Factors influencing public perception and use of municipal drinking water

F. Proulx, M. J. Rodriguez, J. B. Sérodes and L. F. Miranda

ABSTRACT

Despite more stringent regulations concerning drinking water quality in many countries, the public is increasingly concerned about the safety of municipal tap water. For this reason, acquiring a better understanding of consumer perception of tap water is an important issue for water authorities and utility managers. In this study, water consumption choice and profile were investigated. The case under study is the territory of a water supply system in Québec City (Canada). Data on drinking water consumption was obtained through a questionnaire-based survey. Survey results showed that an important proportion (about one third) of the population under study do not drink tap water. To explain consumption choice (tap water or not) and consumption profile (levels of tap water consumption), binary and ordinal logistic regression analyses (LGA) were performed based on survey responses and complementary data resulting from measurements of water quality parameters in 32 locations throughout the water distribution system. Water quality information was managed through a water quality index (WQI). The WQI of each sampling point was associated with the location of each survey respondent using a geographical information system (GIS). LGA results showed that the geographical location of the consumer within the distribution system, the WQI and perceived risk toward water consumption were the main factors explaining both the water consumption choice and tap water consumption profile.

Key words | drinking water, logistic regression, risk perception, taste and odor, water quality, water quality index

F. Proulx (corresponding author)
Division des laboratoires du Service de l'environnement de la Ville de Québec,
210 St-Sacrement,
Québec,
Canada G1N 3X6
E-mail: *francois.proulx@ville.quebec.qc.ca*

M. J. Rodriguez
Ecole supérieure d'aménagement du territoire,
Université Laval,
Pavillon Savard,
Québec,
Canada G1K 7P4
E-mail: *manuel.rodriguez@esad.ulaval.ca*

J. B. Sérodes
Département de génie civil,
Université Laval,
Pavillon Pouliot,
Québec,
Canada G1K 7P4
E-mail: *jean.serodes@gci.ulaval.ca*

L. F. Miranda
Department of civil Engineering, Macdonald Engineering Building,
McGill University,
817 Sherbrooke Street West,
Montreal,
Canada H3A 2K6
E-mail: *luis.miranda-moreno@mcgill.ca*

INTRODUCTION

Public interest in the quality of drinking water has increased significantly in the last decade. Episodes of drinking water quality contamination occurring in various locations in the world have had an impact on public perception of drinking water, even influencing those not directly affected by such episodes (Meyer-Emerick 2004). An increasing number of people are using alternatives to tap water. In fact, in Canada, sales of bottled water increased by 69% between 2000 and 2003 (ICBWA 2004). This phenomenon may be associated with a greater perception of risk by consumers regarding municipal drinking water (Anadu & Harding 2000). According to Doria *et al.* (2005), the aesthetic characteristics of water are the most important factors influencing risk perception of drinking water. According to Jardine *et al.* (1999), consumers choose alternatives to tap water for aesthetic and sanitary reasons.

In the Province of Quebec (Canada), it has been established that some 25% of the population associate a risk with drinking tap water (Hudon *et al.* 1991). The risk associated with drinking tap water is often related to events of water quality failure (Harding & Anadu 2000). For example, in communities where there are persistent problems of water quality (boiling notifications, colored water, taste and odors, among other problems.), further

doi: 10.2166/ws.2010.511

risks are perceived by the population (Anadu 1997). Perception is also influenced by the type of information received on events concerning drinking water (external information such as media, information from friends, among others) (Doria *et al.* 2005). Life experiences related or not to water quality (chronic or acute disease, for example) may also influence the perception of risk associated with tap water (Meyer-Emerick 2004).

Few studies have focused on public perception regarding tap water, and particularly its relationship with the spatial variability of physicochemical and microbiological water quality, leading for calls for further research in this area (Doria 2010). The goal of this study was to identify the factors associated with public perception of tap water quality; in particular, water consumption choice (drinking tap water or alternatives) and profile (quantity of tap water consumed). Special emphasis was placed on the impact on perception of water quality from a geographical standpoint. Information for the study included a population survey on drinking water consumption, perception and satisfaction and the development of an integrated quality index representing the geographical variations of water quality throughout the distribution system. Data analysis revolved around a spatially based analysis of three indicators related to consumers' perception of tap water: consumption, risk perception and global satisfaction. A robust multivariate statistical analysis was applied to explain the variability of these three indicators.

METHODOLOGY

Case under study

The case under study was a distribution system supplying drinking water to a sector of Québec City (Canada). This sector is known as Beauport. Water for Beauport is pumped from the Montmorency River, a tributary of the St. Lawrence River. Water treatment consists of filtration through sand within the river bed (river bank filtration), ozonation and, finally, chlorination before distribution. About 70,000 individuals are served by this treatment plant. The Beauport distribution system is an interesting case study because the system supplies a large territory (74 km^2) and, given the number of people served, water residence times in the network can be relatively long. This can affect the aesthetics of water quality because of potential bacterial growth and interaction with pipes, among other factors.

Public survey

The first step of the research project consisted in conducting a survey and analyzing results using a geographical information system (GIS). For the purpose of this study, a questionnaire-based mail survey was sent to 1,200 residents of Beauport. The questionnaire was designed to obtain information on drinking water consumption patterns, the degree of respondents' overall satisfaction with tap water quality, perceived risk associated with the consumption of tap water and the socio-demographic characteristics of respondents (the questionnaire contained 42 questions). The majority of questions in the questionnaire were presented in a multiple choice form. Thus, answers were represented by nominal variables for statistical analysis purposes. Potential respondent addresses were chosen randomly from the Beauport telephone directory. Each questionnaire was coded with a number linked to a spatial location within a database. The distribution of addresses used for the survey was homogeneous over the entire territory of the Beauport sector.

All questionnaires were returned within 10 days of their receipt. The survey response rate was 27%. Figure 1 shows respondent distribution. Given the size of the sample population, the error was estimated at less than 6% for a confidence interval of 95%. It was observed that the distribution of the socio-economical profile of the survey sample (age, education and income) was close to the profile of the population of Beauport (Statistics Canada 2001).

Water quality index

The physicochemical and microbiological quality of drinking water is important information to consider in the assessment of perception of tap water. Under some circumstances, parameters such as color, turbidity, residual chlorine concentration and heterotrophic plate count (HPC) may be used to define the aesthetical quality of tap water. For example, color and turbidity are related to the appearance of water. Residual chlorine may be a precursor

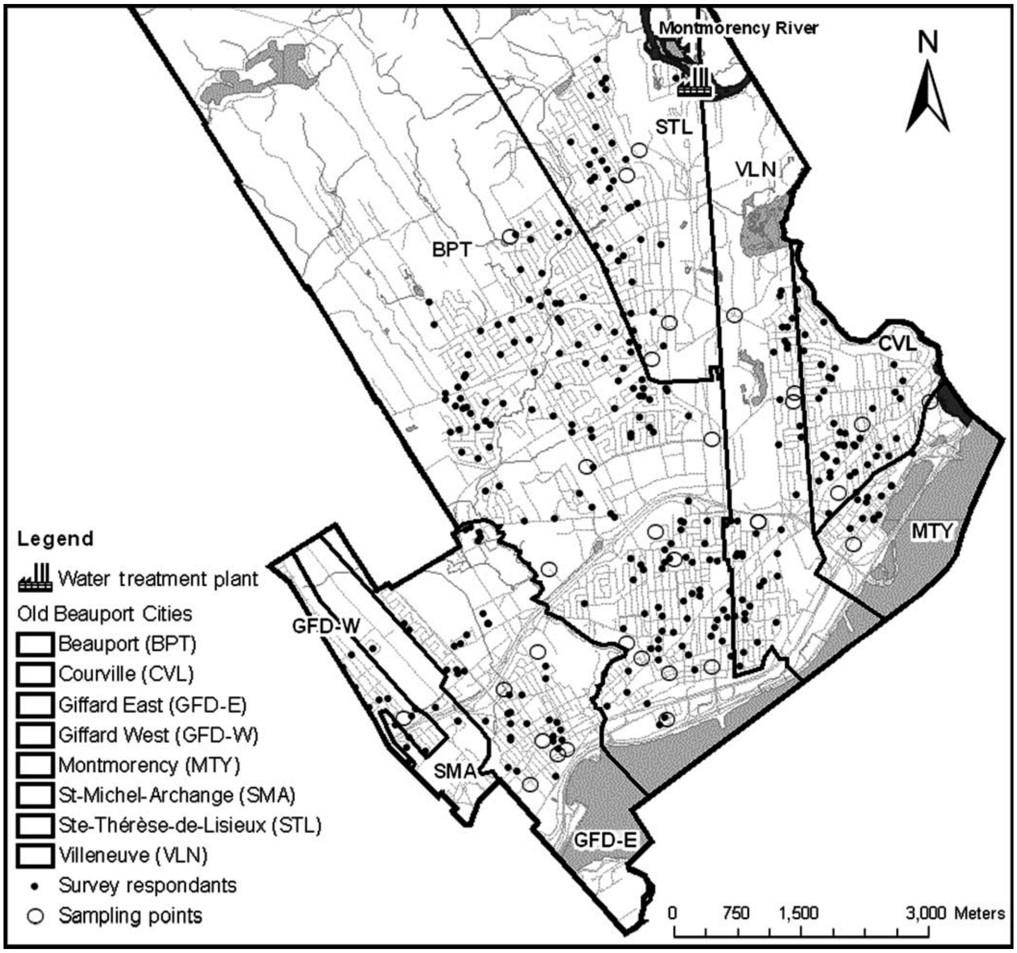

Figure 1 | Distribution of survey's respondents in Beauport's territory.

of water taste. In fact, the residual chlorine in distributed water is responsible for the majority of complaints involving North American municipal water systems (Suffet *et al.* 1993). HPC may be related to the aging of water in distribution networks and may indicate possible degradation of microbiological water quality, eventually leading to a aesthetic degradation of drinking water quality (Kitasawa 2006; Francisque *et al.* 2007).

In the present study, data on water quality parameters were not available for each location corresponding to respondents of the mail survey. Alternatively, data generated from the routine surveillance of water quality were used to evaluate the "status" of water quality corresponding to each survey respondent. For surveillance purposes, the municipality monitors 32 points in the distribution system of Beauport. These locations are shown in Figure 1. Each point is sampled weekly and analyzed for microbiological (total coliforms, *E. coli*, HPC, algal count) and physicochemical parameters (apparent color, free residual chlorine, pH, temperature, ultraviolet absorbance at 254 nm). Table 1 shows the major physicochemical and microbiological characteristics of water in Beauport.

Based on water quality monitoring data collected during the two years prior to the population survey, a water quality index (WQI) was built in order to establish a global organoleptic quality evaluation of distributed water at each point of the survey. The WQI was implemented with the parameters having moderate or high spatial variability. Other available water quality parameters were excluded because of their low variability within the distribution system.

A sub-index for each parameter was established by determining thresholds above or below which the

Table 1 | Treated water quality characteristics of Beauport (Average values of 2003 and 2004)

Parameters	Minimum	Mean	Median	Maximum
Absorbance at 254 nm (/10 cm)	0.018	0.46	0.47	1.2
Algal count (unit/10 ml)	0	108	64	1,700
Apparent color (ACU)	2	10	10	112
E. coli (CFU/100 ml)	0	0	0	0
Free residual chlorine (mg/l)	<0.03	0.69	0.60	3.36
HPC (CFU/ml)	0	17	0	6,000
pH	5.0	7.2	7.2	9.8
Total coliforms (CFU/100 ml)	0	0	0	0
Temperature	0.8	10.1	9.3	25.0
Turbidity (NTU)	0.10	0.69	0.54	39

Notes: ACU: Apparent color unit are equal to platinocobalt unit for unfiltered samples.

parameter values might have an influence on the population's positive or negative perception concerning aesthetics of water. The establishment of these thresholds must consider the specific type of water distributed by this utility. In fact, due to its minimal water treatment, the Beauport utility requires a relatively higher chlorine dosage than that of other utilities of Québec City in order to ensure adequate protection from microbiological contamination. Moreover, during summer, when source water levels are low, frequent episodes of colored water are observed within the distribution system. The values for residual chlorine and turbidity in Beauport are usually high throughout the seasons. For this reason, it is probable that the acceptance level for these parameters by the population is higher than normally observed in other systems, as it was shown by Piriou *et al.* (2004). In fact, utility operators observed an increase in the number of complaints in some sectors when the level of residual chlorine reached a value of 0.6 mg/l or when apparent color exceeded 10 ACU (these values approach the mean values for the distribution system under study). Thus, for each parameter used to establish the WQI, appropriate ranges adapted to specific characteristics of the drinking water in Beauport were determined to account for the organoleptic alteration of tap water. Table 2 presents the criteria for water quality parameters used to establish the WQI.

The sub-index representing each water quality parameter was associated with survey respondents by considering the two monitoring points closest to respondent location using a geographical information system (GIS) (Map Info). This procedure considered both geographical and hydraulic-based distances. The WQI was calculated using Equation (1). In this particular case, the same weight was given for each sub-index. This assumption is used in other domains for which environmental indices have been developed (House & Ellis 1987).

$$\mathrm{WQI}_{\mathrm{R}i} = I_{\mathrm{CR}i} + I_{\mathrm{RCR}i} + I_{\mathrm{TR}i} + I_{\mathrm{HPCR}i} \quad (1)$$

where:

$\mathrm{WQI}_{\mathrm{R}i}$: Water quality index for the respondent i;
$I_{\mathrm{CR}i}$: Arithmetic mean of sub-indexes related to apparent color at the two nearest sampling point i;
$I_{\mathrm{RCR}i}$: Arithmetic mean of sub-indexes related to residual chlorine at the two nearest sampling point i;
$I_{\mathrm{TR}i}$: Arithmetic mean of sub-indexes related to turbidity at the two nearest sampling point i;
$I_{\mathrm{HPCR}i}$: Arithmetic mean of sub-indexes related to heterotrophic plate count at the two nearest sampling point i.

Once calculated for each location, the values of WQI varied spatially from 1 to 4.5. Global organoleptic quality decreases as the WQI increases.

Table 2 | Criteria used to establish the WQI

Parameters	Categories for parameters	Sub-index
Free residual chlorine	$[Cl_2] \leq 0.6$ mg/l	0
	0.6 mg/L $< [Cl_2] \leq 1$ mg/l	1
	$[Cl_2] > 1$ mg/l	2
HPC	HPC $=$ 0 UFC/ml	0
	HPC $>$ 1 UFC/ml	1
Apparent color	Color $\leq$ 10 ACU	0
	10 UCA $<$ Color $\leq$ 15 ACU	1
	Color $>$ 15 ACU	2
Turbidity	Turbidity $\leq$ 1 NTU	0
	Turbidity $>$ 1 NTU	1

Notes: Cl_2: 0.6 mg/l corresponds to the 50th percentile value; 1 mg/l corresponds to the mean value plus 1 standard deviation. HPC: the absence or presence of HPC is considered. Apparent color: 10 ACU corresponds to the 50th percentile value; 15 ACU corresponds to the mean value plus 1 standard deviation. Turbidity: 1 NTU corresponds to the value below which there are not complaints concerning water appearance.

Water Science & Technology: Water Supply—WSTWS | 10.3 | 2010

Data analyses

Perception of tap water is a complex concept difficult to express with a single variable. For this reason, three indicators (variables) to express perception were considered for modeling purposes: consumption profile (c), risk perception (r) and global satisfaction (s). The first indicator, consumption profile, may be considered as the ultimate and objective consequence of consumer perception of drinking water. Generally, the consumer makes the decision to stop or reduce tap water consumption after a series of events, successive or not, that vary from one person to another (Anadu 1997). The second indicator, risk perception, depends on more subjective factors such as individual experience, tolerance and external information, among other factors. (Doria *et al.* 2005). Finally, global satisfaction is a function of the organoleptic quality of tap water. It may also be influenced by an individual's life experience and cultural origin, among others (Jardine *et al.* 1999).

In this study, multivariate models for the three indicators of tap water perception presented above were developed to identify factors responsible for their variability. The indicators were modeled as binary and ordinal variables, as detailed below. Explanatory variables included socio-economical characteristics, water quality status, geographical location within the distribution system, and knowledge of drinking water issues.

Binary logistic regression

For the first exploratory analysis, respondents' answers were dichotomized as shown in Table 3. Binary regression was then used for modeling the choice of tap water, or not, for consumption (consumption choice). For example, tap water consumption was denoted as c_i, where $c_i = 1$ if respondent i does not drink tap water and 0 otherwise ($i = 1,2,\ldots,n$ respondents). In this binary formulation, c_i can be associated with a continuous and unobserved

Table 3 | Variables used to evaluate the perception towards tap water

Indicators	Questions and possible answers in the survey	Binary variables*,†	% respondents	Ordinal variables	% respondents
Tap water consumption	*At home*, if you drink the water from the tap, how many glasses of this water do you drink each day?	$c_i = 0$ if i drinks water	64.2	$c_i = 1$ if i does not drink water	35.8
	a) How many	$c_i = 1$ if i does not drink	35.8	$c_i = 2$ if i drinks 1 glasses/day	10.1
	b) Do not drink tap water			$c_i = 3$ if i drinks from 2 to 4 glasses/day	32.0
				$c_i = 4$ if i drinks > 5 glasses/day	22.2
Perceived risks	According to you, now, is the Beauport tap water consumption a high, minor or no risk for your health?	$r_i = 0$ if i does not perceive any risk (answer c)	41.1	NA	NA
	a) High risks	$r_i = 1$ if i perceives a potential risk (answers a and b)	58.9		
	b) Minor risks				
	c) No risk				
Global satisfaction	During the year, your tap water quality is…	$s_i = 0$ if i is rather satisfied (answers a, b)	82.0	NA	NA
	a) Excellent	$s_i = 1$ if i is rather unsatisfied (answers c, d)	18.0		
	b) Good				
	c) Passable				
	d) Poor				

*i refers to respondent.
†For c_i, r_i and s_i, 0 is the reference category for the model.
Note: NA: Not applicable.

outcome c_i^*, defined according Equation (2).

$$c_i = \begin{cases} 1 & \text{if } c_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \qquad c_i^* = \boldsymbol{x}_i\boldsymbol{\beta} + \varepsilon_i \tag{2}$$

where $\boldsymbol{x}_i = (x_{1i}, \ldots, x_{ki})$' is a vector of explanatory variables or predictors. Moreover, $\beta = (\beta_0, \beta_1, \ldots, \beta_k)$ is a vector of regression coefficients to be estimated from the data, and ε_i is the independent model error which is assumed to follow a logistic probability distribution (Hosmer & Lemeshow 2000). In addition, it may be assumed that ε_i is normally distributed when considering the probit modeling framework. The choice of the explanatory variables was made in two steps. In the first step, the variables were chosen for their potential to influence public perception regarding tap water (Meyer-Emerick 2004; Turgeon *et al.* 2004). In the second step, the strength of the association and significance of each variable was tested using a bivariate variance analysis. The criterion to retain a variable was that no association, or a very low one, exists with dependent variables (VCramer < 0.4, $p < 0.1$). Explanatory variables retained for modeling purposes are presented in Table 4.

Ordinal logistic regression

The consumption indicator (c_i) could be also seen as ordinal responses represented by ordered categories as shown in Table 3. Indeed, dichotomous responses can be viewed as a simple special case of ordinal variables with two categories. In order to model this indicator (c) as an ordinal variable, ordered regression modeling was explored as an extension to the logistic regression (Wooldridge 2002).

In this case, each of the three indicators is represented by an ordinal variable containing more than two classes. For instance, considering that tap water consumption (c_i) is a categorical variable that takes the values 1, 2, 3 and 4, the ordered logistic model can be written as:

$$c_i = \begin{cases} 1 \text{ if } & c_i^* \le \mu_1 \\ 2 \text{ if } & \mu_1 < c_i^* \le \mu_2 \\ 3 \text{ if } & \mu_2 < c_i^* \le \mu_3 \\ 4 \text{ if } & \mu_3 < c_i^* \end{cases} \qquad c_i^* = x_i\beta + \varepsilon_i \tag{3}$$

where, as before, c_i^* is a latent (unobserved) continuous response and $\boldsymbol{x}_i$ is a vector of factors explaining c_i^*, with associated parameters β. The parameters, μ_1, μ_2 and μ_3 refer to thresholds or cut-points and are constrained to increase: $0 = \mu_1 < \mu_2 < \mu_3$. The error term ε_i represents the unobserved effect of all unmeasured factors on c_i^*; Moreover, ε_i is assumed to follow a Normal density function, $\varepsilon_i \sim N(0,1)$ under the probit or a logistic distribution under the logit model. Then, the observed ordinal responses c_i, can be generated from c_i^* via the threshold values. Finally, note that when using the ordered logistic approach, the probability that an individual i belongs to a given class may be calculated. For instance, to obtain the probability that a given respondent i belongs to the second class ($c_i = 2$), the following probability was calculated:

$$\Pr(c_i = 2) = \Pr(\mu_1 < c_i^* \le \mu_2)$$

In order to explain the factors influencing water consumption profile, ordinal logistic regression was used.

Effect of perceived risk and satisfaction on tap water consumption

As observed in Tables 5 and 6, risk perception (r_i) and global satisfaction (s_i) may be determinants of tap water consumption (c_i). Then, to test the effect of r_i or s_i on c_i, these two indicators are introduced separately also as explanatory variables in the regression equation:

$$c_i^* = x_i\beta + \alpha_r r_i + \varepsilon_i \tag{4}$$

where, as before, c_i^* represents the latent continuous water consumption and α_r is the regression coefficient measuring its effect on tap water consumption. In this case, r_i and s_i are considered as a dummy variable (0/1).

Note, however, that the introduction of r_i and s_i as water consumption determinants can produce some bias when using the standard binary or ordinal regression models defined previously. In either case, these standard regression techniques can produce inconsistent estimators if unobserved factors affecting water consumption (c_i^*) are correlated with unobserved factors affecting both risk or

Table 4 | Explanatory variables and categories used for binary and ordinal logistic regression

Explanatory variable	Variable definition	% of respondents
Location	Location in distribution network	
Extremity	More than 6 km from water plant	32.9
Middle and beginning REF	Within 6 km of the water plant	67.1
Old municipalities	Respondent's location in a constitutive municipality before the 70's merger	
Beauport	Beauport	44.3
Other REF	Saint-Michel-Archange, Giffard, Villeneuve, Sainte-Thérèse-de-Lisieux, Saint-Grégoire-de-Montmorency and Courville	55.7
Water source knowledge	Identification by the respondent of the water source of Beauport	
Know	Montmorency river.	42.1
Do not know REF	Others	57.9
Housing type	Habitation type	
Multi-residence dwelling	More than one family	75.9
Single-family house REF	Single family	24.1
Global quality	Global quality according to the quality index	
Poor	WQI > 3	41.1
Good REF	WQI ≤ 3	58.9
Owner/tenant	Respondent's status regarding his dwelling	
Tenant	Tenant	25.0
Owner REF	Owner	75.0
Children < 18	Number of children living with the respondent	
Children	Children	36.7
No children REF	No children	63.3
Age group	Age group	
18–34	18–34 years old	19.9
35–54	35–54 years old	46.5
> 55 REF	>55 years old	33.5
Education level	Educational level	
Pre-univ.	Without a university degree	66.8
Univ. REF	With a university degree	33.2
Gender	Respondent's gender	
Male	Male	48.1
Female REF	Female	51.9

Notes: REF denotes reference category for binary and ordinal logistic regression analysis.

satisfaction, e.g. water consumption may be affected by unobserved factors such as unmeasured life style, health problem issues, perceived taste or odor and media information, among other factors. This issue, known in the literature as endogenous switching, can seriously bias regression coefficients (Miranda & Rabe-Hesketh 2006). For instance, including risk (r_i) as an explanatory variable without accounting for the correlation in the error terms (ε_i) can seriously bias the regression coefficient on the consumption profile model.

Table 5 | Distribution of respondent's water choice according to their perceived risk tap water

Drinking water choice	Potential risk perceived	No risk perceived	χ^2	p
Tap water exclusively	26.0	51.0	15.9	< 0.001
Alternatives	52.0	28.0	11.8	0.001

Therefore, in order to test for the presence of endogeneity, a two-system equation model was used where parameters are calibrated simultaneously. For instance, the two-equation system of water consumption and risk is defined as: $c_i^* =$ $^*_i = \boldsymbol{x}_i\boldsymbol{\beta} + \alpha_r r_i + \varepsilon_{1i}$, where $r_i = \boldsymbol{z}_i\boldsymbol{\gamma} + \varepsilon_{2i}$, $\boldsymbol{z}$ is a vector of explanatory variables, γ is a vector of parameters. This approach is very common in economics literature (Heckman 1978; Wilde 2000; Miranda & Rabe-Hesketh 2006). Then, in order to test for endogeneity, endogenous switching models for binary and categorical variables were considered, based on the work of Miranda & Rabe-Hesketh (2006).

Regression analyses were carried out using SPSS (version 13.0) and STATA (version 9.2) for Windows. The performance of binary models was evaluated using the two following criteria: the Hosmer-Lemeshow test (good adjustment is shown by a high signification value) and the chi-square statistic (where a weak value shows a good adjustment) (Hosmer & Lemeshow 2000). For ordinal models, performance was evaluated using the chi-square statistic of the likelihood function (good model fit is shown by a low signification value) (Norušis 2008). The evaluation of all explanatory variables in each model was carried out using the level of significance (p value).

RESULTS AND DISCUSSION

Descriptive statistics

The analysis of data analysis focused on three indicators regarding public perception of tap water: tap water consumption, risk perception of tap water and global satisfaction with tap water.

Tap water consumption

The survey data showed that 41% of respondents drink tap water exclusively, whereas 36% used only alternatives to tap water (mainly bottled water). These results show a higher use of bottled water compared to results observed by Hudon *et al.* (1991), Levallois *et al.* (1999) and Anadu & Harding (2000) and are consistent with the growth rates of per capita consumption of bottled water during the last decade as reported by Doria (2006). Additionally, 17% of respondents use a treatment device to improve the quality of their tap water compared to 10% observed by Hudon *et al.* (1991) and 7% obtained by Levallois *et al.* (1999). This result suggests a relatively high perception of risk or dissatisfaction of Beauport residents with tap water. Table 7 shows that the

Table 6 | Distribution of respondent's risk perception and choice to drink tap water according to their satisfaction on tap water

	Rather satisfied (%)	Rather unsatisfied (%)	χ^2	p
Not perceiving risk				
Odor satisfaction	54.1	4.8	25.6	< 0.001
Taste satisfaction	51.9	7.3	26.5	< 0.001
Color/appearance satisfaction	55.3	4.1	26.8	< 0.001
Global satisfaction	53.7	3.9	33.8	< 0.001
Choosing tap water				
Odor satisfaction	56.8	8.9	10.9	< 0.001
Taste satisfaction	19.9	15.3	39.8	< 0.001
Color/appearance satisfaction	25.8	9.2	39.8	< 0.001
Global satisfaction	57.9	6.9	18.1	< 0.001

Table 7 | Distribution of respondent's water consumption choice, perceived risk, and global satisfaction according to the WQI

	WQI				
	<1.5	2–2.5	>3	χ^2	p
Do not drink tap water	27.0	32.3	36.9	19.4	<0.001
Perceive a risk in drinking tap water	51.4	48.4	37.3	0.54	0.76
Global unsatisfaction with tap water	21.6	19.4	17.1	1.6	0.46

higher the WQI, the higher the proportion of respondents who do not drink tap water. It was also observed that WQI increases with the distance between the treatment plant and customers location ($\chi^2 = 318$, $p < 0.001$). This result suggests that the physicochemical and microbiological quality of drinking water quality may, to some extent, explain the relatively low levels of tap water consumption. The question used to estimate the tap water consumption was: "At home, if you drink the water from the tap, how many glasses of this water do you drink each day?".

Risk perception

Survey results showed that 19% of respondents considered tap water as better for their health, while about half (49%) believed that bottled water was best for their health (regardless of the reasons for the rejection of tap water). Results also indicated that 44% of surveyed individuals who perceived a potential risk with tap water consumption do not drink this water ($p < 0.001$). Among respondents having experienced a health problem attributed to tap water, the large majority (85%) considered tap water consumption to be a (minor or high) health risk ($p < 0.001$), whereas a large majority of respondents (86%) who had never experienced a health problem with distributed water were globally satisfied with it ($p < 0.001$). In addition, risk perception of respondent concerning tap water appeared to contribute for drinking tap water or its alternatives (Table 5). However, the risk perception associated with tap water consumption was not found to be related to the WQI (Table 7). Risk perception could be described here as "perceived health benefits and risks". The question used to evaluate the risk perception was "According to you, now, is the Beauport tap water consumption a high, minor or no risk for your health?".

Global satisfaction

According to our survey, 82% of respondents reported being globally satisfied with the aesthetic quality of their tap water. This result is comparable to that obtained by Levallois *et al.* (1999) and Turgeon *et al.* (2004). In addition, results suggest that the perception of risk is related to the organoleptic perception of water: satisfaction regarding taste, odor and appearance (Table 6). In fact, 59% of respondents who were not satisfied with the quality of distributed water perceived a risk associated with drinking tap water ($p < 0.001$). Furthermore, respondent consumption of tap water was strongly associated with respondent satisfaction concerning the organoleptic aspects of tap water (Table 6), even if measured water quality appeared not to be related to respondent satisfaction with tap water (Table 7). Thus, it is probable that respondents satisfied with tap water perceive fewer risks than do respondents who are not satisfied, and are proportionally more inclined to drink tap water (Table 6). The above reasoning is also supported by the fact that, according to the survey, satisfaction regarding taste and odor represents the main reason for the consumption of tap water alternatives. The question used to estimate global satisfaction was "During the year, your tap water quality is excellent, good, passable or poor".

Binary modeling results

A total of five binary logistic regressions were developed (Tables 8 and 9). In models 1 to 3 in Table 8, the variables "tap water consumption", "risk perception" and "global satisfaction" were first considered as dependent variables. For models 4 and 5 in Table 9, the variable "tap water consumption" was used in all cases as the dependent variable. The difference with Model 1 is that, in addition to the other explanatory variables, Model 4 considers as additional explanatory variable "risk perception" and Model 5 considers "global satisfaction".

For model analysis, only the explanatory variables with significant values, p, greater than 0.1, were considered.

Table 8 | Results of binary logistic regression analysis for the three investigated variables: tap water consumption risk perception, and global satisfaction

Dependent (Model #)	Explanatory variables	Odds ratio
Tap water consumption	Constant*	0.189
(Model 1)	Location†	1.63
Sig: 0.798	Old cities†	0.609
χ^2: 4.618	Quality index*	1.85
Risk perception	Constant	0.771
(Model 2)	Children < 18*	2.19
Sig: 0.032		
χ^2: 16.87		
Global satisfaction	Constant‡	0.019
(Model 3)	Children < 18†	1.94
Sig: 0.768	Education‡	6.942
χ^2: 4.898		

Notes: Odds ratio: Criteria for determining if the probability of a certain event is the same for two populations; χ^2: chi square statistic for binary logistic regression; Sig: Signification level of the model; †$p < 0.1$; *$p < 0.05$; ‡$p < 0.001$.

Results of Model 1 suggest that the fact of consuming or not consuming water from the tap is influenced by the quality of distributed water and location in the distribution system. In fact, the geographical location, belonging to a constitutive municipality, and the WQI were all significant variables in Model 1 (Table 8). Modeling results suggest that respondents are more concerned with tap water safety when they have children at home (Model 2 in Table 8). In fact, parents may perceive a greater risk for their children and can be more sensitive to risk regarding drink tap water (Parkin *et al.* 2001). Results of Model 3 indicate that less educated individuals are more sensitive to aesthetic aspects of tap water. It is possible that less educated individuals have less income and, given the cost of bottled water, do not have any choice but to drink tap water. Thus, those citizens are frequent users of tap water and possibly more judgmental regarding it. Unfortunately, the relationship between income and tap water consumption could not be established because the response rate in the survey for respondent income was very low.

Consideration of risk perception and global satisfaction as explanatory of a tap water consumption profile resulted in the models with highest significance (models 4 and 5). In addition to these two variables, factors having the highest impact on a respondent's profile for tap water consumption were the distributed water quality expressed by the WQI, geographic location in the distribution system and location in one of the merging municipalities (old cities) in the territory. Socio-economic characteristics, such as educational level or having children, were not significant in these models. In fact, these variables are considered intrinsically when including risk perception or global satisfaction as explanatory variables of the water consumption profile. According to Model 4, respondents who consider tap water as a possible risk to their health have a 2.4 greater chance of rejecting it. In addition, Model 5 shows that respondents satisfied with the organoleptic characteristics of tap water have a 3.8 greater chance of selecting this type of water.

According to results in models 4 and 5, measured water quality in the distribution system, represented herein by the WQI, has a significant influence on the tap water consumption profile of respondents (the higher the WQI, the higher the probability that consumers drink tap water). Indeed, after risk perception and global satisfaction, WQI was the most significant variable in these models.

Table 9 | Results of binary logistic regression analysis for tap water consumption (with risk perception or global satisfaction added as explanatory variables)

Dependent (Model #)	Explanatory variables	Odds ratio
Tap water consumption (risk perception as explanatory variable)	Constant*	0.120
(Model 4)	Location†	1.64
Sig: 0.944	Old cities†	0.639
χ^2: 2.841	Habitation type†	2.35
	Quality index*	1.79
	Risk perception‡	2.45
Tap water consumption (global satisfaction as explanatory variable)	Constant*	0.201
(Model 5)	Location†	1.63
Sig: 0.584	Old cities*	0.598
χ^2: 6.570	Quality index*	1.77
	Global satisfaction‡	3.82

Notes: Odd ratio: Criteria for determining if the probability of a certain event is the same for two populations; χ^2: chi square statistic for binary logistic regression; Sig: Signification level of Homer-Lemeshow test; †$p < 0.1$; *$p < 0.05$; ‡$p < 0.001$.

This means that WQI represents a good indicator of measured water quality in the distribution system and that, along with the information of global satisfaction, it contributes to adequately representing the organoleptic quality of drinking water.

Also, according to results for models 4 and 5, respondent consumption of tap water decreases as the respondent location approaches distribution system extremities. According to the models, respondents located at the extremities have a 1.6 greater chance of rejecting tap water than do other respondents. This result might be explained by the deterioration of water along the distribution system. It is possible that the distribution system location represents complementary information on a water quality deterioration phenomenon not considered in the WQI: for example, the presence of compounds responsible for odor such as geosmin and 2-methylisoborneol, presence of iron deposits and presence of biofilm contributing to release of bacteria by-products, among others.

In addition to geographical location in the distribution system, the location of respondents in one of the neighboring municipalities of Beauport has an effect on water consumption (see models 4 and 5, Table 9). In fact when a respondent was located in the former Beauport (BPT in Figure 1), the probability of drinking tap water increased. This phenomenon might be explained by distribution system hydraulics. In fact, as a result of municipal mergers, the actual distribution network is the result of networks of seven networks interconnected to the Beauport network (see Figure 1). The former Beauport network was designed so that pipe diameters (and flow) decreased from the treatment plant to network extremities. Network interconnection implies that water circulation patterns within the former network changed. This possibly produced clear differences in the characteristics of organoleptic quality of water circulating in the different sub-networks. Indeed, when the respondents were located in former municipalities now merged with Beauport, the probability of rejecting the consumption of distributed water was 1.5 times greater than if the respondent belonged to the former Beauport (models 4 and 5 in Table 9).

According to Model 4 (Table 9), when the respondents lived in a multi-residence building, a decrease in the probability of tap water consumption was observed (these respondents had a 2.4 greater chance of using alternatives to tap water than did people living in individual residences). This result suggests that the organoleptic quality of tap water for multi-residence buildings is more greatly influenced by water stagnation in the domestic plumbing system than in the case of single-family dwellings. In fact, the increase in the residence time may cause greater dissolution of metals or plumbing components and biofilm in the domestic plumbing system (AWWARF 1996). These results are consistent with those discussed in Doria (2006) and it must be highlighted that several other conflicting variables (such as income, education, past water quality problems, contextual indicators derived from housing quality) may be involved.

As mentioned earlier in this paper, tests were conducted to ascertain the potential presence of endogeneity between tap water consumption and risk perception and global satisfaction. Based on the procedure shown in earlier, it was concluded that endogeneity was not a problem in models 4 and 5.

One of the shortcomings of the binary logistic regression is the lost of information resulting when categorical data is converted into binary data. However, the benefit of this conversion overcomes the fact that some categories have few observations.

Ordinal modeling results

The binary model serves to identify the determining factors that explain respondent choice whether or not to use tap water for drinking purposes. As a complement to the study, ordinal models were developed to identify factors explaining the tap water consumption profile (in terms of quantity of daily glasses of tap water). As defined in Table 3, respondents were classified into four classes according to their tap water consumption. As was the case with the binary logistic regression, risk perception and global satisfaction were added as explanatory variables for water consumption in the ordinal models. Thus, a total of three ordinal logistic regressions were carried out.

The results of the ordinal logistic regressions showed that the consumption profile could be explained by the WQI, risk perception and global satisfaction. Thus, the number of glasses of tap water consumed by respondents

Table 10 | Results of ordinal logistic regression analysis for the water consumption profile

Dependent variable	Explanatory variables	Estimation*
Tap water consumption profile	Water quality index	
(Model 1)	0. Good ($p < 0.05$)	0.301
Sig <0.05	1. Poor	REF†
Tap water consumption profile (with risk perception as explanatory variable)	Risk perception	
(Model 2)	0. No risk ($p < 0.001$)	0.871
Sig <0.001	1. Potential risks	REF
	Water quality index	
	0. Good ($p < 0.05$)	0.412
	1. Poor	REF
Tap water consumption profile (with global satisfaction as explanatory variable)	Global satisfaction	
(Model 3)	0. Rather satisfied ($p < 0.05$)	1.289
Sig <0.001	1. Rather unsatisfied	REF
	Water quality index	
	0. Good ($p < 0.05$)	0.382
	1. Poor	REF

*For model estimation a minus indicates a negative prediction.
†Reference category.
Sig: Signification level of the model.

increased with the increased quality of distribution system water. In addition, as for binary models, the fact of not perceiving a risk related to tap water and of being satisfied to the organoleptic quality increased the quantity of consumed tap water. It is interesting to note that WQI appears a more relevant factor for the tap water consumption profile than for the choice of tap water or an alternative. In fact, as presented before in Tables 8 and 9, tap water choice was also influenced by other variables such as geographical location or residence in merged cities.

In summary, the ordinal modeling results show that the tap water consumption profile could be explained primarily by the WQI, risk perception (explained by type of habitation and the presence of children at home) and global satisfaction (influenced by educational level and the presence of children at home).

As with the binary model, the potential endogeneity of the ordinal model was tested in Models 2 and 3 in Table 10. It was also concluded that endogeneity is not a problem for this model.

CONCLUSIONS

This investigation aimed at identifying factors explaining public perception of municipal drinking water through a case study of a water supply system in Québec City. The methodology combined a survey and analysis of water quality data based on spatial analysis and modeling with multivariate logistic regression. The study focused on understanding the water consumption profile, risk perception and respondent satisfaction with tap water quality. The results of the survey showed that a relatively low proportion of respondents drink tap water at home. The main findings of this research are the following.

- Respondent tap water consumption patterns are statistically associated with their satisfaction with water and the perception of risk.
- WQI representing spatio-temporal characteristics of measured water quality contributes significantly to explaining the variability of the respondent tap water consumption profile.

- Location within the distribution network, location in a constitutive municipality and type of housing can also explain the rejection of tap water.
- Consumption of tap water decreases as consumer's location approaches system extremities.
- Socio-economical characteristics of respondents (education, household characteristics, among other characteristics) also have an impact on the tap water consumption profile because they contribute to explaining the perception of risk and the satisfaction with tap water.
- Binary and ordinal logistic regression methods are useful statistical tools for understanding and modeling public perception of drinking water.

In Canada and elsewhere, several municipalities are producing high quality tap water, requiring important financial investments. However, a portion of the population still prefers alternatives to tap water. The results of this investigation could help municipal water managers to identify solutions to improve public perception of tap water. According to significant factors identified through the models developed herein, various strategies could be identified for this purpose. Since WQI was an important determinant of the consumption profile in this research, globally improving water quality is a strategy to be favored. This could be achieved by improving water treatment, optimizing post-chlorination or booster chlorination to control bacterial growth and improving network maintenance (i.e. frequent flushing for controlling pipe biofilm and iron deposits), among others. On the other hand, as perceived risk by the population greatly influences tap water consumption, educating the public and increasing public awareness campaigns centered on drinking water issues could enhance public appreciation of municipal water.

To improve the methodology and implications of research in this area, future studies might consider, for example, the following elements:

- spatio-temporal measurement of taste and odor precursors in the distribution system (such as 2-methylisoborneol, geosmin, and trichloroanisol) to be integrated in a WQI;
- measuring organoleptic water quality parameters of tap water supplied to citizens surveyed;
- conducting seasonal-based surveys to evaluate the temporal variability of tap water perception;
- considering external events (media information on water issues, regional boiling advisories) on the temporal variability of perception of tap water; and;
- integrating information provided by sensory analysis (taste and odor panels) to surveys and water quality.

REFERENCES

American Water Works Association Research Foundation (AWWARF) 1996 *Internal Corrosion of Water Distribution Systems*, Denver, CO, p. 586.

Anadu, E. C. 1997 Factors affecting risk perception about drinking water and response to public notification. PhD Thesis, Oregon State University, p. 160.

Anadu, E. C. & Harding, A. K. 2000 Risk perception and bottled water use. *J. Am. Water Works Assoc.* **92**(11), 82–91.

Doria, M. F. 2006 Bottled water versus tap water: understanding consumers-preferences. *J. Water Health* **4**(2), 271–276.

Doria, M. F., Pidgeon, N. & Hunter, P. 2005 Perception of tap water risks and quality: a structural equation model approach. *Water Sci. Technol.* **52**(8), 143–149.

Doria, M. F. 2010 Factors influencing public perception of drinking water quality. *Water Policy* **12**(1), 1–19.

Francisque, A., Rodriguez, M. J., Miranda, L. & Sadiq, R. 2007 *Modeling of heterotrophic bacteria in a water distribution system* Proc. AWWA Water Quality Technology Conference, Charlotte, North Carolina.

Harding, A. K. & Anadu, E. C. 2000 Consumer response to public notification. *J. Am. Water Works Assoc.* **92**(8), 32–41.

Heckman, J. J. 1978 Dummy endogenous variables in a simultaneous equation system. *Econometrica* **46**, 931–959.

Hosmer, D. W. & Lemeshow, S. 2000 *Applied Logistic Regression*. John Wiley & sons inc, NY, p. 373.

House, M. A. & Ellis, J. 1987 The development of water quality indices for operational management. *Water Sci. Technol.* **19**(9), 145–154.

Hudon, E., Zayed, J., Lainesse, P. & Loranger, S. 1991 Habitudes de consommation de l'eau potable au Québec et perception du risque pour le consommateur. *Sciences et techniques de l'eau* **24**(4), 357–362.

International Council of Bottled Water Associations (ICBWA) 2004 Global bottled water statistics 200–2003 http://www.icbwa.org/stats.htm (visited on June 2008).

Jardine, C. G., Gibson, N. & Hrudey, S. E. 1999 Detection of odour and health risk perception of drinking water. *Water Sci. Technol.* **40**(6), 91–98.

Kitasawa, H. 2006 Keeping residual chlorine and decreasing unpleasant odor caused by disinfection of tap water. *Water Sci. Technol. Water Supply* **6**(2), 193–199.

Levallois, P., Grondin, J. & Gingras, S. 1999 Evaluation of consumer attitudes on taste and tap water alternatives in Quebec. *Water Sci. Technol.* **40**(6), 135–139.

Meyer-Emerick, N. 2004 Are we answering the right questions? Improving CCR communication. *J. Am. Water Works Assoc.* **96**(8), 104–111.

Miranda, A. & Rabe-Hesketh, S. 2006 Maximum likelihood estimation of endogenous switching and sample selection models for binary, ordinal, and count variables. *Stata J.* **3**(6), 285–308.

Norušis, M. J. 2008 *SPSS 16.0 Advanced Statistical Procedures Companion*. Prentice Hall, NY, p. 432.

Parkin, R., Balbus, J., Waters, W., Willnat, L., Rivera, I., Rivera-Torres, E. & Caparas, M. 2001 Vulnerable subpopulations' perceptions and use of drinking water. *Paper presented at the Annual Meeting of the American Water Works Association*. Washington, DC.

Piriou, P., Mackey, E., Suffet, I. H. & Bruchet, A. 2004 Chlorinous flavor perception in drinking water. *Water Sci. Technol.* **49**(9), 321–328.

Statistics Canada 2001 Recensement 2001, Gouvernement du Canada.

Suffet, I. H., Corado, A., Chou, D., Butterworth, S. & McGuire, M. J. 1993 *AWWA taste and odor survey*. Proc. AWWA Water Quality Technology Conference, Denver, Colorado.

Turgeon, S., Rodriguez, M. J., Thériault, M. & Levallois, P. 2004 Perception of drinking water in the Quebec City region (Canada): the influence of water quality and consumer location in the distribution system. *J. Environ. Manage.* **70**, 363–373.

Wilde, J. 2000 Identification of multiple equation probit models with endogenous dummy regressors. *Econ. Lett.* **69**, 309–312.

Wooldridge, J. M. 2002 *Econometric Analysis of Cross Section and Panel Data*. MIT Press, p. 752.