Estimation of the consumption of cold tap water for microbiological risk assessment: an overview of studies and statistical analysis of data

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ABSTRACT

The volume of cold tap water consumed is an essential element in quantitative microbial risk assessment. This paper presents a review of tap water consumption studies. Study designs were evaluated and statistical distributions were fitted to water consumption data from The Netherlands, Great Britain, Germany and Australia. We conclude that the diary is to be preferred for collecting water consumption data. If a diary is not feasible, a 24 h recall would be the best alternative, preferably repeated at least once. From the studies evaluated, the mean daily consumption varies from 0.10 L to 1.55 L. No conclusions could be drawn regarding the effects of season, age and gender on tap water consumption. Physical activity, yearly income and perceived health status were reported to influence water consumption.

Comparison of the different statistical probability distribution functions of the datasets demonstrated that the Poisson distribution performed better than the lognormal distribution as suggested by Roseberry and Burmaster.

For quantitative microbiological risk assessment (QMRA) it is recommended to use country-specific consumption data and statistical distributions, if available. If no country specific data are available we recommend to use the Australian distribution data from the Melbourne diary study (Poisson, $\lambda = 3.49$ glasses/d) as a conservative estimate.

Key words | drinking water consumption, microbiological risk assessment, statistical distribution functions

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INTRODUCTION

In the new *WHO Guidelines for Drinking-water Quality* (WHO 2004) the Water Safety Plan is the central approach to safeguarding the health of the drinking water consumer. Within a Water Safety Plan, Quantitative Microbial Risk Assessment (QMRA) can be used to assess the microbial safety of drinking water. QMRA has been suggested by various authors as the scientific basis for assessing risks of pathogen exposure (Regli *et al.* 1991; Teunis *et al.* 1997; Haas *et al.* 1999; Havelaar *et al.* 2000; Medema *et al.* 2003). When assessing the exposure to pathogens through drinking water, both the concentration of pathogens in drinking water and the volume of drinking water consumed are important parameters. In the first QMRA's that were conducted on drinking water, a water consumption of 2 L per person per day has been assumed (Regli *et al.* 1991). Subsequent QMRA studies used the data of Roseberry & Burmaster (1992) who fitted a statistical

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distribution to their consumption data. Statistical distributions are preferable for QMRA, because the variability in the consumption within the consumer population is included in the overall risk assessment. The median value Roseberry and Burmaster reported was 0.96 L/d. This value, however, represents consumption of tap water in total, while for microbial risk assessment only the volume of cold tap water without heat treatment (coffee, tea, cooking) is relevant. Teunis *et al.* (1997) obtained data on cold tap water consumption in the Netherlands for use in QMRA. The median consumption they report is 0.15 L/d, which is much lower than the total tap water consumption reported by Roseberry & Burmaster (1992). Several other authors have assessed the consumption of cold and/or total tap water consumption.

The objective of this study was to review the different studies on tap water consumption. The design of the consumption studies was evaluated, including factors that might influence consumption.

From four countries raw consumption data were obtained, collected with different study designs. Statistical models were fitted to these data to determine the variability in drinking water consumption and the implications of the study design on the outcomes and their statistical distribution. Recommendations are given for future studies on consumption of tap water and for consumption estimates within QMRA.

METHODS FOR COLLECTING CONSUMPTION DATA

Drinking water consumption studies have been carried out for several purposes: to determine possible relationships between drinking water quality and human health, to determine the fraction that drinking water comprises of the individual's total liquid consumption or just to calculate the amount of water ingested in relation to other uses of drinking water in households, like bathing, dishwashing etc.

Methods to collect consumption data on the individual level can roughly be divided into two categories: short-term and long-term instruments. Short-term dietary assessment methods collect dietary information on current intake. They vary from recalling the intake from the previous day (24 h recall) to keeping a record of the intake of food and drinks over one or more days (dietary record). Long-term dietary assessment methods collect information on the usual food intake over the previous months or years (dietary history or food frequency questionnaire) (Biró *et al.* 2002). The drinking water consumption studies reported used similar methods for data collection. In the following tables an overview will be given of the available literature on drinking water consumption and the study designs applied.

ASSESSING THE VOLUME OF WATER CONSUMED

To assess the volume of water consumed most studies use the number of cups or glasses as a measure (DWI 1996; Robertson *et al.* 2000*a*, 2002; Gofti-Laroche *et al.* 2001; Dangendorf 2003; Hunter 2003 personal communication; Sinclair 2003 personal communication; Westrell *et al.* 2004). This is a very easy way of estimating the water consumption and it is close to the everyday habits of the consumer. The disadvantage is that possible bias can be introduced because glasses and cups of different sizes may be used. In addition it might miss non-glass consumption of drinking water like icecubes, tooth brushing, taking medicines, etc. To enlarge the reliability of the volume estimates several studies had the volume of the drinking vessels measured by either the participant or the interviewer (Hopkin & Ellis 1980; DWI 1996; USEPA 2000). Meyer *et al.* (1999) and Beaudeau *et al.* (2003) used pictures of a cup or glass to make the estimations more accurate.

The most accurate way of estimating consumption is by determining the amount of water consumed in millilitres, or by weighing, but this is also the most elaborate way. A good alternative in prospective research designs is to give people a standard measuring cup. Alternatives for retrospective research are pictures of drinking vessels, assessment of the volumes of vessels, or the type of cups and glasses used by the consumer.

CONSUMPTION OF DRINKING WATER

The water consumption data from the evaluated surveys are presented in Table 1 and Figure 1. From Table 1 it can be seen that the average consumer reported consumption of cold tap water ranging from 0.2–1.55 L per day. Consumed amount of total water for this group ranges from 0.71–2.58 L per day. Figure 1 shows that consumption was relatively high in

Table 1 | Summary of drinking water consumption data. If difference was made between consumers and non-consumers data are presented for the total population including non-consumers. Consumption in L. The lines in bold refer to the studies that have been analysed statistically in this article

				Mean consumption					
Population	**Country**	**Study type**	***N***	**Cold tap water**	**Heated tap water**	**Total tap water**	**Bottled water**	**Total water**	**Reference**
Average consumer	USA	24 h r	15 303	0.508		0.927	0.161 0.737^{*}	1.232 1.241^{*}	USEPA (2000)
Average consumer	USA	Q/D	26 081			1.108		1.785	Roseberry & Burmaster (1992)
Average consumer	USA	Q	1183			1.91			Williams *et al.* (2001)
Average consumer	C	D	970			1.34			EHD (1981)
Average consumer	NL	FFQ	3200			1.5			Foekema & Engelsma (2001)
Average consumer	NL	Q	4620	0.25 0.38^{*}				1.14	Haring *et al.* (1979)
Average consumer	NL	Q	–	0.153					Teunis *et al.* (1997)
Average consumer	**NL**	**D**	**6250**	**0.178**					**Anon. (1998), Hulshof personal communication (2003)**
Average consumer	**D**	**FFQ**	**195**	**0.5**	**1.08**			**1.58**	**Dangendorf (2003), Dangendorf personal communication (2004)**
Average consumer	F	D	373 (w) 427 (s)	0.77^{**} 0.90^{**}	0.54^{*} (w) 0.61^{*} (s)	1.55^{*}(w) 1.78^{*}(s)	0.85^{*}(w) 1.07^{*}(s)	1.83^{*}(w) 2.19^{*}(s)	Gofti-Laroche *et al.* (2001)
Average consumer	S	Q	157	0.86	0.94	1.80	0.06	1.86	Westrell *et al.* (2004)
Average consumer in two cities	S	Q/D	35 40	1.14 1.55	0.81 1.05	1.95 2.58			Berg & Viberg (2003)
Average consumer	UK	D	3564	0.103 0.203^{*}	0.785 1.065^{*}	0.955 0.958^{*}			Hopkin & Ellis (1980)

Table 1 | *(continued)*

				Mean consumption					
Population	**Country**	**Study type**	***N***	**Cold tap water**	**Heated tap water**	**Total tap water**	**Bottled water**	**Total water**	**Reference**
Average consumer	UK	D	1018			1.138			DWI (1996)
Average consumer	**UK**	**Q**	**416** **421**	**0.704** **1.187**					**Hunter *et al.* 2004**
Average consumer	**Aus**	**Q** **D** **Q**	**253** **234** **231**	**0.991** **0.892** **0.964**					**Robertson *et al.* (2000*a*, *b*), Sinclair (unpublished data)**
Average consumer	**Aus**	**Q (Melb)**	**950**	**0.842**					**Robertson *et al.* (2000*a*, *b*), Sinclair (unpublished data)**
Average consumer	**Aus**	**Q (Adel)**	**644**	**0.718**					**Robertson *et al.* (2000*a*, *b*), Sinclair (unpublished data)**
Average adult cons.	Aus	D	10	1.325	0.45			2.7	Froese *et al.* (2002)
Average adult cons. age 20–64	C	Q/D	125	0.386^{***}		1.617	0.27		Levallois *et al.* (1998)
Average adult cons. age >18	C	D	639			1.49			EHD (1981)
Average adult cons. in 2 cities	F	FFQ	100 100			0.783 1.105		1.8 1.8	Meyer *et al.* (1999)
Average adult cons. age 15–65	F	D	1809	0.27 0.4^{*}	0.23 0.21^{*}		0.27 0.19^{*}	1.0 1.0^{*}	Beaudeau *et al.* (2003)
Average male adult consumer	USA	Q/D	33	0.47	0.31	0.78		1.68	Shimokura *et al.* (1998)
Babies <1 year	USA	24 h r	359	0.058			0.111	0.484 0.563^{*}	USEPA (2000)
Breast fed/formula fed babies <1 yr	D	D	300 BF 758 FF			15 g/kg BF 49 g/kg FF		17g/kg BF 53g/kg FF	Hilbig *et al.* (2002)

Table 1 | *(continued)*

				Mean consumption					
Population	**Country**	**Study type**	***N***	**Cold tap water**	**Heated tap water**	**Total tap water**	**Bottled water**	**Total water**	**Reference**
Mixed fed young children (1–3 yr)	D	D	904			15 g/kg		19 g/kg	Hilbig *et al.* (2002)
Children 9–21 months	S	D	430	0.62					Petterson & Rasmussen (1999)
Children age 1–10	USA	24 h r	3980	0.263			0.071	0.528 0.532*	USEPA (2000)
Children age < 3	C	D	34	0.47	0.14	0.57 (s) 0.66 (w)			EHD (1981)
Children age 2–3	D	D	858	0.045	0.077		0.130	1.114	Sichert-Hellert *et al.* (2001)
Children age 3–5	C	D	47	0.77	0.09	0.86 (s) 0.88 (w)			EHD (1981)
Children 4–8	D	D	1795	0.036	0.069		0.179	1.363	Sichert-Hellert *et al.* (2001)
Children age 9–13	D	D	541 (b) 542 (g)	0.062 (b) 0.056 (g)	0.087 (b) 0.087 (g)		0.282(b) 0.242(g)	1.891 (b) 1.676 (g)	Sichert-Hellert *et al.* (2001)
Children age 6–17	C	D	250	0.95	0.19	1.14 (s) 1.13 (w)			EHD (1981)
Children age 11–19	USA	24 h r	1641	0.477			0.118	0.907	USEPA (2000)
Pregnant women	USA	24 h r	188	0.695	0.329		0.89	2.076	Ershow *et al.* (1991)
Pregnant women	USA	Q/D	34	0.56	0.23	0.78		1.86	Shimokura *et al.* (1998)
Pregnant women	USA	24 h r	70	0.819 0.872*			0.355	1.318	USEPA (2000)
Pregnant women	USA	FFQ	71	3.2	0.2	3.4			Zender *et al.* (2001)

Table 1 | (*continued*)

				Mean consumption					
Population	**Country**	**Study type**	***N***	**Cold tap water**	**Heated tap water**	**Total tap water**	**Bottled water**	**Total water**	**Reference**
Pregnant women	UK	Q/D	143	0.814	0.57	1.39	0.94	2.33	Kaur *et al.* (2004)
Pregnant women	I	Q/D	210	0.6				2.6	Barbone *et al.* (2002)
Pregnant women	NL	D	52					0.219	Löwik *et al.* (1994)
Pregnant women	NL	D	50	0.153					Kistemaker *et al.* (1998)
Lactating women	USA	24 h r	77	0.677	0.458		0.178	2.242	Ershow *et al.* (1991)
Lactating women	USA	24 h r	41	1.38 1.665*				1.806	USEPA (2000)
Women repr. age	USA	24 h r	6201	0.583	0.439		0.78	1.940	Ershow *et al.* (1991)
Women repr. age	USA	24 h r	2332	0.922 0.984*			0.212	1.258	USEPA (2000)
Women repr. age	USA	FFQ	43	2.7	0.3	3.0			Zender *et al.* (2001)
Workers industry	Hun	O****	97 67 (w) 30 (z)				2.4 1.8 (w) 3.7 (z)		Toth *et al.* (1977)

Data in bold are analysed in this article.

* = data for consumers, non-consumers not included.

** = cold tap water consumed at home directly from the tap (cold tap water added to e.g. lemonade and cold tap water consumed outside the house are not included in this figure).

*** = cold tap water consumed at home and away (cold tap water added to e.g. lemonade and filtered water not included).

**** = drinking water was measured during work by the investigator. Drinking water was *ad libitum*.

w = winter, s = spring, z = summer.

b = boys, g = girls.

BF = breast fed, FF = formula fed.

Q = Questionnaire, D = Diary, FFQ = food frequency questionnaire, 24 h r = 24 h recall. O = other.

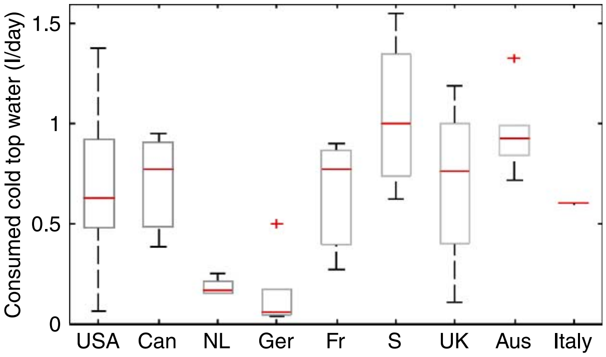

Figure 1 | Summary results (box–whisker plot, showing average (central line), 25–75% (box) and minimum and maximum (error bars) consumption) of cold tap water per country.

Sweden and Australia and low in Germany and the Netherlands. Consumption data from the USA, Canada, France, Italy and the UK were quite similar.

Factors influencing water consumption

Several factors might influence the amount of water consumed, like temperature (seasonal and/or regional effects), aesthetic quality of drinking water, cultural differences but also age, gender, physical activity and diet.

From the available studies not many conclusions could be drawn regarding the influence of these factors on tap water consumption. Some found an influence of season, age or gender on water consumption (Haring *et al.* 1979; Hopkin & Ellis 1980; EHD 1981; DWI 1996; Shimokura *et al.* 1998; USEPA 2000; Gofti-Laroche *et al.* 2001; Beaudeau *et al.* 2003; Westrell *et al.* 2004) but conclusions were contradictory.

Relatively high consumption data were obtained by Tóth *et al.* (1977) for workers in the steel industry, doing heavy physical work. They consumed 1.8 L a day in winter up to 3.7 L in summer. The maximum amount of drinking water consumed was 8.5 L. EHD (1981) found that people not at all active during their work or in their spare time consumed about 1.30–1.35 L/d, whereas people that were extremely active during work or in spare time consumed 1.72L and 1.57 L, respectively.

Other routes of tap water intake

Routes for intake of cold tap water other than direct consumption include ice cubes, food preparation, intake of medicines with water and tooth brushing. Not many studies report data on these routes. Reported water intake via food was 0.02–0.1 L/d (Levallois *et al.* 1998; Ershow & Cantor 1989 cited by Levallois *et al.* 1998; Gofti-Laroche *et al.* 2001). Beaudeau *et al.* (2003) estimated that the recorded water consumption might be 23–25% lower than in reality, because of the possible contribution of food to the water intake.

STATISTICAL ANALYSIS OF WATER CONSUMPTION

From the Netherlands, Great Britain, Germany and Australia we obtained datasets on the consumption of cold unboiled tap water. In the following subsections the specific data characteristics and the fitting of the statistical distributions are described and discussed. To characterize the gathered data a set of characterisation measurements have been determined. For this purpose the mean, median and spacing breadth have been calculated.

To determine the statistical distribution of the data we have applied the Poisson, Exponential, Gamma and Lognormal distribution to the datasets. To compare the data and determine the goodness of fit the mean error, Root Mean Square Error (RMSE) and the Fraction Declaring Variance (FDV) were determined for each dataset. For satisfactory fit the mean error should approach zero, the RMSE should be low and the FDV should be close to 100%.

The Netherlands

In the Dutch National Food Consumption Survey 1997/1998 data on cold tap water consumption were also collected (Anon. 1998). During this two-day diary survey consumption data on cold tap water were obtained for 6250 respondents. Consumption was registered in grams per person. To obtain a time homogenous dataset each participant wrote down the consumption during two separate random days. Trained dieticians visited the households in advance for instruction and afterwards for collection and control of the diaries and to measure the volume of the used drinking vessels.

Statistical analysis

Because of the continuous character of the data, both a continuous and a discrete approach are used to analyse the consumption.

Continuous consumption data

Table 2 and Figure 2 present the characteristics and distribution functions of the continuous tap water consumption data. Consumption of less than 20 g was considered to be zero.

The empirical distribution is given as a non-cumulative histogram with class space 45 mL. The Poisson distribution has not been included as it can only be used for discrete data. The goodness of fit for comparison between the empirical and the modelled data is given in Table 3.

Table 3 | Statistical distribution performance measurements: continuous tap water consumption

Parameter	Exponential	Gamma	Lognormal
Mean Error	**0**	0	0
RMSE	**0.0328**	0.0622	0.0542
FDV (R^2)	**93.13%**	5.25%	6.94%
Estimated parameters	$\alpha = 1.9171$	$\alpha = 0.3012$	$m = -2.4118$
	$\beta = -0.7803$	$\beta = 0.5861$	$s = 1.5313$

Discrete consumption data

For discrete analysis of the data, the continuous data in litres per day were translated into discrete values of glasses per day, assuming a glass to be 250 mL. Due to the large number of participants in the survey (6250), the internal variation in glass capacities can be considered irrelevant in comparison with the external variation between the respondents.

In Table 4 and Figure 3 the characteristics of the discrete tap water consumption data and the probability distribution are presented. Table 5 presents the performance characteristics for the discrete Dutch consumption data.

Table 2 | Statistical data characteristics: The Netherlands (continuous)

Parameter	L/d
Mean	0.177
Median	0.052
Spacing breadth*	0.780
N	6250

*Difference between 5% and 95% confidence limit.

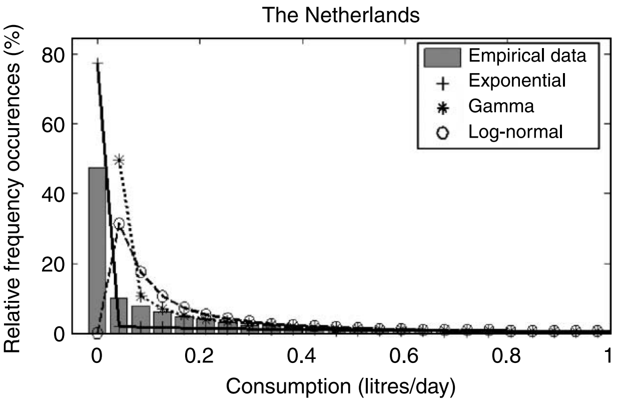

Figure 2 | Empirical probability distribution continuous tap water consumption.

Table 4 | Statistical data characteristics: the Netherlands (discrete)

Parameter	Glass/d
Mean	0.706
Median	0.00
Spacing breadth	3.00
N	6250

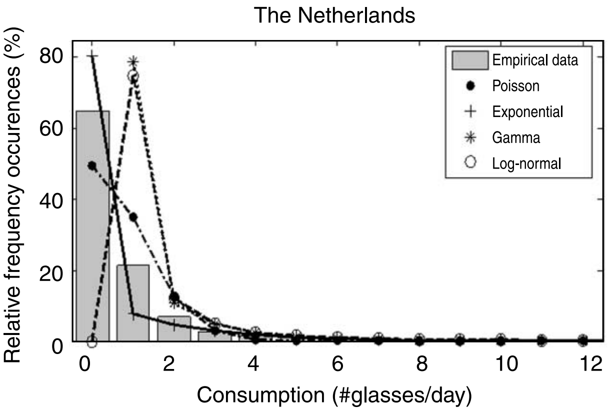

Figure 3 | Statistical probability distributions for discrete tap water consumption.

Table 5 | Statistical distribution performance measurements: discrete tap water consumption

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0**	**0**	**0**	**0**
RMSE	**0.0504**	0.052	0.2044	0.2108
FDV (R^2)	89.46%	**94.66%**	6.13%	5.49%
Estimated parameters	$\lambda = 0.7061$	$\alpha = 0.4828$	$\alpha = 0.3012$	$m = -1.0255$
		$\beta = -3.3657$	$\beta = 2.3444$	$s = 1.5313$

Discussion and conclusions

For the continuous consumption data the Exponential distribution performed best. For the discrete data both the Poisson and Exponential distribution showed an adequate fit. In both cases the Lognormal distribution as suggested by Roseberry & Burmaster (1992) and the Gamma distribution resulted in poor performance characteristics.

In Figures 2 and 3 it can be seen that the observed number of zeroes significantly differs from the shape of the statistical models. More than half of the respondents (approx. 65%) reported no cold tap water consumption at all. We do not have an explanation for this as Dutch drinking water is of high quality and aesthetical problems are not common for most of the Dutch drinking waters.

Analyses of the data excluding the non-consumers (data not shown) resulted in less performance of the statistical probability distributions than for the overall data including non-consumers.

We also investigated whether a seasonal trend could be seen in the consumption data (background analysis not presented here). The percentage of non-consumers was slightly higher in fall and winter, but no seasonal trend could be observed.

In the Netherlands a smaller study more specifically on drinking water consumption was analysed by Teunis *et al.* (1997) who, similar to Roseberry & Burmaster (1992), fitted their data to a Lognormal distribution. The median concentration they reported was 0.153 L/d and the average 0.222 L/d. The data we have evaluated in this study yield a median consumption of 0.052 L/d and an average of 0.177 L/d, so even lower than from Teunis *et al.* Because of the very skewed distribution it is difficult to derive an average consumption figure from the data. For QMRA, we recommend to use the data themselves to describe the variability of consumption or to use the Poisson distribution since this gives higher probabilities for consumption and is therefore more conservative than the Exponential distribution (see Figure 3).

Great Britain

In Great Britain a case–control study on sporadic cryptosporidiosis was conducted by Hunter *et al.* (2004) over a year's period from February 2001 to May 2002. The questionnaire was completed by 427 patients and 427 controls. Since this was a case–control study the study population did not reflect the general population, but contained a high percentage of children (50% of the population was of age < 13 years).

Questions were asked on several possible risk factors for cryptosporidiosis. Considering cold tap water consumption the first question was whether the consumer *in general* consumed cold tap water, or drinks containing cold tap water. If the answer was 'yes', the next question was how many glasses per day, assuming one glass to be 1/3 pint (~190 mL). These questions were repeated considering cold tap water consumption during *the last two weeks*. The latter was especially important for the water consumption by the cases. However, as it is not clear whether water consumption by the cases was influenced by the fact that they had been ill, these data were left out.

Statistical analysis

In Table 6, 7 and 8 the data characteristics and the performance measurements are presented for the two-week-based

Table 6 | Statistical data characteristics: Great Britain

	Consumption (glass/d)	
Parameter	**2 week recall**	**General recall**
Mean	2.815	4.748
Median	2.500	4.00
Spacing breadth	3.00	15
N	416	421

and the general data. The empirical and modelled statistical distributions are presented in Figures 4 and 5. For visual purposes the exponential distribution has been truncated.

Discussion and conclusions

In Figure 5 it can be seen that the data regarding general consumption show no smooth distribution, but two separate data blocks. In the first block (0–6 glasses per day) all outcomes have more or less similar frequencies. A possible explanation for this result might be that below a certain level (in this case six glasses or less) the respondents' feeling about the general daily consumption is rather indiscriminate. For example, the perception that consumption is three glasses per day might be similar to the perception of consuming four or two glasses per day.

The empirical distribution of the two-week-based consumption data follow a smoother line (daily consumption of more than 12 glasses per day were combined into one class).

When visually comparing Figures 4 and 5 the distributions of the general consumption and the two-week consumption look quite different from each other. However, despite the apparent differences, statistical analysis does not substantiate this assumption and rejects significant differences. From the data no difference between the medians can be concluded (nonparametric Wilcoxon rank sum test: $p = 0.1540$ and $\alpha = 5\%$). Also both empirical distributions do not show significant statistical differences (Pearson Chi-square test: $p = 1.00$ and $\alpha = 5\%$).

Table 7 | Statistical distribution performance measurements: discrete 2-week-based tap water consumption

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0.0002**	0	0.0137	0.0021
RMSE	**0.0355**	49.3219	0.0617	0.0664
FDV (R^2)	**83.09%**	0.65%	51.86%	49.81%
Estimated parameters	$\lambda = 2.8149$	$\alpha = 1.8772$	$\alpha = 1.2185$	$m = 0.9767$
		$\beta = 2.5712$	$\beta = 2.3102$	$s = 0.6441$

Table 8 | Statistical distribution performance measurements: discrete general tap water consumption

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	0	0.0002	0.0047	**0**
RMSE	0.0415	0.0347	**0.0327**	0.0359
FDV (R^2)	57.68%	**61.52%**	60.33%	56.75%
Estimated parameters	$\lambda = 4.4782$	$\alpha = 0.2280$	$\alpha = 1.1388$	$m = 1.3888$
		$\beta = -0.0894$	$\beta = 4.1696$	$s = 0.7764$

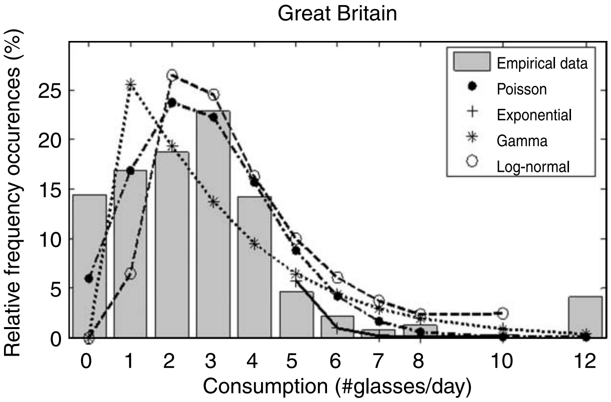

Figure 4 | Statistical probability distributions for discrete 2-week-based tap water consumption.

Similarities between the shapes of the two distributions are, however, not statistically substantiated. The performances of the fitted probability distribution functions are different for the datasets. Considering tap water consumption in general none of the distributions performed very well and none surpassed the others. For the two-week-based consumption data the Poisson distribution performed best and the Exponential distribution performed worst.

We consider the two-week-based consumption data to be preferred above the general consumption data because the best performance was obtained by the Poisson distribution on the two-week-based data set. In addition the empirical distribution of the two-week-based consumption data is smoother. We also believe that the short-term data will be more precise because recall bias will be less for recent consumption than for consumption in general.

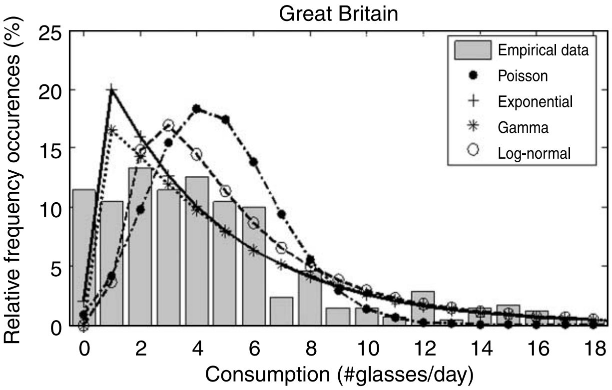

Figure 5 | Statistical probability distributions for discrete general tap water consumption.

Germany

Dangendorf (2003) conducted a telephone survey (food frequency questionnaire type) about the distribution of gastrointestinal diseases in a region in Germany (Rheinisch-Bergischer Kreis). In total 195 persons between 14 and 88 years old were interviewed and questioned about the consumption of cold tap water in general. The period of survey covered the summer months of 2000, as well as the winter months January, February and March of 2001, in order to account for possible seasonal fluctuations of tap water consumption.

Consumption of cold tap water was estimated in cups a day (assuming 150 mL/cup). Consumption of more than 3 cups (ca. 0.5 L) was estimated in multiple units of 0.5 L (i.e. 0.5 L, 1.0 L, 1.5 L, 2.0 L, 2.5 L).

Statistical analysis

In Tables 9 and 10 and Figure 6 the data characteristics, empirical and modelled statistical distributions and the performance measurements are presented.

Discussion and conclusions

Within the original data collection, the results were divided into non-equidistant classes. However, for the fitting of statistical probability distribution functions to discrete consumption in glasses per day, equidistance is recommended. Therefore the original data were transformed into equidistant discrete data (number of glasses per day, assuming one glass to be 250 mL) before the statistical analysis was conducted. From Figure 6 it can be seen that the obtained empirical distribution does not follow a smooth line. One of the causes is the fact that the number of non-consumers is remarkably low compared with the

Table 9 | Statistical data characteristics

Parameter	Glass/d
Mean	2.508
Median	1.00
Spacing breadth	7.00
N	195

Table 10 | Statistical distribution performance measurements: discrete general tap water consumption

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0**	-0.0006	**0**	0.001
RMSE	0.1152	0.1313	**0.0778**	0.1188
FDV (R^2)	35.38%	22.78%	**74.42%**	36.70%
Estimated parameters	$\lambda = 2.5077$	$\alpha = 0.3585$	$\alpha = 1.0676$	$m = 0.5955$
		$\beta = -0.9789$	$\beta = 2.3489$	$s = 0.7530$

number of people drinking one glass per day. This disjunction is also expressed by the fitted statistical probability distribution functions. None of the proposed functions is able to fit both the low value for non-consumption as well as the high value for one glass per day.

This was possibly caused by the design of the interview and the way of questioning. In this study questions on consumption were asked like: "How much plain tap water do you consume?" (And then suggesting:) "2 or 3 cups, less or more?" This way of questioning can suggest the consumer that the answer of consumption of 0 cups is less likely, or maybe even less preferred. In the German data set only one respondent indicated to drink no tap water (0.5%) whereas more than half of the respondents (54%) indicated to drink one glass.

Because of the lack of harmony between the 0 and 1 value of the empirical distribution as well as the non-equidistance of the original gathered data there is not a satisfactory way for statistical analysis. Therefore, it is not possible to draw conclusions about the underlying statistical probability distribution function and about the consumption behaviour of the respondents.

Australia

In a study reported by Robertson *et al.* (2000a) both a questionnaire and a diary study were conducted as a pilot study to obtain more insight in the concordance of volumes reported in a questionnaire and in a diary. This study was conducted in Melbourne between September and December 1997 with 253 respondents. After the first questionnaire was administered, participants were mailed the diary. Four weeks after the original interview, the same questionnaire was repeated. Water intake was reported in average-sized glasses, which were assumed to be 250 mL. The questionnaire inquired into cold tap water consumption in general (food frequency). Instruction with the diary asked participants to record their intake as soon as possible over a four-day period.

In the final study by Robertson *et al.* (2002) questionnaires were conducted in participants from a case–control study on sporadic cryptosporidiosis. These case–control studies were conducted in Melbourne from June 1998 to May 2001 and in Adelaide from November 1998 to May 2001. Similar to the Great Britain study the case–control population did not reflect the general population (median age 11 years). The questionnaire inquired into demographic information, clinical details of the case's illness, education level, employment, consumption of tap water on a usual day, consumption of particular food groups and other possible risk factors for cryptosporidiosis.

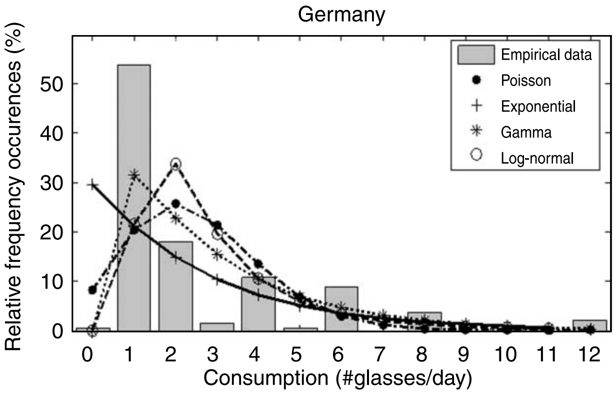

Figure 6 | Statistical probability distributions for discrete general tap water consumption.

Table 11 | Statistical data characteristics

	Consumption (glasses/d)		
Parameter	**Questionnaire 1**	**Diary**	**Questionnaire 2**
Mean	3.964	3.566	3.856
Median	4.00	3.00	3.00
Spacing breadth	8.00	7.80	9.00
N	253	234	231

Results – pilot study Melbourne

Table 11 presents the statistical data characteristics of the three elements of the pilot study. The empirical data as well as the statistical probability distributions are presented in Figures 7–9 and the performance measurements in Tables 12–14. For visual purposes the exponential distribution has been truncated.

Discussion and conclusions – pilot study Melbourne

Robertson *et al.* (2000b) concluded that there was only moderate agreement between the telephone questionnaire and diary recordings. Although this may be true at the individual level, the differences are much smaller when considering the population as a whole. To analyse possible differences between the questionnaires and the diary we conducted the non-parametric ranksum test of Wilcoxon. The results are presented in Table 15.

Based on these it can be concluded that there are no significant differences between the three parts of the pilot study as $p > 0.05$ for all three comparisons.

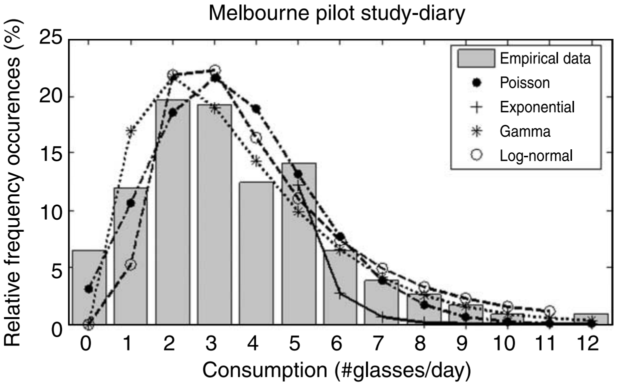

Figure 8 | Statistical probability distributions for discrete momentous tap water consumption, Melbourne pilot study–diary.

Results final study: Melbourne

In the final cryptosporidiosis case–control study in Melbourne the same questionnaire was administered as in the pilot study. Table 16 presents the statistical data characteristics of the final study in Melbourne. The empirical data as well as the statistical probability distributions are presented in Figure 10 and the performance measurements in Table 17. For visual purposes the exponential distribution has been truncated.

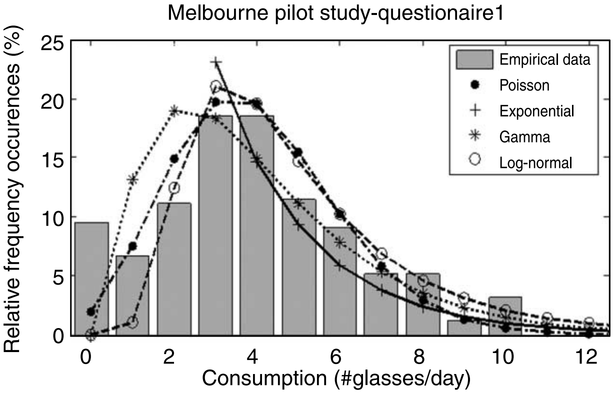

Figure 7 | Statistical probability distributions for discrete momentous tap water consumption, Melbourne pilot study–questionnaire 1.

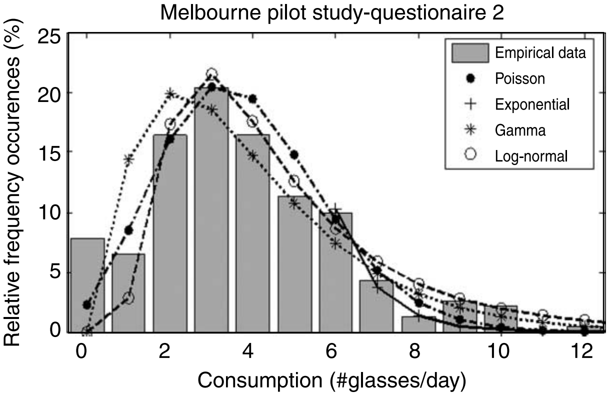

Figure 9 | Statistical probability distributions for discrete momentous tap water consumption, Melbourne pilot study–questionnaire 2.

Table 12 | Statistical distribution performance measurements: discrete general tap water consumption, Melbourne pilot study – questionnaire 1

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0**	-0.0001	0.0006	**0**
RMSE	0.0249	0.2197	0.0358	**0.0031**
FDV (R^2)	**88.17%**	5.56%	71.57%	79.97%
Estimated parameters	$\lambda = 3.9644$	$\alpha = 0.4557$	$\alpha = 2.4023$	$m = 1.3284$
		$\beta = 0.9912$	$\beta = 1.6503$	$s = 0.5751$

Table 13 | Statistical distribution performance measurements: discrete momentous tap water consumption, Melbourne pilot study – diary

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0**	**0**	0.0015	0.0018
RMSE	**0.0227**	23.0734	0.0266	0.0329
FDV (R^2)	**91.97%**	5.37%	87.97%	81.61%
Estimated parameters	$\lambda = 3.4915$	$\alpha = 1.5109$	$\alpha = 2.3083$	$m = 1.1107$
		$\beta = 2.7695$	$\beta = 1.5126$	$s = 0.6837$

Table 14 | Statistical distribution performance measurements: discrete momentous tap water consumption, Melbourne pilot study – questionnaire 2

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0**	**0**	0.0007	**0**
RMSE	**0.0195**	7.6464	0.0301	0.0242
FDV (R^2)	**93.04**	0.65%	81.08%	87.83%
Estimated parameters	$\lambda = 3.8004$	$\alpha = 1.0225$	$\alpha = 2.3618$	$m = 1.2356$
		$\beta = 3.2120$	$\beta = 1.6093$	$s = 0.6485$

Results final study: Adelaide

In the final case–control study in Adelaide the same questionnaire was administered as in the pilot study and the final study in Melbourne. Data were obtained for 644 respondents. Table 18 presents the statistical data characteristics of the final study in Adelaide. The empirical data as well as the statistical probability distributions are presented in Figure 11 and the performance measurements in Table 19. For visual purposes the exponential distribution has been truncated.

Discussion and conclusions

From Tables 12–14 it can be concluded that the Poisson distribution fits best to the data from the pilot study. The data from the final study in Melbourne are also best

Table 15 | Analysis of differences between questionnaires and diary in pilot study Melbourne

	Questionnaire 2	Diary
Questionnaire 1	$p = 0.4351$	$p = 0.0899$
Diary	$p = 0.2498$	

described by the Poisson distribution and the difference with the performance of the other distributions is enlarged, compared to the pilot study.

The distribution of the data from Adelaide is again best described by the Poisson distribution, but it can be seen in Table 19 that R^2 is low compared to the other Australian datasets. This is mainly caused by the high percentage of non-consumers in Adelaide, which may be due to the historically lower aesthetic quality of the Adelaide drinking water. Additional analysis excluding the non-consumers (results not shown) did not increase the performance of the probability distribution functions either.

In all Australian recall (questionnaire) studies, the percentage of non-consumers was higher than the percentage of consumers drinking one glass, except for the diary study (pilot Melbourne). This suggests that the recall studies may have overestimated the percentage of non-consumers. We therefore consider the results from the diary study in Melbourne to be the most valuable. This is in line with the conclusions by Robertson *et al.* (2000*a*) who concluded that the questionnaire was less accurate than the diary.

To analyse for possible difference between the distributions of the final studies in Melbourne and Adelaide and the pilot study the non-parametric ranksum test of Wilcoxon is conducted. Results are presented in Table 20.

Table 16 | Statistical data characteristics

Parameter	Glass/d
Mean	3.368
Median	3.00
Spacing breadth	8.00
N	950

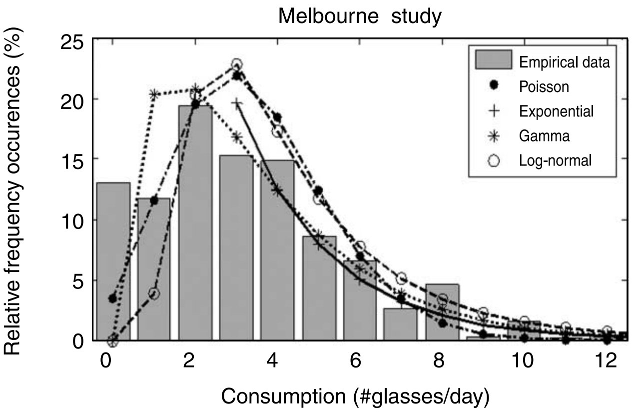

Figure 10 | Statistical probability distributions for discrete momentous tap water consumption.

From Table 20 it can be concluded that the data from the final study in Melbourne do not differ significantly from the diary in the pilot study, but they do from the data from the two questionnaires in the pilot study. The data from the final study in Adelaide differ significantly from the data from both the pilot study and the final study in Melbourne.

DISCUSSION AND CONCLUSIONS

Design of the study

In the analysis of the Australian data it was demonstrated that estimations of drinking water consumption were higher in the questionnaires than in the diaries. Similar findings were reported by Kaur *et al.* (2004) and Levallois *et al.* (1998). Also the number of non-consumers was higher in the questionnaire studies compared to the diary study. Therefore we believe the diary is to be preferred for collecting water consumption data. The longer the period for data collection, the more representative data can be obtained. On the other hand, if the duration of the study is too long this might result in less accurate reporting. We believe that probably 3–4 days would be most feasible.

If a diary study is not possible because of limitations in time or money, a 24 h recall is an appropriate alternative. In order to get more information of the within-person variation, it is advisable to repeat the 24 h recall at least once on a non-consecutive day (Brussaard *et al.* 2002). During the

Table 17 | Statistical distribution performance measurements: discrete momentous tap water consumption

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0**	**0**	0.0023	**0**
RMSE	**0.0315**	0.1623	0.0382	0.0478
FDV (R^2)	**82.75%**	15.85%	71.52%	60.64%
Estimated parameters	$\lambda = 3.3684$	$\alpha = 0.4522$	$\alpha = 1.7983$	$m = 1.1467$
		$\beta = 0.6394$	$\beta = 1.8731$	$s = 0.6496$

study attention should be paid to the way of questioning to avoid wrong representation of non-consumers.

To obtain a generalisation in time and to include variation between respondents a large number of respondents should be questioned and the moments of data collection should be homogenously distributed over one or more years. However, the number of repeated measurements and participants needed in dietary surveys are often a compromise between theoretical considerations (e.g. reliability of the index number calculated) and practical constraints (costs, respondent burden, etc.). Taking such considerations into account Brussaard *et al.* (2002) concluded that a minimum sample size of 2000 adults in each country will be needed in order to identify trends in the mean intakes of foods and nutrients in Europe.

To increase the participation rate, measures such as sending a letter in advance explaining the study, special training of interviewers and money incentives should be considered.

The water consumption data can be collected as continuous data (e.g. grams or litres per day) or as discrete data (e.g. glasses per day). From a statistical point of view, continuous data are preferable above discrete data because of the lack of classes. However, it can be questioned whether in theory tap water consumption is distributed continuous or discrete. During continuous measurements the consumer is often asked the number of glasses or cups consumed and afterwards this is recalculated to millilitres or litres. The actual result of this way of gathering data is false continuous data. Discrete data also have the advantage that they are easier to collect than continuous data. When collecting data in discrete measures the volume consumed will be best estimated by measuring the volume of the used drinking vessels by the interviewer or with the use of pictures of cups and glasses.

Table 18 | Statistical data characteristics

Parameter	Glass/d
Mean	2.87
Median	2.00
Spacing breadth	8.00
N	644

Considering the effects of season, age or gender on tap water consumption no unambiguous information could be obtained from the studies reported. Intuitively, cold tap water consumption is expected to be higher in summer than in winter. This was also confirmed by Gofti-Laroche

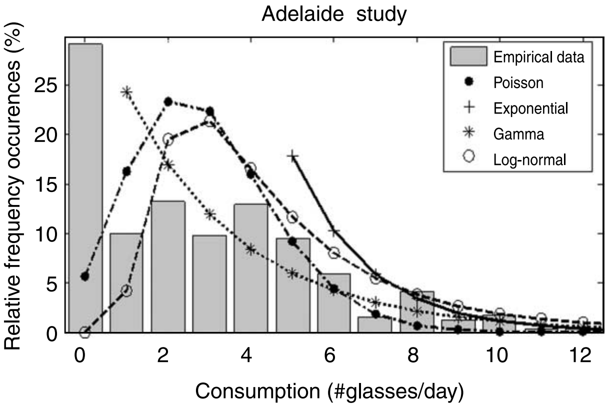

Figure 11 | Statistical probability distributions for discrete general tap water consumption.

Table 19 | Statistical distribution performance measurements: discrete general tap water consumption

Parameter	Poisson	Exponential	Gamma	Lognormal
Mean Error	**0**	0	0	0
RMSE	**0.0594**	0.7224	0.0739	0.0663
FDV (R^2)	**41.01%**	15.83%	20.44%	23.26%
Estimated parameters	$\lambda = 2.8676$	$\alpha = 0.5538$	$\alpha = 0.9542$	$m = 1.1843$
		$\beta = 2.4293$	$\beta = 3.0051$	$s = 0.6854$

Table 20 | Analysis of differences between the results of the final studies in Melbourne and Adelaide and the pilot study in Melbourne

		Adelaide	Melbourne		
		Final study	Final study	Pilot study Quest. 2	Pilot study Diary
Melbourne	Pilot study Quest. 1	0^*	0^*	0.4351	0.0899
	Pilot study Diary	0^*	0.0959	0.2498	–
	Pilot study Quest. 2	0^*	0.0027^*		–
	Final Study	0^*			–

*Significant difference ($p < 0.05$).

et al. (2001) and EHD (1981). However, analysis of the Dutch data did not show such influences. Finley *et al.* (1994) concluded that the distribution of tap water intakes in a population is driven more by variation and personal preference for fluid intake than by the need for additional water cooling.

Higher consumption of cold tap water was reported by people with a lot of physical activity and people who regarded themselves to be of very bad health.

Statistical distribution function

Roseberry & Burmaster (1992) and Teunis *et al.* (1997) fitted the Lognormal distribution to their water consumption data. Using the datasets from the Netherlands, UK and Australia, the Poisson distribution performed better than the Lognormal distribution. The Poisson distribution also has the advantage of having a relatively simple method of parameter estimation and is more suited for discrete datasets. The fraction of non-consumers is an aspect that needs attention in water consumption studies. Often the number of non-consumers lies far outside the curve of the empirical consumption distribution. In the Dutch data, the fraction of non-consumers is approximately 65%, which is very high compared to the data from Melbourne and Great Britain. Because the fraction of non-consumers did not fit the statistical distributions well, a second method of statistical data analysis was applied to the studies. The idea was that by eliminating the derogatory value of non-consumption a smoother empirical distribution could be obtained. However, the fitted statistical probability distribution functions performed less well. Therefore, it is better to fit the statistical probability distribution functions on the total dataset, including the non-consumers.

When comparing studies on tap water consumption conclusions regarding differences in consumption between countries, sexes, etc., should be drawn very carefully, taking into account the many differences in study design. Attention should be paid to the study population (specific group or whole population), the moment/season of data collection within a year, the methods of data collection (e.g. diary record or recall), the method to assess the volume tap water consumed and the types of water included in the surveys (food, medicines, lemonade, ice cubes, etc.). The experiences of this study illustrate that these factors can have a large impact on the (distribution of the) consumption data.

Recommendations for the estimation of water consumption in QMRA

Assessing water consumption in QMRA it would be best to use country-specific data and statistical distributions, if available. Given the skewed distribution, the mean will be higher than the median and is therefore more conservative in QMRA. For the average consumer, the reported mean consumption of cold tap water varies between 0.10–1.55 L. Differences occur between countries, but also within countries (see Table 1). If more datasets are available for a country, we recommend to select the data that have been collected with the best study design. If the selection cannot be based on study design, the study that yields the highest consumption data should be used, as a conservative estimate of the consumption of cold tap water.

To account for the variability in water consumption over the population, a statistical distribution can be fitted to the consumption data. The Lognormal distribution, as suggested by Roseberry & Burmaster (1992), did not provide the best fit to the consumption datasets we examined. In the Lognormal distribution the number of non-consumers is per definition 0, while the UK, Australian and Dutch dataset contained 7–65% non-consumers. Tap water consumption (or at least the way information on consumption is collected) is more a discrete than a continuous parameter. Therefore, the Poisson distribution is more appropriate and proved to have a good fit to the datasets. The Poisson distribution also has the advantage that parameter estimation is easy.

For Great Britain, a Poisson distribution with a mean of 2.81 glasses/d (1 glass = 190 mL) (2 week-recall) can be used in QMRA and for Australia a Poisson distribution with a mean of 3.49 glasses/d (1 glass = 250 mL) (diary study, Melbourne) can be used. For the Netherlands, the Poisson distribution with a mean of 0.71 glasses/d (1 glass = 250 mL) could be used, but it is also possible in Monte Carlo analysis to draw from the Dutch consumption data themselves and not from a statistical distribution. The latter is recommended for the German dataset.

If no country-specific data are available we recommend to use the Australian distribution data from the Melbourne diary study (Poisson, $\lambda = 3.49$ glasses/d) as a conservative estimate, because the water consumption in these data is relatively high.

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