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# Water consumption habits of a south-western Ontario community

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## ABSTRACT

A cross-sectional telephone survey ($n = 2,332$) was performed to better understand the drinking water consumption patterns among residents in Waterloo Region, Ontario, Canada. We investigated the daily volume of water consumed (including tap and bottled) and factors related to that consumption. In addition, we investigated the daily volume of cold tap water consumed by those respondents who consumed no bottled water and the factors that influence this consumption. Among study respondents, 51% exclusively drank tap water, 34% exclusively drank bottled water and 14.5% drank both, with 10 to 75% of all cold water consumed in the previous day being bottled. The mean volume of water consumed in a day (including bottled and tap water) was 1.39 l. Among those who reported to exclusively consume tap water, the mean daily volume of tap water consumed was 1.45 l. The daily amount of cold water consumed in a day was lower for older respondents, more markedly for men than women. More educated respondents consumed more water during the day. Roughly 45% of households reported that they used a carbon filter to treat their water. Roughly 5% of respondents used advanced home treatment devices, including ultraviolet light, reverse osmosis, ozonation or distillation.

**Key words** | bottled, consumption, drinking water, home treatment, telephone survey

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## INTRODUCTION

Water quality and quantity in Canada continue to be critical to public health, in response to the pressures from global climate change (and increased droughts and floods), population growth and changing demographics, ageing and failing water infrastructure and deteriorating raw water quality. The trend in the water industry is to embrace the multi-barrier source protection model (similar to the HACCP (Hazard Analysis and Critical Control Point) model for food safety) in the treatment and distribution of water, thus identifying critical control points between the source (watershed) and the consumer's tap. The WHO *Guidelines for Drinking Water Quality* (WHO 2006) highlight the importance of developing water safety plans, which integrate risk assessment and risk management, similar to the multi-barrier approach. In response to these new approaches, quantitative microbial risk assessment (QMRA) has been proposed as a tool to address the growing need to identify and subsequently manage waterborne microbial risks.

It is essential to know the volume of water that a person consumes in a day in order to quantify their risk of exposure to a waterborne contaminant. The volume consumed can be incorporated in the model as either a point estimate or distribution. Because estimates of water consumption vary widely within the literature and by country of study, it is useful to develop population-specific estimates. In addition, it is important to consider: (a) the consumption volume of cold tap water (rather than heated or boiled water); and (b) the

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frequency of bottled water consumption, since these forms of water represent different risks to the consumer. Finally, the use of home treatment systems alters the potential microbial or chemical risk, depending on the type of system used. This is an emerging industry and there are little data available to estimate the use of these devices in Canadian communities. Most recently, there has been a call for more information on the consumption of water and factors that influence this volume (LeChevallier & Buckley 2007).

The overall goal of this study was to understand a Canadian community's drinking water consumption practices to inform quantitative risk assessments. Within that goal, we addressed two objectives. The first objective was to determine the daily volume of total cold water (including tap and bottled) consumed by the survey respondents and different factors related to that consumption, including the use of home water treatment devices and the frequency of bottled water use. The second objective was to determine the daily volume of cold tap water consumed by those respondents who reported to have consumed no bottled water and what factors influence this consumption volume.

## METHODS

### Study design

In 2006, a cross-sectional random digit dialling (RDD) telephone survey was administered to residents in Waterloo Region, Ontario, Canada. Waterloo Region comprises three cities (Cambridge, Kitchener and Waterloo) and four townships (North Dumfries, Wellesley, Wilmot and Woolwich). In 2006, the population was estimated at 483,392 residents (50.1% female, 49.9% male) (Population and Household Estimates, Regional Municipality of Waterloo, accessed May 2007). Waterloo Region is also the first sentinel site of Canada's integrated enteric disease surveillance system, C-EnterNet, a joint initiative of the Public Health Agency of Canada and Agriculture and Agri-food Canada. Between November 2005 and March 2006, the water consumption survey was performed as a component of a larger food consumption survey. Interviews were conducted by trained interviewers at the Centre for Evaluation of Medicines (St Joseph's Hospital, Hamilton, Ontario, Canada) using a computer-assisted telephone interviewing system. Multi-stage random sampling was used with households sampled from a list of residential telephone numbers (SelectPhone Canada, TM, InfoUSA Inc, version 5.2) and the individual in the household with the next birthday was selected to perform the interview (provided they were eligible and consented).

Sample size calculations incorporated objectives of the larger food and water consumption study (Nesbitt 2006). Expected frequencies of 24.3%, 32.2% and 51.0% for eating egg dishes with runny yolk, using treated tap water and washing hands after handling raw meat, respectively, were used to calculate sample size (CDCP 2004; Bremer *et al.* 2005). The final sample size of a minimum of 2,300 was based on a combination of these sample size calculations, using an allowable error of 2% and a 95% confidence level. Sample size calculations were performed with Epi-Info 2004 Version 3.3 (CDC, Atlanta) (Nesbitt 2006).

Households were called up to three times, on different days and during different times of day, with a minimum of five rings per call. When an eligible individual within that household was identified, five attempts were made to contact the individual to complete the survey. If necessary, call-backs were scheduled for the day and time requested by the individual. Eligible individuals were English speaking, over the age of 18 months, and resided at a listed telephone number in the study area. Proxy respondents were interviewed for eligible individuals under 12 years of age, and at the discretion of the parent or guardian for individuals between 12 and 17 years of age. Individuals who had travelled outside of Canada within the seven days prior to the interview were excluded, because the goal of the study was to capture typical consumption patterns in the Canadian context.

Survey questions were adopted from previous questionnaires (Public Health Agency of Canada 2001; CDC FoodNet Population Survey 2003). Drinking water consumption questions pertained to the day before the interview (1-day recall). Individual- and household-level demographic variables were collected. The survey was approved by the Human Subjects Committee of the University of Guelph (Guelph, Ontario, Canada). Informed consent was obtained verbally from all respondents and from a parent or guardian of all respondents under 18 years of age.

## Statistical analyses

Prior to statistical analysis, a causal diagram was developed to identify direct and indirect causal effects and possible confounding among the measured predictor variables and outcomes and to guide the statistical analyses.

All statistical analyses were performed with Stata for Windows® Version 9 (Stata Corporation, Texas, USA). Data screening was performed in OpenOffice 2.3.1 (openoffice.org). Respondents for whom answers were missing for a particular variable (including 'don't know' and 'refused') were excluded from the analysis of that variable.

Representativeness of the survey respondents was compared with the target population using Pearson's $\chi^2$ test. Comparisons were made on the basis of resident regional distribution, age and gender, and compared with population data for 2006 from the Region of Waterloo, Planning, Housing and Community Services, Planning Information and Research Department (ROW 2006).

Daily consumption of tap and bottled water among survey respondents was assessed using both non-parametric and parametric methods. Daily consumption was originally collected in a discrete form (number of cups of cold water consumed) and was transformed into a continuous form (litres of cold water consumed). Interviewers prompted respondents to report the volume of cold water (including both tap and bottled water that had not been boiled or heated) consumed by asking how many 8 ounce servings of water they consumed in the previous day. Respondents were reminded that an 8 ounce serving is equal to 250 ml, or a small carton of milk, whereas a regular sized bottle of water is 500 ml and a china tea cup and juice glass are only 125 ml (4 ounces). Respondents also reported the proportion of their daily water intake that was bottled. When interviewers asked about bottled water consumption, respondents were reminded that a regular bottle is 500 ml (2 cups), and if respondents reported consuming a large bottle, they were asked to report the volume in millilitres. To develop a representative distribution of the exclusive consumption of cold tap water (for those respondents who drank no bottled water), the subset of respondents who consumed no bottled water were analysed in a separate linear model, and the influence of various predictors was investigated. Responses were analysed to understand the potential associations between various demographic factors and total daily volume of water consumed.

Some predictor variables were re-categorized for analysis. Age was classified into seven groups: 0–5, 6–12, 13–17, 18–25, 26–39, 40–60 and 60 + years of age. Water source was classified into two groups: municipal water and private water (including wells and cisterns). The proportion of daily water consumed that is bottled was categorized into four levels: >0–25%, 25–50%, 50–75% and 75–100%. Home water treatment device use was classified into three groups based on degree of protection from microbial contaminants: those devices that afford no protection (water softeners or iron removal units); those that provide some protection (carbon filter, including filters on the tap, jug, refrigerator and charcoal/graphite filters); and those that provide advanced protection (including ultraviolet light, reverse osmosis, ozonation or distillation).

Prior to running both linear models, univariable analyses were performed to screen individual-level variables for inclusion, using a liberal $p$-value (0.3). The Mann-Whitney rank sum test was used to explore the associations between the volume of cold water (total and tap-only) consumed per day and dichotomous predictors (gender and water source). The Kruskal-Wallis test was used to explore the associations between the volume of cold water consumed per day (total and tap-only) and categorical predictors with more than two levels (age (7 levels), education (7 levels), % bottled water (5 levels), and home treatment use (3 levels)). Spearman rank correlation analyses were performed between predictor variables to identify variables that were highly correlated. Income was not considered in the analyses due to the large proportion (46%) of missing data. For both linear models (total and tap-only water consumed in one day), multivariable least squares regression was performed using manual stepwise backward elimination. Confounding was assessed by looking for a change of 30% or more in model coefficients. Diagnostic plots of residuals and influence measures were used to identify unusual patterns or influential respondents.

Because the total daily volume of water did not fit a normal distribution, the original outcome was $\log_{10}$ transformed after a constant (0.25) was added to all responses (to account for the '0' responses) (Snedecor & Cochrane 1989). The main reason to add a constant is that the log transform is not defined for 0, and therefore log (0) would be set to missing. Since 0 is a real observation, it would not be useful to throw these responses out. The tap-only volumes were $\log_{10}$ transformed to satisfy the normality assumption, and since there were no '0' responses, a constant was not required. Outliers and leverage points were examined in the final model for unusual predictor variable values and DFIT values to detect influential respondents.

## RESULTS

### Representativeness of the survey respondents

A total of 11,134 residents were contacted, of whom 7,142 were eligible; 2,332 completed interviews were performed, resulting in a response rate of 32.7%. Statistical comparisons between demographic variables among the survey population and residents in Waterloo Region illustrated that survey respondents were more likely to be female, reside in Kitchener, Waterloo or Cambridge (versus the four townships), older and with a higher household income (Table 1).

### Descriptive results

Respondents were asked to report the percentage of water consumed the previous day that was bottled. There were three types of water consumer identified. Of the 2,189 responses regarding water consumption in the previous day, 51% (1,124) reported that 0% was bottled, 34% (747) reported that 100% was bottled, and 14.5% (163) reported that between 10 and 75% was bottled (Figure 1).

For home water treatment use, 70 respondents reported using some 'other' form of water treatment, including 'something under the sink', water cooler or 'we buy our water' and were omitted from the analysis. Based on reported home water treatment use, roughly 57% (1,283/2,262) used a device to treat their water in their home. Approximately 12% reported the use of water softeners or iron removal units. Almost 45% of respondents used some type of carbon filter. Finally, 5% of respondents used advanced treatment devices, such as ultraviolet light, reverse osmosis, ozonation or distillation.

### Daily volume of total cold (including tap and bottled) water consumed by survey respondents

The mean daily volume of water consumed among respondents (including cold water, from tap or bottle, and cold drinks made with water, but not coffee or tea) was 1.39 l, 95% CI (1.36, 1.43), ranging from 0 to 6.25 l per day (Figure 2). Table 2 provides summary statistics for the daily cold tap and bottled water intake, as a total and categorized by gender, age, use of bottled water and education. Only significant predictor variables ($p < 0.05$) from the univariable analysis are included.

To achieve normality, a constant of 0.25 (the minimum volume of water consumed, greater than 0) was added to all of the data points (to eliminate the 0 responses) and the data were then $\log_{10}$ transformed, as is commonly done for water intake data (Roseberry & Burmaster 1992; Teunis *et al.* 1997; Burmaster 1998; Westrell *et al.* 2006). The final transformed model was significant, with an adjusted $R^2$ of 5.6%, F-value of 4.48 and a significant associated p-value of less than 0.0001, suggesting that at least one coefficient in the final model contributes to the daily volume of water consumed. The following predictor variables were significant at $p < 0.05$ and were retained in the model: gender, age, gender by age interaction, proportion of daily water consumed that is bottled water, use of a home treatment system and education (Table 3). Water source (municipal or private well/cistern) was retained in the final model as a potential confounder.

The final model findings suggest that, while all other variables in the model are held constant, men consume less water than women. Because age and gender interacted in the final model, rather than examining the associations individually, the association is best described in Figure 3, which illustrates that men consume less water than women. Total volume consumed is greatest among middle-aged respondents and then decreases with older respondents. Frequent bottled water drinkers (75–100% of their daily water intake) consumed less water overall than those respondents who mostly consumed tap water. More education was associated with more water consumption, except for those respondents who held an advanced post-graduate degree, who consumed less water than the referent (some trade, college or university training). Respondents

**Table 1** | Summary of descriptive statistics of dataset ($n = 2{,}332$)

| Variable | | $n$ | Survey respondents % ($n$ = 2,332) | Waterloo region residents % ($n$ = 483,392) |
|---|---|---|---|---|
| Gender | Male | 830 | 35.6%* | 49.2% |
| | Female | 1,502 | 64.4%* | 50.8% |
| Region of Waterloo | North Dumfries | 35 | 1.50% | 1.9% |
| | Wellington | 53 | 2.3%* | 5.0% |
| | Wilmot | 61 | 2.6%* | 3.5% |
| | Woolwich | 73 | 3.1%* | 4.0% |
| | Cambridge | 423 | 18.1%* | 24.9% |
| | Kitchener/Waterloo | 1,687 | 72.3%* | 63.5% |
| Personal classification of living area | City or urban | 1,700 | 72.90% | – |
| | Suburban | 321 | 13.77% | – |
| | Town/village | 211 | 9.05% | – |
| | Rural | 100 | 4.29% | – |
| Age_Categories | | | ($n = 2{,}250$) | |
| | Mean | | 41.40 | 35.3% |
| | Median | | 40.00 | 7.1% |
| | 0–5 | 57 | 2.5%* | 9.3% |
| | 6–12 | 117 | 5.2%* | 7.2% |
| | 13–17 | 143 | 6.40% | |
| | 18–25 | 236 | 10.50% | 11.6% |
| | 26–39 | 548 | 24.4%* | 20.2% |
| | 40–59 | 670 | 29.80% | 28.9% |
| | 60 plus | 479 | 21.3%* | 15.7% |
| | Refused/Missing | 82 | | |
| Private or municipal source of water | | | ($n = 2{,}294$) | |
| | Private well | 160 | 6.97% | – |
| | Private other (cistern) | 7 | 0.31% | – |
| | Municipal | 2120 | 92.41% | – |
| | Both Private and Municipal | 2 | 0.09% | – |
| | Other | 5 | 0.22% | – |
| | Did not know/Not sure | 34 | | |
| | Refused | 4 | | |
| Household income | | | ($n = 1{,}267$) | |
| | Less than 20 K | 126 | 9.9%* | 13.6% |
| | Btw 20 and 40 K | 215 | 17%* | 20.4% |
| | Btw 40 and 60 K | 257 | 20.30% | 19.8% |
| | Btw 60 and 80 K | 209 | 16.50% | 17.3% |
| | Btw 80 and 100 K | 200 | 15.8%* | 12.0% |
| | 100 K or more | 260 | 20.5%* | 17.0% |
| | Did not know/Not sure | 193 | | |
| | Refused | 643 | | |
| | Missing | 229 | | |

Table 1 | (continued)

| Variable | | n | Survey respondents % (n = 2,332) | Waterloo region residents % (n = 483,392) |
|---|---|---|---|---|
| Education | | | (n = 2,302) | |
| | Grade 8 or less | 229 | 9.95% | – |
| | Some highschool | 399 | 17.33% | – |
| | Highschool | 322 | 13.99% | – |
| | Some college or university | 480 | 20.85% | – |
| | College | 323 | 14.03% | – |
| | Undergrad | 379 | 16.46% | – |
| | Postgrad | 138 | 5.99% | – |
| | Professional | 8 | 0.35% | – |
| | Other | 24 | 1.04% | – |
| | Did not know/Not sure | 30 | | |
| L of water consumed per day | 0.000 | 103 | 4.42% | – |
| | 0.125 | 2 | 0.09% | – |
| | 0.250 | 103 | 4.42% | – |
| | 0.375 | 1 | 0.04% | – |
| | 0.500 | 223 | 9.56% | – |
| | 0.625 | 1 | 0.04% | – |
| | 0.750 | 255 | 10.93% | – |
| | 0.875 | 2 | 0.09% | – |
| | 1.000 | 329 | 14.11% | – |
| | 1.250 | 218 | 9.35% | – |
| | 1.500 | 341 | 14.62% | – |
| | 1.750 | 88 | 3.77% | – |
| | 2.000 | 270 | 11.58% | – |
| | 2.250 | 37 | 1.59% | – |
| | 2.500 | 144 | 6.17% | – |
| | 2.750 | 6 | 0.26% | – |
| | 3.000 | 111 | 4.76% | – |
| | 3.250 | 2 | 0.09% | – |
| | 3.500 | 15 | 0.64% | – |
| | 3.750 | 23 | 0.99% | – |
| | 4.000 | 11 | 0.47% | – |
| | 4.250 | 1 | 0.04% | – |
| | 4.500 | 5 | 0.21% | – |
| | 4.750 | 1 | 0.04% | – |
| | 5.000 | 8 | 0.34% | – |
| | 5.500 | 1 | 0.04% | – |
| | 5.750 | 1 | 0.04% | – |
| | 6.250 | 1 | 0.04% | – |
| | Did not know/Not sure | 29 | | |

**Table 1** | (continued)

| Variable | | n | Survey respondents % (n = 2,332) | Waterloo region residents % (n = 483,392) |
|---|---|---|---|---|
| % of daily water consumption that is bottled | 0 | 1,124 | 48.20% | – |
| | 4 | 1 | 0.04% | |
| | 8 | 1 | 0.04% | |
| | 10 | 15 | 0.64% | – |
| | 20 | 33 | 1.42% | – |
| | 25 | 28 | 1.20% | – |
| | 30 | 30 | 1.29% | – |
| | 33 | 8 | 0.34% | – |
| | 35 | 7 | 0.30% | – |
| | 40 | 14 | 0.60% | – |
| | 45 | 1 | 0.04% | |
| | 50 | 123 | 5.27% | – |
| | 55 | 2 | 0.09% | – |
| | 60 | 9 | 0.39% | – |
| | 66 | 7 | 0.30% | – |
| | 70 | 2 | 0.09% | – |
| | 75 | 14 | 0.60% | – |
| | 80 | 16 | 0.69% | – |
| | 90 | 7 | 0.30% | – |
| | 100 | 747 | 32.03% | – |
| | Did not know/Not sure | 12 | | |
| | Missing | 131 | | |
| Does house treat water? | Yes | 1,326 | 56.86% | – |
| | No | 979 | 41.98% | – |
| | Did not know/Not sure | 19 | 0.81% | |
| | Missing | 8 | 0.34% | |
| How does house treat water | Boiling | 11 | 0.82% | – |
| | Reverse Osmosis | 96 | 7.19% | – |
| | Filter on tap | 208 | 15.57% | – |
| | Jug filter | 698 | 52.25% | – |
| | Filter on fridge | 92 | 6.89% | – |
| | Ozone disinfection | 0 | 0.00% | – |
| | UV disinfection | 10 | 0.75% | – |
| | Water softener | 153 | 11.45% | – |
| | Iron removal | 1 | 0.07% | – |
| | Showerhead filters | 3 | 0.22% | – |
| | Other | 52 | 3.89% | – |
| | Did not know/Not sure | 11 | | |
| | Refused | 1 | | |

*Proportion of survey respondents differed significantly from the Waterloo Region residents, $p < 0.05$.

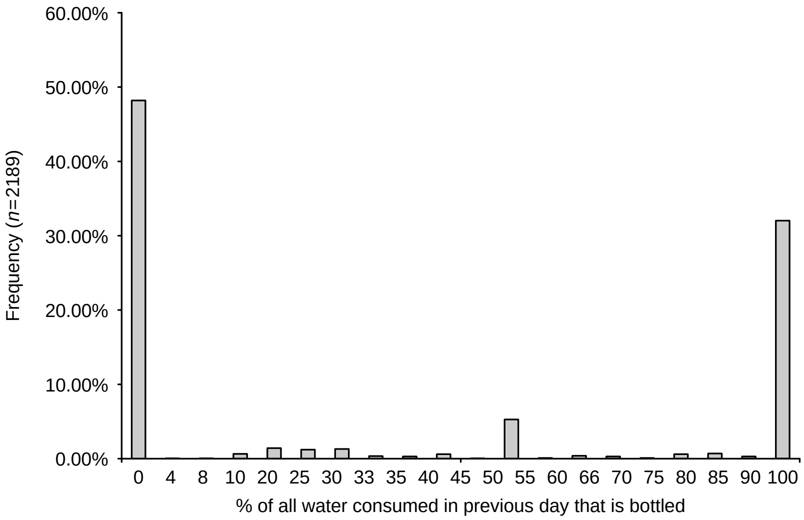


**Figure 1** | Distribution of proportion of water consumed daily that is bottled ($n = 2189$).

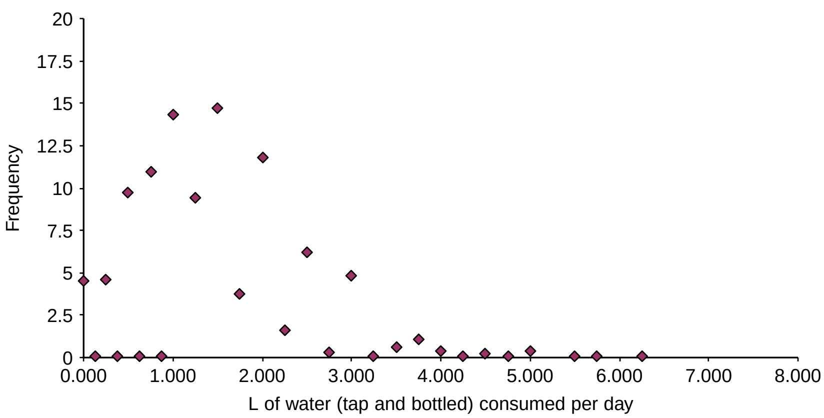


**Figure 2** | Frequency distribution of reported daily volume of water (tap and bottled) consumed per day by study respondents ($n = 2216$).

who used an advanced form of home treatment consumed 13% less water daily than those who used a carbon filter system (the referent). Home treatment use and proportion of bottled water use interacted, as shown in Figure 4, which identifies a different association between total volume of water consumed and use of bottled water among 'advanced home treatment system' respondents versus respondents who reported to use either a carbon filter system or no home treatment. Respondents who invested in an advanced home treatment system drank more water in a day if they also consumed more bottled water. Conversely, respondents consumed less total water in a day if they consumed bottled water and had either no home water treatment system or a simple carbon filter system. This complex interaction identifies two sub-populations with different exposure patterns in this community.

## Daily volume of cold tap water consumed for those respondents who consumed no bottled water

Nearly half ($n = 1,124$, 48%) of the survey respondents reported that none of their total water intake was bottled, thus we inferred that their intake was exclusively tap water. Among these respondents, the mean daily volume of tap

**Table 2** | Daily consumption of cold (tap and bottled) water among survey respondents, classified by significant predictor variables

| | Mean ± St. Dev L/day | Percentiles N | 25th | 50th | 75th |
|---|---|---|---|---|---|
| Total | 1.39 ± 0.89 | 2,303 | 0.75 | 1.25 | 2 |
| Gender ($p = 0.000$) | Women 1.45 ± 0.89 | 1,486 | 0.75 | 1.5 | 2 |
| | Men 1.28 ± 0.87 | 817 | 0.75 | 1 | 1.5 |
| Use of home treatment ($p = 0.0001$) | No protection 1.32 ± 0.86 | 1,120 | 0.75 | 1.25 | 1.875 |
| | Some protection 1.48 ± 0.89 | 978 | 0.75 | 1.5 | 2 |
| | High protection 1.25 ± 0.89 | 106 | 0.75 | 1 | 1.75 |
| Age ($p = 0.0001$) | Age 0–5 1.27 ± 0.79 | 57 | 0.75 | 1.25 | 1.75 |
| | Age 6–12 1.13 ± 0.66 | 116 | 0.63 | 1 | 1.5 |
| | Age 13–17 1.31 ± 0.77 | 138 | 0.75 | 1.25 | 1.75 |
| | Age 18–25 1.58 ± 1.00 | 233 | 1.00 | 1.25 | 2 |
| | Age 26–39 1.57 ± 0.99 | 545 | 0.75 | 1.5 | 2 |
| | Age 40–59 1.38 ± 0.90 | 664 | 0.75 | 1.25 | 2 |
| | Age 60 + 1.21 ± 0.71 | 475 | 0.75 | 1 | 1.5 |
| Proportion of daily water consumed that is bottled ($p = 0.0001$) | 0% bottled water 1.45 ± 0.84 | 1,124 | 0.75 | 1.25 | 2 |
| | 1–25% bottled water 2.13 ± 0.96 | 78 | 1.50 | 2 | 2.5 |
| | 26–50% bottled water 1.56 ± 0.82 | 183 | 1.00 | 1.5 | 2 |
| | 51–75% bottled water 1.63 ± 0.84 | 34 | 0.75 | 1.5 | 2.25 |
| | 75–100% bottled water 1.36 ± 0.83 | 770 | 0.75 | 1.25 | 2 |
| Education ($p = 0.0001$) | Grade 8 or less 1.18 ± 0.69 | 224 | 0.75 | 1 | 1.5 |
| | Some highschool 1.30 ± 0.83 | 392 | 0.75 | 1.25 | 1.75 |
| | Highschool 1.27 ± 078 | 319 | 0.75 | 1.25 | 1.75 |
| | Some college/university 1.47 ± 0.96 | 475 | 0.75 | 1.25 | 2 |
| | College 1.54 ± 0.94 | 322 | 0.75 | 1.5 | 2 |
| | University 1.52 ± 0.94 | 375 | 0.75 | 1.5 | 2 |
| | Postgraduate 1.34 ± 0.86 | 146 | 0.75 | 1.25 | 2 |

water consumed was 1.45 l, 95% CI (1.40, 1.50) (Figure 5). The data were $\log_{10}$ transformed and multivariable linear regression was performed. Table 4 provides summary statistics for daily cold tap water intake, as a total and categorized by gender, age, use of a home treatment system, education and water source. Only significant predictor variables ($p < 0.05$) from the univariable analysis are included, as well as the potential confounder (water source).

The final model was significant (Table 5), with an adjusted $R^2$ value of 4.5%, F-value of 3.19 and a significant associated p-value of less than 0.0001. Water source (either private or municipal) was retained in the model as a potential confounder. As with the first model, an interaction between age and gender was observed (Figure 6). Older respondents consumed less water than middle-aged respondents and the effect was more pronounced among males than females. Overall, male respondents consumed less water than female respondents. Again, more education was associated with more water consumption, except for those respondents who held an advanced post-graduate degree, who consumed slightly less (7%) than the referent group (respondents who had some trade, college or university

**Table 3** | Final regression model for total volume of plain water consumed in a day (including both tap and bottled water) $n = 1961$, $F(33, 1927) = 4.48$, $P > F = 0.0000$, Adj R-squared = 0.0554, Root MSE = 0.49

| Logwaterday | | Coefficient | Standard Error | T | P > \|t\| | 95% Confidence | Interval |
|---|---|---|---|---|---|---|---|
| Water Source (Municipal was referent) | Private well/cistern | −0.009 | 0.02 | −0.40 | 0.69 | −0.05 | 0.03 |
| Gender (female was referent) | Males | −0.100 | 0.04 | −2.40 | 0.02 | −0.19 | −0.02 |
| Age (40–59 group was referent) | Age (0–5) | −0.048 | 0.12 | −0.40 | 0.69 | −0.28 | 0.19 |
| | Age(6–12) | −0.157 | 0.10 | −1.65 | 0.10 | −0.34 | 0.03 |
| | Age(13–17) | −0.064 | 0.07 | −0.91 | 0.36 | −0.20 | 0.07 |
| | Age (18–25) | −0.022 | 0.05 | −0.46 | 0.65 | −0.13 | 0.08 |
| | Age(26–39) | 0.097 | 0.04 | 2.33 | 0.02 | 0.01 | 0.16 |
| | Age (60 + ) | −0.067 | 0.04 | −1.72 | 0.09 | −0.14 | 0.01 |
| Interaction between gender and age | GenderXAge1 | 0.110 | 0.15 | 0.74 | 0.46 | −0.19 | 0.41 |
| | GenderXAge2 | 0.208 | 0.11 | 1.98 | 0.05 | 0.00 | 0.41 |
| | GenderXAge3 | 0.111 | 0.10 | 1.12 | 0.26 | −0.08 | 0.31 |
| | GenderXAge4 | 0.187 | 0.08 | 2.27 | 0.02 | 0.03 | 0.35 |
| | GenderXAge5 | −0.101 | 0.06 | −1.58 | 0.11 | −0.23 | 0.02 |
| | GenderXAge7 | 0.007 | 0.07 | 0.10 | 0.92 | −0.12 | 0.14 |
| Bottled water consumption habits (0% water consumed was bottled' was referent) | Bottled (>0–25%) | 0.339 | 0.10 | 3.47 | 0.00 | 0.15 | 0.53 |
| | Bottled (25–50%) | 0.086 | 0.06 | 1.44 | 0.15 | −0.03 | 0.20 |
| | Bottled (50–75%) | −0.023 | 0.11 | −0.21 | 0.837 | −0.24 | 0.2 |
| | Bottled (75–100%) | −0.035 | 0.03 | −1.04 | 0.30 | −0.10 | 0.03 |
| Home treatment use (some protection was referent) | No protection (water softener/iron removal) | 0.062 | 0.03 | 1.87 | 0.06 | 0.00 | 0.13 |
| | High protection (UV, Ozone, Reverse Osmosis) | −0.128 | 0.06 | −2.01 | 0.04 | −0.25 | 0.00 |
| Interaction between bottled water use and home treatment use | Bottled (>0–25%)xNo protection | −0.065 | 0.13 | −0.52 | 0.60 | −0.31 | 0.18 |
| | Bottled (>0–25%)xHigh protection | 0.000 | 0.50 | 0.00 | 1.00 | −0.98 | 0.98 |
| | Bottled (25–50%)xNo protection | −0.017 | 0.09 | −0.19 | 0.85 | −0.19 | 0.15 |
| | Bottled (25–50%)xHigh protection | −0.051 | 0.26 | −0.20 | 0.84 | −0.56 | 0.46 |
| | Bottled (50–75%)xNo protection | 0.292 | 0.19 | 1.56 | 0.11 | −0.07 | 0.66 |
| | Bottled (75–100%)xNo protection | −0.102 | 0.05 | −1.86 | 0.07 | −0.21 | 0 |
| | Bottled (75–100%)xHigh protection | 0.276 | 0.12 | 2.30 | 0.02 | 0.04 | 0.51 |

**Table 3** | (continued)

| Logwaterday | Coefficient | Standard Error | T | P > \|t\| | 95% Confidence | Interval |
|---|---|---|---|---|---|---|
| Education *(referent = 'some trade, college or university training') | | | | | | |
| Education (Gr.8 or less) | −0.054 | 0.07 | −0.78 | 0.437 | −0.19 | 0.08 |
| Education (some highschool) | −0.010 | 0.04 | −0.25 | 0.806 | −0.09 | 0.07 |
| Education (Highschool) | 0.006 | 0.04 | 0.17 | 0.868 | −0.07 | 0.08 |
| Education (College Diploma) | 0.081 | 0.04 | 2.12 | 0.034 | 0.01 | 0.16 |
| Education (University Degree) | 0.082 | 0.04 | 2.26 | 0.024 | 0.01 | 0.15 |
| Education (Advanced Degree) | −0.004 | 0.05 | −0.07 | 0.942 | −0.1 | 0.1 |
| Constant | 0.426 | 0.07 | 5.7 | 0 | 0.28 | 0.57 |

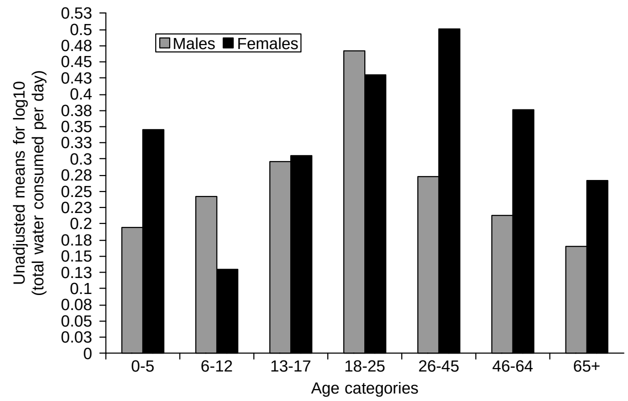


**Figure 3** | Interaction between gender and age on volume of cold water (bottled and tap) consumed daily.

training but did not hold a diploma or degree). Home treatment use was significant in the final model, as seen in the first model. Respondents who used an advanced home treatment device consumed roughly 21% less water than those who used a carbon filter, holding all other factors constant.

## DISCUSSION

The primary objective of this study was to develop a better understanding of the daily consumption of drinking water in Waterloo Region. Previous studies have estimated the mean volume of daily cold drinking water intake, which ranges from 0.101 to 1.551 (Ershow *et al.* 1991; Levallois *et al.* 1998; EPA 2000; Jones *et al.* 2006; Westrell *et al.* 2006; Mons *et al.* 2007). However, estimates vary by study and country. In order to more accurately reflect water

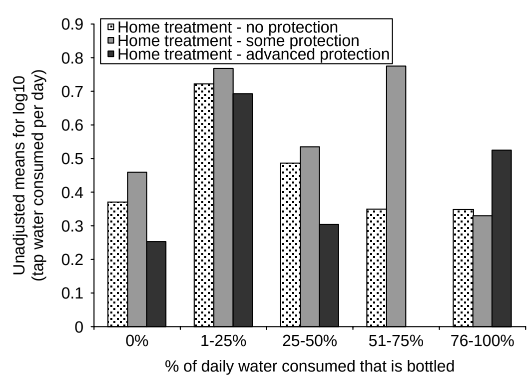


**Figure 4** | Interaction between use of home treatment and % of daily water intake that is bottled on volume of cold water (bottled and tap) consumed daily.

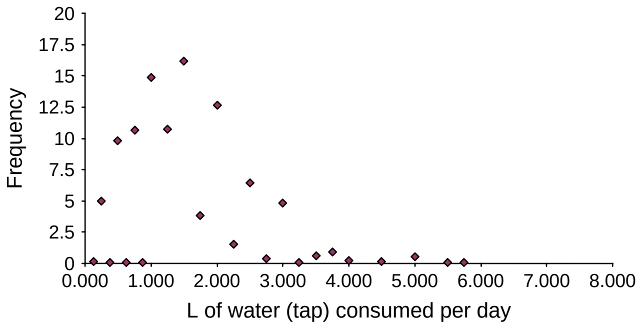


**Figure 5** | Frequency distribution of reported daily volume of tap water consumed per day by study respondents who consumed no bottled water ($n = 1124$).

consumption habits in the study community, a more representative probability distribution of daily tap water consumption volumes was needed. Probability distributions are preferable for risk assessments since they incorporate an estimate of variability in the risk estimate. In addition, we were interested in understanding the influence of bottled water consumption and the use of home treatment systems on individual risk scenarios.

An important aspect of assessing an individual's risk from exposure to any substance is that populations and behaviours are inherently dynamic over time, and thus need to be periodically reassessed. For example, in this study we observed that older respondents consumed less water overall than younger respondents. It is unclear with this type of cross-sectional study design whether this is a cohort effect or a period effect, and follow-up is recommended. It is clear from this study that there are different sub-groups within the study population that exhibit different risk behaviours related to drinking

**Table 4** | Daily consumption of cold tap water among survey respondents, who reported to have not consumed any bottled water, classified by significant predictor variables

| | Mean ± St.Dev | Percentiles | | | |
|---|---|---|---|---|---|
| | L/day | N | 25th | 50th | 75th |
| Total | 1.45 ± 0.84 | 1,124 | 0.75 | 1.25 | 2 |
| Gender ($p = 0.000$) | Women 1.53 ± 0.78 | 742 | 1.00 | 1.5 | 2 |
| | Men 1.31 ± 0.86 | 382 | 0.75 | 1.25 | 1.5 |
| Age ($p = 0.0001$) | Age 0–5 1.25 ± 0.43 | 27 | 1.00 | 1.25 | 1.5 |
| | Age 6–12 1.28 ± 0.70 | 60 | 0.75 | 1.25 | 1.75 |
| | Age 13–17 1.35 ± 0.61 | 57 | 1.00 | 1.5 | 1.75 |
| | Age 18–25 1.56 ± 0.83 | 106 | 1.00 | 1.5 | 2 |
| | Age 26–39 1.63 ± 0.96 | 257 | 1.00 | 1.5 | 2 |
| | Age 40–59 1.45 ± 0.95 | 294 | 0.75 | 1.25 | 2 |
| | Age 60 + 1.32 ± 0.66 | 285 | 0.75 | 1.25 | 1.75 |
| Use of a home treatment system ($p = 0.0001$) | No protection 1.38 ± 0.82 | 380 | 0.75 | 1.25 | 1.875 |
| | Some protection 1.52 ± 0.84 | 632 | 1.00 | 1.5 | 2 |
| | High protection 1.17 ± 0.71 | 73 | 0.75 | 1 | 1.5 |
| Education ($p = 0.0018$) | Grade 8 or less 1.31 ± 0.64 | 122 | 0.75 | 1.25 | 1.75 |
| | Some highschool 1.31 ± 0.78 | 175 | 0.75 | 1.25 | 1.75 |
| | Highschool 1.33 ± 0.71 | 152 | 0.75 | 1.25 | 1.75 |
| | Some college/university 1.53 ± 0.90 | 234 | 1.00 | 1.25 | 2 |
| | College 1.6 ± 0.91 | 153 | 1.00 | 1.5 | 2 |
| | University 1.59 ± 0.91 | 191 | 1.00 | 1.5 | 2 |
| | Postgraduate 1.3 ± 0.74 | 76 | 0.75 | 1.125 | 1.75 |
| Water source ($p = 0.0692$) | Municipal source 1.46 ± 0.84 | 1025 | 0.75 | 1.25 | 2 |
| | Private source (well or cistern) 1.25 ± 0.68 | 74 | 0.75 | 1.25 | 1.5 |

**Table 5** | Final regression model for volume of cold tap water consumed in a day N = 1015, F(22,992) = 3.19, P > F = 0.0000, Adj R-squared = 0.045, Root MSE = 0.62

| Logwaterday | | Coefficient | Standard Error | T | P > \|t\| | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| Water Source (municipal was referent) | Private well/cistern | 0.04 | 0.04 | 1.07 | 0.29 | −0.04 | 0.12 |
| Gender (female was referent) | Males | −0.14 | 0.08 | −1.79 | 0.07 | −0.29 | 0.01 |
| Age (40–59 group was referent) | Age (0–5) | −0.03 | 0.21 | 0.25 | 0.80 | −0.36 | 0.03 |
| | Age(6–12) | −0.17 | 0.16 | −1.01 | 0.31 | −0.46 | 0.15 |
| | Age(13–17) | 0.00 | 0.13 | 0.54 | 0.59 | −0.18 | 0.32 |
| | Age (18–25) | 0.02 | 0.09 | 0.72 | 0.47 | −0.11 | 0.25 |
| | Age(26–39) | 0.16 | 0.07 | 2.96 | 0.00 | 0.07 | 0.32 |
| | Age (60 + ) | 0.00 | 0.07 | 0.22 | 0.82 | −0.11 | 0.14 |
| Interaction between gender and age | GenderXAge1 | 0.12 | 0.27 | 0.29 | 0.78 | −0.45 | 0.60 |
| | GenderXAge2 | 0.29 | 0.18 | 1.86 | 0.07 | −0.02 | 0.70 |
| | GenderXAge3 | 0.21 | 0.19 | 0.88 | 0.38 | −0.20 | 0.53 |
| | GenderXAge4 | 0.17 | 0.15 | 0.91 | 0.36 | −0.16 | 0.43 |
| | GenderXAge5 | −0.30 | 0.12 | −2.87 | 0.00 | −0.57 | −0.11 |
| | GenderXAge7 | −0.03 | 0.11 | −0.20 | 0.84 | −0.24 | 0.20 |
| Education *(referent = 'some trade, college or university training') | Education (Gr.8 or less) | 0 | 0.11 | −0.69 | 0.49 | −0.29 | 0.14 |
| | Education (Some highschool) | −0.11 | 0.07 | −2.14 | 0 | −0.29 | −0.13 |
| | Education (Highschool) | −0.04 | 0.07 | −1.54 | 0.12 | −0.24 | 0.03 |
| | Education (College Diploma) | 0.09 | 0.07 | 0.88 | 0.38 | −0.07 | 0.19 |
| | Education (University Degree) | 0.11 | 0.06 | 1.12 | 0.265 | −0.05 | 0.19 |
| | Education (Advanced Degree) | −0.07 | 0.09 | −1.33 | 0.18 | −0.29 | 0.05 |
| Home Treatment (referent = some protection) | No protection | −0.06 | 0.04 | −1.37 | 0.179 | −0.14 | 0.027 |
| | High level of protection | −0.21 | 0.08 | −2.6 | 0.01 | −0.36 | −0.05 |
| Constant | | 0.12 | 0.14 | 0.86 | 0.39 | −0.14 | 0.38 |

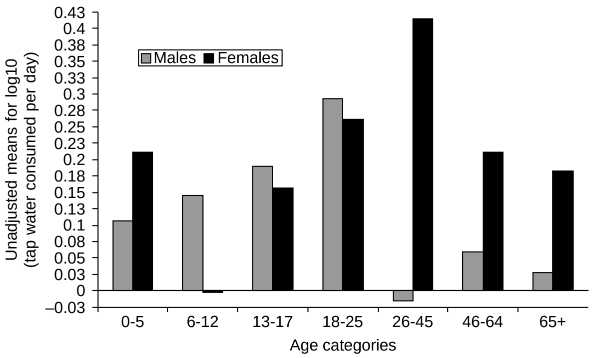


**Figure 6** | Interaction between gender and age on volume of tap water consumed daily for those respondents who consumed no bottled water.

water, whether we consider home treatment use, bottled water consumption or total volume (of tap and bottled water) consumed in one day.

Here we found a significant interaction between age and gender and daily volume of water consumed, for both total water consumed and tap-only water consumed. Both older men and women consumed less water than younger respondents, and this difference was more dramatic in men than women. The association between age and tap water consumption is unclear; Westrell *et al.* (2006) found that tap water consumption was greatest in those over 60, Levallois *et al.* (1998) found no clear association, while Beaudreau *et al.* (2003) and DWI (1996) observed that tap water intake increased with age up to 50 and then declined. However, Jones *et al.* (2006) found that consumption decreased with increasing age, and this is the most comparable population to ours. The association between gender and tap water consumption has been previously evaluated by a number of studies, of which only one (Westrell *et al.* 2006) found that water consumption was higher among women than men. Most other studies found no significant association (EHD 1981; Levallois *et al.* 1998; Gofti-Laroche *et al.* 2001; Beaudreau *et al.* 2003; Jones *et al.* 2006). It was clear in our study that both age and gender are associated with water consumption, but that the two variables must be considered together. However, given that there is no consensus in the literature on the association between age, gender and water consumption practices, this interaction must be more fully explored before the findings are used to predict behaviours or inform intervention or education strategies. In this study, the association was significant, and at the very least, future studies on factors influencing drinking water consumption should account for both age and gender and explore their interaction. This is particularly important if results will be used to inform waterborne risk scenario development for exposure estimates by gender and age.

Education level was significantly associated with water consumption in this study; overall, more highly educated respondents consumed more water on a daily basis, except for those respondents with an advanced post-graduate degree. A similar association was observed by Jones *et al.* (2006) for a similar Canadian study population. We speculate that more highly educated people may be more aware of the health benefits of consuming water, therefore incorporate water into their diets more frequently than other beverage choices. We are not clear on the significance of the advanced post-graduate degree respondents.

Bottled water consumption was an important aspect of this investigation, as Canadians continue to rely on bottled water as a significant source of daily consumption. Bottled water represents the fastest growing segment of the non-alcoholic beverage market (Ferrier 2001). In Canada, bottled water is regulated as a food, whereas tap water is regulated by provincial drinking water regulations. Since the methods in which tap and bottled water are treated and delivered to the end user differ, they represent different risk scenarios for exposures to both chemicals and pathogens. Bottled water use has continued to increase over the past decade, influenced by public perception of the quality of tap water. Doria (2006) reviewed the main drivers that influence a consumer's decision to buy bottled water and identified four important factors: dissatisfaction with tap water organoleptics (taste and colour), relevance of risk, access and price. Often, bottled water consumption is higher in communities with poor tap water quality.

In this study, although half the respondents exclusively drank tap water, approximately one-third exclusively drank bottled water. This information illustrates the popularity of alternative water sources, which influence an individual's risk of exposure to a waterborne pathogen. Similar trends were observed by Jones *et al.* in (2006) in Hamilton, Ontario, Canada. While the data were categorized slightly differently, bottled water often represented 75% or more of the total daily water intake of respondents. Not only are these findings relevant for future risk assessment modelling initiatives, but also for future research to understand why consumers are choosing bottled water over tap water.

We estimated the frequency of use of home water treatment devices within the study population. Home water treatment can affect the exposure estimate for a waterborne chemical or microbial risk assessment, since certain treatment devices can significantly reduce the concentration of chemicals and pathogens in water. If such home treatment devices are not accounted for, risk assessments could potentially overestimate representative risk. In this study, respondents identified whether they had any home treatment systems installed. Carbon filters were the most common type of home treatment used. This was not surprising, since carbon filters are the most readily available and least expensive home treatment option available to North American consumers. However, the degree of protection these treatment devices provide for the consumer, for both microbial or chemical contaminants, is still unclear, depending on the chemical or pathogen of study (Daschner *et al.* 1996; Matsui *et al.* 2004; Pawlowicz *et al.* 2006; Levesque *et al.* 2006; Clasen & Menon 2007).

In the study population, a relatively small proportion (5%) invested in advanced forms of home treatment, such as reverse osmosis, ultraviolet light and distillation systems. This is similar to the Jones *et al.* 2006 findings, where almost half of their survey respondents used a home treatment device, and approximately 5% reported the use of heat or light treatment or reverse osmosis. We found that home treatment use was significantly associated with volume of water consumed, and those respondents who used an advanced form of home water treatment consumed less water overall than those with simple carbon treatment devices, such as jug filters or tap filters. The trends in use of such devices are worth following, as they may have an impact on a population's exposure to current and future waterborne risks.

Source of water (municipal versus private well/cisterns) appeared to confound the model results and should be considered in future studies. We approached confounding by controlling for it in our analyses.

## STUDY LIMITATIONS

One of the survey limitations was that it was performed between the months of November and March, and therefore did not include a summer period. One might expect water consumption practices to differ during a North American summer, although this was not further investigated in this study.

For reasons of cost and ease of sampling, population-based studies are often based on telephone surveys using RDD sampling methods, where randomisation helps to minimise selection bias. The response rate for this study was 32.7% and therefore the results may be susceptible to non-response bias and affect the ability to generalize our findings. Telephone surveys are subject to low response rates (Kalton & Piesse 2007), although the response rate for this study was consistent with previous Canadian dietary surveys (Mendelson *et al.* 2003; Forster-Coull *et al.* 2004). This is a limitation faced by many researchers whose objectives involve determining individual level exposure practices related to public health issues. While no survey tool can ensure high response rates, telephone surveys are one of the most common and effective methods used for assessing individual level exposure factors or practices in epidemiological studies. We attempted to maximize participation with the repeated call-back approach and by providing flexibility of the timing of the interview to suit the participants' schedules.

To determine the generalizability of our findings, we compared the survey respondents with the Waterloo Region census population (Table 1), and found that respondents were more likely to be female, more educated and from higher income families. These differences were expected and were most likely the result of the sampling tool (a telephone survey).

This survey determined water consumption practices based on a 24-h recall history. Single-day intake data tend to over- or under-estimate the usual intake of an individual. However, this practice is commonly used to collect dietary intake data. Although single 24-h recall periods (or even repeated recalls) do not accurately estimate typical water intakes of individuals (Robertson *et al.* 2000; CCHS 2004), there are limited approaches to collecting water intake data. In addition, the use of a 24-h recall period limits the amount of recall bias. In 2007, Mons *et al.* reviewed tap water intake studies and evaluated the diary method and 24-h recall method for collecting water consumption data. While they concluded that the diary was the preferred method, they conceded that 24-h recall is the best alternative. We suggest further study of Canadian water consumption practices, and the incorporation of an extended recall period or diary method for data collection in the study design, to reduce the effects of day-to-day variability on the estimates.

While the findings of the multivariable analyses provide information on the likely associations between volume of water consumed and key demographic variables, including gender, age and education, the models suffer from a small adjusted $R^2$. Thus, these results may only serve to guide future study development and refine research hypotheses rather than as a predictive tool for water consumption in other populations. Additional factors that were not examined in this study but that have been shown to influence the volume of tap water consumed include pregnancy and lactation status, ethnicity, physical activity, perceived health status and medical status (Ershow & Cantor 1989; Zender *et al.* 2001; Mons *et al.* 2007). Demographic information was collected on cultural groups in this survey but data were sparse and difficult to interpret, and therefore the influence of cultural group on water consumption was not analysed. Further exploration of the influence of ethnicity on water consumption is particularly needed, as we understand the role of ethnicity on food consumption practices and risk. As well as cultural group, daily volume of water consumed appears to increase with yearly income across studies (Mons *et al.* 2007). Despite efforts to consider household income in this study, the large number of refusals or non-response precluded inclusion of this variable in the analysis.

The final potential source of bias of this survey was that it was only delivered in English. However, only 2.5% of survey respondents (179/7,142) did not participate due to language or hearing problems. It is therefore likely that English-only survey administration did not significantly bias our findings.

## SUMMARY

This study provided a current, site-specific summary of water consumption habits of a south-western Ontario community (Waterloo Region). The data can be used for future risk assessments. In addition, this study provided information on the community's use of home water treatment devices, illustrating that carbon filters are the most favoured form of treating tap water, and that only a small proportion of the population invests in advanced forms of home treatment. Finally, this study quantified three distinct risk groups within the study population: 32% who drank only bottled water, 48% who drank only tap water and a small proportion (20%) who drank both bottled and tap water. As the issue of bottled water continues to be raised as a health, environmental and policy issue, this information will be useful for informing discussions and guiding future research.

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