Exploring the relationships between small non-community drinking water system characteristics and water system performance in Ontario, Canada

Wendy Pons, Ian Young, David Pearl, Andria Jones-Bitton, Scott A. McEwen, Katarina Pintar and Andrew Papadopoulos

ABSTRACT

The objectives of this work were to investigate the relationships between characteristics of small non-community drinking water systems (SDWSs) and the performance of these systems with respect to *Escherichia coli* testing and risk ratings. Ontario-wide SDWS data were analysed using regression models with outcomes of (1) having an adverse *E. coli* test result in the 12 months prior to the last inspection and (2) the SDWS risk rating (high/medium vs. low risk) that is assigned by public health inspectors. Almost 34% (2,364/7,003) of SDWSs did not utilize treatment, more commonly for ground water than surface supplies ($P < 0.001$). The odds of having a positive *E. coli* test result were greater in systems using ground water with treatment (OR = 2.00; 95% CI 1.23–3.24) and surface water with treatment (OR = 1.97; 95% CI 1.05–3.71) compared to ground water with no treatment. The odds of having a water system rated high or medium compared to low risk was greater if the water system operated seasonally (OR = 1.36; 95% CI 1.17–1.59), had an adverse *E. coli* test result (OR = 1.66; 95% CI 1.09–2.53), and in specific facility types. This research helps to inform existing training opportunities available to SDWS operators in Ontario, and to better standardize the SDWS risk assessment process.

Key words | drinking water, public health, public health inspection, risk assessment, small drinking water system, water quality

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ABBREVIATIONS

MOE	Ministry of the Environment
MOHLTC	Ministry of Health and Long-Term Care
OR	Odds ratio
PHI	Public health inspector
SDWS	Small non-community drinking water systems
UV	Ultraviolet

INTRODUCTION

Small non-community drinking water systems (SDWSs) provide water to an estimated 15% of the population in Canada (Moffatt & Struck 2011). SDWSs are defined as non-municipal and non-community water systems used by a business or premise to provide drinking water to the public, such as water systems serving rural restaurants, hotels, and campgrounds. In Ontario, responsibility for drinking water regulation is shared among the Ontario Ministry of the Environment (MOE), the Ministry of Health and Long-Term Care (MOHLTC), and local public health agencies (Table 1). SDWSs under the oversight of the MOHLTC are the focus of this study.

A systematic review of SDWSs in Canada and the United States found that 293 outbreaks occurred from

doi: 10.2166/wh.2016.007

Table 1 | Types of drinking water systems overseen by the MOE and the MOHLTC in Ontario, Canada

		Ministry Responsible for Regulatory Oversight		
Water system type	**Definition**	**MOE**	**MOHLTC[a]**	**System ownership**
Large residential	Serves >100 private residences	X		Municipal
Small residential	Serves 6–100 private residences	X		Municipal
Large non-residential	Serves a facility with a water rate >2.9 L/sec	X Serves designated facilities[b]	X Serves non-designated facilities	Municipal or non-municipal
Small non-residential	Serves a facility with a water rate <2.9 L/sec	X Serves designated facilities	X Serves non-designated facilities	Municipal or non-municipal
Year round residential	Serves >5 residences or >5 connections at a campground that is open year round	X		Non-municipal
Seasonal residential	Serves >5 residences or >5 connections at a campground and is closed for at least 60 consecutive days/year	X Serves designated facilities	X Serves non-designated facilities	Non-municipal

Source: Drinking Water Ontario (2014).
[a]Water systems in this column are the focus of this study.
[b]Designated facility is a children's camp, health care facility, social care facility, school, university, college or other degree-granting institution.

1970–2014, resulting in 41,862 illnesses and three deaths (Pons *et al.* 2015), and a report by the National Research Council (1997) found water systems in the United States serving fewer than 500 people exceeded microbial and chemical water standards twice as often as larger water systems. SDWSs are required to provide the same water quality as larger systems, but face added challenges (Ontario Drinking Water Advisory Council 2005; United States Environmental Protection Agency 2006; British Columbia Ministry of Health 2013). These include greater difficulty in accessing laboratory services for water sampling in a timely manner (British Columbia Ministry of Health 2013), lack of resources and funding support for improvements to infrastructure (Rupp 2001; Butterfield & Camper 2004; United States Environmental Protection Agency 2006; British Columbia Ministry of Health 2013), inadequate treatment methods (Rupp 2001; Butterfield & Camper 2004; British Columbia Ministry of Health 2013), and poor access to operator training (Boag *et al.* 2010; Kot *et al.* 2011; British Columbia Ministry of Health 2013).

Previous studies have been conducted to investigate the characteristics of public water supplies in Ontario (Odoi *et al.* 2003), and a number of qualitative studies have examined the challenges faced by small community drinking water systems in Canada (Jalba & Hrudey 2006; Boag *et al.* 2010; Kot *et al.* 2011); however, there is a need to assess characteristics of SDWSs in Ontario to increase our knowledge and understanding of these systems and to identify further opportunities for interventions to improve the water supply, such as promoting training for targeted high risk SDWSs. In Ontario, training for all small water operators is available through multiple providers including the Ontario MOE and Climate Change and the Walkerton Clean Water Centre (as of the date of this publication) (Walkerton Clean Water Centre 2016). The objectives of this work were to investigate the relationships between characteristics of SDWSs in Ontario, and the performance of these systems with respect to whether an adverse *Escherichia coli* test had been reported, and whether the system had been rated as a high or medium risk (compared to low risk), according to criteria developed by the MOHLTC.

METHODS

Data source

We obtained de-identified Ontario-wide SDWS data from the MOHLTC on system characteristics and risk assessment ratings. In Ontario, SDWSs are regulated under *Ontario*

Regulation 319/08 Small Drinking Water Systems (Government of Ontario 2013), which outlines the requirements for water treatment, frequency of microbial sampling and testing, and the responsibilities of the owner and operator. Under MOHLTC oversight, which began in 2009, public health inspectors (PHIs) conduct a regular site-specific risk assessment of SDWSs to evaluate the risk of microbial water contamination. The PHI interviews the SDWS operator/owner to determine their competency as a water operator, reviews historical water sample test results (which includes a test for *E. coli* and total coliforms), and completes a risk assessment instrument (questionnaire) which focuses on the water source, treatment, and distribution system criteria (MOHLTC 2008). The risk assessment tool provides one grade for water source and treatment and a second grade for distribution system criteria. The two grades are combined using a matrix to rank the overall risk level of the water system as high (significant level of risk), medium (moderate level of risk) or low (negligible level of risk) (Table 2). Subsequently, re-assessments are conducted at intervals of two years for high risk systems and four years for low and medium risk systems.

Data obtained from the MOHLTC were collected by PHIs, between January, 2009 and December, 2013, during routine inspections and risk assessments of the SDWSs across Ontario. The database is updated each time a SDWS is inspected, so the data reflected only the most recent inspection and assessment for each system. This data set comprised information on 7,730 SDWSs from 35 of the 36 provincial health units, including the postal code of the system, the risk rating (high, medium or low), any positive *E. coli* or total coliform test results in the 12 months prior to the last inspection, the primary water source (ground water, surface water, or other), water treatment method (disinfection, filtration, both filtration and disinfection, or no treatment), premise type (provincial park, commercial facility, community centre, club/golf course, hotel/motel/bed and breakfast [B&B], restaurant, trailer park/rental cabins, place of worship, park/campground, other), whether they operated seasonally, if the water operator had taken formal operator training (defined as having completed any basic training or certificate course), and the number of people served by the water supply (however, this latter variable was not used in the analysis as the data were not collected in a consistent manner). Some data were not available for all variables, so analyses were conducted with smaller sample sizes, as noted.

Table 2 | Matrix used to categorize level of risk of the water supply for SDWSs in Ontario, Canada

		Grade for source and treatment criteria*			
		A	**B**	**C**	**D**
Grade for distribution criteria	A	Low	Low	Medium	High
	B	Low	Low	Medium	High
	C	Medium	Medium	Medium	High
	D	High	High	High	High

*Low risk = Negligible level of risk.
Medium risk = Moderate level of risk.
High risk = Significant level of risk.
Source: Recreated from MOHLTC (2008).

Data analyses

A Pearson chi-square test was used to assess the association between water system characteristics (including: presence of water treatment, water source, having a seasonal water system) and operator training and the outcomes: having a positive *E. coli* test result in the prior 12 months; and risk rating. Unadjusted odds ratios (ORs) were calculated using Fisher's exact test to assess the relationship between selected sub-categories of dichotomous variables, with statistical significance ($P < 0.05$). All statistical analyses were conducted with STATA version 12.0 (StataCorp 2011).

Two logistic regression models were developed to explore the relationships between SDWS characteristics and performance. The first model investigated whether water system characteristics were associated with testing positive for *E. coli* in the 12 months prior to the last inspection. This model included the SDWS postal code as a random effect to take into consideration the effect of location on a positive test result. The second model used crossed random-effects logistic regression (which took into consideration the effect of postal code and health unit in the model) to assess whether water system characteristics were associated with the outcome of the SDWS risk assessment rating (high or medium compared to low risk classification of the water system). High and medium risk categories were combined because few systems (7%; 504/7,196) were classified as high risk. A crossed random effects approach was used for this model because the data set did not have a strictly hierarchal data structure (Raudenbush 1993; Rasbash & Goldstein 1994). That is, SDWSs were cross-classified by local public health agency jurisdiction and postal code (since postal codes do not follow health agency geographic areas, and a single postal code may be located in more than one health agency). The crossed random-effects model included three levels of variation: water system (level 1), postal code (level 2), and local public health agency (level 3).

For the *E. coli* model, seven predictor variables were assessed for significance in univariable analyses: completion of formal operator training defined as any previous course-based training (yes/no); whether the water system operated year round (yes/no); the water source type; premise type; water treatment type; regional location of health agency jurisdiction (North West, North East, South West, Central West, Central East, Eastern); risk level (high, medium, low); and water source and treatment type categorized into one variable (ground water with or without treatment, and surface water with or without treatment).

For the risk assessment rating model, three predictor variables were assessed for significance in univariable analyses: whether the water system operated year round (yes/no); premise type (same categories as above); and having a positive *E. coli* test result in the 12 months prior to the last inspection (yes/no). The variables operator training, water source and treatment type were weighted variables in the MOHLTC risk assessment tool, used to assign the risk level to the water supply, and as such were excluded from this analysis. While water quality test results are not explicitly included in this risk assessment tool used, the inspector may manually increase the risk rating when there is an adverse water test. Regional location was not assessed in this model because local public health agency was modelled as a random effect.

Collinearity between variables was assessed using the Spearman correlation coefficient, and if two variables were highly correlated (coefficient greater than |0.8|), only the more biologically plausible one was included in the analysis. The predictors were screened in univariable random-effects logistic regression models and were initially included in the multivariable model if $P \leq 0.20$. A manual backwards-selection process was used to build the final model, and statistical significance was set at $P \leq 0.05$. All variables were re-evaluated for significance using a likelihood ratio test and assessed for confounding (changes > 20% in the remaining variable coefficients). Two-way interactions were investigated between all covariables in the final model. Best linear unbiased predictors, and Pearson and deviance residuals, were used to assess model fit and identify outliers (Dohoo *et al.* 2009).

The proportion of variance in the outcome due to postal code and health unit was calculated using the following formulae (Dohoo *et al.* 2009):

$$\rho_{\text{postal code}} = \frac{\sigma_{\text{postal code}}}{\left(\sigma_{\text{postal code}} + \frac{\pi^2}{3}\right)} \tag{1}$$

$$\rho_{\text{health unit}} = \frac{\sigma_{\text{health unit}}}{\left(\sigma_{\text{health unit}} + \frac{\pi^2}{3}\right)} \tag{2}$$

RESULTS

Water system characteristics

The data set obtained from the MOHLTC included 7,730 SDWSs; 400 (5.1%) of these were removed because they were not given a risk rating and another 134 (1.7%) because an associated postal code could not be found. Therefore, a total of 7,196 SDWSs were included in data analysis.

The distribution of water source by treatment type is shown in Figure 1. Treatment information was missing for 193 systems, and almost 34% (2,364/7,003) of SDWSs did not utilize treatment. When examined by water source, 5% (46/860) of surface supplies, 35% (2,023/5,774) of ground water supplies and 99% (295/296) of 'other' supplies were not treated, while 266 systems did not have these data available. The 'other' water source category was unspecified.

Univariable analyses

A surface water supply had higher odds of using treatment when compared to ground water supplies (OR = 10.0; 95%

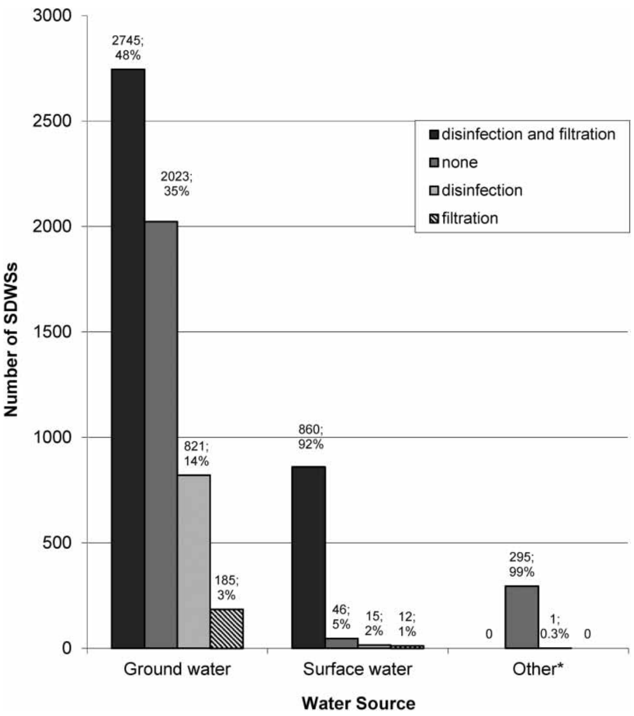

Figure 1 | SDWS treatment type by water source in Ontario, Canada ($n = 7{,}003$), as of December, 2013. *Other water source was not specified.

CI 7.1–12.5; $P < 0.001$). Data pertaining to water system characteristics stratified by premise type are shown in Table 3. The highest numbers of premises with no water system treatment were categorized as 'place of worship' (49%; 363/732) or 'other' premises (41%; 313/766). The 'other' premise type included tourist centres, fire halls, migrant housing, not specified, and roadside garages.

Approximately two-thirds (66%, 4,630/6,985) of water operators reported that they had not received formal drinking water operator training. Almost 66% (3,802/5,763) of system operators utilizing ground water, 69% (644/927) of system operators utilizing surface water, and 62% (184/295) of 'other' water system operators, respectively, had not taken formal operator training. Operators of surface water systems were more likely to have reported completing a formal training course than operators of ground water systems (OR = 1.17; 95% CI 1.01–1.36; $P = 0.039$). The premise types with the two highest proportions of trained operators were provincial parks (75%; 94/126) and community centres (56%; 402/717), while the premise types with the two lowest proportions of trained operators were hotels/motels/B&Bs (20%; 263/1,285) and restaurants (22%; 212/984).

A total of 45% (3,134/6,970) of SDWSs were seasonal water systems. Seasonal water systems had a higher odds of utilizing surface water (81%, 751/927) than ground water (40%, 2,319/5,759) (OR = 0.16; 95% CI 0.13–0.19; $P < 0.001$). Approximately 32% (1,009/3,134) of operators that oversaw seasonal premises had formal operator training, compared to 35% (1339/3836) of operators with year-round premises; this difference was statistically significant (OR = 0.89; 95% CI 0.81–0.97; $P = 0.017$). Trailer parks/rental cabins (89%; 692/778) and park/campgrounds (88%; 600/684) were the premise types most commonly reported as seasonal systems.

Water system characteristics stratified by risk assessment rating category are shown in Table 4. Seventy-one percent (368/516) of high risk water systems had no treatment, 13% (162/1214) of medium risk systems had no treatment and 37% (2027/5466) of low risk systems had no treatment. Water systems with no treatment had a higher odds of being ranked as high risk compared to medium risk systems (OR = 16.10; 95% CI 12.47–20.86; $P < 0.001$), and low risk systems (OR = 4.20; 95% CI 3.45–5.17; $P < 0.001$). Only 15% (78/511) of high risk water system operators reported participating in formal training, which is low compared to medium and low risk systems (26%; 315/1210; OR = 0.51; 95% CI 0.39–0.67; $P < 0.001$ and 37%; 1962/5265; OR = 0.3; 95% CI 0.24–0.40; $P < 0.001$, respectively). A significantly greater proportion of systems in the high risk category were seasonal (58%; 299/513), compared to medium and low risk categories (52%; 629/1211; OR = 1.29; 95% CI 1.04–1.59; $P = 0.017$ and 42%; 2210/5259; OR = 1.92; 95% CI 1.59–2.32; $P < 0.001$, respectively).

Summary statistics and univariable associations between having a positive *E. coli* test result in the 12 months prior to the last inspection and water system characteristics are shown in Table 5. There was no correlation between predictor variables.

Logistic regression modelling of risk factors for positive *E. coli* test results

Results from the final regression model of having a positive *E. coli* test result are shown in Table 6. Postal code

Table 3 | Premise category, water treatment type, water source, operator training, and seasonal use classification of SDWSs ($n = 7{,}003$) in Ontario, Canada as of December 2013

	Premise type									
SDWS characteristics	**Hotel/motel/ B&B No. (%)**	**Restaurant No. (%)**	**Trailer park/ rental cabins No. (%)**	**Other[a] No. (%)**	**Community centre No. (%)**	**Place of worship No. (%)**	**Park/camp-ground No. (%)**	**Club/golf course No. (%)**	**Commercial facility No. (%)**	**Provincial park No. (%)**
Treatment										
None	469 (35)	325 (33)	261 (32)	313 (41)	226 (31)	363 (49)	221 (32)	201 (35)	142 (33)	36 (28)
Disinfection	102 (7)	128 (13)	58 (7)	83 (11)	67 (9)	84 (11)	125 (18)	93 (16)	57 (13)	40 (32)
Filtration	55 (4)	21 (2)	29 (3)	24 (3)	18 (2)	17 (2)	15 (2)	9 (2)	9 (2)	0
Filtration and disinfection	725 (54)	512 (52)	470 (57)	346 (45)	413 (57)	268 (36)	333 (48)	266 (47)	222 (52)	50 (40)
Total	1,351	986	818	766	724	732	694	569	430	126
Water source										
Ground water	887 (69)	892 (90)	530 (68)	630 (86)	662 (92)	636 (90)	585 (85)	511 (91)	347 (84)	94 (74)
Surface water	394 (30)	53 (5)	248 (32)	34 (5)	12 (2)	7 (1)	88 (13)	19 (3)	53 (13)	25 (20)
Other[b]	12 (1)	41 (4)	4 (1)	69 (9)	44 (6)	63 (9)	13 (2)	32 (6)	11 (3)	7 (6)
Total	1,293	986	782	733	718	706	686	562	411	126
Operator is trained										
Yes	263 (20)	212 (22)	260 (33)	272 (37)	402 (56)	188 (27)	315 (46)	186 (33)	163 (40)	94 (75)
No	1,022 (80)	772 (78)	521 (67)	461 (63)	315 (44)	515 (73)	368 (54)	377 (67)	248 (60)	32 (25)
Total	1,285	984	781	733	717	703	683	563	411	126
Premise operates seasonally										
Yes	743 (58)	220 (22)	692 (89)	197 (27)	123 (17)	8 (1)	600 (88)	361 (64)	111 (27)	83 (66)
No	542 (42)	763 (78)	86 (11)	536 (73)	594 (83)	697 (99)	84 (12)	202 (36)	299 (73)	42 (34)
Total	1,285	983	778	733	717	705	684	563	410	125

[a]Other category includes tourist centres, fire halls, migrant housing, not specified, and roadside garages.
[b]Other water source was not further specified.

Table 4 | Cross-tabulations and univariable associations between the risk rating of the water system and treatment, water source, operator training, seasonal systems, and having an adverse water sample for *E. coli* for SDWSs ($n = 7{,}196$) in Ontario, Canada as of December 2013

	Risk rating of the water system			
SDWS characteristics	**High, No. (%)**	**Medium, No. (%)**	**Low, No. (%)**	***P* value**[a]
Water source				$P < 0.001$
Ground water	399 (77)	931 (77)	4,444 (84)	
Surface water	111 (22)	272 (22)	550 (10)	
Other[b]	6 (1)	11 (1)	279 (6)	
Total	516	1,214	5,273	
Treatment type				$P < 0.001$
None	368 (71)	162 (13)	2,027 (37)	
Disinfection	30 (6)	141 (12)	666 (12)	
Filtration	44 (8)	18 (1)	135 (2)	
Both disinfection and filtration	74 (14)	893 (74)	2,638 (49)	
Total	516	1,214	5,466	
Operator is trained				$P < 0.001$
Yes	78 (15)	315 (26)	1,962 (37)	
No	433 (85)	1,962 (74)	3,303 (63)	
Total	511	1,210	5,265	
Water system operates seasonally				$P < 0.001$
Yes	299 (58)	629 (52)	2,210 (42)	
No	214 (42)	582 (48)	3,049 (58)	
Total	513	1,211	5,259	
Adverse test result for *E. coli*				$P = 0.11$
Yes	13 (3)	28 (2)	81 (1)	
No	503 (97)	1,186 (98)	5,383 (99)	
Total	516	1,214	5,466	

[a]*P* value was calculated using a Pearson chi-square test.
[b]Other water source was not further specified.

contributed <0.001% of the total variation in this model. Relative to SDWSs using ground water with no treatment, the odds of having a positive *E. coli* test result in the previous 12 months was 2.00 times greater for SDWSs using ground water with treatment ($P = 0.005$), 4.33 times greater for SDWSs using surface water with no treatment ($P = 0.052$), and 1.97 times greater for SDWSs using surface water with treatment ($P = 0.036$). None of the other variables were significant in the final model. No issues were identified when assessing model fit and outliers.

Table 5 | Cross-tabulations and univariable associations between having an adverse *E. coli* test result in the 12 months prior to the last inspection of the water system and treatment, water source, operator training and seasonality for SDWSs ($n = 7{,}196$) in Ontario, Canada as of December 2013

	Adverse test result for *E. coli*		
	Yes (%)	**No (%)**	***P* value**[a]
Treatment type			$P = 0.02$
None	27 (22)	2,530 (36)	
Disinfection	18 (15)	819 (12)	
Filtration	4 (3)	193 (3)	
Disinfection and filtration	73 (60)	3,532 (50)	
Total	122	7,074	
Water source			$P = 0.54$
Ground water	98 (80)	5,676 (82)	
Surface water	20 (16)	913 (13)	
Other[b]	4 (3)	292 (4)	
Total	122	6,881	
Operator is trained			$P = 0.83$
Yes	40 (33)	2,315 (34)	
No	82 (67)	4,549 (66)	
Total	122	6,864	
Water system operates seasonally			$P = 0.97$
Yes	55 (45)	3,083 (45)	
No	67 (55)	3,778 (55)	
Total	122	6,861	

[a]*P* value was calculated using a Pearson chi-square test.
[b]Other water source was not further specified.

Table 6 | Final logistic regression model for the odds of having an adverse test result for *E. coli* in the 12 months prior to the last inspection compared to not having a positive *E. coli* test result among SDWSs in Ontario, Canada ($n = 6{,}707$)

Variable	**OR**	**SE**	**95% CI**		***P* value**
Water source by treatment type ($P = 0.01$)					
Ground water with no treatment	Referent				
Ground water with treatment	2.00	0.25	1.23	3.24	0.005
Surface water with no treatment	4.33	0.76	0.99	18.92	0.052
Surface water with treatment	1.97	0.32	1.05	3.71	0.036

Wald $Chi^2 = 9.62$, $P = 0.022$.
Total variation attributed to postal code <0.001%.

Crossed random-effects logistic regression model examining risk level

Results from the final regression model with the outcome being the risk level of the drinking water system (high or medium vs. low) are shown in Table 7. High correlation was not observed among predictor variables and no issues were identified when assessing model fit and outliers. Local public health agency contributed 21% of the total variation in the model, while postal code contributed 13% of the total variation. Relative to SDWSs that operated year round, the odds of having a water system rated high or medium risk compared to low risk was 1.36 times greater if the water system operated seasonally. Relative to SDWSs that did not have an adverse *E. coli* test result in the 12 months prior to the last inspection of the water system, the odds of having a water system rated as high or medium risk was 1.66 times greater if systems reported an adverse *E. coli* test result. Relative to SDWSs associated with a community centre, the odds of having a water system rated high or medium risk was greater for commercial facilities, hotels/motels/B&Bs, parks/campgrounds, restaurants, and trailer parks/rental cabins.

Table 7 | Final crossed random effects logistic regression model for the odds of having a water system rated as high or medium compared to low risk among SDWSs in Ontario, Canada ($n = 6{,}983$)

Variable	OR	SE	95% CI		*P* value
Water system operates year round					
No	Referent				
Yes	0.73	0.078	0.629	0.853	<0.001
Adverse test result for *E. coli* in the 12 months prior to the last inspection					
No	Referent				
Yes	1.66	0.214	1.09	2.53	0.017
Premise type					<0.001[b]
Community centre	Referent				
Place of worship	1.32	0.150	0.98	1.77	0.067
Club/golf course	1.07	0.163	0.78	1.48	0.664
Commercial facility	1.51	0.167	1.08	2.09	0.014
Hotel/motel/B&B	1.80	0.133	1.39	2.34	<0.001
Other[a]	1.06	0.151	0.79	1.42	0.715
Park/campground	1.62	0.153	1.19	2.18	0.002
Provincial park	1.10	0.287	0.63	1.93	0.732
Restaurant	2.02	0.134	1.55	2.61	<0.001
Trailer park/rental cabins	2.24	0.149	1.67	2.97	<0.001

[a]Other includes tourist centres, fire halls, migrant housing, not specified, and roadside garages.
[b]*P* value refers to significance of all categories for this variable.
Wald $\text{Chi}^2 = 114.29$, $P < 0.001$.
Total variation attributed to local public health agency 21%.
Total variation attributed to postal code 13%.

DISCUSSION

In Ontario, water sampling frequency for SDWSs varies and may be required once every week to once every three months; frequency is determined by the PHI and is based on a number of factors including the history of water sampling results, whether water treatment is used, and if source protection is in place (MOHLTC 2008). Samples that are positive for *E. coli* are required to be reported to the PHI by both the operator and the laboratory conducting the analysis. The PHI then responds by issuing a boil water advisory, establishing corrective action and resampling the water supply (Government of Ontario 2013). The presence of enteric bacteria such as generic *E. coli* in drinking water is an indication of faecal contamination (Reynolds *et al.* 2008). A test for *E. coli* can also provide a measure of the efficacy of water treatment procedures in place (Payment & Pintar 2006). The use of water treatment to remove or otherwise inactivate microbial pathogens in drinking water has a central role in reducing the incidence of waterborne diseases worldwide and is considered one of the most successful interventions for improving public health (Ngwenya *et al.* 2013). We found that water systems with any treatment were more likely to have a positive *E. coli* test result than a ground water system with no treatment, indicating that treatment systems may not be performing as intended in SDWSs in Ontario. We hypothesize that the treatment systems in place were either inadequate for their needs or the treatment systems were not properly maintained and monitored. Conversely, water supplies with traditionally good quality water and no treatment had fewer positive water samples. Previous studies (Rupp 2001; Butterfield & Camper 2004; British Columbia Ministry of Health 2013) noted that operators of SDWSs have trouble identifying appropriate treatment systems for their particular water supply. Ultraviolet light (UV) disinfection is the most common treatment system used by SDWSs; 67% of operators in Ontario reported using UV disinfection for their water systems (Pons *et al.* 2014). UV disinfection can be effective for eliminating microbiological contamination, but effectiveness is dependent on the chemical, physical, and microbiological qualities of the incoming water (Health Canada 2008). A pre-filter is often needed to reduce turbidity and UV disinfection alone has no residual disinfectant properties that protect the water supply as it travels through the distribution system. Establishing a temporal relationship between positive water samples and treatment in a cross-sectional study such as this is a challenge, since we did not have date of treatment initiation relative to test results. There is a need to further assess whether the relationship between water supply type and the likelihood of an *E. coli* positive water sample is related to the specific water treatment used, and if there is a need to train operators to ensure they fully understand the strengths and limitations of various treatment systems and can ensure their proper operation.

We found that 66% of SDWS operators had not received formal training, and that the proportion of trained operators varied by premise type, with operators of community centres and provincial parks having the highest rates of formal training, and restaurant owners and hotel/motel/B&Bs having the lowest rates of formally trained operators. While operator training was not a significant variable in the *E. coli* model in our study, other research has shown that operators play an important role in the safety of the water supply and are needed to maintain and operate treatment systems as well as respond to adverse events (Jalba & Hrudey 2006; Bowman *et al.* 2009). Our results have valuable implications for targeting training efforts to specific groups of operators, emphasizing the utility of customizing training to the needs of operators responsible for different premise types.

Seasonal SDWSs were more likely to rely on surface water sources than ground water, reported fewer trained operators than year round systems (with differences being small but significant), and were more likely to be rated high or medium risk than low risk. Seasonal water systems often face increased demands for water during specific periods and may have many visitors during short periods of time (Craun & Gunn 1979). Surface water sources are at an increased risk of contaminants entering the water supply through run-off and agricultural and wildlife contamination (Reynolds *et al.* 2008). Systems that provide water on a seasonal basis should have the same level of ongoing monitoring and care, including water operator knowledge, awareness and diligence in maintaining the supply, as year-round systems. It is important that health agencies provide targeted messaging at the beginning of the season to these operators to raise their awareness of these issues.

The regression model examining water system characteristics by the assigned risk level (high or medium vs. low) showed the odds of being categorized as high or medium risk relative to low risk was greater if the water supply was seasonal, the system had an adverse *E. coli* test result in the prior 12 months, and if the system was associated with certain premises. The risk rating for a system is given based on the water source, treatment and distribution system. Having an adverse *E. coli* test result does not automatically increase the risk rating of a water system; however, the PHI may decide to change the risk rating accordingly at their discretion. The findings of this model are valuable in targeting water safety information and training efforts to the operator that will improve safety measures in those systems that tend to have a higher risk rating.

Health unit and postal code variables were modelled as random effects in order to take into account the multi-level structure of the data (Dohoo *et al.* 2009). The observed health unit effect on the risk assessment model was notable (21%), indicating there is some variation in risk assessment ratings between health unit, likely as a result of differences between PHIs who assign the ratings. These differences could contribute to misclassification bias since risk rankings are assigned by numerous inspectors who may categorize systems differently. This result suggests a need to provide more standardization in the use of the risk assessment instrument across the province; this could be achieved through evaluation of the instrument for reliability and validity, and via additional training in the use of the risk assessment tool for PHIs. There was also a smaller geographical effect with postal code contributing 13% of the variation in this model. Ground water quality is influenced by the hydrogeology of an area, and some areas of Ontario are inherently more susceptible to surface water intrusion with subsequent ground water contamination (Hynds *et al.* 2014).

This analysis would have been strengthened with further information on the type of water treatment used, a standard measure for the number of people using or having access to the water supply, the date of the adverse test result, having multiple test results and dates, and the months during which seasonal systems operate; unfortunately, such data were unavailable. This information should be considered for collection by PHIs in their future inspections in order to facilitate greater understanding of these factors in the operation and safety of the water supply. Furthermore, monitoring and analysing repeated water quality test results would add more in-depth information on the quality of the water supply. Frequency of testing could impact the likelihood of having a positive test result and was not taken into consideration in this study due to the unavailability of these data.

CONCLUSION

This research has provided a detailed description of the characteristics of SDWSs in Ontario, Canada. We found that the number of formally-trained water operators was low, as was the number of water systems that used water treatment. Additionally, we found that water treatment, as it was used in SDWSs in Ontario, may not be sufficient to reduce the risk of positive *E. coli* test results. Furthermore, SDWSs that have had a positive *E. coli* water result were more likely to be from specific premise types, and those that operated seasonally were more likely to be ranked as high or medium risk than low risk. Hence, this research has highlighted opportunities for targeting water operator training to specific groups of SDWS operators based on the premise type, water source and treatment level in order to increase water protection measures, and future data collection needs in these water systems by PHIs. Further research is needed to fully understand the relationship between adverse *E. coli* water tests and water treatment, including examining types of water treatment, surrounding land uses, and the distribution system.

COMPETING INTERESTS

The authors declare that they have no competing interests.

ACKNOWLEDGEMENTS

The authors thank David Pearl for assistance with the data analysis for this project.

REFERENCES

Boag, G., Pollon, D., Shuster-Wallace, C. J, Elliot, S. J. & Tye, M. 2010 *Safe Water Provisioning in Small Systems: A Key Informant Needs Assessment*. Report for the United Nations University Institute for Water, Environment and Health.

Bowman, W., Messner, M., Regli, S. & Bender, J. 2009 Measuring the effectiveness of performance-based training. *J. Water Health* **7** (1), 155–167.

British Columbia Ministry of Health, Health Protection Branch 2013 Small water system guidebook. www.health.gov.bc.ca/protect/pdf/small-water-system-guidebook.pdf. (accessed 12 January 2015).

Butterfield, P. & Camper, A. 2004 Development of a toolbox to assess microbial contamination risks in small water systems. *J. Water Health* **2** (4), 217–232.

Craun, G. F. & Gunn, R. A. 1979 Outbreaks of waterborne disease in the United States: 1975–1976. *J. Am. Water Works Assoc.* **71** (8), 422–428.

Dohoo, I., Martin, W. & Stryhn, H. 2009 *Veterinary Epidemiologic Research*, 2nd edn. VER Inc., Charlottetown, Prince Edward Island.

Drinking Water Ontario 2014 *An overview of drinking water system types regulated by the Ministry of the Environment*. http://www.ene.gov.on.ca/environment/dwo/en/responsibilities/STDPROD_095957.html (accessed 10 January 2015).

Government of Ontario 2013 *Ontario Regulation 319/08: Small Drinking Water Systems*. Queens Printer for Ontario.

Health Canada 2008 UV disinfection factsheet. www4.agr.gc.ca/resources/prod/doc/terr/pdf/uv_tech_bull_e.pdf (accessed 15 January 2015).

Hynds, P. D., Thomas, M. K. & Pintar, K. D. M. 2014 Contamination of groundwater systems in the US and Canada by enteric pathogens, 1990–2013: a review and pooled-analysis. *PLoS ONE* **9** (5), 1–12.

Jalba, D. I. & Hrudey, S. 2006 Drinking water safety and risk management for public health agencies. *Environ. Health Rev.* Summer, **3**, 37–44.

Kot, M., Castleden, H. & Gagnon, G. 2011 Unintended consequences of regulating drinking water in rural Canadian communities: examples from Atlantic Canada. *Health Place* **17** (5), 1030–1037.

Ministry of Health and Long-Term Care 2008 *Small Drinking Water Systems Risk Assessment Directives Guidance Document*. Ontario. Available from: http://www.health.gov.on.ca/en/pro/programs/publichealth/oph_standards/docs/guidance/gd_drinking_water.pdf (accessed 5 January 2015).

Moffatt, H. & Struck, S. 2011 *Water-borne Disease Outbreaks in Canadian Small Drinking Water Systems*. National Collaborating Centre for Environmental Health, Vancouver.

National Research Council 1997 *Safe Water from Every Tap: Improving Water Services to Small Communities*. The National Academies Press, Washington, DC, p. 218.

Ngwenya, N., Ncube, E. J. & Parsons, J. 2013 Recent advances in drinking water disinfection: successes and challenges. *Rev. Environ. Contam. Toxicol.* **222**, 111–170.

Odoi, A., Aramini, J., Majowicz, S., Meyers, R., Martin, W. S., Sockett, P., Michel, P., Holt, J. & Wilson, J. 2003 The status of drinking water in Ontario, Canada (1992–1999). *Can. J. Public Health* **94** (6), 417–421.

Ontario Drinking Water Advisory Council (ODWAC) 2005 Report and Advice on Ontario Regulation 170/03. http://www.odwac.gov.on.ca/reg_170/020805_Reg_170_Final_Report.pdf (accessed 10 December 2014).

Payment, P. & Pintar, K. 2006 Waterborne pathogens: a critical assessment of methods, results and data analysis. *J. Water Sci.* **19** (3), 233–245.

Pons, W., McEwen, S. A., Pintar, K., Jones-Bitton, A., Young, I. & Papadopoulos, A. 2014 Experience, training and confidence among small, non-community drinking water system operators in Ontario, Canada. *J. Water Health* **12** (4), 782–790.

Pons, W., Young, I., Truong, J., Jones-Bitton, A., McEwen, S. A., Pintar, K. & Papadopoulos, A. 2015 A systematic review of waterborne disease outbreaks associated with small non-community drinking water systems in Canada and the United States. *PLoS ONE* **10** (10), e0141646.

Rasbash, J. & Goldstein, H. 1994 Efficient analysis of mixed hierarchical and cross-classified random structures using a multilevel model. *J. Edu. Behav. Stat.* **19**, 337–350.

Raudenbush, S. W. 1993 A crossed random effects model for unbalanced data with applications in cross-sectional and longitudinal research. *J. Edu. Stat.* **18** (4), 321–349.

Reynolds, K. A., Mena, K. D. & Gerba, C. P. 2008 Risk of waterborne illness via drinking water in the United States. *Rev. Environ. Contam. Toxicol.* **192**, 117–158.

Rupp, G. L. 2001 The challenges of installing innovative treatment in small water systems. *J. Environ. Health* **64** (1), 22–25.

StataCorp 2011 *Stata Statistical Software: Release 12*. StataCorp LP, College Station, TX.

United States Environmental Protection Agency 2006 *Much effort and resources needed to help small drinking water systems overcome challenges*. Report No. 2006-P-00026. www.epa.gov/oig/reports/2006/ 20060530-2006-P-00026.pdf. (accessed 3 December 2014).

Walkerton Clean Water Centre 2016 Training. https://www.wcwc.ca/en/training/ (accessed 10 January 2015).

First received 11 January 2016; accepted in revised form 2 July 2016. Available online 22 August 2016