Water Resources Management
https://doi.org/10.1007/s11269-020-02653-x

Risk, Drinking Water and Harmful Algal Blooms: A Contingent Valuation of Water Bans

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Received: 30 March 2020 / Accepted: 18 August 2020/Published online: 22 August 2020

Abstract
Facilities using surface water to provide drinking water to communities must contend with the risk of cyanobacteria and cyanotoxin infiltration. Although risk management protocols can be put in place to anticipate the presence of cyanotoxins in concentrations exceeding guidelines, based on cyanobacterial cell count for example, this indicator is not infallible. The Canadian province of Quebec, among other jurisdictions, issues water bans when high concentrations of cyanotoxins are detected. While necessary, these bans are costly to communities. We perform a contingent valuation survey in areas at risk of being impacted by a water ban in the future to assess the preferences of residents and the economic value of detection and treatment tools that could eliminate cyanotoxins. The survey was completed by 240 people. Each respondent was asked a double-bounded dichotomous choice question. The scenario implied changes to the current situation regarding the possibility of predicting the presence of cyanotoxins in the facility, the average duration of water bans, the possibility of providing advance notice, all relative to the cost of these measures. The analysis of the survey responses allowed us to determine the willingness to pay (WTP) of households for diagnostic and treatment tools in drinking water facilities. Our analysis indicates that the mean WTP was \$135 per household per year. Given that the experts developing the tools estimate the cost of implementation at \$110 per household per year, our results suggest that implementation is economically viable.

Keywords Water quality · Public health · Risk assessment · Water bans · Harmful algal blooms · Contingent valuation

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1 Introduction

Cyanobacteria, or blue-green algae, are micro-organisms naturally living in waterbodies. Their presence in low concentrations is usually not problematic, but harmful algal blooms (HAB) can have severe detrimental impacts. Blooms generally occur in areas where waterbodies are excessively enriched by nutrients coming in part from agricultural and urban runoff. In urban areas, impervious surfaces reduce water absorption by the soil and increase runoff, which also puts pressure on combined sewers (Scholz et al. 2017). At the lake level, a number of factors amplify the severity and occurrence of blooms, namely temperatures above 23 degrees Celsius, extreme rainfall events that contribute to erosion, the presence of pollutants, and invasive species (Saxton et al. 2011, Steffen et al. 2014, Scholz et al. 2017). Furthermore, climate change contributes to enhancing the suitability of lakes to cyanobacterial growth (Paerl and Huisman 2008; Scholz et al. 2017).

Algal blooms can become harmful when cyanobacteria release toxins. According to the WHO, the most likely route of exposure to cyanotoxins is via drinking water (World Health Organization (WHO) 2003). The most common cyanotoxins are Microcystins, which are produced by more than one cyanobacterial species. To protect human health, maximum exposure levels for the presence of Microcystin-LR are included in the WHO guidelines for drinking water quality (World Health Organization (WHO) 2017). The human health effects of common cyanotoxins typically include skin irritation, sore throat, irritation to the eyes, fever, vomiting, stomach-ache, headache, and diarrhea (MAPAQ, Ministère de l'Agriculture, Pêcheries et Alimentation – Ministry of Agriculture, Fishing and Food 2008).

Surface water, coming from lakes, rivers, streams, and a mix of surface and groundwater, is used in 34% of the province of Quebec's drinking water plants (MELCC, Ministère de l'Environnement et de la Lutte contre les changements climatiques – Ministry Environment and Fight against climate change 2019). These facilities are at risk of having to deal with infiltration of cyanobacteria and cyanotoxins, especially when the water source is a lake. Monitoring of surface water in areas at risk should be undertaken, as the presence of HAB could be indicative of the presence of cyanotoxins. When cyanotoxins are detected in the water coming into the facility, further tests, which can take a few days to perform, must be undertaken in laboratories to determine the concentration of cyanotoxins (Groupe scientifique sur l'eau 2017). As a result, there can be a delay between the time when toxins are present in the water, when they are detected, and when the public is advised to stop using water. To overcome this problem, diagnostic approaches that could be used to test the water onsite are currently under development. If cyanotoxins are found in concentrations exceeding the norms for drinking water (1.5 μg/L, as per the *Regulation respecting the quality of drinking water* [Q-2, r.40] [LégisQuébec 2019]), a water ban must be issued. Such bans can also be issued in a preventative manner, especially for vulnerable populations such as infants, based on results of field tests that indicate whether toxins are present, (Health Canada 2016). It implies that water cannot be used for drinking, cooking, and brushing teeth. The latest information indicates that water can be used for hygiene, washing the dishes and washing clothes, unless it has a greenish color, an unusual color or odor (Government of Quebec 2019). Boiling the water does not eliminate these toxins. Rather, it can increase toxin concentration (Government of Quebec 2019), so bottled water must generally be used, especially since there is usually no prior notice of the ban. As a result, water bans entail substantial costs. For example, the cost of one harmful algal bloom (HAB) in Lake Erie for public facilities in Ohio was estimated at $417,200 (Weicksel and Lupi 2013; Bingham et al. 2015). In Quebec, between 2006 and

2012, 31 preventative drinking water bans have been issued due to the presence of HAB in the water source. Yet, in none of these cases did concentrations exceed the norm for drinking water (Arbour et al. 2014; Groupe scientifique sur l'eau 2017).

With climate change, the phenomenon of HAB is expected to intensify due to rising temperatures, to the timing of lake stratification, and to changes in the hydrological cycle, all of which benefit cyanobacteria (Paerl and Huisman 2008; Scholz et al. 2017). A better prediction and treatment system would therefore allow a faster response to the presence of cyanotoxins in a drinking water facility, which could improve the well-being of affected populations. Our research question is then: How much are communities located in municipalities at risk willing to pay (WTP) for the implementation of diagnostic and treatment tools in drinking water facilities? The originality of this research is that, through the use of a survey, we can explore the elements that influence the WTP of respondents, for an issue that might become exacerbated with climate change. In what follows, Section 2 discusses the methodology used, Section 3 presents the theoretical background for the statistical analysis, Section 4 describes the results, Section 5 discusses those results in contrast with similar studies, and Section 6 concludes.

2 Methodology

In most of the province of Quebec, households do not directly pay for water distributed by municipalities. Although there exist ways of estimating the market value of water, the value obtained would be underestimated from the perspective of users, because it would not include its passive value. Methods used to estimate non-market value are divided into revealed preference and stated preference methods. The former are based on observed behavior, such as transport cost, hedonic pricing and avoidance costs. It is largely recognized that these approaches only reflect minimum WTP (Bateman et al. 2002). Additionally, it can be difficult to differentiate between the motives of households that undertake these costs, because of the issue of imperfect information in the case of avoidance costs and because of multicollinearity among characteristics of the goods, especially when it comes to property value (Pearce et al. 2006). Stated preference approaches mostly use data coming from surveys, and generally use contingent valuation and choice modelling methods. The advantages of these methods include the fact that they accurately yield the total economic value of a good. Also, the use of a questionnaire to obtain a WTP value enables the researchers to gather more information about the respondents and the elements that motivate their choices.

The main objective of this research is to estimate the WTP of households in areas prone to HAB for the introduction of new diagnostic and treatment tools in drinking water facilities. We opted for a contingent valuation approach because the introduction of such tools would change only two aspects of water bans: the duration of the ban and whether there can be advance notice. In particular, there is no added value in using choice modelling techniques. Moreover, the magnitude of the change can be estimated with reasonable accuracy, which limits the appeal of estimating marginal changes.

2.1 Data Collection

The data collection was performed face to face between August and November 2017. Answers were recorded by the interviewers on electronic tablets. A total of 255 questionnaires were compiled, of which 240 were completed. Respondents were met in 24 municipalities of our four regions of study. Given the time required to complete the questionnaire (20 min), we find this response rate (43.47%) to be satisfactory.

Two data collection approaches were followed, as the data collection was performed for two studies from one research project, to limit respondent fatigue. The first approach involved a cluster sampling technique, where each cluster referred to a municipality at risk in Montérégie and Estrie. We supposed that a municipality at risk would have had a HAB at least once in the last 10 years. Occurrences of blooms were recurrent in some of the sampled municipalities but rare in others. The second approach involved a convenience sampling approach where the data collection site should include access to a waterbody (e.g. beach, dock, marina) that had been affected by an algal bloom event in the last 10 years.

2.2 Questionnaire

The questionnaire, developed using the Qualtrics survey software, includes a brief introduction (Section 1), questions about the water consumption habits of respondents (Section 2) and about their knowledge of HAB (Section 3). Section 4 is the double-bounded dichotomous contingent valuation question, and Section 5 concludes with socio-demographic questions. When designing the questionnaire, we paid special attention to the NOAA's recommendations on contingent valuation surveys (Arrow et al. 1993; Portney 1994). To this end, we ensured that the WTP question was framed with regard to a future event, that it was a referendum question, that a clear and precise description of the good was provided, and that there was a reminder of the budget constraint and of the presence of substitute goods. Also, the decision to carry out the survey in person was based on the NOAA's recommendations (Arrow et al. 1993).

To precisely define the future scenarios for the contingent valuation question, two focus groups were undertaken with experts in the fields of hydraulic engineering, environmental engineering, management of water resources, water treatment and water quality and pollution. The scenarios that emerged from these meetings are presented in Table 1. The values associated with the "Increase in the value of the municipal tax" represent the payment levels presented to respondents as part of the double-bounded dichotomous choice (DBDC) question. These amounts were defined after discussions with the experts. During the data collection, the amount proposed to respondents were randomized.

The questionnaire was pre-tested before collecting data. The contingent valuation question was (translated from French):

> "Keeping in mind that there is no right or wrong answer, and that the amount proposed will no longer be available to you for the purchase of other goods or services:
> Would you be willing to pay an additional $x every year on your municipal taxes (or as a rent increase) to finance the installation of new treatment and diagnostic tools in your municipal drinking water facility?"

2.3 Target Population

The target population for this study is all households in Quebec that could be impacted by a water ban caused by a HAB in the future. Currently, there exists no consensus about which areas could be impacted in the future, because of the uncertainties surrounding algal blooms and the release of cyanotoxins. Incidentally, we have decided to consider the regions in the

Table 1 Description of the scenarios (translated from French)

Factors of change	Current situation	Proposed policy
Diagnostic	Toxins can only be detected when they are already present in the water reservoir.	Toxins (and their potential for harm) can be predicted before they are present in the water reservoir.
Likelihood of a ban	Once every 5 years, during the at-risk period.	Once every 5 years, during the at-risk period.
Average duration of a ban	10 days	2 days
Advance notice?	No advance notice. Ban starts immediately.	One-day advance notice. Ban starts the next day.
Increase in the value of the municipal tax[1]	–	\$50; (yes: \$75; no: \$25) \$80; (yes: \$120; no: \$40) \$110; (yes: \$165; no: \$55) \$140; (yes: \$210; no: \$70)

*"\$$A_i$; (yes: \$$B_i$; no: \$$C_i$)" means that the respondent is first presented with amount A. She is then presented with amount B_i upon answering "yes" to A_i, or with amount C_i upon answering "no" to A_i

province of Quebec that have been affected by an algal bloom event in the past as regions at risk of experiencing water bans in the future, i.e. Montérégie, Estrie, Outaouais and Lanaudière (see Fig. 1). Although the occurrence of a HAB is not a perfect predictor of risk in this context, it is our best proxy. Furthermore, the probability that people living in areas where algal blooms have already occurred increase the chances that these individuals are aware of the issue, which increases the potential quality of their response.

3 Theory: Statistical Analysis

The estimation of the WTP was performed using the *probit* model, the bivariate probit model, and the interval data model. The contingent valuation approach estimates the value of non-

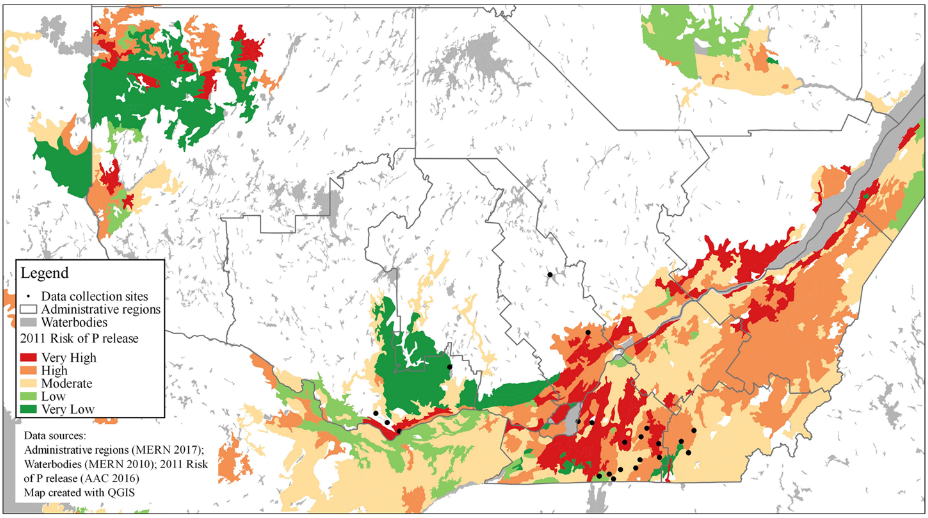

Fig. 1 Map of data collection sites in the south of Quebec, Canada (Data sources: MERN 2010; AAC 2016; MERN 2017)

market goods through WTP and an indirect utility function (Willinger 1996). In this research, we evaluated the following indirect utility function (V_{in}) for a drinking water ban:

$$V_{in} = {}_0 + {}_D*Diagnostic + {}_P*Probability + {}_{Du}*Duration + {}_N*Notice + {}_{in} \quad (1)$$

Where the coefficients β_0, $\beta_{D,}$ β_P, β_{Du}, β_N represent the marginal utility associated to the status quo alternative (rejection of the proposed policy) and the characteristics of the proposed policy (i.e. Diagnostic, Probability/likelihood of occurrence, Duration of the water ban, possibility of advance Notice) (see Table 1). The variable ε_{in} represents the random error and the factors not taken into account in the indirect utility function.

3.1 Probit and Interval Data Models

The contingent valuation question we developed as part of this study is a DBDC. We chose this formulation because more information can be obtained from respondents in this way. To limit the anchoring bias, respondents were not informed that there was a second question, which also allowed us to perform an analysis of a single bounded dichotomous choice (SBDC). We carried out the SBDC analysis using the probit model. A comparison of the probit model with the other analysis allows for an exploration of the potential biases of respondents regarding the second question. With the probit analysis, we estimated the WTP in \$ per household per year (\$/hh/yr) using the following equation:

$$WTP_{1i}(x_{1i}, {}_{1i}) = x_{1i1} + {}_{1i} \quad (2)$$

Here, the x_{1i} represents a vector of observable explanatory variables for an individual i, β_1 is a vector of parameters that we want to estimate, and ε_{1i} is an error term. We work under the assumption that the error term is normally distributed, such that ε_{1i} $N(0, \sigma_1{}^2)$ and that a respondent will answer "Yes" to the dichotomous choice question if $Price_1 \leq WTP_{1i}$.

An interval data model was used to analyze the DBDC. Although similar to a bivariate probit analysis, it assumes that there is only one distribution for the WTP and only one error term ε_i (Lopez-Feldman 2012; Hanemann et al. 1991). As a result, we can estimate the WTP of individual i with the following linear function:

$$WTP^*{}_i(x_i, {}_i) = x_i + {}_i \quad (3)$$

Here, x_i represents a vector of variables representing individual i, β is a vector of parameters to be estimated and ε_i is a normally distributed error term.

Successive analyses of the data with the two models will allow us to determine which generates the most precise value of WTP. According to Alberini (1995), the interval data model is generally the best model, although it is preferable to test the probit models for comparison.

4 Results

4.1 Data Validation

The statistical representativeness of our results regarding the province of Quebec's population is presented in Table 2. Overall, the sample is fairly representative of the population, despite some disparities. These disparities include an underrepresentation of the 18-to-24 age group, an over-representation of the 55-years-old-and-over age group, and an overall education level that is higher in the sample relative to the population.

We also validated the data with regard to economic theory. A succinct analysis shows that, in accordance with economic theory, there is a negative elasticity of demand for the price of the good (Pearce et al. 2006). For Question 1, the percentage of positive answers to the proposed prices were 85% ($50), 71% ($80), 70% ($110) and 60% ($140). When a positive answer was provided to Question 1, the percentage of positive answer to the second price was 80% ($75), 58% ($120), 55% ($165) and 43% ($210). Finally, when a negative answer had been provided to Question 1, the positive answers to Question 2 were 25% ($25), 25% ($40), 50% ($55) and 36% ($70). This result, along with the representativeness of the sample, allows us to proceed with some measure of confidence.

4.2 Estimation of WTP without Control Variables

This first step in the estimation of the WTP is to obtain values of WTP without considering explanatory factors, to obtain confidence intervals for these WTP values and to observe the

Table 2 Socio-demographic data for the sample and the Quebec population

Socio-demographic data	All answers (n = 240)	Census data [a]—Quebec population
Gender		
Female (%)	53.75	50.3
Male (%)	46.25	49.7
Age [b]		
18 to 24 years old (y.o.) (%)	2.08	10.90
25 to 39 y.o. (%)	20.83	23.13
40 to 54 y.o. (%)	19.58	29.52
55 to 64 y.o. (%)	31.67	17.62
65 y.o. and over (%)	25.83	18.80
Education		
Elementary and below (%)	3.75	20.74
High school (%)	31.25	40.81
College (%)	27.50	17.61
University (%)	37.50	20.89
Gross household income (n = 206)		
Less than $24,999 (%)	14.08	13.97
$25,000—$49,999 (%)	21.84	23.24
$50,000—$69,999 (%)	16.99	16.65
$70,000—$99,999 (%)	21.36	18.93
$100,000 and more (%)	25.72	27.20
Household size		
1 person (%)	21.25	29.72
2 people (%)	52.08	36.03
3 people (%)	11.25	14.64
4 people (%)	10	13.12
5 people and more (%)	5.42	6.49
Property owners (%)	77.5	69.57

[a] Statistics Canada, 2017 (for all variables, expect Age)

[b] Statistics Canada, 2012

correlation between the distributions of WTP for the different amounts proposed to respondents.

4.2.1 Simple Probit

Model 1 is a simple probit, used to estimate the WTP for the SBDC based solely on the first question. The first column (without control variables) of Table 3 presents the results of the analysis for the probit model. The mean WTP value was obtained using the *nlcom* command in Stata.

Table 3 displays a negative and significant value for β_1 (p value <1%). This suggests that, as the amount proposed to a respondent increases, the probability of getting a positive response to the contingent valuation question decreases.

4.2.2 Interval Data Model

The results for the analysis without control variables, using the interval data model, are presented in column 1 (without control variables) of Table 3. The *doubleb* command, in Stata, was used to obtain the parameters β and σ (Lopez-Feldman 2012), such that the mean WTP is $x_i'\widehat{\beta}$.

The estimated WTP value using the interval data model is \$134.96/hh/yr (SE = \$7.07; p value <1%), a value smaller than the one obtained for Model 1. This result is consistent with the literature, where we typically observe lower mean WTPs for DBDC than for SBDC choices (Alberini 1995; Carson et al. 2001; Carson and Groves 2007). Regarding Model 1, since the interval data model takes all the information from our sample and uses it as a single distribution, there is an efficiency gain, as Model 1 only uses information from the first question. This efficiency gain, and the fact that the second answer to a DBDC usually shifts the WTP to the left (Alberini 1995, Carson et al. 2001, Carson and Groves 2007), is translated into a reduction in the value of the estimated mean WTP. In addition, the interval data model shows greater precision, with a standard error of only \$7.07/hh/yr, which further highlights the efficiency gain of using all of the information from the questionnaire.

Table 3 Willingness to pay (\$/hh/yr)—Summary of main results

Model	Parameters	Without control variables	With control variables
Simple *Probit*	Mean WTP (\$/hh/yr)	\$171.57 *** [\$145.55; \$197.64]	\$162.81 *** [\$144.21; \$181.41]
	β1 (1st question)	−0.008 *** (0.003)	
	constant_1 (1st question)	1.329 *** (0.281)	
	Log-likelihood	−140.403	
Interval data model	Mean WTP (\$/hh/yr)	\$134.96 *** [\$121.11; \$148.80]	\$135.45 *** [\$129.36; \$141.55]
	$\widehat{\sigma}$	\$93.72 *** (\$7.63)	
	Log-likelihood	−305.145	
	N	240	

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$; 95% confidence intervals are in brackets; Values in parentheses represent the standard errors relative to the 95% confidence intervals

4.3 Estimation of WTP with Control Variables

We only perform the analysis with control variables on the interval data model, because it is the most precise model and because it enhances efficiency by relying on all the available information from the questionnaire. This last reason is especially important for smaller samples.

From a total of 44 possible control variables, we selected a subset of 33 by removing variables that exhibited a small explanatory power, by removing correlated data and by performing Wald tests. Table 4 presents the results of the analysis with the selected control variables. The table shows that only eight of these variables (β_i) have significant explanatory power ($p < 0.05$). These variables are: the presence of an artesian well (*well*), confidence in the municipal government (*conf_mun*), compliance in case of a water advisory (*compliance*), willingness to have more information on health risks of not complying to water advisory (*health*), being environmentally conscious (*env*), household income (*income*), age, and education level (*educ*).

The results of this model suggest that respondents who own a well have a lower WTP than those whose water supply comes from the municipality (−46.15). Respondents who trust the information coming from the municipality (+54.88), those who plan to follow the instructions in case of a water ban (+47.35), and those who want more information about the health risks in case of a water ban (+89.99) all have a higher WTP relative to their base groups. When it comes to trust towards the municipality, the result does not come as a surprise because the payment mechanism is a municipal tax administered by the municipality. Individuals who put the environment in their top 3 priorities (+31.07) and those who have a higher income ($50,000 to $69,999; $100,000 and more) (+54.01; +74.07) also displayed a higher WTP. These observations are also consistent with our expectations, as people with higher income tend to have more disposable income, and people who have environmental preoccupations are also more willing to pay to solve environmental issues. Age also seems to affect WTP, especially for the 18-to-24-years-old age group; however, given the size of this group (n = 5), it may be premature to make generalizations. With regard to the education level, WTP is lower, when compared with the base group (high school), for respondents with a Master or equivalent (univ. 2nd cycle) (−58.34) and for respondents with a collegial degree (−31.91). This can be caused by the evaluation of the risk posed by cyanotoxins and by the proposed solution made by these groups as a function of their education. Finally, the sampling approach (E1), whether the data was collected at respondents' doorstep or in recreational areas, had no significant effect on the WTP.

4.4 Willingness to Pay

Table 3 displays the final estimation for WTP for both the simple probit and the interval data model, with and without control variables. We include the WTP value for the simple probit model mainly for comparison purposes, to showcase the difference when considering only the SBDC. The mean WTP with control variables were obtained using the *nlcom* command in Stata. We applied the command to [constant + $\overline{x}_i'\beta$] for the interval data model, and to [−constant$_t$ + $\overline{x}_i'\widehat{\beta}$ / $\widehat{\beta}$_bid] for the probit.

The results from Table 3 indicate that including control variables to obtain the mean WTP has little influence on this value, especially for the interval data model. However, including these variables does tighten the confidence interval.

Table 4 Interval data model with control variables

Variables	Marginal effect	p value
Parameters of vector beta (βi)		
Cyanobacteria		
knowledge	−64.89	0.120
information	10.05	0.457
concern	7.44	0.644
Water advisory		
well	−46.15 ***	0.002
non-consumption	−21.32	0.149
conf_mun	54.88 **	0.036
conf_env_ministry	26.69	0.122
compliancet	47.35 **	0.023
health	89.99 **	0.018
Socio-demographic characteristics		
language_french	−24.96	0.294
household_size	28.72 *	0.080
children	−9.54	0.585
transportation	−32.63	0.329
env	31.07 **	0.023
effort_water ban	−13.51	0.639
property_near_lake	−20.39	0.124
income = $25,000 to $49,000	12.56	0.573
income = $50,000$ to $69,000	54.01 **	0.025
income = $70,000 to $99,000	35.73	0.132
income = $100,000 and more	74.07 ***	0.004
income = no answer	42.01 *	0.081
age = 18 to 24 y.o.	180.50 ***	0.006
age = 40 to 54 y.o.	−12.77	0.523
age = 55 to 64 y.o.	5.73	0.767
age = 65 y.o. and more	−9.43	0.637
educ = elementary	−43.42	0.189
educ = college	−31.91*	0.052
educ = univ 1st cycle	−22.49	0.189
educ = univ 2nd cycle	−58.34**	0.010
educ = univ 3rd cycle	−20.78	0.677
Other		
E1	13.95	0.293
constant	−4.85	0.946
Parameter sigma		
constant	75.38***	0.000
Model		
Log likelihood	−262.08	
Wald $\chi^2(26)$	69.07	
Prob χ^2	0.0001	

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

5 Discussion

The results suggest that the interval data model with control variables is the best estimation of the average annual WTP per household, with an estimated value of $135.45/hh/yr. Using this value, the development and implementation of tools for the detection and treatment of cyanotoxins is economically viable based on the expected costs of $110/hh/yr provided by experts. The project remains economically viable for all the estimated WTP values presented in Table 3, even when considering the lower bound of the confidence intervals.

Drawing on the literature on WTP for safe drinking water, we see that the value obtained as part of our study is lower than the one in Van Houtven et al. (2017). Based on the results of a meta-analysis from 60 studies, they computed an estimated WTP value that ranges from \$1147/hh/yr to \$1922/hh/yr[1] for North America. Their value is most likely affected by the gap in access to drinking water over the world, the mean income per household, and the method used to obtain WTP in the primary studies (Van Houtven et al. 2017). Indeed, the studies used in the meta-analysis come mostly from contingent analysis in countries of Central America, South America, Africa, Middle East and Asia. Because access to safe drinking water is lacking in many countries of these regions, the situation is markedly different from that of most Quebec municipalities. In comparison, a study by Latinopoulos (2014),[2] in Greece, estimated the WTP relative to the non-occurrence of water supply interruptions at \$21/hh/yr, and the WTP relative to water quality at \$165/hh/yr. The gap between our results and those of Latinopoulos (2014) may be caused by the relationship between water quality (health risks) and the likelihood of water bans.

In recent years, some studies have focused on the measurement of WTP for water quality in southern Quebec using stated preference techniques. For instance, the WTP for the water treatment service provided by wetlands ranged from \$206 to \$254/hh/yr (He et al. 2017[3]), the WTP for implementing agri-environmental practices that would improve water quality ranged from \$438 to \$458/hh/yr (Dupras et al. 2017[4]), the WTP for the restoration and conservation of the Montreal Blue Network was estimated at \$32/hh (Poder et al. 2016[5]), and the WTP for four water quality related services (i.e. visual aspects, recreational activities, odors, ecosystem health) yielded a value of \$353/hh/yr (L'Ecuyer-Sauvageau et al. 2019).

Although our results are not perfectly comparable to those provided here, they are still within the range of values. Differences between these studies can be explained by several factors, including the type of ecosystem services evaluated (e.g. individual or bundle service), the contexts in which the surveys were conducted (e.g. wetlands restoration, agro-environmental practices, conservation scenarios), and the methods used (e.g. choice modelling vs. contingent valuation, in person vs. online surveys).

As shown in Table 4, many factors influence the WTP of individuals. Some of these factors, including the compliance to water bans and the importance of having information on health consequences of these water bans can indicate the sensitivity of respondents to risk. Individuals who are more sensitive to risk tend to have a higher WTP. More precisely, respondents who planned on complying to a water ban had a higher WTP than those who did not plan to abide by it (in whole or in part) (+\$47.35 $p < 0.05$), and individuals who wanted more information about health-related risks also had a higher WTP than those who were not interested in having this information (+\$89.99 $p < 0.05$). By contrast, people who had already experienced a water ban showed a lower WTP (−\$21.32 $p = 0.149$) than those who had not. This higher propensity to pay as a function of anticipated risk is consistent with the results of Hunter et al. (2012). This study showed that concern for environmental issues and risk perception relative to HAB have an impact on the willingness to participate in a risk-

[1] The values were transformed from USD (2008) to CAD (2017) using PPP (Canada: 1.234) and CPI: 1 dollar in 2008 = 1.138 dollar in 2017. Reference date: 2002 CPI = 100.0. Sources OECD 2020; Bank of Canada.
[2] The values were transformed from EUR (2012) to CAD (2017) using PPP (Euro: 0.774; Canada: 1.245) and CPI: 1 dollar in 2012 = 1.068 dollar in 2017
[3] The values were transformed from CAD (2013) to CAD (2017) using CPI: 1 dollar in 2013 = 1.061 in 2017.
[4] The values were transformed from CAD (2008) to CAD (2017) using CPI: 1 dollar in 2008 = 1.138 in 2017.
[5] The values were transformed from CAD (2014) to CAD (2017) using CPI: 1 dollar in 2014 = 1.037 in 2017.

reduction program and to influence WTP (Hunter et al. 2012). Our results also indicate that environmental concerns have an influence on WTP. These relationships should however be treated with caution, since they are self-reported.

In addition to the quantitative information analyzed above, the questionnaire was rich in qualitative information that can be used to contextualize the results and get a better understanding of the elements respondents took into consideration when making their decision. The justification for the decisions varied significantly between people who accepted both amounts and people who accepted only one amount. Aside from the amounts per se, respondents who accepted both amounts explained their decision by referring to the importance of water quality (39.6%), the importance of health in general (32.7%) and the health of their children/grandchildren (6.93%). In some cases, respondents further added that their acceptance of the amounts was conditional on transparent accountability and adopting measures to deal with pollution at the source (5.94%). Those who accepted only one of the amounts generally mentioned their budget constraint to reject the larger amount (74.5% of justifications), mentioned that taxes were already high enough (13.8%); some individuals mentioned that they had little trust in governments (7.4%). Among other reasons given was the fact that they did not feel concerned about the problem (10.6%), or that the issue would be better resolved by dealing with nutrient inputs at the source (8.5%). This latter comment was mentioned, overall, by 7.5% of respondents, included those who rejected both amounts, and it resonates with the concerns and suggestions of many researchers interested in sustainable water management and the control of algal blooms (Hamilton et al. 2016). Finally, in the comments left by respondents, the issue of communication was frequently raised about accountability and the transmission of information to residents. This latter observation is consistent with a recommendation of the *National Science and Technology Council Subcommittee on Ocean Science and Technology* (Hardy et al. 2016, National Academies of Sciences, Engineering and Medicine (NASEM) 2016) and it should be taken into consideration when implementing prediction and treatment tools in drinking water facilities.

Although our sample is representative of the target population and the data validation was successful with regard to the theory, the small size of our sample is a limitation of the study. Despite having taken every precaution to obtain high-quality data, it is risky to extrapolate the answers of 240 people to the entire population of Quebec. The sample size can also limit our ability to identify factors that influence the mean WTP of individuals.

A second limitation has to do with the uncertainty of the prediction and treatment tools that could be implemented in municipalities. This has an influence on the study's reach, as the information used to estimate the feasibility of the tools' implementation are based on projected estimates from experts developing these tools. As a result, if the costs or any other variable from Table 1 were to change, it would influence the applicability of our results.

6 Conclusion

In accordance with the objective of this study, we were able to determine the mean annual WTP of households located in areas susceptible of being impacted by a water ban due to the presence of cyanotoxins, and to collect information about the preferences of these individuals. Our most robust mean WTP, obtained using the interval data model, suggest that respondents are willing to pay \$135.45/hh/yr for detection and treatment tools for cyanotoxins in drinking water facilities.

Water consumption habits, and the relationship people have with HAB have little impact on the mean WTP of households. However, trust towards provincial and municipal governments, the intention of complying to water bans, and interest in having more information on the health risks of cyanotoxins in case of water bans have significant marginal effects on the estimated mean WTP. Finally, household income, ownership of a well, and the importance of environmental values also have an impact on the estimated mean WTP.

The information generated as part of this research allows for new information to emerge, especially about the factors that contribute to the variations in the mean WTP for residents in at-risk municipalities. Future projects could draw on our results and make changes to the policy characteristics of water bans in terms of the duration, the possibility of having an advance notice, and the likelihood of the bans occurring. Future research would benefit from the advancement of knowledge on cyanobacteria, on toxin production, on amplifying factors of HAB, and on technical expertise of tools to predict, diagnose and treat cyanotoxins.

Acknowledgements We are grateful to Sébastien Sauvé, Dana Simon, Caroline Simard, Benoit Barbeau, Sarah Dorner and Arash Zamyadi for their very useful comments on the study design.

Funding Information We acknowledge the financial support from Genome Canada and Genome Québec under the *Algal Blooms, Treatment, Risk Assessment, Prediction and Prevention through Genomics* (ATRAPP) project [10512], from the Social Sciences and Humanities Research Council of Canada [project 435–2017-1078], and from the Social Sciences and Humanities Research Council of Canada for a Joseph Armand Bombardier Canada Graduate Scholarships—Master's Program.

Compliance with Ethical Standards

Conflicts of Interest/Competing Interests The authors declare that they have no conflict of interest.

Code Availability Not applicable.

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