Bacteriological testing of private well water: A trends and guidelines assessment using five years of submissions data from southeastern Ontario

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ABSTRACT

OBJECTIVE: Rural populations are at an elevated risk of gastrointestinal illness, as they are dependent on private groundwater sources, and water quality remains the responsibility of the owner. Previous research suggests that only a minority of well water owners test their wells for bacteriological contamination. The aim of this study was to use testing records, in conjunction with current provincial guidelines, to assess submission rates and temporal trends in southeastern Ontario.

METHODS: Using five years of data (2008-2012) from the Public Health Ontario Laboratory in Kingston, Ontario, submissions of well water samples from unique properties (identified through geocoding) were descriptively analyzed. Temporal trends in guideline compliance were tested using a Cochran Armitage test. Finally, correlations between time and submission numbers were investigated using a 10-year provincial dataset to identify long-term temporal trends.

RESULTS: There were 107,547 submissions in the five years studied, 84% of which were geocoded, culminating in 30,687 unique properties. Although 11%-12% of owners met the guidelines in any given year, only 0.3% met them every year in the five-year study. Statistically significant decreases were found temporally both in the number of properties that met current guidelines and in all samples tested.

CONCLUSIONS: This study is the first to use submission records, rather than surveys, to definitively demonstrate that private well water submission guidelines are not being met in Ontario. However, there are no consistent guidelines across the country or continent, and limited supporting scientific literature is available. Significant research is required to develop evidence-based policies.

KEY WORDS: Drinking water; water wells; water quality; guidelines

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Waterborne illness is an ongoing concern in rural regions of Canada. The populations in these regions, estimated to be three to four million¹ in number, are dependent on private water supplies, typically groundwater, which is vulnerable to contamination with pathogenic agents, including bacteria, protozoa and viruses.² The last major study of private drinking water wells (1,300 wells) in Ontario, conducted between 1991 and 1992, found that 34% of tested wells had evidence of fecal contamination.³ Research in Canada and other developed nations has also demonstrated that populations dependent on private water supplies face a higher risk of gastrointestinal illness.^{4,5} For example, the risk of enteric disease was 5.2 times higher for individuals living on land parcels serviced by private wells than for those with access to municipal groundwater systems in British Columbia.⁵

The maintenance and potability of private well water are the responsibility of the owner, and water quality can be determined by submitting samples for laboratory analysis.⁶ In Ontario, bacteriological water testing is performed by the Public Health Ontario Laboratories (PHOL), and private well owners are encouraged to submit their water for routine testing. Historically, the guidelines published by Public Health Ontario (PHO)⁷ and the Ontario Ministry of the Environment⁶ recommended that private well owners needed three non-bacterially contaminated

water sample tests over a year to determine the stability of the water quality.⁷

Previous research in Ontario, primarily from surveys, has suggested that bacteriological testing is performed by only a quarter of the well owner population,^{8,9} with only a small subset of these owners meeting the thrice-yearly guidelines.⁸⁻¹⁰ The objective of this study was to assess private well owners' compliance with Ontario's historic well water testing guidelines using laboratory records from a five-year period and to identify any trends in submission rates that may have public health implications. Furthermore, the study evaluated policy implications in conjunction with our findings in the context of scientific literature and current North American practices.

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Table 1. Number of properties, categorized by the number of years (and the specific years) they submitted over a five-year period

Any 1 year		Any 2 years		Any 3 years		Any 4 years		All 5 years
Properties	Year	Properties	Years	Properties	Years	Properties	Years	Properties
4468	2008	966	2008-2009	413	2008-2010	306	2008-2011	871
4276	2012	828	2011-2012	341	2010-2012	278	2009-2012	
3861	2010	660	2009-2010	258	2008-2009,2011	263	2008-2010,2012	
3794	2011	631	2010-2011	225	2008-2009,2012	197	2008-2009,2011-2012	
3650	2009	622	2008,2010	219	2009-2011	183	2008,2010-2012	
		542	2008,2012	206	2008,2010-2011			
		507	2008,2011	198	2008,2011-2012			
		485	2010,2012	196	2009-2010,2012			
		485	2009,2012	188	2009,2011-2012			
		399	2009,2011	171	2008,2010,2012			

METHODS

Data preparation

All private well water sample records and results are stored in the Water Testing Information System (WTIS) database, which is owned by PHO. For this study, two datasets were retrieved from the database: all samples tested by the PHOL in Kingston (PHOL-K) in the five-year period between January 1, 2008, and December 31, 2012, and all samples submitted to all PHOLs in the 10-year period between January 1, 2003, and December 31, 2012. Samples not meeting the criteria for testing (e.g., improperly collected) were rejected, and neither of the datasets examined included these unprocessed samples. The 5-year dataset was retrieved for detailed analysis, whereas the 10-year dataset was examined to provide greater context when analyzing temporal trends. Ethics approval for the study was obtained from the Queen's University Health Sciences and Affiliated Teaching Hospitals Research Ethics Board in Kingston, Ontario.

Data representing unique properties with drinking wells were used in this study as the unit of analysis since the aim was to capture the number of properties whose owners met the suggested private well water guidelines in Ontario. To identify unique properties and to match multiple submissions from a single property in and across years, geocoordinates (geocodes) were determined for records from the five-year dataset. The multistage geocoding process used here has been previously published.¹¹ Included in this process were both automated algorithms and subsequent manual review, to address differences in information provided from multiple submissions for individual wells. This ensured that there was a one-to-one ratio between a well address and a geocode, and verified that all submissions from a unique location were captured.

The five-year dataset (all data from PHOL-K as captured by WTIS) was used during analysis; however, some samples tested by PHOL-K were from regions typically serviced by other PHOLs. Therefore, not all samples from these unique properties may have been received at PHOL-K. Using geocoded provincial submission data and PHOL locations, natural intake boundaries for each laboratory were defined (unpublished data, Majury et al.), creating an approximate catchment region for PHOL-K. Water samples from wells within this region had the highest probability of not being submitted to other laboratories. To determine the effects of wells outside the catchment zone, sensitivity analyses were performed, which involved re-analyzing the data with these wells removed. All visualizations and mapping were done using ArcMap (version 10.0, ESRI Inc., Redlands, CA).

Table 2. Summary of the percentage of unique properties that meet Ontario private well water submission guidelines from 2008 to 2012

Year (s)	Meet guidelines (%)
Independently by year*	
2008	12.83%
2009	12.45%
2010	10.75%
2011	11.10%
2012	10.88%
Across all 5 years†	
Exactly 1 year	9.70%
Exactly 2 years	1.72%
Exactly 3 years	0.67%
Exactly 4 years	0.44%
All 5 years	0.31%

* As a percentage of all unique properties in that year.

† As a percentage of all unique properties in the 5-year dataset.

Finally, a five-year (2008 to 2012) dataset for the entire province of Ontario was retrieved from WTIS to provide information on the extent of contamination in the province.

Data analysis

Properties were designated as “having met guidelines”^{6,7} for an individual year if a minimum of three well water samples were submitted for that property to PHOL-K in the given year and had no significant evidence of bacterial contamination (NSBC), defined by standard practice at the PHOLs, namely, any sample that had no *E. coli* colony forming units (CFUs) per 100 mL and ≤5 total coliform CFUs per 100 mL. The percentage of properties that met guidelines was determined individually by year, and across years, culminating in the percentage of properties that met guidelines in all five years of study.

Temporal trends in the rate of properties meeting guidelines were investigated using the Cochran Armitage Trend Test; JMP 11 (SAS Institute Inc., Cary, NC) was used for this statistical analysis. Specifically, the number of properties that met guidelines in each year was compared against those that did not as time progressed. For the primary analysis, properties that did not submit in a given year were omitted from counts for that year (a sensitivity analysis was performed in which these wells were included and assumed to have not submitted). The goal of this analysis was to determine whether there was a temporal shift in the number of wells in the region that were meeting Ontario submission guidelines in either a positive or negative direction. Additionally, using the catchment area defined above, a second sensitivity analysis was performed on the results of the Cochran Armitage test.

The 10-year dataset was used to plot the number of submissions over time in order to observe possible temporal trends. Additionally, Pearson's correlation coefficient was

Figure 1. Map of unique properties separated by the number of years of private well water submissions from each property (1 [red] representing one year submitted between 2008 and 2012 to 5 [dark green] representing submissions from all five years)

Table 3. Number of unique properties by year, categorized by number of submissions per year with no significant evidence for bacterial contamination, as determined by the Cochran Armitage Trend Test

Year	Fewer than 3 submissions* (%)	3 or more submissions (%)	Total
2008	9062 (87.17%)	1334 (12.83%)	10,396
2009	8382 (87.55%)	1192 (12.45%)	9574
2010	8663 (89.25%)	1043 (10.75%)	9706
2011	8360 (88.90%)	1044 (11.10%)	9404
2012	8669 (89.12%)	1058 (10.88%)	9726

* Includes wells that had only one submission in a year, which was found to be contaminated.

calculated for year (as the independent variable) and the number of submissions (the dependent variable), together with its statistical significance, using IBM SPSS Statistics 21 (IBM Corp., Armonk, NY).

RESULTS

The five-year dataset from PHOL-K contained 107,547 submissions, of which 83.82% were successfully geocoded, resulting in a dataset of 90,149 records. These records represented 30,687 unique properties across the five years, ranging from 9,404 to 10,396 unique properties by year. The unique properties can be found in Figure 1, displayed by the number of years a property had submitted water samples (between one and five). The majority of properties (65.33%) submitted well water samples during only one year of the five-year study period; the specific distribution of the number of properties and which years samples were submitted can be found in Table 1.

In any given year, between 10.75% and 12.83% of the properties included in the analysis met the three NSBC samples per year submission guidelines (Table 2). However, when considered across the five-year time period, only 0.31% of all 30,687 properties in the study met the guidelines each and every year. Of all study properties, 12.84% met the guidelines at least once between 2008 and 2012; however, of these, the majority

(75.55%) met the guidelines only once in this timeframe. When all properties outside the catchment zone were removed in a sensitivity analysis, the rate of properties that met the guidelines in all five years did not change.

Table 3 shows the data that were used for the Cochran Armitage Trend Test. The test showed a statistically significant trend towards fewer properties meeting guidelines per year as time progressed (p value <0.01 ; Z of 5.19). This represented a 15.20% decrease in the rate of properties meeting the guidelines (from 12.83% in 2008 to 10.88% in 2012). Neither of the performed sensitivity analyses (one using all wells in the study, another using the natural catchment zone) altered the p value.

The Ontario well water submission numbers from 2003-2012 can be found in Figure 2 (along with the number of contaminated samples split by season). Additionally, there was a very strong negative relationship between time and number of tested private well water samples submitted to the PHOLs over the 10-year period (Pearson $r=0.98$; $p<0.01$). Specifically, there was a 37.66% decrease over the 10 years in the entire province (from 275,524 samples in 2003 to 171,764 samples in 2012).

There were 927,394 tested submissions in Ontario from 2008 to 2012. The average rate of bacterial contamination (defined as any *E. coli* and/or more than 5 total coliforms) in these submissions (not individual wells) was 23.29% with a range of 21.24% to

Figure 2. All tested samples submitted to the entire PHOL (2003-2012) and number contaminated (split by season)

25.07%; for *E. coli* positives this was 4.11% with a range of 3.25% to 4.37%.

DISCUSSION

Using multi-year regional data, this study describes private well water submission rates and trends in the context of historical guidelines, which recommend three NSBC results per year.

The study dataset comprised solely the properties that submitted at least one well water sample over the five-year period, resulting in a total of 30,687 unique properties; 29,577 of these fell within the defined approximate PHOL-K catchment zone determined by the study. According to the best available private well database for the region there are 91,738 wells within this catchment zone,¹² suggesting that the dataset used by the study accounts for only 32.24% of actual wells. The dataset used represents 83.82% of all samples submitted to PHOL-K within the five-year time frame. Therefore, it is likely that the majority of the remaining wells did not have a sample submitted to the closest public health laboratory within the study period. Thus, it is reasonable to conclude that the limited compliance observed by the study is actually considerably more prevalent.

Previous research in Ontario suggests that 4.5%-8.0% of well owners test their water according to the Ontario guidelines.⁸⁻¹⁰ This evidence was compiled from surveys and records from a single year. Our study found that, on average, 11.60% of properties included in the study had at least three NSBC bacteriological analyses performed in any given year. Extrapolated to the actual number of wells in the region, the average was approximately 3.73% of wells, which is similar to the previously established range. However, when studied in a five-year succession, only 0.31% of the wells studied met the guidelines, which corresponds to 0.10% of all wells within the region. The addition of the temporal tracking of submissions per year provides clear evidence that 99.69%-99.90% of wells are not bacteriologically tested enough to meet traditional Ontario public health guidelines.⁷ Therefore, users of private well supplies are consuming water of unknown quality and subsequently may be at risk of illness.

A significant benefit of using multiple years of data is the ability to detect trends over time; this was the first study to conduct such a multi-year assessment, with the intent of examining trends. The results from the two temporal analyses (the percentage of wells that met guidelines by year across five years from PHOL-K and the total number of tested samples across 10 years for the province) provided strong statistically significant evidence of decreased submission practices over time. On the basis of these identified trends, it is reasonable to project that submission levels will likely continue to decline without external factors, for example increasing education on the importance of well water testing, or a tragic outbreak like the one that

occurred in Walkerton, Ontario¹³ and highlighted the risks associated with drinking non-potable water.

By using unique locations with wells as the unit of analysis rather than well owners, this study was limited in its ability to make direct inferences about well owner behaviours. Furthermore, multiple wells may be owned by a single individual, in which case that owner's submission patterns may be captured multiple times. The study examined convenience samples of submitters to the local PHOL. Other testing facilities exist within the study area, and thus individual or multiple submitters may not be identified when owners submit samples to other laboratories. The catchment zone sensitivity analyses were used to limit the effects of other public health laboratories. There is only one certified private laboratory within the region, and this laboratory provides fee-based bacteriological testing. Additionally, previous research suggests that real estate transactions are a primary reason for water testing;¹⁰ these submissions would increase the testing numbers observed by the study but do not reflect underlying water testing behaviours. There is no reason to suspect economic bias in the samples received at the laboratory, as there is no direct cost associated with the test. Finally, if a sample tests positive, health units often recommend chlorinating the well and following up with a second submission. These re-submissions might limit the study's ability to track true "meeting guidelines" submission patterns, as we were not able to distinguish such re-submissions. Therefore, the percentage of wells that are tested on the basis of current recommendations may be under-represented in the study.

The investigation used calendar year as the unit of time in all analyses. This is the best available timespan for analyzing yearly submission data, as the cut-off is opposite the primary submission season (summer). Over 10 years, 67.16% of samples were submitted between April and September (inclusive). Furthermore, as observed in Figure 2, the majority of contaminated samples are submitted during the summer, so it is least likely that the cut-off interrupts any samples being submitted subsequent to an earlier positive result.

The results of this study describe only southeastern Ontario, in particular those submissions associated with the PHOL-K. Given the magnitude of records required to perform this analysis (over 100,000 records for this region for five years), it was not feasible to perform the analysis for the entire province (over 900,000 records). However, the individual year findings were comparable with the results of previous studies, which occurred in other regions of the province.⁸⁻¹⁰ Furthermore, the population demographics of the study region are appropriate for private well research, as the population is 47% rural (and therefore dependent on private water supplies) as compared with 14% in the entire province.¹⁴

Additionally, the study substantially added to the current body of knowledge on the prevalence of bacterial contamination in private wells in Ontario, since the last major study was conducted 20 years earlier.³ The provincial results of our study, which are based on a higher number of wells (greater than 900,000 submissions compared with 1,300 wells), found considerably lower rates of contamination than the 1992 study: 23% coliform contamination compared with 34% and 4% *E. coli* contamination compared with 20%. These findings can be used to assess the current bacteriological contamination risk in the province.

POLICY IMPLICATIONS

This paper, together with previous studies in the province,⁸⁻¹⁰ provides definitive evidence that the majority of private well owners in Ontario are not meeting the historic guidelines. Furthermore, submission levels are declining. This would suggest a need to develop public health programming to improve testing behaviours. However, before resources are allocated, it is first necessary to examine the rationale and requirement for submitting an NSBC water sample three times per year, as outlined in the guideline.

Bacteriological testing guidelines for private wells are intended to ensure stable biological potability. The recommendations vary across the country regarding how often well water needs to be tested to meet this standard. Only Newfoundland and Labrador also promotes testing three times per year.¹⁵ Health Canada recommends testing private well supplies two to three times per year,¹⁶ whereas three provinces (Saskatchewan, Manitoba and Prince Edward Island) recommend only once per year¹⁷⁻¹⁹ and three provinces recommend twice per year (Quebec, New Brunswick and Nova Scotia).²⁰⁻²² Currently, British Columbia provides no numerical guidelines,²³ and Alberta suggests between two and four times a year based on well depth.²⁴

This variability in private well water testing policy also exists across North America. The US Environmental Protection Agency recommends annual testing for coliforms and more regular testing if there has previously been a water quality issue within the well or if members of the household have experienced recurrent gastrointestinal illness.²⁵ Generally in the US, testing is conducted at private laboratories, but some county health departments offer the service or have targeted programs for at-risk populations, such as households with young children.²⁶

As noted by de Loë and Kreutzweiser in their review of groundwater policy after the Walkerton outbreak, self-supplied groundwater sources are no less at risk of contamination than public groundwater systems, but regulations require a higher

testing frequency of public sources.¹³ The Canadian Drinking Water Guidelines Technical Documentation notes that municipal systems should be tested for *E. coli* contamination at a minimum of once a week.²⁷ The *Ontario Safe Drinking Water Act* requires groundwater-sourced non-municipal residential systems (systems that service more than six residences) to test the raw water once a month.²⁸

There is insufficient scientific literature to support any of these testing frequencies. A study in Quebec that conducted monthly and bimonthly sampling over a nine-month period found significant variation in total coliform count, one well increased from 1 to 2,419 total coliform count in a one-month period.²⁹ Variation in *E. coli* contamination was also observed with some seasonal patterns. Furthermore, recent evidence suggests that there can be considerable variability in fecal indicator counts in a 24-hour period.³⁰

Given that testing frequency guidelines have a) a lack of compliance, b) variability across Canada and North America and c) no supporting scientific evidence, the need for a re-evaluation of private well water testing policies in Ontario and across Canada is evident. Two stages are required: 1) the development of a scientific body of literature on groundwater bacteriological contamination and the evaluation of human health risks in order to create evidence-based testing frequency guidelines; and 2) the implementation of general and targeted public health programs and policies to ensure that there is compliance with the developed guidelines.

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RÉSUMÉ

OBJECTIF : Les populations rurales ont un risque élevé de maladies gastrointestinales, car elles dépendent de sources d'eau souterraine privées; or, la qualité de cette eau est encore la responsabilité des propriétaires. Selon des études antérieures, seule une minorité de propriétaires de puits testent leur eau pour dépister une contamination bactérienne. Le but de notre étude était d'utiliser les dossiers de prélèvement d'échantillons d'eau, conjointement avec les directives provinciales en vigueur, pour évaluer les taux et les tendances temporelles des envois d'échantillons dans le Sud-Est de l'Ontario.

MÉTHODE : À l'aide de données compilées sur cinq ans (2008-2012) par le laboratoire de Santé publique Ontario à Kingston, en Ontario, nous avons fait l'analyse descriptive des envois d'échantillons d'eau de puits de propriétés uniques (identifiées par géocodage). Les tendances temporelles de conformité aux directives ont été évaluées à l'aide du test de Cochran-Armitage. Enfin, les corrélations entre le temps et le nombre d'envois ont été étudiées à l'aide d'un jeu de données provincial de 10 ans pour en dégager des tendances temporelles à long terme.

RÉSULTATS : Il y a eu 107 547 envois d'échantillons au cours des cinq années de l'étude, dont 84 % géocodés, ce qui donne 30 687 propriétés uniques. Bien qu'entre 11 et 12 % des propriétaires aient respecté les directives au cours d'une année donnée, à peine 0,3 % les ont respectées tous les ans au cours des cinq années de l'étude. Des baisses significatives dans le temps ont été observées, tant du nombre de propriétés conformes aux directives en vigueur que du nombre total d'échantillons testés.

CONCLUSIONS : Cette étude est la première à utiliser des dossiers d'envoi d'échantillons, plutôt que des enquêtes, pour faire la preuve définitive que les directives d'envoi d'échantillons d'eau de puits privés ne sont pas suivies en Ontario. Toutefois, ces directives ne sont pas uniformes à l'échelle du pays ou du continent, et les études scientifiques à l'appui sont limitées. Des recherches considérables sont nécessaires pour élaborer des politiques fondées sur les preuves.

MOTS CLÉS : eau potable; puits d'eau; qualité de l'eau; directives