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Temporal and Spatial Variation of Trihalomethanes and Haloacetic Acids Concentration in Drinking Water: A Case Study of Queensland, Australia

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Abstract: A broad survey of regulated trihalomethanes (THM) and haloacetic acids (HAA) concentrations in Queensland drinking water was undertaken and the data were evaluated to assess the overall compliance of the region to Australian Drinking Water Guidelines (ADWG). The results presented here indicate that drinking water total trihalomethane (tTHM) concentrations were predominantly compliant with ADWG, with regions using chlorination being the only regions that exceeded the ADWG for THM. tTHM levels were highest in chlorinated water, whereas levels in combined chlorinated/chloraminated water were much lower. Chloraminated water produced the lowest tTHM levels in the regions examined. tTHM levels generally increased during summer and decreased in winter regardless of disinfection method. Surface waters formed a higher proportion of more highly chlorinated THM species relative to more highly brominated THM species, whereas bore water had a higher proportion of more highly brominated THM species due to the frequently higher bromide concentration and lower natural organic matter (NOM) concentration of these waters. The majority of regions were continuously compliant with ADWG for HAA concentrations, with primarily the trichloroacetic acid guideline value being exceeded, in chlorinated waters only.

Keywords: disinfection by-products, THMs, HAAs, chlorination, chloramination

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Introduction

The disinfection of drinking water is one of the greatest public health advances of the last century, but this process also enables the formation of potentially toxic disinfection by-products (DBPs) which have been associated with an increased risk of cancer and reproductive/developmental effects.[1] The two major classes of DBPs currently regulated in the ADWG are the THM and HAA, although several hundred individual DBPs have been reported in the literature.[1]

DBPs are formed by the reaction of disinfectants such as chlorine or chloramines with organic material and/or halides present in the source water. In Queensland, most drinking water is disinfected by either chlorination or chloramination. Chlorination is known to form higher concentrations of THM and HAA than chloramination, although chloramination leads to an increased risk of forming some other DBPs, such as *N*-nitrosodimethylamine (NDMA).[2]

While chloroform is often the most prevalent of all the THM, its brominated or iodinated counterparts can be formed under circumstances when these halides are present in the source water, often arising from salt water intrusion.[1] The Australian context has potential for regions with high Br-THM and I-THM concentrations, due to the high salinity and low rainfall of many catchments, and the recent movement into desalinated water as an alternative water source.

Chloroform has been found not to be mutagenic or genotoxic in a wide array of systems *in vivo* and *in vitro*. However, it is understood to be a non-genotoxic carcinogen whose mechanism of action includes cytotoxicity and regenerative cell proliferation.[3] Interestingly, the brominated THM differ from chloroform in that they are all mutagenic after activation by glutathione S-transferase-theta (GSTT1–1), and are in fact dependent on the presence of this enzyme to exert their mutagenic affect.[4] The four regulated THM are all carcinogenic in rodents.[3,5,6] Recent research indicates that route of exposure is of great importance when assessing the risk associated with THM.[7–9] For example, bromodichloromethane (BDCM) blood concentrations in humans have been reported as being 25 – 130 times higher from dermal exposure than from oral exposure in controlled experiments.

The general haloform reaction is considered to be a formation pathway responsible for the formation of THM in drinking water. Organic compounds with ketone or aldehyde functionality react with chlorine in a base catalysed addition/elimination reaction to produce chloroform, and bromination of chloroform occurs by substitution.[10] Some amino acids, proteins, haloacetonitriles, purines and pyrimidines have been shown to be precursors for THM.[11] In addition, studies have shown seasonal algal chlorophyll-a is an important THM precursor.[12]

The current ADWG recommend 250 μg/L for tTHM, with the revised 2010 ADWG remaining unchanged from previous revisions, however, this is currently under public consultation.[13] The ADWG surrounding HAA are; monochloroacetic acid (150 μg/L), dichloroacetic acid (100 μg/L) and trichloroacetic acid (100 μg/L), with none of the brominated HAA being currently regulated in Australia.

Monochloroacetic acid has been shown to be mutagenic in bacterial cells [14] and genotoxic in mammalian cells, however it has given no evidence of carcinogenicity.[15,16] Dichloroacetic acid is only weakly mutagenic and weakly genotoxic, but is known to be carcinogenic. Trichloroacetic acid has generally given negative results for mutagenicity, and investigations into its genotoxicity have not been reproducible.[17] Trichloroacetic acid is, however, carcinogenic.[15] The mode of action for the carcinogenicity of dichloroacetic acid and trichloroacetic acid is as yet unknown, however it is not anticipated that the mechanism would be genotoxic in either case.

During this study, a survey of regulated THM and HAA concentrations in Queensland drinking water was undertaken and the data evaluated to assess the overall compliance to ADWG, with the aim of providing insight into what specific regions experienced comparatively higher concentrations of these DBPs in the finished water, and why.

Experimental

Sampling preservation and storage

Grab samples were taken in all cases. Samples were transported and stored in 200 mL amber glass bottles, with Teflon lined screw-caps to protect against the loss of volatile compounds. Bottles were completely filled, leaving no headspace. All samples for THM or HAA analysis were dosed with 200 mg NH_4CI to remove residual chlorine and prevent further DBPs formation. Sample bottles were detergent-washed, then rinsed with purified water and finally washed in acetone and dried prior to use.

Sampling sites

For each of the 32 regions listed in Table 1, 2–15 individual sample points were defined at different stages of distribution, and these were sampled from 4–12 times over one year. Most sample points were sampled monthly (12 times) however, this was not possible in all cases. The water sources were primarily dams, rivers, and bores, with a small percentage of regions being supplied by creeks and lakes, or a combination of bore and surface waters. The disinfection method and water source for each region is detailed in Table 1. Figures 1 and 2 show

Table 1. Source waters and disinfection methods used in each of the regions studied.

Region	Disinfection method	Source water	No of sample sites
Beaudesert	Chlorine	Logan River	5
Brisbane	Chloramine	Wivenhoe Dam	8
Bundaberg	Chlorine	Burnett River	8
Caboolture	Chlorine/chloramine	Wivenhoe Dam/Bribie Lagoon	12
Caloundra/Maroochy	Chlorine	Lake Baroon	4
Carpentaria	Chlorine	Norman River/Bore	6
Cooloola	Chlorine	Teewah Creek	6
Dalby	Chlorine	Condamine River/Bore	6
Eidsvold	Chlorine	Wuruma Dam	2
Esk	Chlorine	Wivenhoe Dam	9
Gladstone	Chlorine	Awonga Dam	12
Gold Coast	Chlorine	Hinze Dam	6
Hinchinbrook	Chlorine	Bore	15
Ipswich	Chloramine	Wivenhoe Dam	12
Isis	Chlorine	Gregory River	6
Jondaryan	Chlorine	Bore/Toowoomba Dam	7
Logan	Chlorine	Logan River	5
Mackay	Chlorine	Pioneer River/Bore	6
Maryborough	Chlorine	Tinana Creek	8
Monto	Chlorine	Bore	8
Mount Isa	Chlorine	Lake Moondarra	7
Peak Downs/Capella	Chlorine	Capella Creek/Mackenzie River	2
Pine Rivers	Chlorine	North Pine Dam/Wivenhoe Dam	8
Redcliffe	Chlorine/chloramine	North Pine Dam/Wivenhoe Dam	7
Redland	Chlorine	Bore/Leslie Harrison Dam	8
Rockhampton	Chlorine	Fitzroy River	5
Sarina	Chlorine	Bore/Middle Creek Dam	9
Thuringowa	Chlorine	Crystal Creek	4
Toowoomba	Chlorine	Bore/Cooby Dam/Perseverance Dam/Cressbrook Dam	1
Warroo	Chlorine	Bore/Balonne River	6
Wide Bay	Chlorine	Lenthalls Dam	4
Wondai	Chlorine	Boondooma Dam	6

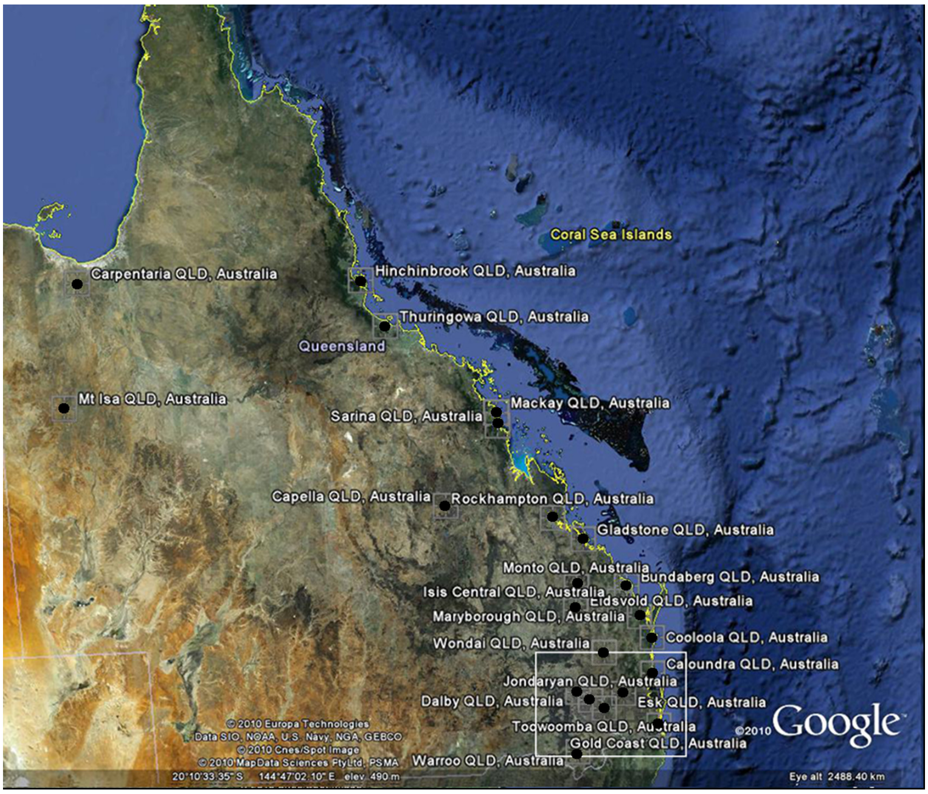

Figure 1. Map of Queensland showing all regions which were sampled as a part of this study. A detailed view of the boxed area of the Queensland map is shown in Figure 2.

maps of the regions of Queensland studied, and indicate sampling regions, and major drinking water sources.

Analytical methods and analysis

Trihalomethane analysis was conducted by extracting organics from the aqueous sample into hexane and analysing the extract by gas chromatography with electron capture detection (ECD), in accordance with the method outlined in APHA, AWWA, WEF Standards Methods for the Examination of Water and Wastewater, 28th edition, 1992. This was achieved using a Hewlett Packard 5890 gas chromatograph with a DB1701 column with length 15 m and diameter 0.32 mm. The oven temperature was ramped from 60 °C (held for 6 minutes) to 235 °C. The carrier gas (hydrogen) pressure was programmed to maintain a pressure of 20 kPa. THM concentrations were quantified by interpolation from a standard curve. The method reporting limit was 4 µg/L for total tTHM, and 1 µg/L for individual THM. The uncertainty for the method was 10%.

HAA were extracted from aqueous samples by partitioning into methyl tert-butyl ether (MTBE) after addition of sulfuric acid and sodium sulphate. The MTBE extracts were then methylated using methanolic sulfuric acid, then neutralised and analysed by gas chromatography using a GC 17 A Shimadzu Gas Chromatograph with electron capture detector (ECD), and subsequently quantified by interpolation from a standard curve. The method reporting limit was 10 µg/L for each HAA analyte, and the uncertainty for the method was 20%.

Results and Discussion

Chlorine disinfection was used in the majority of locations examined, with a small percentage of regions having chloraminated drinking water, or a combination of chlorinated and chloraminated water (Fig. 3). It is important to note that this study focussed on Southeast Queensland supplies, with some additional data from other Queensland regions. The raw water sources were primarily dams (41%), with rivers, bores, a combination of bore and surface

Figure 2. The boxed area in the Figure 1 map (Southeast Queensland) is shown, with all regions sampled in this study indicated. The major dams/lakes used for water supply in the area are also shown.

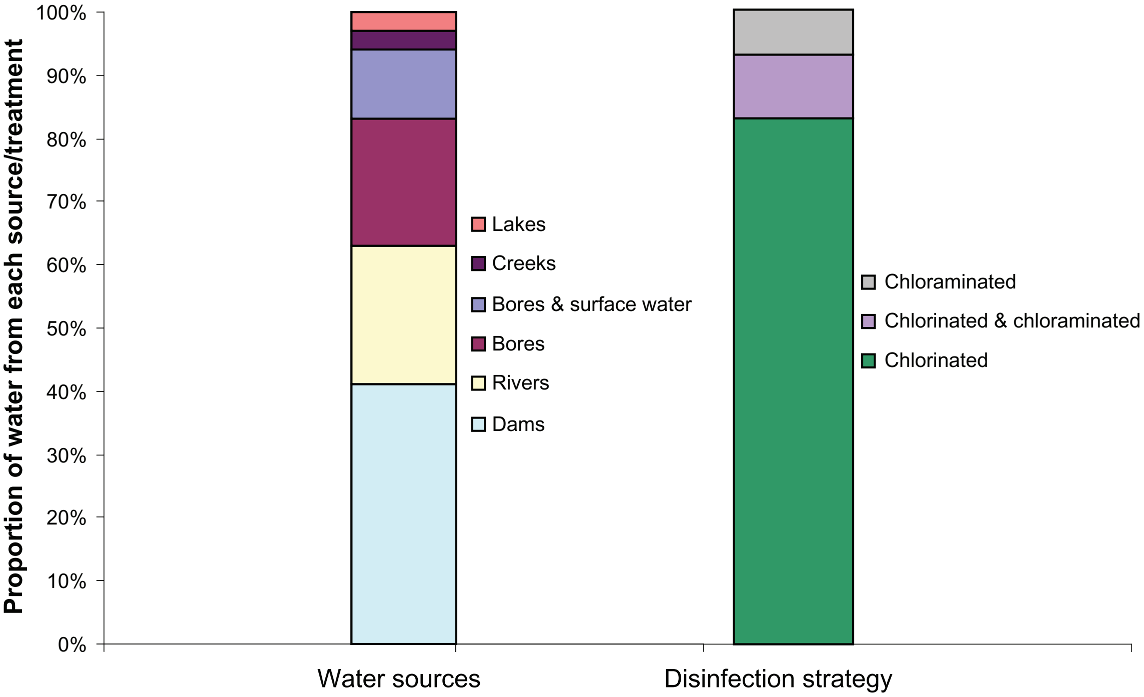

Figure 3. Proportion of different drinking water disinfection methods employed in Queensland regions examined in this study, as well as the proportion of different water sources utilised for drinking water across the regions studied.

Table 2. Summary of tTHM levels in Southeast Queensland drinking waters studied over the one year sampling period. Region names have been removed for confidentiality reasons.

Region	Mean annual tTHMs (µg/L)	Mean tTHMs Oct–Mar (µg/L)	Mean tTHMs April–Sept (µg/L)
A	138.4	160.4	111
B	50.4	52.1	48.1
C	114.6	127.3	101.4
D	126.1	137.3	115.4
E	52.3	54	51.3
F	81.8		
G	119.8	115.7	123
H	72.7	72.5	72.7
I		33.5	
J	92.9	98.8	95.5
K	130.3	140	123.1
L	55	49.8	58.7
M	10.9	10.1	12
N	62.5	63	62.6
O	151.3	197	136
P	119.3	123.9	114.1
Q		61.6	
R	61.5	65.7	56.8
S	217.1	245.8	188.9
T	19.6	20.6	18.6
U	99.7	107.6	90.6
V	139.5	161	129
W		63.3	
X	73	84.2	61.9
Y	48	53.8	30.4
Z	60.2	60.2	60.4
AA	24.6	30.8	17.9
AB	49	66.9	42.3
AC	85.1	98.2	63.2
AD		126.8	
AE	165.9	152.3	159.1
AF		176	

Table 3. Average annual individual THM concentrations (µg/L) in Queensland locations studied.

Region	Chloroform (µg/L)	BDCM (µg/L)	DBCM (µg/L)	Bromoform (µg/L)
A	73	39	23	4
B	15	18	16	2
C	17	29	42	27
D	65	34	17	1
E	27	18	8	1
G	54	34	25	7
H	1	3	20	49
J	45	27	17	5
K	47	44	35	3
L	32	16	6	0
N	20	20	18	3
O	32	38	49	32
P	50	40	28	3
R	24	20	17	2
S	110	69	35	3
T	1	2	5	12
U	39	34	24	3
V	113	22	5	1
X	36	23	13	1
Y	33	14	10	5
Z	32	20	9	1
AA	9	12	7	6
AB	42	7	1	1
AC	31	29	23	3
AD	99	26	2	1
AE	118	30	6	1
AF	55	66	48	8

waters, creeks and lakes making up the remainder (Fig. 3). The mean pH across all samples was 7.3, and the water temperature across Southeast Queensland ranged from 21–24 °C.

Table 2 details the average tTHM concentration at each of the specific regions examined in this study. The regions have had their identities removed for confidentiality reasons, and are described as regions A-AF herein. tTHM levels varied significantly between regions, and tTHM concentrations were generally higher in the warmer months than during the colder months for all three treatment processes although the increase in tTHM in spring/summer was often marginal. Similar trends have been found in several other studies.[19–21] This observation may be explained by seasonal variations in water temperature, NOM and water quality. Higher water temperatures promote the production of THM, as does the typical increase in NOM concentration in surface waters during summer arising from increased biological activity, rainfall and thus runoff.[22] Importantly, every region studied maintained an average annual tTHM concentration that was below the ADWG concentration (250 µg/L). Average tTHM concentrations in the warmer months of the year also remained under this guideline concentration for all regions, despite the increase in tTHM experienced at this time. Krasner and colleagues found bromide levels may also increase during drought [23] although this was not assessed here. Figure 4 shows the annual concentration range for tTHM found in chlorinated, chloraminated and combined chlorinated/chloraminated drinking waters, over both the summer and winter months. Chlorinated drinking waters had the widest range of tTHM

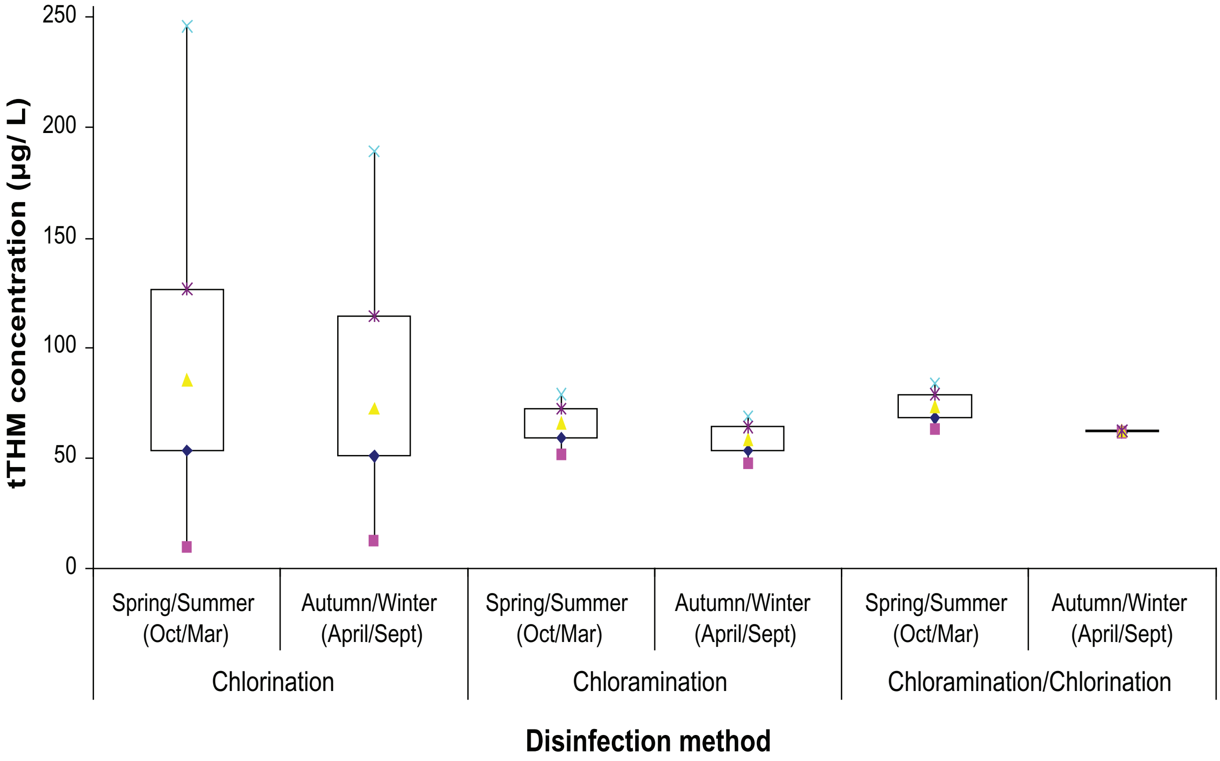

Figure 4. Variation in tTHM concentration between warmer and colder months, and between different disinfection methods. Upper and lower points of each box plot show the actual maxima and minima for each dataset, and ▲ indicates the median tTHM concentration.

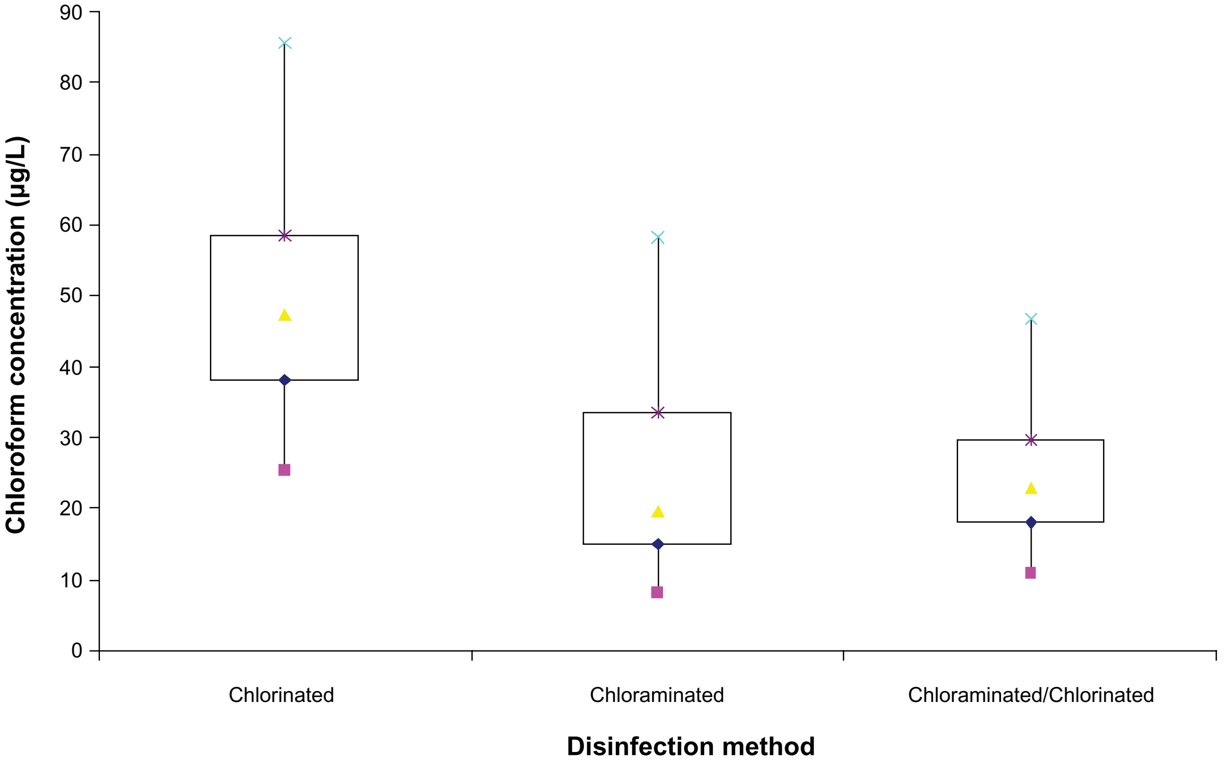

Figure 5. Distribution of chloroform concentrations for chlorinated, chloraminated and chlorinated/chloraminated drinking waters. Upper and lower points of each box plot show the actual maxima and minima for each dataset, and ▲ indicates the median chloroform concentration.

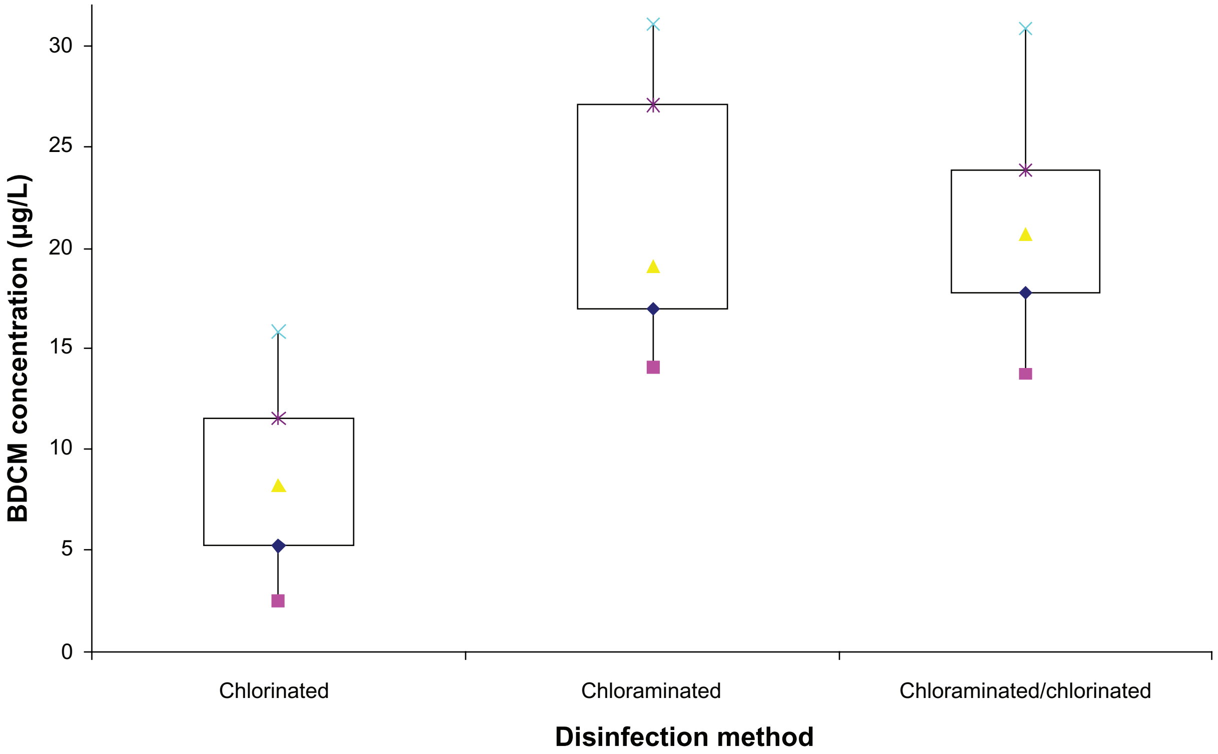

Figure 6. Variation in BDCM concentrations in chlorinated, chloraminated and chlorinated/chloraminated drinking waters. Upper and lower points of each box plot show the actual maxima and minima for each dataset, and ▲ indicates the median BDCM concentration.

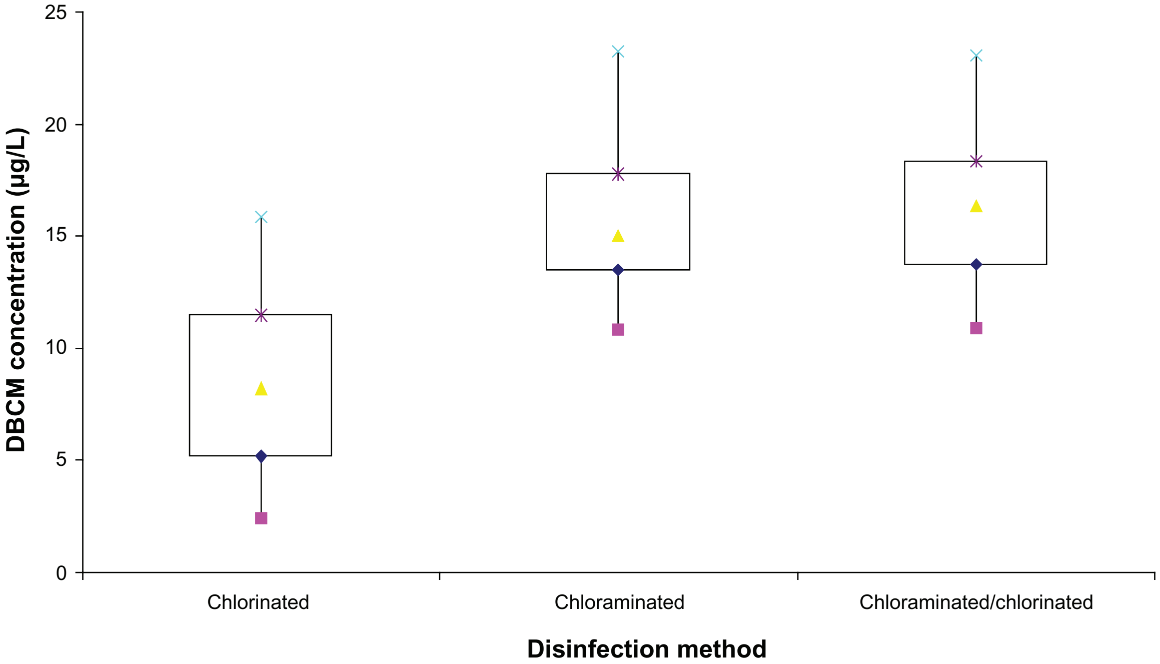

Figure 7. Distribution of DBCM concentrations for chlorinated, chloraminated and chlorinated/chloraminated drinking waters. Upper and lower points of each box plot show the actual maxima and minima for each dataset, and ▲ indicates the median DBCM concentration.

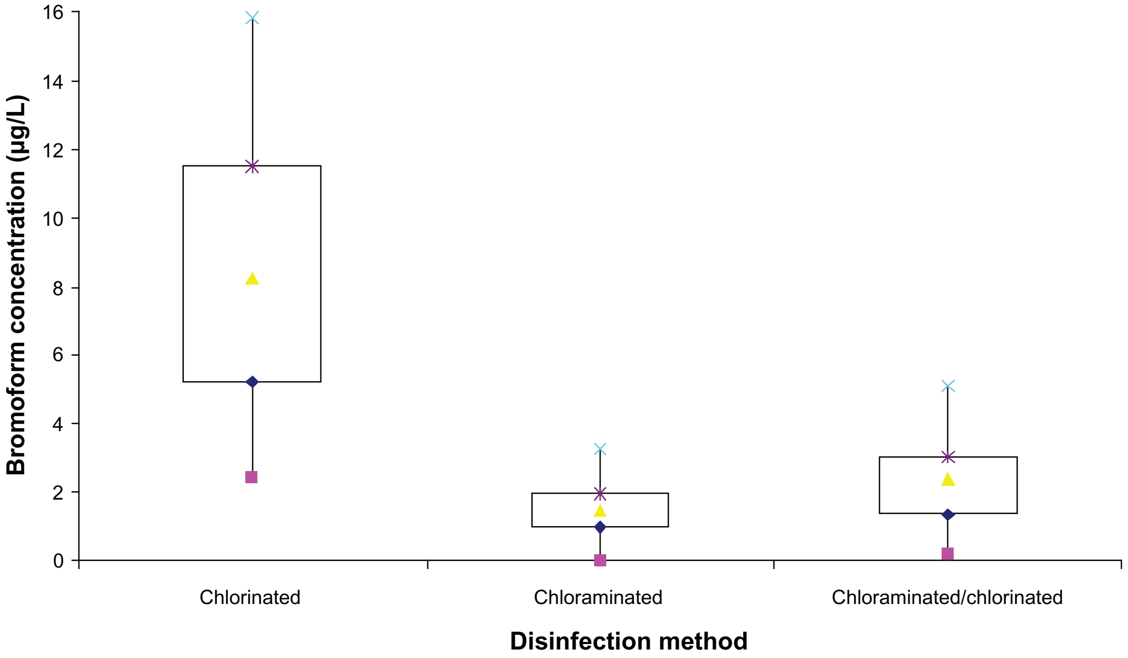

Figure 8. Distribution of bromoform concentrations for chlorinated, chloraminated and chlorinated/chloraminated drinking waters. Upper and lower points of each box plot show the actual maxima and minima for each dataset, and ▲ indicates the median bromoform concentration.

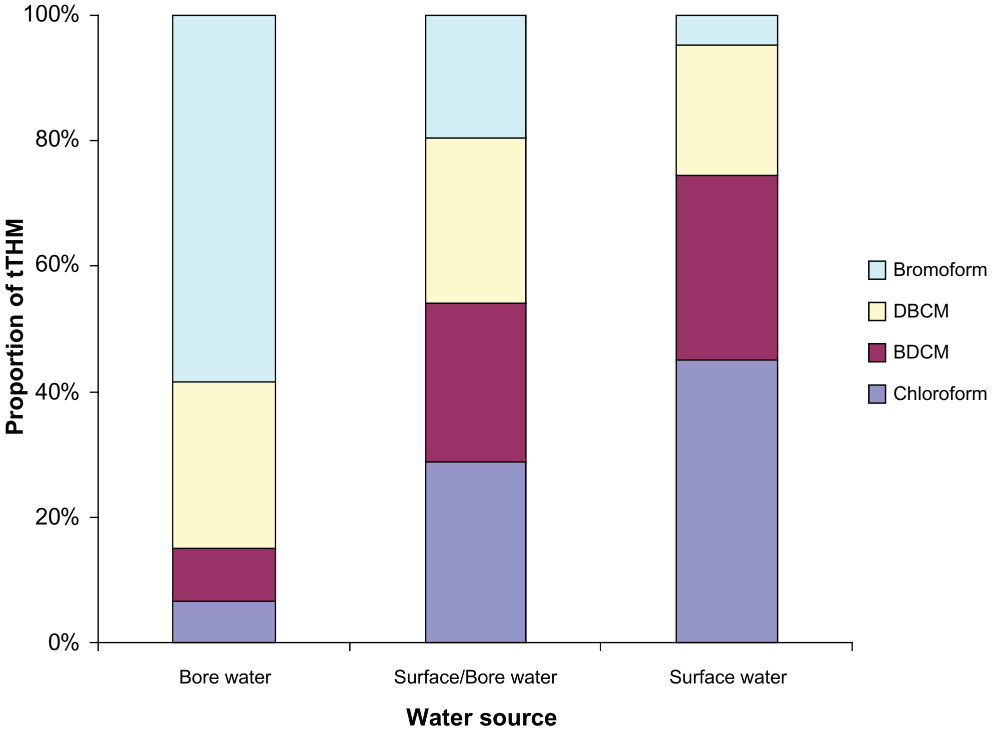

Figure 9. Proportion of individual THM from different water sources.

concentrations, as well as the highest median and highest maximum tTHM levels compared to drinking water disinfected with chloramine or exposed to both chloramine and chlorine. Chloraminated water had the lowest levels of tTHM in comparison to the other disinfection methods, with 75% of samples having tTHM concentrations below 64 µg/L.

The distributions of individual THM for the regions surveyed are reported in Table 3, as annual mean concentrations. Figures 5–8 show that chlorinated waters had the highest concentrations of chloroform in comparison to the other disinfectants, however chloraminated and chloraminated/chlorinated waters both had much higher BDCM and dibromochloromethane (DBCM) levels than chlorinated waters. Overall, concentrations of bromoform were the lowest of all THM for all three treatment processes, although bromoform levels were higher in chlorinated water in comparison to chloraminated or chloraminated/chlorinated waters. In chlorinated waters there was wide variation in chloroform levels between samples whereas levels of the brominated THM were consistently less variable. Concentrations of chloroform may be more irregular because its formation increases over time, thus concentrations are dependent on residence time, chlorine residual and the structural integrity of the distribution system.[24]

Although the concentration of individual and tTHM varies with region and disinfection method, the average proportion of total brominated to non-brominated (chloroform) species was similar, overall, for all three treatment processes. Aspects other than disinfection method, such as source water NOM and bromide concentrations, will also impact on the speciation of individual THM formed[25] therefore this information, in addition to the disinfection method, must also be taken into account in considering which individual THM are likely to arise from a particular water source.

Regardless of disinfection method, the following general trend was noted; often chloroform concentrations were highest, followed by BDCM, then DBCM and lastly bromoform. The significant exception to this was in regions where water supplies were supplemented with bore water, in which case bromoform was the predominant THM, and chloroform concentrations were comparatively low (Fig. 9). There were clear differences in the concentrations of individual THM formed in bore and surface waters. Thus, a great deal of the variation in THM speciation and concentration among regions can be attributed to the water source. Surface water formed a higher proportion of chlorinated THM species, whereas bore water had a higher proportion of brominated THM species. The low levels of NOM and high bromide levels

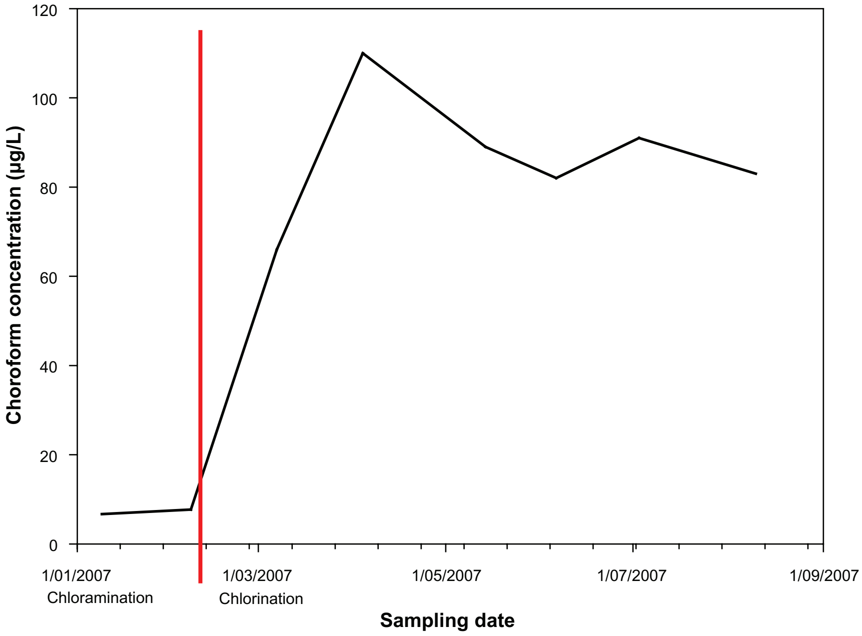

Figure 10. Variation in chloroform concentration in E-WTP over nine months of sampling.

characteristic of many bore water sources produce a naturally high bromide to organic matter ratio.[26] The combination of low NOM and high bromide concentration leads to an increase the proportion of brominated THM formed.[27] This is of concern from a public health perspective, given the greater toxicity of the brominated THM compared to chloroform.[4]

During the course of this survey, one of the Southeast Queensland water treatment plants studied (E-WTP) changed disinfection method from chloramination to chlorination. The data for chloroform concentration is shown in Figure 10. In this case the other regulated THM were generally undetected regardless of whether chlorination or chloramination were employed. This illustrates that a given source water may demonstrate a large change in chloroform (and potentially other DBPs) concentrations, based predominantly on the disinfection method employed, and that in this case, this appears dominant over other variations in source water occurring over the same time.

Regions Exceeding ADWG Values for tTHM

About 12% of Queensland regions surveyed in this study demonstrated tTHM concentrations that exceeded the ADWG value (250 µg/L) at least once over the twelve month sampling period (detailed herein). Regions with chlorinated water were the only regions that exceeded the ADWG for THM. Chloraminated water produced the lowest tTHM levels in the regions examined, with all samples complying with the ADWG. Australia's guideline value for tTHM is about three times higher than that of the USA, and 2.5 times higher than for Canada. The WHO recommends separate guidelines be introduced for each THM, given their different toxicity, and this approach has been adopted in New Zealand, where guidelines are completely aligned with the WHO for regulated DBPs.[28] The WHO recommended guidelines are as follows: chloroform 300 µg/L, BDCM and DBCM 100 µg/L, and bromoform 60 µg/L, provided the sum of the ratio of the concentration of each THM to its guideline value does not exceed 1. Under WHO recommended guidelines for THM, approximately half of the regions surveyed in this study would fail to comply at least once over the twelve months examined here. The revised 2010 ADWG still recommend 250 µg/L for tTHM, however, this is currently under public consultation.

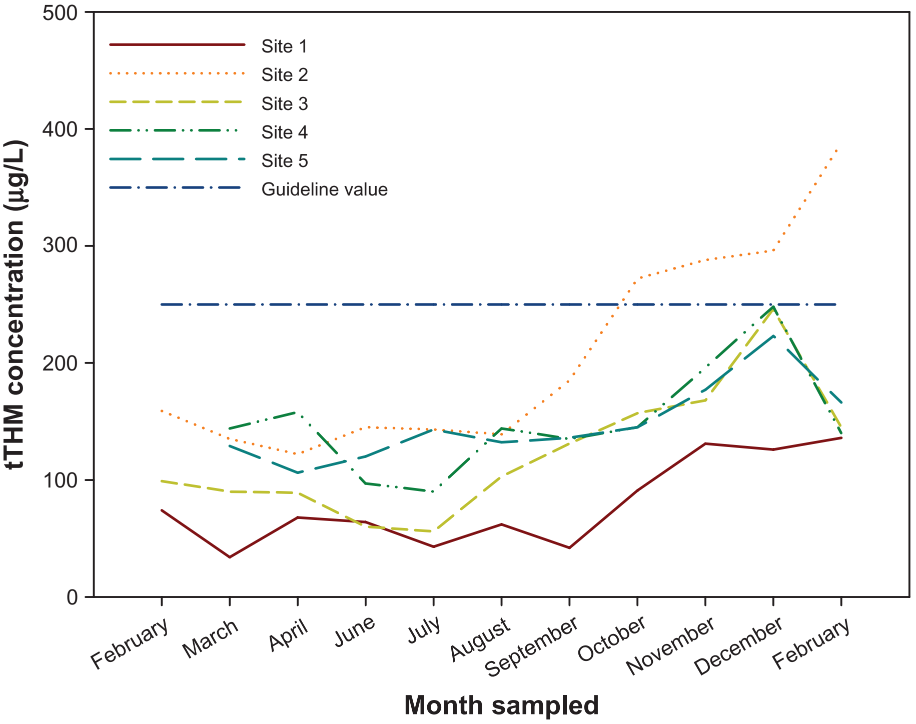

Figure 11. Change in tTHM concentration in drinking water in region A over 12 months.

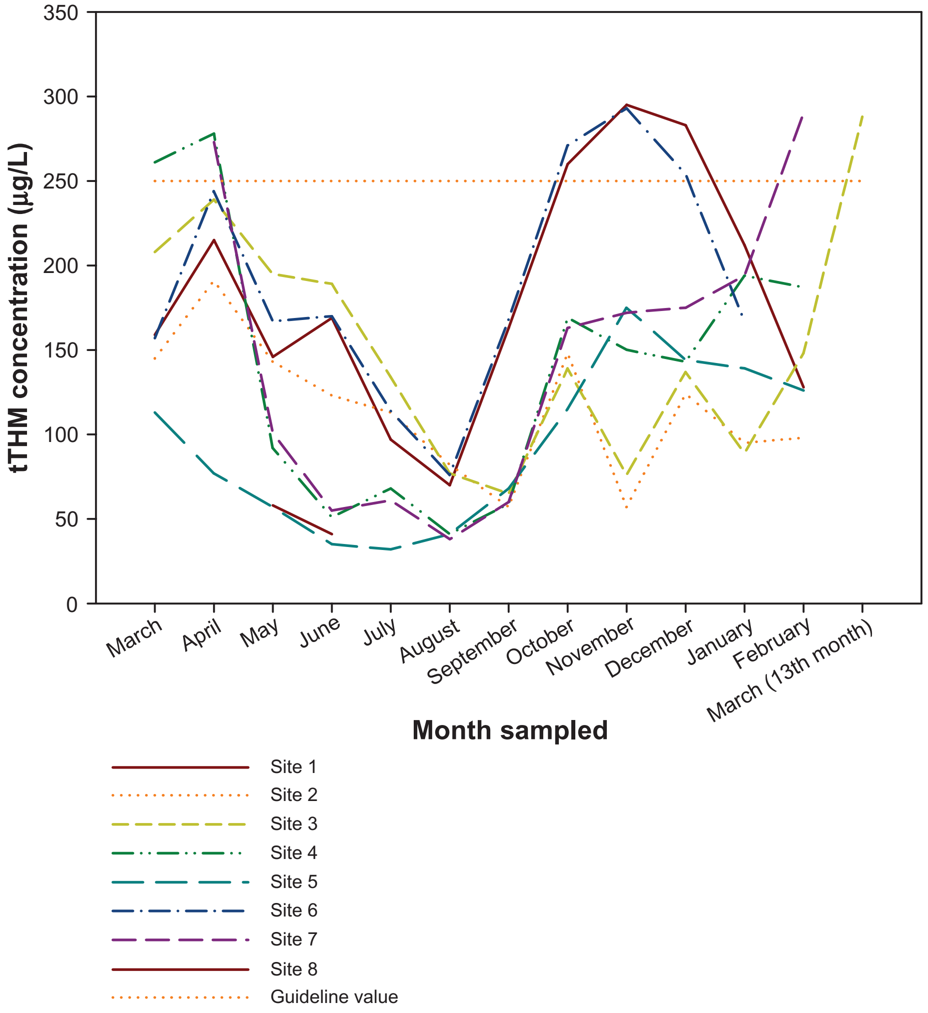

Figure 12. Changes in tTHM concentration in drinking water within region D over twelve months.

Given Australia's high guideline value for tTHM compared to international and WHO recommendations, public comment may suggest that the revised ADWG for THM be altered to be more aligned with these standards. The introduction of individual guidelines rather than simply a tTHM guideline would allow water quality to be more appropriately assured from a public health perspective, given that the four regulated THM have very different toxicity,[1] so should intuitively have individual guideline values, or alternatively a tTHM guideline value which is based conservatively on the most toxic THM. Toxicity arising from THM cannot realistically be monitored by measuring only a tTHM concentration. Under a system with individual guideline values for each of the four regulated THM, lower toxicity THM (eg, chloroform) would be allowed at greater concentrations than the higher toxicity THM, rather than assuming an acceptable distribution of the four separate species and only taking into account their total concentration.

Four regions studied experience failures to adhere to the tTHM guideline value at least once over the monitoring period. Region A exceeded the guideline four times at the same sample location, equating to 4.5% of all samples taken in that area (Fig. 11). Region D exceeded the tTHM guideline value eleven times over the course of this survey, mostly in the summer months, equating to 8.3% of all samples taken in that area (Fig. 12). Considerable fluctuations in the distribution of individual THM was seen between sample locations within both region A and region D.

Region S exceeded the guideline concentration for tTHM ten times over twelve months of monitoring,

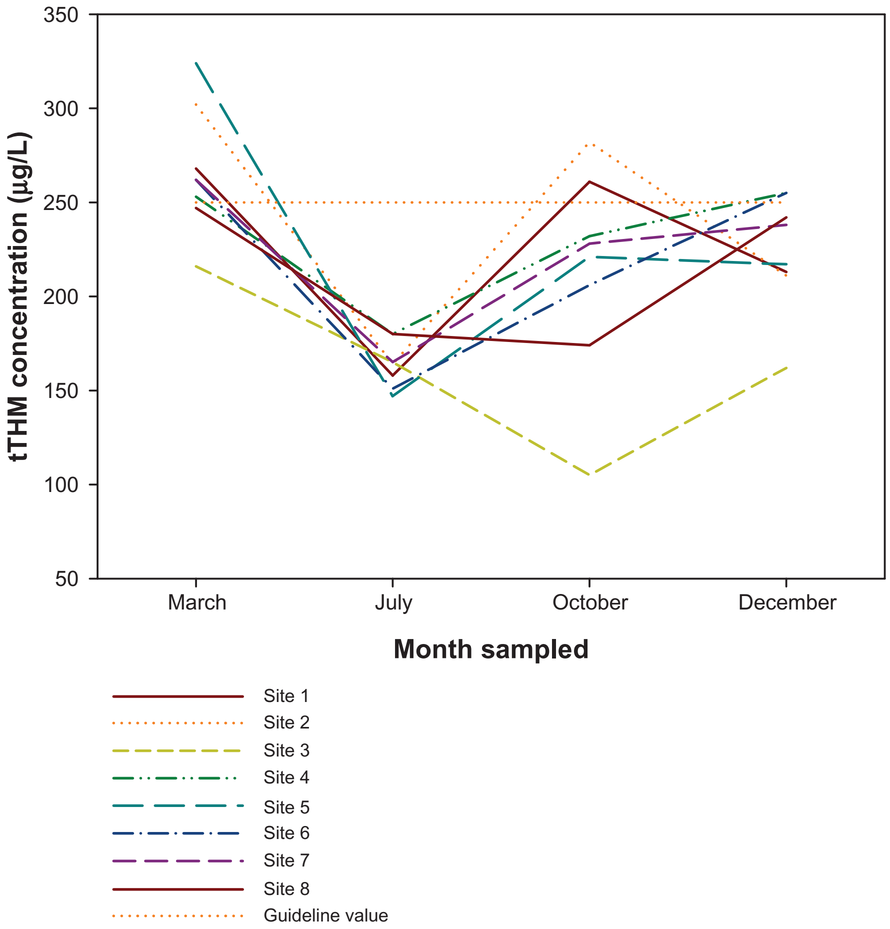

Figure 13. Variation in tTHM concentration in drinking water in region S over ten months.

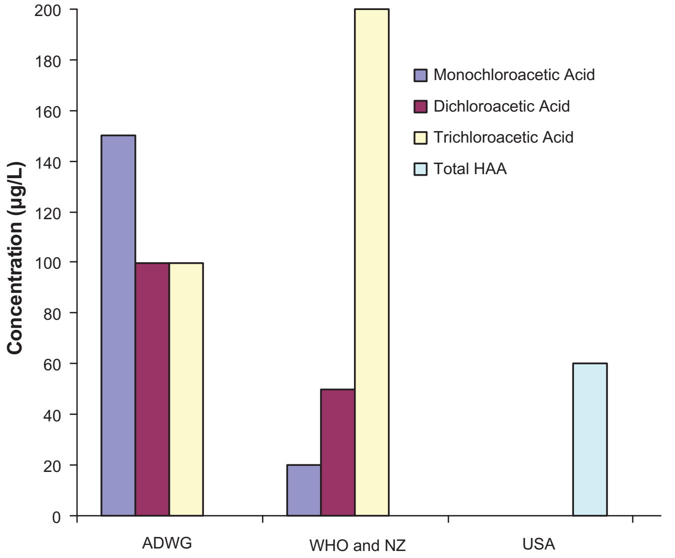

Figure 14. Worldwide guideline values for regulated HAA (current in 2010) Note: Total HAA is total of monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid and dibromoacetic acid.

which was 31.3% of all samples taken (Fig. 13). Region S's tTHM levels were the highest of all the regions surveyed. The distributions of the individual THM were similar between sample locations in this region. Finally, region O experienced 3 incidences of non-compliance to guidelines for tTHM over the survey period, equating to 7.1% of all samples taken in the area.

Regions Exceeding ADWG Values for HAA

Approximately 18% of surveyed regions had samples that exceeded the HAA ADWG guideline values (Fig. 14) at least once over the twelve month sampling period. The trichloroacetic acid guideline value was exceeded in 88% of these cases, with 12% of failures being attributed to high dichloroacetic acid. Monochloroacetic acid con-

Table 4. Mean annual concentration of regulated HAA in the various Queensland regions.

Region	Monochloroacetic acid	Dichloroacetic acid	Trichloroacetic acid
A	BRL	30	55
B	BRL	10	10
C	BRL	6	5
D	BRL	25	32
E	BRL	4	11
F	BRL	39	36
G	BRL	18	28
H	BRL	BRL	BRL
I	BRL	BRL	BRL
J	BRL	28	36
K	BRL	16	28
L	BRL	6	18
M	BRL	BRL	BRL
N	BRL	10	7
O	BRL	11	12
P	BRL	17	19
Q	BRL	6	7
R	BRL	8	8
S	BRL	11	45
T	BRL	BRL	BRL
U	BRL	14	18
V	BRL	55	81
W	BRL	15	10
X	BRL	9	15
Y	BRL	BRL	3
Z	BRL	7	10
AA	BRL	3	3
AB	BRL	16	17
AC	BRL	16	17
AD	BRL	25	31
AE	BRL	31	55
AF	BRL	11	10

Abbreviation: BRL, below reporting limit.

centrations were consistently within the ADWG values. Interestingly, only chlorinated waters had trichloroacetic acid concentrations that exceeded the guideline values. Overall, mean annual concentrations of HAA were low in comparison to their guideline values, as shown in Table 4. Over the time studied, the total concentration of the currently non-regulated HAA, monobromoacetic acid and dibromoacetic acid, was generally below the total concentration of regulated HAA. These brominated HAA are regulated in the USA and Canada, however they are yet to be regulated in Australia and New Zealand.

Figure 14 shows that Australia's guideline value for monochloroacetic acid of 150 μg/L is high compared to the WHO suggested guideline of 20 μg/L. However, concentrations found across Queensland were all below the method reporting limit of 10 μg/L. Thus, the introduction of stricter guidelines would appear to have little effect on compliance in these regions of Queensland. Similarly, Australia's guideline value for dichloroacetic acid of 100 μg/L is double the WHO recommended guideline of 50 μg/L, and in fact, about 19% of regions would fail to comply with this stricter guideline over the course of the twelve month monitoring period. Conversely, Australia's guideline value for trichloroacetic acid (100 μg/L) is more stringent than the WHO recommendation of a maximum of 200 μg/L. Although the Australian trichloroacetic acid guideline value was exceeded a number of times in the above regions, the WHO

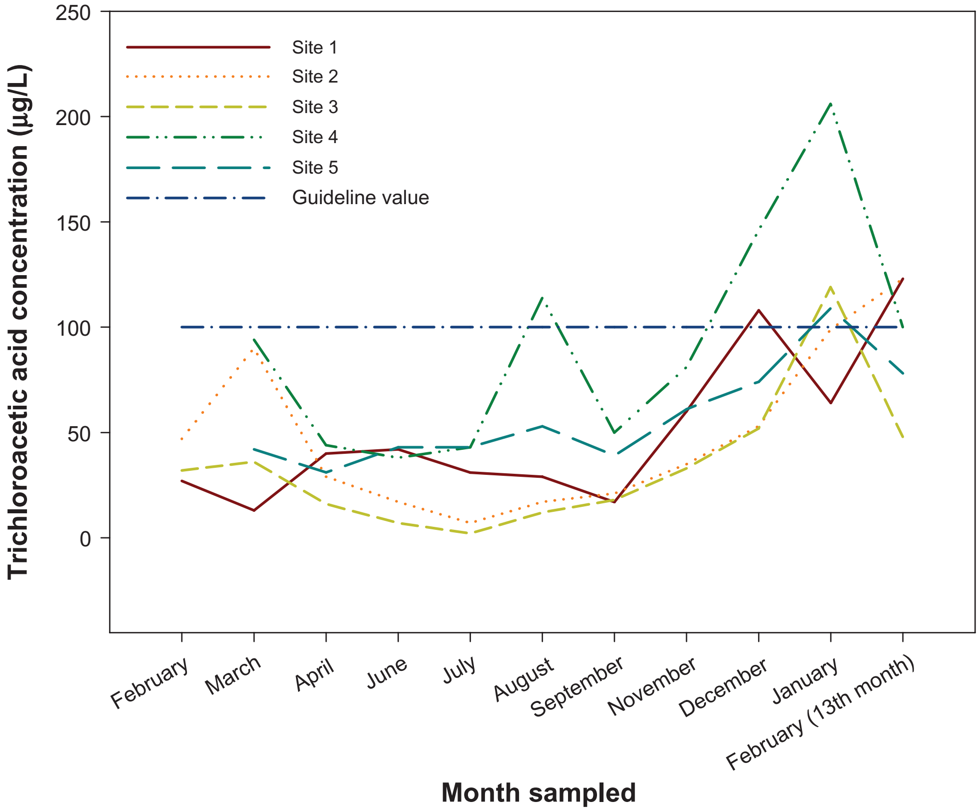

Figure 15. Trichloroacetic acid concentration in drinking water of region A.

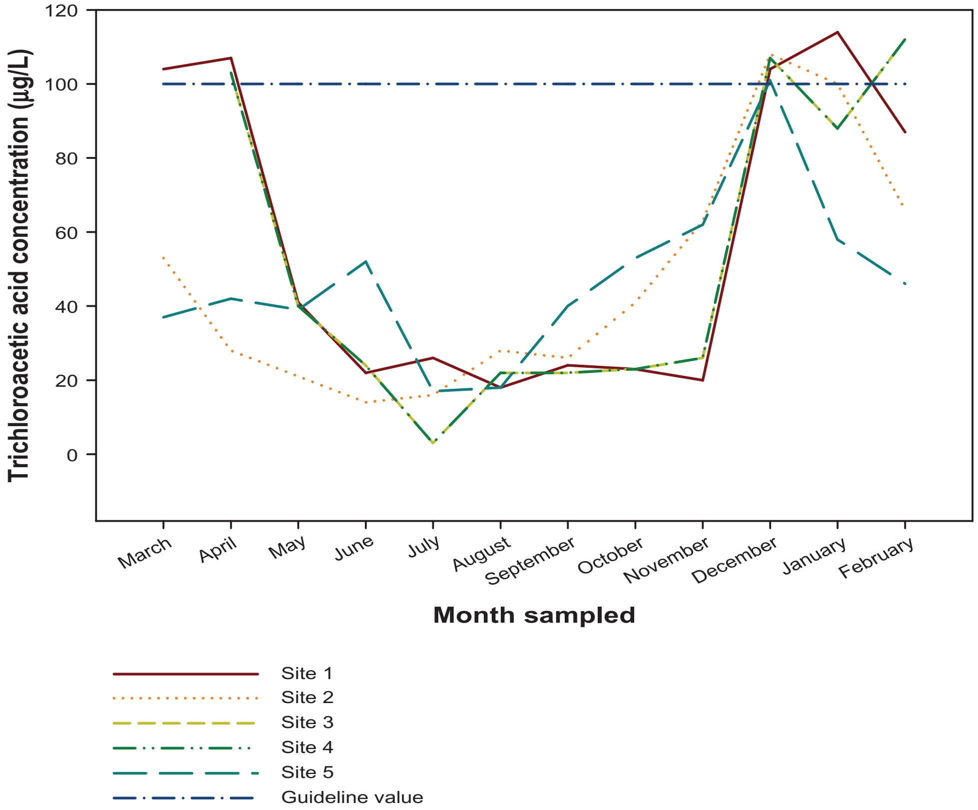

Figure 16. Trichloroacetic acid concentration in water from region D over twelve months of monitoring.

recommended concentration was rarely exceeded (1%). That is, trichloroacetic acid concentrations almost always complied with the WHO guideline value. Incidence of non-compliance to guideline values for trichloroacetic acid would probably be rare if WHO recommendations were adopted in Australia, however incidence of non-compliance to guideline values for dichloroacetic acid would be likely to increase.

Again, four regions experienced at least one failure to adhere to the ADWG for HAA over the one year monitoring period, with two of these regions being the same as those that failed to adhere to tTHM guidelines (regions A and D). All sample locations in region A had trichloroacetic acid concentrations in excess of guideline values over the sampling period. The trichloroacetic acid guideline value was exceeded ten times over the twelve months, equating to 15% of all samples taken. Figure 15 shows most failures occurred in the summer months.

Four sample locations in region D had trichloroacetic acid concentrations exceeding ADWG recommendations over the sampling period. The trichloroacetic acid guideline value was exceeded ten times over the twelve month monitoring period, which equals 7% of all samples taken in the area. Figure 16 shows that in this case also, most failures occurred in the summer months.

One sampling location in region G had a trichloroacetic acid failure over the monitoring period, in September (1.5% of all samples taken in that area). Finally, two sample locations had trichloroacetic acid failures in region AE, exceeding the guideline four times (8% of all samples taken in the area).

Conclusions

THM and HAA levels varied between different suppliers' water, and overall THM and HAA levels were within the regulatory limits for the majority of the time, with 12% of regions failing to adhere to guideline values for tTHM at least once over the one year sampling period and 18% of regions studied failing to adhere to guideline values for HAA at least once over the twelve months of monitoring.

Chlorinated waters in general had higher tTHM and HAA concentrations than combined chlorinated/chloraminated waters, with chloraminated waters having the lowest average tTHM and HAA concentrations overall. All failures to adhere to ADWG arose in chlorinated waters.

Total THM concentrations were generally higher in summer than in winter for all three disinfection processes. Also, the higher bromide and lower NOM concentrations of bore waters relative to surface waters led to a higher proportion of brominated THM in bore water and supplies supplemented with bore water.

Although bromoform and chloroform appeared at highest concentrations in chlorinated water supplies, BDCM and DBCM formed in the highest concentrations in chloraminated and blended chlorinated/chloraminated waters.

Of the 32 regions studied, six experienced some incidences of non-compliance to ADWG for DBPs over the time studied. This could be a result of, for example, high concentrations of organic material and/or bromide in the source water at the point of disinfection or high water age at the point of supply, however, without a specific investigation into water treatment and distribution in these regions the reasons are unclear. Importantly, all of these regions exclusively use chlorine disinfection, which contributes to the high concentrations of the observed DBPs.

From this work the recommendation would be to favour the use of chloramination rather than chlorination in Queensland drinking water, in order to attain lower THM and HAA concentrations. However, it is important to note that this study has focused only on these two classes of DBPs, which are known to be predominantly formed by chlorination, rather than by other disinfection methods.[1] Chloramination produces its own suite of DBPs, which are not all known at this time, therefore, although adherence to ADWG may be more readily attainable using chloramination, the risks of other, unregulated DBPs occurring at significant concentrations when using this disinfection strategy also needs to be considered.

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