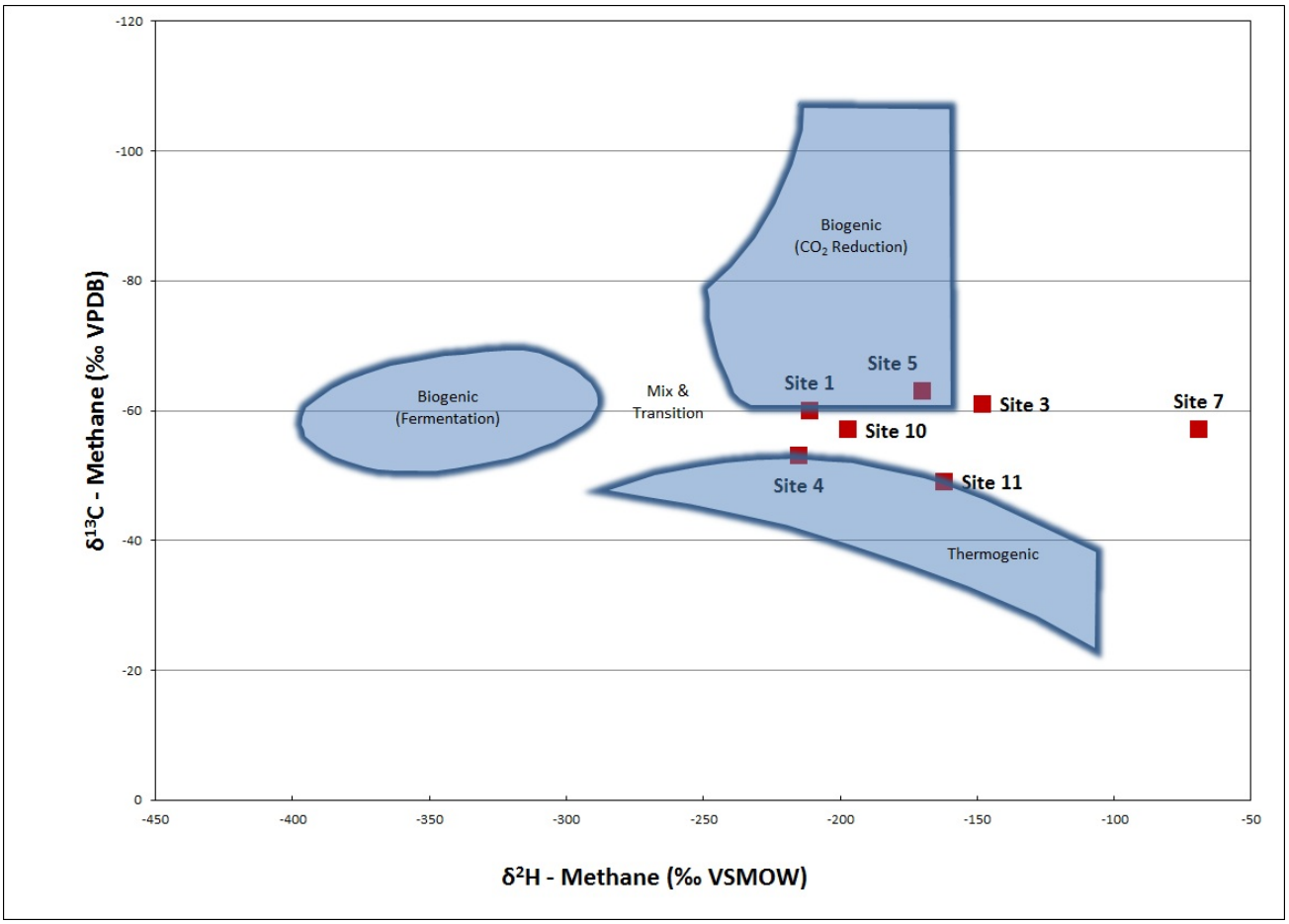

Figure 3. Plot of isotope results—δ^2H-CH_4 versus δ^{13}C-CH_4 (biogenic and thermogenic classification ranges from Whiticar, 1999).

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Appendix A

The Appendix A table appears on the next page.

Table A. 2013 Methane survey results (arranged by county).

Sample#	Sample Date	Community	County	Northing	Easting	Well Type	Groundwater Region	Methane (mg/L)
AC47940	16-Sep-2013	Monastery	Antigonish	5052198	608570	Drilled	Carbonate Evaporite	0.16
AC47927	10-Sep-2013	Frasers Mills	Antigonish	5038351	583004	Drilled	Sedimentary	<0.003
AC47929	10-Sep-2013	Frasers Mills	Antigonish	5038351	583004	Not Known	Sedimentary	<0.003
AC47931	10-Sep-2013	Pomquet	Antigonish	5052941	589236	Drilled	Sedimentary	<0.003
AC47923	10-Sep-2013	Maryvale	Antigonish	5064967	574413	Drilled	Sedimentary	<0.003
AC47936	16-Sep-2013	Aulds Cove	Antigonish	5056352	621353	Not Known	Sedimentary	<0.003
AC47946	16-Sep-2013	Beech Hill	Antigonish	5051059	580379	Drilled	Carbonate Evaporite	<0.003
AC48176	2-Dec-2013	Marion Bridge	Cape Breton	5096264	715962	Drilled	Sedimentary	0.31
AC48556	12-Sep-2013	Sydney	Cape Breton	5109125	716355	Drilled	Sedimentary	0.056
AC48470	9-Sep-2013	Groves Point	Cape Breton	5123077	704628	Drilled	Surficial	0.020
AC48487	11-Sep-2013	Balls Creek	Cape Breton	5114322	708501	Drilled	Carbonate Evaporite	<0.003
AC48151	20-Sep-2013	Bras d'Or	Cape Breton	5125847	708013	Drilled	Sedimentary	<0.003
AC48497	11-Sep-2013	Coxheath	Cape Breton	5109656	710580	Drilled	Sedimentary	<0.003
AC48466	9-Sep-2013	Albert Bridge	Cape Breton	5101205	729287	Drilled	Surficial	<0.003
AC48468	9-Sep-2013	Albert Bridge	Cape Breton	5101205	729287	Dug	Sedimentary	<0.003
AC48553	12-Sep-2013	Howie Centre	Cape Breton	5104403	708793	Drilled	Sedimentary	<0.003
AC48473	10-Sep-2013	East Bay	Cape Breton	5099862	704018	Drilled	Carbonate Evaporite	<0.003
AC48157	20-Sep-2013	Albert Bridge	Cape Breton	5102220	726799	Drilled	Sedimentary	<0.003
AC48559	12-Sep-2013	Sydney River	Cape Breton	5109282	714877	Drilled	Sedimentary	<0.003
AC48753	24-Sep-2013	Shubenacadie East	Colchester	4993320	469495	Dug	Surficial	0.059
2013JD001	30-Jul-2013	Mattatall Lake	Colchester	--	--	Drilled	Sedimentary	0.010
AC49093	17-Sep-2013	Upper Stewiacke	Colchester	5008759	500667	Drilled	Carbonate Evaporite	0.008
AC49090	17-Sep-2013	Brookfield	Colchester	5011797	478958	Dug	Surficial	0.006
AC48441	18-Sep-2013	Balmoral Mills	Colchester	5054710	484690	Drilled	Sedimentary	<0.003
AC48443	18-Sep-2013	Denmark	Colchester	5061780	487536	Drilled	Sedimentary	<0.003
AC48756	24-Sep-2013	Shubenacadie East	Colchester	4993320	469495	Dug	Surficial	<0.003
AC48754	24-Sep-2013	Shubenacadie East	Colchester	4993455	468868	Dug	Surficial	<0.003
AC49099	17-Sep-2013	Hilden	Colchester	5017179	477370	Drilled	Carbonate Evaporite	<0.003
AC49096	17-Sep-2013	Upper Stewiacke	Colchester	5007420	500325	Drilled	Sedimentary	<0.003
AC49114	19-Sep-2013	Bass River	Colchester	5029329	438824	Drilled	Sedimentary	<0.003
AC49111	19-Sep-2013	Bass River	Colchester	5029329	438824	Drilled	Sedimentary	<0.003
AC49074	16-Sep-2013	Londonderry	Colchester	5033355	454667	Drilled	Sedimentary	<0.003
AC49162	9-Dec-2013	River Hebert	Cumberland	5060507	391242	Drilled	Sedimentary	0.27
AC49109	18-Sep-2013	River Hebert	Cumberland	5061434	392736	Drilled	Sedimentary	0.045
AC48430	18-Sep-2013	Wallace	Cumberland	5073360	463158	Drilled	Sedimentary	0.020
AC48433	18-Sep-2013	Wallace	Cumberland	5070979	462429	Drilled	Sedimentary	0.015
AC48397	10-Sep-2013	Parrsboro	Cumberland	5030496	393235	Drilled	Sedimentary	<0.003

Table continues next two pages.

Table A. (*continued*).

Sample#	Sample Date	Community	County	Northing	Easting	Well Type	Groundwater Region	Methane (mg/L)
AC48417	17-Sep-2013	Pugwash	Cumberland	5078562	448662	Drilled	Sedimentary	<0.003
AC49079	16-Sep-2013	Wentworth Centre	Cumberland	5059137	452740	Drilled	Sedimentary	<0.003
AC48419	17-Sep-2013	Upper Gulf Shore	Cumberland	5080262	451438	Drilled	Sedimentary	<0.003
AC48407	17-Sep-2013	Port Howe	Cumberland	5080393	441617	Drilled	Sedimentary	<0.003
AC47948	17-Sep-2013	Shinimicas Bridge	Cumberland	5080085	429366	Drilled	Sedimentary	<0.003
AC47950	17-Sep-2013	Tidnish Cross Roads	Cumberland	5093949	421624	Drilled	Sedimentary	<0.003
AC49102	18-Sep-2013	Fort Lawrence	Cumberland	5078424	402372	Drilled	Sedimentary	<0.003
AC48400	10-Sep-2013	Shulie	Cumberland	5050621	394334	Drilled	Sedimentary	<0.003
AC48402	17-Sep-2013	Amherst Shore	Cumberland	5089881	431682	Drilled	Sedimentary	<0.003
AC48421	17-Sep-2013	North Wallace	Cumberland	5075864	466218	Drilled	Sedimentary	<0.003
AC48389	9-Sep-2013	Wentworth	Cumberland	5052847	455576	Drilled	Sedimentary	<0.003
AC48435	18-Sep-2013	Wallace	Cumberland	5073178	460940	Drilled	Sedimentary	<0.003
AC48411	17-Sep-2013	Pugwash	Cumberland	5078010	448750	Drilled	Sedimentary	<0.003
AC48414	17-Sep-2013	Pugwash	Cumberland	5078178	448833	Drilled	Sedimentary	<0.003
AC48396	10-Sep-2013	Advocate Harbour	Cumberland	5022369	359939	Drilled	Sedimentary	<0.003
AC48405	17-Sep-2013	Northport	Cumberland	5087625	432439	Drilled	Sedimentary	<0.003
AC49082	16-Sep-2013	Wentworth Centre	Cumberland	5056698	457111	Drilled	Sedimentary	<0.003
AC49121	30-Sep-2013	Fort Lawrence	Cumberland	5077500	403500	Not Known	Sedimentary	<0.003
AC49105	18-Sep-2013	Fort Lawrence	Cumberland	5077500	403500	Not Known	Sedimentary	<0.003
AC47232	6-Sep-2013	Fall River	Halifax	4963250	451603	Not Known	Metamorphic	0.005
AC47384	11-Sep-2013	Oakfield	Halifax	4974331	454141	Drilled	Metamorphic	<0.003
AC47250	9-Sep-2013	North Noel Road	Hants	5008748	441590	Drilled	Sedimentary	0.014
AC47246	6-Sep-2013	Enfield	Hants	4977100	457903	Not Known	Carbonate Evaporite	0.003
AC47391	13-Sep-2013	Brooklyn	Hants	4985312	420934	Drilled	Carbonate Evaporite	<0.003
AC47234	6-Sep-2013	Milford Station	Hants	4989332	465306	Drilled	Carbonate Evaporite	<0.003
AC47371	9-Sep-2013	Upper Rawdon	Hants	4989792	444175	Drilled	Metamorphic?	<0.003
AC47354	9-Sep-2013	Lower Selma	Hants	5015768	451388	Drilled	Sedimentary	<0.003
AC47393	13-Sep-2013	McKay Section	Hants	4984934	424229	Drilled	Surficial	<0.003
AC47352	9-Sep-2013	Maitland	Hants	5018717	460613	Drilled	Sedimentary	<0.003
AC47243	6-Sep-2013	Milford Station	Hants	4987966	465270	Drilled	Carbonate Evaporite	<0.003
AC47367	13-Sep-2013	Noel	Hants	5015643	441386	Drilled	Sedimentary	<0.003
AC47239	6-Sep-2013	Milford Station	Hants	4984374	464710	Drilled	Carbonate Evaporite	<0.003
AC47363	9-Sep-2013	Kennetcook	Hants	5003428	443648	Drilled	Surficial	<0.003
AC47357	9-Sep-2013	Maitland	Hants	5017687	460503	Drilled	Sedimentary	<0.003
AC47375	9-Sep-2013	Upper Rawdon	Hants	4990976	443971	Drilled	Metamorphic	<0.003
AC48577	19-Sep-2013	Terre Noire	Inverness	5150098	647606	Drilled	Sedimentary	4.4
AC48582	17-Sep-2013	Judique	Inverness	5088327	616380	Drilled	Carbonate Evaporite	<0.003
AC48570	17-Sep-2013	Pleasant Bay	Inverness	5187907	667991	Drilled	Carbonate Evaporite	<0.003

Table A. *(concluded)*.

Sample#	Sample Date	Community	County	Northing	Easting	Well Type	Groundwater Region	Methane (mg/L)
AC48575	16-Sep-2013	Pleasant Bay	Inverness	5189460	668817	Not Known	Surficial	<0.003
AC48586	17-Sep-2013	North East Margaree	Inverness	5132874	653931	Drilled	Sedimentary	<0.003
AC49285	4-Dec-2013	McLellans Brook	Pictou	5045438	531320	Drilled	Sedimentary	6.0
AC49281	4-Dec-2013	Thorburn	Pictou	5045673	534912	Drilled	Sedimentary	0.38
AC47913	10-Sep-2013	Pictou	Pictou	5058846	520961	Drilled	Sedimentary	0.012
AC47986	9-Sep-2013	Sutherlands River	Pictou	5048903	538471	Drilled	Sedimentary	0.011
AC47901	9-Sep-2013	Salt Springs	Pictou	5042186	508498	Drilled	Carbonate Evaporite	0.009
AC47920	10-Sep-2013	Scotsburn	Pictou	5055489	511196	Drilled	Sedimentary	0.009
AC47906	9-Sep-2013	Lyons Brook	Pictou	5057780	516946	Drilled	Sedimentary	<0.003
AC48424	18-Sep-2013	Welsford	Pictou	5064593	495563	Drilled	Sedimentary	<0.003
AC47915	10-Sep-2013	Braeshore	Pictou	5063198	526953	Drilled	Sedimentary	<0.003
AC47908	10-Sep-2013	Kings Head	Pictou	5056476	537522	Drilled	Sedimentary	<0.003
AC47910	10-Sep-2013	Little Harbour	Pictou	5055559	533981	Drilled	Sedimentary	<0.003
AC47995	9-Sep-2013	Salt Springs	Pictou	5043374	509482	Drilled	Sedimentary	<0.003
AC47917	9-Oct-2013	Waterside	Pictou	5067550	516685	Drilled	Sedimentary	<0.003
AC48427	18-Sep-2013	River John	Pictou	5066315	495539	Drilled	Sedimentary	<0.003
AC47998	9-Sep-2013	Salt Springs	Pictou	5042024	508442	Drilled	Sedimentary	<0.003
AC48480	10-Sep-2013	Martinique	Richmond	5047990	650520	Not Known	Surficial	<0.003
AC48462	9-Sep-2013	St. Peter's	Richmond	5057246	666047	Drilled	Sedimentary	<0.003
AC48573	16-Sep-2013	Cape North	Victoria	5195551	689811	Drilled	Sedimentary	<0.003
AC48594	19-Sep-2013	Englishtown	Victoria	5129030	689594	Dug	Surficial	<0.003
AC48591	19-Sep-2013	Baddeck	Victoria	5106781	670773	Dug	Surficial	<0.003
AC48495	11-Sep-2013	Iona	Victoria	5090761	669118	Drilled	Carbonate Evaporite	<0.003
AC48562	16-Sep-2013	Ingonish	Victoria	5174399	700566	Drilled	Plutonic	<0.003
AC48589	19-Sep-2013	Middle River	Victoria	5114963	660013	Drilled	Carbonate Evaporite	<0.003
AC48154	19-Sep-2013	Boularderie East	Victoria	5122111	693855	Drilled	Sedimentary	<0.003
AC48567	16-Sep-2013	Aspy Bay	Victoria	5199996	691358	Drilled	Carbonate Evaporite	<0.003
AC48493	11-Sep-2013	Iona	Victoria	5090603	668942	Drilled	Sedimentary	<0.003

Appendix B

Table B1. Well construction and geologic information for wells with elevated methane levels.

Site	Community	County	Methane (mg/L)	Methane Source	Well Type	Well Depth (m)	Casing Depth (m)	Groundwater Region	Geologic Formation
1	McLellans Brook	Pictou	6.0	Biogenic	Drilled	46	13	Bedrock - Sedimentary	Cumberland Group, Stellarton Fm
2	Terre Noire	Inverness	4.4	Thermogenic?	Drilled	33*	32*	Bedrock - Sedimentary	Mabou Group
3	Thorburn	Pictou	0.38	Biogenic (oxidized)?	Drilled	41	13	Bedrock - Sedimentary	Cumberland Group, Stellarton Fm
4	Marion Bridge	Cape Breton	0.31	Thermogenic	Drilled	93*	30*	Bedrock - Sedimentary	Windsor Group
5	River Hebert	Cumberland	0.27	Biogenic	Drilled	43	21	Bedrock - Sedimentary	Cumberland Group, Joggins Fm
6	Shubenacadie East	Colchester	0.059	--	Dug	6	6	Surficial	Glaciofluvial
7	Sydney	Cape Breton	0.056	Biogenic (oxidized)?	Drilled	46	18	Bedrock - Sedimentary	Cumberland Group. South Bar Fm
8	River Hebert	Cumberland	0.045	Thermogenic?	Drilled	43	11	Bedrock - Sedimentary	Cumberland Group, Joggins Fm
9	Groves Point	Cape Breton	0.020	--	Drilled	24	20	Bedrock - Sedimentary	Windsor Group
10	Wallace	Cumberland	0.020	Mixed	Drilled	--	--	Bedrock - Sedimentary	Cumberland Group, Boss Point Fm
11	Wallace	Cumberland	0.015	Thermogenic	Drilled	43*	12*	Bedrock - Sedimentary	Cumberland & Mabou Group
12	North Noel Road	Hants	0.014	--	Drilled	--	--	Bedrock - Sedimentary	Cumberland Group, Scotch Village Fm

*Records indicate multiple wells are present at this location. Well construction information shown here is for the most recently installed well.

Table B2. Water chemistry results.

Parameter	Units	Canadian Drinking Water Guideline	Detection Limit	Site 1 McLellans Brook Pictou Co. -	Site 2 Terre Noire Inverness Co. 08/Jun/2010	Site 3 Thorburn Pictou Co. 15/Sep/2005
General Chemistry						
Total Alkalinity (Total as CaCO3)	mg/L	-	5	-	270	190
Chloride (Cl)	mg/L	250 AO	1	-	35	40
Colour	TCU	15 AO	5	-	ND	2.5
Hardness (CaCO3)	mg/L	500 AO	-	-	50	60
Nitrate + Nitrite	mg/L	10	0.05	-	ND	0.16
Nitrite (N)	mg/L	1	0.01	-	ND	ND
Nitrate (N)	mg/L	10	0.05	-	ND	0.16
Nitrogen (Ammonia Nitrogen)	mg/L	-	0.05	-	ND	0.05
Total Organic Carbon (C)	mg/L	-	0.5	-	1.9	0.25
Orthophosphate (P)	mg/L	-	0.01	-	ND	ND
pH	pH	6.5 - 8.5 AO	-	-	8.7	8.12
Silica (SiO2)	mg/L		0.5	-	9.4	10
Sulphate (SO4)	mg/L	500 AO	2	-	5	4.5
Turbidity	NTU	5 AO	0.1	-	2.6	0.3
Conductivity	uS/cm	-	-	-	610	470
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	-	1	-	259	186
Calculated TDS	mg/L	-	1	-	351	292
Carb. Alkalinity (calc. as CaCO3)	mg/L	-	1	-	12	2
Ion Balance (% Difference)	%	-	-	-	1.87	0.06
Langelier Index (@ 20C)	N/A	-	-	-	0.669	0.248
Langelier Index (@ 4C)	N/A	-	-	-	0.42	-0.001
Calcium (Ca)	mg/L	-	0.1	-	9.7	19
Magnesium (Mg)	mg/L	-	0.1	-	6.2	3.1
Phosphorus (P)	mg/L	-	0.1	-	ND	ND
Potassium (K)	mg/L	-	0.1	-	0.82	2.4
Sodium (Na)	mg/L	200 AO	0.1	-	120	100
Fluoride (F)	mg/L	1.5	0.1	-	ND	0.6
Metals						
Aluminum (Al)	ug/L	-	10	-	180	13
Antimony (Sb)	ug/L	6	2	-	ND	ND
Arsenic (As)	ug/L	10	2	-	ND	ND
Barium (Ba)	ug/L	1000	5	-	440	310
Beryllium (Be)	ug/L	-	2	-	ND	ND
Bismuth (Bi)	ug/L	-	2	-	ND	ND
Boron (B)	ug/L	5000	5	-	910	86
Cadmium (Cd)	ug/L	5	0.3	-	ND	ND
Chromium (Cr)	ug/L	50	2	-	ND	ND
Cobalt (Co)	ug/L	-	1	-	ND	ND
Copper (Cu)	ug/L	1000 AO	2	-	26	19
Iron (Fe)	ug/L	300 AO	50	-	120	160
Lead (Pb)	ug/L	10	0.5	-	ND	0.6
Manganese (Mn)	ug/L	50 AO	2	-	ND	28
Molybdenum (Mo)	ug/L	-	2	-	ND	ND
Nickel (Ni)	ug/L	-	2	-	ND	ND
Selenium (Se)	ug/L	10	2	-	ND	ND
Silver (Ag)	ug/L	-	0.5	-	ND	ND
Strontium (Sr)	ug/L	-	5	-	270	540
Thallium (Tl)	ug/L	-	0.1	-	ND	ND
Tin (Sn)	ug/L	-	2	-	ND	ND
Titanium (Ti)	ug/L	-	2	-	ND	ND
Uranium (U)	ug/L	20	0.1	-	ND	ND
Vanadium (V)	ug/L	-	2	-	ND	ND
Zinc (Zn)	ug/L	5000 AO	5	-	ND	17

Table continues next two pages.

All guidelines are health-based values, except those indicated as aesthetic objectives.
AO = Aesthetic Objective
ND = Not Detected.

Table B2. *(concluded).*

Parameter	Units	Canadian Drinking Water Guideline	Detection Limit	Site 4 Marion Bridge Cape Breton Co. 14/Sep/2010	Site 5 River Hebert Cumberland Co. 30/Sep/2002	Site 6 Shubenacadie East Colchester Co. 07/Sep/2004
General Chemistry						
Total Alkalinity (Total as CaCO3)	mg/L	-	5	130	250	210
Chloride (Cl)	mg/L	250 AO	1	110	350	4
Colour	TCU	15 AO	5	ND	14	ND
Hardness (CaCO3)	mg/L	500 AO	-	86	466	199
Nitrate + Nitrite	mg/L	10	0.05	ND	ND	0.07
Nitrite (N)	mg/L	1	0.01	ND	ND	ND
Nitrate (N)	mg/L	10	0.05	ND	ND	0.07
Nitrogen (Ammonia Nitrogen)	mg/L	-	0.05	0.12	0.3	ND
Total Organic Carbon (C)	mg/L	-	0.5	ND	0.25	0.8
Orthophosphate (P)	mg/L	-	0.01	ND	0.02	ND
pH	pH	6.5 - 8.5 AO	-	8.2	7.9	7.6
Silica (SiO2)	mg/L		0.5	8.2	10	7.5
Sulphate (SO4)	mg/L	500 AO	2	41	46	14
Turbidity	NTU	5 AO	0.1	1.4	13.4	0.2
Conductivity	uS/cm	-	-	690	1730	422
Bicarb. Alkalinity (calc. as CaCO3)	mg/L	-	1	127	248	209
Calculated TDS	mg/L	-	1	380	870	233
Carb. Alkalinity (calc. as CaCO3)	mg/L	-	1	2	2	ND
Ion Balance (% Difference)	%	-	-	1.68	1.42	4.56
Langelier Index (@ 20C)	N/A	-	-	0.266	0.95	0.3
Langelier Index (@ 4C)	N/A	-	-	0.018	0.55	-0.1
Calcium (Ca)	mg/L	-	0.1	25	147	68.5
Magnesium (Mg)	mg/L	-	0.1	5.4	24.1	6.9
Phosphorus (P)	mg/L	-	0.1	ND	ND	ND
Potassium (K)	mg/L	-	0.1	2.1	6.8	1.5
Sodium (Na)	mg/L	200 AO	0.1	110	135	4.3
Fluoride (F)	mg/L	1.5	0.1	0.4	0.26	0.05
Metals						
Aluminum (Al)	ug/L	-	10	11	50	ND
Antimony (Sb)	ug/L	6	2	ND	10	ND
Arsenic (As)	ug/L	10	2	ND	10	68
Barium (Ba)	ug/L	1000	5	100	110	5
Beryllium (Be)	ug/L	-	2	ND	25	ND
Bismuth (Bi)	ug/L	-	2	ND	10	ND
Boron (B)	ug/L	5000	5	430	110	12
Cadmium (Cd)	ug/L	5	0.3	ND	1.5	ND
Chromium (Cr)	ug/L	50	2	ND	10	ND
Cobalt (Co)	ug/L	-	1	ND	5	ND
Copper (Cu)	ug/L	1000 AO	2	14	10	46
Iron (Fe)	ug/L	300 AO	50	ND	1400	ND
Lead (Pb)	ug/L	10	0.5	ND	2.5	0.8
Manganese (Mn)	ug/L	50 AO	2	97	410	9
Molybdenum (Mo)	ug/L	-	2	4.6	10	ND
Nickel (Ni)	ug/L	-	2	ND	10	ND
Selenium (Se)	ug/L	10	2	ND	10	ND
Silver (Ag)	ug/L	-	0.5	ND	2.5	ND
Strontium (Sr)	ug/L	-	5	2000	650	120
Thallium (Tl)	ug/L	-	0.1	ND	0.5	ND
Tin (Sn)	ug/L	-	2	ND	10	ND
Titanium (Ti)	ug/L	-	2	ND	10	ND
Uranium (U)	ug/L	20	0.1	0.17	0.5	0.6
Vanadium (V)	ug/L	-	2	ND	10	ND
Zinc (Zn)	ug/L	5000 AO	5	6.9	61	6

All guidelines are health-based values, except those indicated as aesthetic objectives.
AO = Aesthetic Objective
ND = Not Detected.

Site 7 Sydney Cape Breton Co. 05/Aug/2004	Site 8 River Hebert Cumberland Co. 20/Sep/2005	Site 9 Groves Point Cape Breton Co. 27/Jul/2010	Site 10 Wallace Cumberland Co. 31/May/2000	Site 11 Wallace Cumberland Co. 30/Sep/2002	Site 12 North Noel Road Hants Co. 27/Jul/2005
57	190	140	-	220	180
117	54	30	15.5	370	4.6
39	ND	ND	5	19	ND
130.89	92	330	111	638	160
ND	ND	ND	-	ND	0.06
-	ND	ND	-	ND	ND
-	ND	ND	0.19	ND	0.06
0.05	0.3	ND	0.21	ND	ND
3.2	0.25	0.5	0.5	0.25	0.25
0.15	ND	ND	-	ND	ND
7.2	8.37	7.8	7.4	7.8	7.56
14.7	12	5.9	-	8.3	11
11	33	190	32	6	21
47	0.6	11	7	31.7	0.8
524	630	810	380	1710	380
56.91	191	143	-	219	181
272	358	500	209	807	238
ND	4	ND	-	1	ND
1.72	0.03	4.18	-	0.42	0.04
-	0.634	0.584	-	0.93	0.093
-0.84	0.385	0.335	-	0.53	-0.157
41.8	26	120	44.6	199	47
6.44	6.3	6.1	1.2	34.2	9.6
-	ND	ND	-	ND	0.1
1.5	8.5	2.7	2	8.5	3.2
45.3	100	9.3	40.3	48.8	31
0.25	0.3	0.2	ND	ND	0.1
ND	ND	ND	50	50	13
ND	ND	ND	ND	10	ND
8.2	ND	ND	ND	10	ND
96	82	34	ND	640	74
ND	ND	ND	-	25	ND
-	ND	ND	-	10	ND
50	97	ND	2500	25	34
ND	ND	ND	0.05	1.5	ND
ND	ND	ND	ND	10	ND
2	ND	ND	-	5	ND
4	ND	4.1	25	10	4
5090	130	1200	ND	2100	140
0.5	ND	2.9	ND	2.5	0.6
3010	19	110	25	120	75
2	ND	ND	-	10	ND
6	ND	ND	-	10	ND
ND	ND	ND	ND	10	ND
1	ND	ND	-	2.5	ND
127	350	16000	-	440	230
0.4	ND	ND	-	0.5	ND
10	ND	ND	-	10	ND
-	ND	ND	-	10	ND
ND	ND	0.21	0.2	3.1	1.2
ND	ND	ND	-	10	ND
12	8	570	25	44	20

Appendix C

Table C. Quality assurance and quality control sample results.

Site	Sample#	Sample Date	Community	County	Methane (mg/L)	Percent Difference
1	AC47993	9-Sep-2013	McLellans Brook	Pictou	2.1	78%
1	AC49284	4-Dec-2013 (primary)	McLellans Brook	Pictou	4.8	22%
1	AC49285	4-Dec-2013 (duplicate)	McLellans Brook	Pictou	6.0	
2	AC48577	19-Sep-2013	Terre Noire	Inverness	4.4	12%
2	AC48228	11-Dec-2013 (primary)	Terre Noire	Inverness	3.9	23%
2	AC48229	11-Dec-2013 (duplicate)	Terre Noire	Inverness	3.1	
3	AC47991	9-Sep-2013	Thorburn	Pictou	0.35	8%
3	AC49281	4-Dec-2013 (primary)	Thorburn	Pictou	0.38	24%
3	AC49282	4-Dec-2013 (duplicate)	Thorburn	Pictou	0.30	
4	AC48500	12-Sep-2013	Marion Bridge	Cape Breton	0.23	30%
4	AC48176	2-Dec-2013 (primary)	Marion Bridge	Cape Breton	0.31	14%
4	AC48177	2-Dec-2013 (duplicate)	Marion Bridge	Cape Breton	0.27	
5	AC49124	30-Sep-2013	River Hebert	Cumberland	0.15	38%
5	AC49161	9-Dec-2013 (primary)	River Hebert	Cumberland	0.22	20%
5	AC49162	9-Dec-2013 (duplicate)	River Hebert	Cumberland	0.27	