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Taste and odour and public perceptions: what do our customers really think about their drinking water?

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ABSTRACT

Customers primarily perceive the safety of drinking water on aesthetic qualities. Chlorine, geosmin and 2-methylisoborneol (2-MIB) are common causes of taste and odour complaints in Australia. Variance in customer preference, perception, cultural differences and individual experiences make regulation of these, in the form of guidelines, challenging to establish. Here, analysis of historical water quality and customer complaint data showed the use of customer complaints as an indicator of deteriorating water quality is not robust. The use of a modified Flavour Ratings Assessment showed a statistical decrease in customer acceptance from control samples when chlorine concentration in drinking water increased above 0.2 mg/L and when geosmin or 2-MIB concentration was greater than 10 ng/L. However, geosmin was only rated 'unacceptable' at 30 ng/L while chlorine and 2-MIB were not rated 'unacceptable' for the range tested. For all samples, including 'blanks', customers indicated a greater tendency to complain in a social setting rather than formally to their water provider.

Key words | Australian Drinking Water Guidelines, customers, drinking water, organoleptics, sensory test, taste perception

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INTRODUCTION

The primary purpose of drinking water treatment is to provide safe, clean drinking water. In most countries, water quality monitoring programmes are in place to ensure drinking water is free of pathogens and potentially harmful chemicals. Regardless of the safety of drinking water, it is reported that customers primarily perceive safety based on aesthetic qualities (organoleptics) where an unusual taste, odour, mouth-feel or colour is perceived as an indicator of unsafe water (Jardine *et al.* 1999; Doria 2010).

Over recent years, the Australian water industry has experienced significant change with the widespread implementation of economic regulation. The Australian Drinking Water Guidelines (ADWG) (NHMRC & NRMMC 2011) present the acceptable levels of various microbiological and chemical contaminants of health concern and these guidelines have generally become state legislation throughout Australia. The ADWG also include aesthetic guidelines for many chemicals and other parameters, although limits for these components ultimately remain the discretion of drinking water providers.

Regulation, in the form of guidelines, of the aesthetic parameters of water is challenging to establish due to the variance in customer preference and perception, cultural differences and individual experiences (Jardine *et al.* 1999; Doria 2010). Aesthetics of water are important both for customer satisfaction and safety, considering that unpleasant taste and odour (T&O) may cause individuals to drink water from less safe water sources (for example, rainwater tanks) (WHO 2008). Some examples of guidelines applying to T&O of drinking water are provided in Table 1. These guidelines are subjective and difficult to implement in an objective and quantifiable manner for individual T&O causing compounds. Anecdotally, as a result of the variance among customer perception and preference and the subjective nature of these guidelines, water treatment plant (WTP) operators often rely on customer

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Table 1 | Guidelines for taste and/or odour of drinking water

Organisation	Guideline	Reference
World Health Organization	The appearance, taste and odour of drinking water should be acceptable to the consumer	WHO (2008)
The Council of the European Union	Acceptable to consumers and no abnormal change	The Council of the European Union (1998)
Health Canada	Inoffensive	Health Canada (2012)
Australian National Health and Medical Research Council	The taste and odour of water should not be offensive to most customers	NHMRC & NRMMC (2011)

T&O complaints as a trigger for making operational decisions such as when to dose activated carbon. This is likely to result in inconsistent operation across different systems and, if customers do not lodge complaints to the water utility, may result in poor water quality and poor customer satisfaction.

In Australia, three frequent sources of T&O complaints are (1) chlorine, (2) 2-methylisoborneol (2-MIB; musty flavour) and (3) geosmin (earthy flavour). Chlorine is a strong chemical oxidant used to disinfect drinking water in order to reduce the risk of waterborne disease (NHMRC & NRMMC 2011). The ADWG clearly state that for consumer safety chlorine must not exceed 5 mg/L with an aesthetic guideline of 0.6 mg/L. The ADWG also require that, for chlorinated distribution systems, there must be disinfection residual throughout the system. This means chlorine concentration must be high enough at the treatment plant to remain to the end of the distribution system. Naturally occurring geosmin (Gerber & Lechevalier 1965) and 2-MIB (Gerber 1969; Medsker *et al.* 1969) are terpenoid secondary metabolites. These compounds are known to be produced by cyanobacteria (Watson 2003) and actinomycetes (Gerber 1979) among other sources. There are no known health effects associated with geosmin and 2-MIB at naturally occurring levels (Nakajima *et al.* 1996); therefore, the ADWG does not specify a health-based guideline.

Conventional water treatment processes including coagulation, flocculation, sedimentation and media filtration are not effective at removing dissolved geosmin and 2-MIB in water to below detectable concentrations under normal circumstances (Srinivasan & Sorial 2011). A number of additional or alternative approaches are available, including powdered activated carbon (PAC) dosing, granular activated carbon (GAC) filtration, biofiltration, advanced oxidation processes or a combination of these treatments which are reviewed in detail by Srinivasan & Sorial (2011). Increasing chlorine dose at the treatment plant may also be performed with the goal of masking earthy/musty flavours. However, the efficacy of this practice is questionable (Oestman *et al.* 2004). Furthermore, increasing chlorine dose, and in turn chlorinous odour, can cause a decrease in customer satisfaction (McDonald *et al.* 2013). PAC dosing is the most common treatment for control of 2-MIB, geosmin as well as other organic parameters (Kennedy *et al.* 2013). This treatment is expensive, challenging and hazardous for WTP operators to handle as light powder can become airborne and inhaled during dosing (Srinivasan & Sorial 2011; Knoblauch 2013). With widespread introduction of economic regulation of the Australian water industry treatment costs, particularly those that do not relate directly to health-based targets, such costs must be justified. To do this it is necessary to understand the social perception of earthy/musty T&O caused by geosmin and 2-MIB.

The ADWG only provide a recommendation that water utilities may experience increased complaints at concentrations of geosmin or 2-MIB above 10 ng/L. This appears to be based on studies which show the odour threshold concentration (concentration when 50% of the population can detect an odour) of geosmin and 2-MIB at 10 ng/L (Young *et al.* 1996); then applying the assumption that any geosmin or 2-MIB detection will be considered offensive by customers. There are two flaws with this reasoning, first being that detection at low level may not be offensive, and second, that if it is offensive then 49% of customers can be provided offensive water and it will still meet ADWG recommendations. The only published study known to the authors that directly links customer complaints and geosmin concentration documented increased complaints when geosmin concentration in drinking water was greater than 45 ng/L; below 30 ng/L complaints were at background level (Burlingame et al. 1986). The ADWG guideline for T&O is 'The taste and odour of water should not be offensive to most customers'. This guideline is highly subjective and does not readily allow specific treatment targets to be set for geosmin and 2-MIB.

Here we investigate customer perceptions of the T&O of drinking water in the context of the subjective guideline described in the ADWG and the similar guidelines from other organisations working towards an evidence-based treatment target for 2-MIB and geosmin. In order to investigate perceptions, up to 12 years of historical chlorine, 2-MIB and geosmin concentration data from the South Australian Water Corporation (SA Water) were correlated to customer complaints specific to T&O (sorted according to SA Water call centre procedures). In addition, the Flavour Ratings Assessment Standard Method 2160C (APHA, AWWA & WEF 1998) was modified and applied to 107 volunteers to gain quantitative data on the levels of the three key T&O compounds (chlorine, geosmin and 2-MIB) that would cause a perceived deterioration in water quality.

METHODS

Complaint data

Twelve years of data (July 2000 to July 2012) relating to free chlorine, 2-MIB and geosmin concentrations at 'customer tap' sample points and WTP product water were extracted from SA Water's water quality database. Water quality analysis was performed as a routine monitoring programme by the National Association of Testing Authorities (NATA)-accredited Australian Water Quality Centre, Adelaide. Customer water quality complaints, classified by customer responses to standardised questions, over the same 12 year period were retrieved from SA Water's works management system. The frequency of customer complaints per month was normalised as a per cent of the population served by each treatment plant distribution system, and correlated to the maximum monthly chlorine, 2-MIB or geosmin concentration for that system. The statistical package R 3.0.1 (R Core Team 2013) with R Commander-guided user interface (Fox 2005) was used for linear regression analysis.

Drinking water systems

This broad and preliminary work investigated complaints across South Australia covering 64 drinking water systems which serve more than 1.5 million customers. These systems include sources of diverse surface waters (reservoirs and the Murray River), ground water and seawater. Treatment strategies include conventional treatment (coagulation, flocculation, sedimentation and media filtration), microfiltration, ultrafiltration, reverse osmosis, dissolved air flotation and filtration (DAFF), MIEX® resin pre-treatment (Orica Watercare), PAC dosing and GAC contact. Chemical disinfection strategies include chlorination and chloramination.

Sensory testing

The Flavour Ratings Assessment Standard Method 2160C (APHA, AWWA & WEF 1998) was simplified and adopted for this investigation. Water samples supplied to volunteers were tap water from the location of testing with added 2-MIB or geosmin, or tap water passed through a point-of-use filter with added chlorine. The investigation included chlorine concentrations representative of a South Australian metropolitan distribution system of 0, 0.2, 1, 2 and 3 mg/L and geosmin and 2-MIB concentrations of 0–30 ng/L equivalence.

It is important to note that only the (−) isomer of geosmin is formed naturally, synthetic geosmin contains the (+) and (−) isomers in equal proportions (a racemic mixture). The (+) isomer of geosmin is reported to have an 11-fold lower detection threshold (Polak & Provasi 1992) and is assumed to contribute negligibly to T&O in this investigation; therefore, the 'adjusted geosmin concentration' noted herein is 50% the racemic concentration.

Human subjects

Volunteers included water industry personnel and members of the public from metropolitan Adelaide, two regional South Australian locations and a location in regional Victoria, Australia. Metropolitan Adelaide is chlorinated and supplied by a desalination plant sourced from Gulf St Vincent as well as five conventional treatment plants and a DAFF plant. These plants treat surface water from ten reservoirs and the Murray River, all of which are susceptible to seasonal geosmin and 2-MIB issues from cyanobacterial growth. The two regional South Australian locations included a groundwater system with no filtration and disinfection by chlorine, and a chloraminated system with conventional treatment sourced from the Murray River. The regional Victorian system is chlorinated, supplied by surface water and treated by DAFF treatment plant, and this system has a history of T&O events related to 2-MIB. Volunteers were recruited through social media, Volunteers SA and internal communications from SA Water and Grampians Wimmera Mallee Water. Verbal informed consent for use of data was obtained from the 107 volunteers who included five aged 15–18, 26 aged 19–25, 19 aged 26–35, 29 aged 36–45, 15 aged 46–55, 10 aged 56–65 and three aged >65. Gender data were not recorded. No pre-screening or training of volunteers was performed in order to ensure that volunteers would best represent the diversity of water utility customers.

Plastic, 180 mL cups were removed from packaging 1 day prior to testing to allow any plastic/resin T&O to dissipate. Testing was undertaken in air conditioned rooms free of noise, distractions and odours. Approximately 30 mL of each sample at room temperature (20–24 °C) was added to cups in the order shown in Table 2. To retain sample odour 5 cm diameter Petri dishes were immediately placed on top of each cup. Each volunteer was asked to hold the sample in their mouth for a moment then discharge into supplied spittoons. Volunteers were then asked to mark next to the statement that best matched their feelings about each sample (Table 3), rinse with blank (tap water passed through a point-of-use filter) and move to the next sample. Other information gathered included town/suburb of residence, age group, main source of drinking water, whether or not they are wearing fragrant deodorant/perfume, any recent eating or drinking, smoking status and whether the volunteer would complain socially or formally if they were supplied with any of the sample waters.

For analysis of results, each statement was assigned a number between one and nine with nine being most acceptable (Table 3). Data were analysed by one-way or two-way analysis of variance (ANOVA) with Tukey multiple comparison of means using R 3.0.1 and R Commander-guided user interface (Fox 2005; R Core Team 2013).

Analysis

The 2-MIB and geosmin concentration in water samples supplied to volunteers was confirmed before and after sensory testing by headspace solid-phase microextraction and gas chromatography-mass spectrometry, limit of detection 4 ng/L. Full details of this method are documented in Graham *et al.* (1998). Free and combined chlorine concentration in sample waters was confirmed before and after sensory testing using Standard Method 4500-Cl (F), N,N-diethyl-p-phenylenediamine – ferrous ammonium sulphate titrimetric procedure (APHA, AWWA & WEF 1998).

RESULTS

Complaints data analysis

Correlation of T&O complaints to chlorine produced poor linear relationships, even after data were reprocessed to exclude points where no customer complaints were recorded and where chlorine concentration was at or below the limit of detection (LOD). The strongest linear relationships produced for geosmin and 2-MIB were only seen after reprocessing to remove zero data (Table 4). Other regression including exponential, logarithmic and polynomial were trialed with no strong correlations (data

Table 2 | Order (left to right) of samples presented to volunteers with sample details

Chlorine concentration (mg/L)					Adjusted geosmin concentration (ng/L)							2-MIB concentration (ng/L)						
1A	1B	1C	1D	1E	2A	2B	2C	2D	2E	2F	2G	3A	3B	3C	3D	3E	3F	3G
0	0.2	1	2	3	0	5	10	15	20	25	30	0	5	10	15	20	25	30
Tap water passed through point-of-use filter					Tap water							Tap water						

Table 3 | Statements used in the modified Flavour Ratings Assessment sensory test to rate the acceptability of samples. Associated numerical values were used for data analysis

Three-point scale	Nine-point scale responses	Value
Acceptable	I would be very happy to accept this water as my everyday drinking water	9
	I would be happy to accept this water as my everyday drinking water	8
	I am sure that I could accept this water as my everyday drinking water	7
	I could accept this water as my everyday drinking water	6
Indifferent	Maybe I could accept this water as my everyday drinking water	5
Unacceptable	I don't think I could accept this water as my everyday drinking water	4
	I could not accept this water as my everyday drinking water	3
	I could never drink this water	2
	I can't stand this water in my mouth and I could never drink it	1

not shown). Investigation of T&O complaints and geosmin and 2-MIB concentrations revealed events where concentrations were in excess of 13 times the ADWG recommended treatment target of 10 ng/L in several distribution systems without any recorded water quality complaints (Table 5).

Sensory test application

Individual samples and their respective concentrations of chlorine, geosmin and 2-MIB are shown in Table 2. Sample 2A, the first sample presented to the volunteer containing only tap water, not passed through a point-of-use filter, served as a control for the geosmin trial. Some volunteers responded that this plain tap water sample was not acceptable (Figure 1). Metropolitan Adelaide and regional Victorian volunteers indicated that this sample was acceptable at 76% and 81%, respectively. Volunteers from regional South Australia were less accepting at 60% with 36% indicating it was unacceptable.

Sensory testing responses from all volunteers were averaged and for each sample rounded to the nearest integer. All responses indicated decreasing acceptance with increasing concentration of chlorine, geosmin and 2-MIB (Figure 2). Overall chlorine acceptance showed a trend of decreasing acceptance with increasing concentration. However, at no point was the average response rated indifferent or unacceptable. A statistical approach indicated a deterioration in aesthetics at concentrations of 1 mg/L ($p = 1.5 \times 10^{-6}$) or greater (2 mg/L, $p = <2.2 \times 10^{-16}$; 3 mg/L, $p = <2.2 \times 10^{-16}$) compared to 0 mg/L control.

Both geosmin and 2-MIB were rated as 'acceptable' up to the 10 ng/L sample (Figure 2). Geosmin is rated unacceptable at the 30 ng/L sample, although 2-MIB is not rated 'unacceptable' for the range tested in this study. For both geosmin and 2-MIB, a significant decrease in volunteer acceptance is seen at concentrations greater than 10 ng/L (Figure 2).

Volunteers were also asked if they would complain socially (to friends, colleagues or on social media) or formally (to their drinking water provider) about the sample water if it were supplied to them. For chlorine, geosmin

Table 4 | Linear regression details for maximum monthly chlorine, geosmin and 2-methylisoborneol concentration against customer complaints as per cent population serviced by treatment plant. Using either: all available data; values below limit of detection removed; values where no complaints were registered; or both data below limit of detection and data where no complaints were recorded omitted

		All data	Omitted <LOD	Omitted 0 complaints per month	Omitted all 0 or <LOD data
Chlorine	R^2	0.0010	0.0006	0.0160	0.0148
	P-value	0.1402	0.2779	0.0011	0.0024
	n	2115	1963	665	619
Geosmin	R^2	0.1053	0.1028	0.1454	0.7754
	P-value	2.24×10^{-12}	1.12×10^{-7}	1.63×10^{-7}	$<2.2 \times 10^{-16}$
	n	445	262	177	175
2-MIB	R^2	0.0436	0.0441	0.3958	0.4041
	P-value	0.0352	0.0832	2.57×10^{-4}	2.57×10^{-4}
	N	102	69	29	18

Table 5 | Concentration of geosmin and 2-methylisoborneol in South Australian distribution systems where no associated water quality complaints were recorded

Geosmin			2-MIB		
System	**Detected concentration (ng/L)**	**Sample type**	**System**	**Detected concentration (ng/L)**	**Sample type**
A	131	Customer tap	B	155	WTP product
A	103	Customer tap	G	109	WTP product
B	81	WTP product	H	42	Customer tap
C	46	WTP product	D	35	Customer tap
A	35	Customer tap	B	25	WTP product
A	30	Customer tap	A	20	Customer tap
D	29	WTP product			
E	26	WTP product			
F	24	Customer tap			
D	22	WTP product			

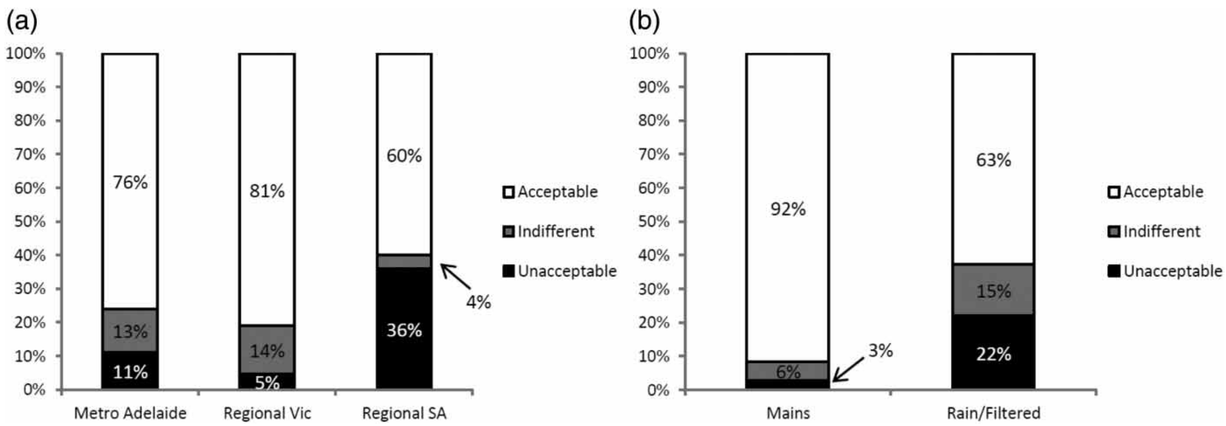

Figure 1 | Responses for sample 2A, 0 ng/L geosmin control (tap water only), by location (a) and source of water usually consumed (b).

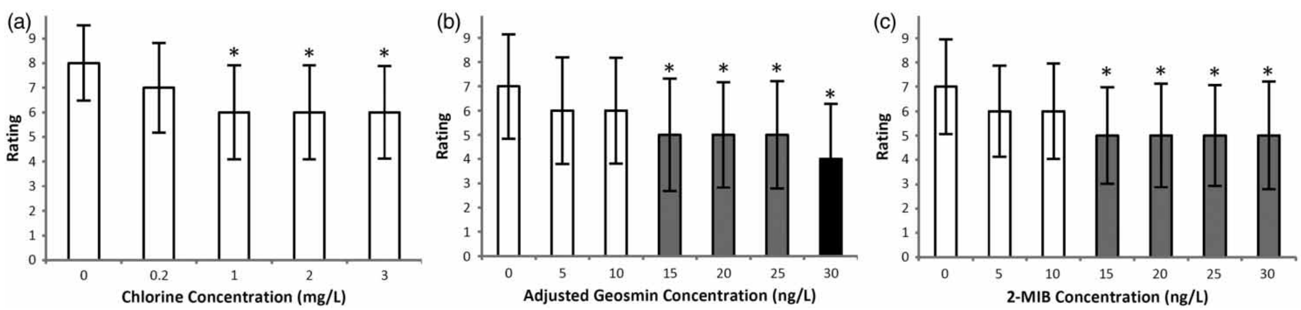

Figure 2 | Average rating for chlorine (a), geosmin (b) and 2-MIB (c) samples where rating is the numerical value assigned to statements used by volunteers (see Table 1) and colour represents acceptable (white), indifferent (grey) and unacceptable (black) ratings. Adjusted geosmin concentration is 50% the racemic geosmin concentration. Error shown is the standard deviation of the mean of up to 107 volunteer responses. Significance shown (*) is difference to the control sample by one-way ANOVA with Tukey multiple comparison of means at the 95% confidence interval.

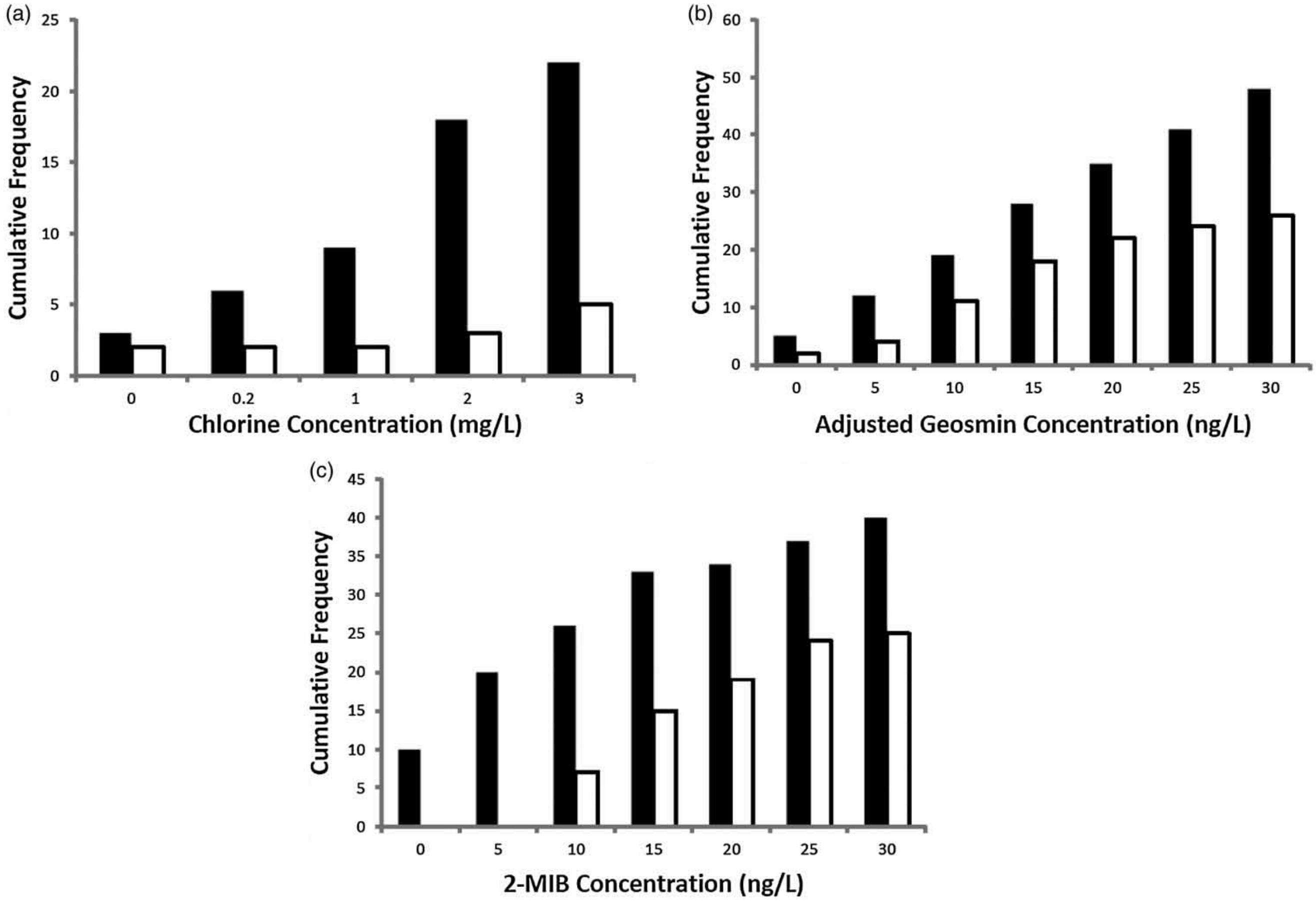

Figure 3 | Frequency of volunteers who responded that they would complain socially (black) and formally (white) if they were provided with sample water as their everyday drinking water. Adjusted geosmin concentration is 50% the racemic geosmin concentration.

or 2-MIB, volunteers indicated an inclination to complain socially with a greater frequency than formally (Figure 3).

DISCUSSION

Complaints data analysis

Anecdotal evidence suggests that in many water utilities customer complaints are used as an indicator of customer satisfaction. While an increase in customer water quality complaints should be a clear indication of decreasing customer satisfaction, it is hypothesised that an absence of customer complaints does not necessarily reflect a static level of water quality and customer satisfaction. This broad investigation into chlorine, geosmin and 2-MIB acceptance does not specifically investigate the impact of source waters, treatment strategies or disinfection strategies on customer perception; future research should be performed to determine how acceptance may change with these factors. For the purpose of addressing a nation-wide recommendation and guideline, a large diverse group of volunteers has been used and overall trends are investigated rather than individual T&O events specific to particular systems and demographics. In order to determine whether there is a link between customer complaints and water quality, customer complaints were correlated with chlorine, geosmin and 2-MIB concentrations over a period of 12 years (2000–2012). The lack of strong linear correlations between customer complaints and chlorine, geosmin and 2-MIB concentrations, in conjunction with the number of events with high geosmin or 2-MIB without any complaints (as well as responses by sensory test volunteers – discussed later) suggests that the frequency of complaints alone is not a robust indicator of either water quality or customer satisfaction.

Sensory testing

For the purposes of this study, a method for performing sensory tests that could provide a subjective response to the aesthetics of water samples was required. Three existing sensory test methods were considered for application in this study: the method detailed by Australian/New Zealand Standard™ (AS/NZS) 4020:2005 for the testing of products for use in contact with drinking water, the method used by SA Water WTP operators to assess odour, and three affective sensory test approaches described by Lim (2011). Of these, the Flavour Ratings Assessment, Standard Method 2,160C (APHA, AWWA & WEF 1998), based on a nine-point hedonic scale approach, was assessed as the most suitable primarily due to the subjective nature of responses which would allow assessment in the context of the ADWG taste and odour guideline. Other factors considered were expected costs, materials required and time demand for set up, completion, and data analysis. Table 3 shows the statements and the scaling used to measure the participant's acceptance or otherwise of the taste of the water samples. This method is used routinely by the City of Seattle, Washington, USA (Dietrich *et al.* 2004).

Hedonic scaling approaches to sensory testing have some limitations, reviewed in detail by Lim (2011). Context effects, where the volunteer will bias responses in order to utilise the entire range of ratings available, or to avoid the most extreme ratings in case a future sample is more or less pleasant, are potential sources of inaccuracy. The use of specific statements may minimise context effects and there did not appear to be any bias in volunteer responses in this study. Sensory fatigue, where sensitivity is reduced due to recent exposure, is a potential source of error and is the primary influence in ordering samples in increasing concentrations so as not to dull senses for future samples. The use of plastic disposable cups introduced a risk of a plastic odour contamination. Using glassware was not practical due to cost and time demand to set up and re-set the test, and paper cups were not used due to concern of imparting a papery sensation. Airing cups for one or more days allowed any plastic odour to dissipate.

The large sample size of 107 volunteers represents a robust data set suitable for statistical analysis and interpretation. While these data are non-parametric, Lim (2011) reported that parametric statistical approaches such as ANOVA are suitable for application to data obtained from hedonic scaling methods which satisfy normality. This study supports the principle that data obtained from hedonic scaling are normally distributed and therefore suitable for parametric data analysis without mathematical transformation.

Sensory test application

Sample 2A, plain tap water, was more widely accepted among sensory test volunteers from metropolitan South Australia and regional Victoria than regional South Australia. This can be explained due to a higher percentage of volunteers from these locations indicating that unfiltered mains water was their main source of drinking water. A larger percentage of respondents from the regional South Australia group indicated their main source of drinking water was rain water. While each rain water system is unique, these typically have lower taste than treated mains water and typically lack chlorine odour. This indicates that volunteers used to drinking mains water were highly accepting of it, at 92%, whereas volunteers who indicated they mainly drink rain or point-of-use filtered water were less accepting, at 63%. It is uncertain whether volunteers were less accepting of mains water because they are accustomed to water with different T&O; or if these people drink the water of different T&O because they find the taste of mains water unacceptable. It is expected that both scenarios are influencing factors in customer choice. It is also noted that customer choice to drink tap water can be influenced by the perception of safety (Dupont *et al.* 2010), although no comments regarding safety of tap water were noted here.

The effect of temperature was not investigated in this study but is important to note. The intensity of T&O causing compounds including chlorine, geosmin and 2-MIB is reported to increase at an elevated temperature (Whelton

& Dietrich 2004). Here, room temperature was chosen to reflect water that is taken directly from a household tap. Future work should investigate the acceptance of waters containing these T&O causing compounds in relation to temperature but these investigations should consider relative exposure times that customers have to water at different temperatures.

Chlorine odour was rated acceptable at all concentrations used for disinfection in South Australian metropolitan areas and is seen here to adhere to the ADWG taste and odour guideline of 'the taste and odour of drinking water should not be offensive to most customers' as well as specific chlorine guidelines. However, a statistical approach indicated a deterioration in aesthetics at concentrations of 1 mg/L or greater. The deterioration in aesthetics is important as it may cause customers to seek less safe sources of drinking water (WHO 2008). The importance of maintaining chlorine residual for the removal of pathogenic organisms to protect public health (NHMRC & NRMMC 2011) is paramount and should have greater priority than aesthetic preferences when considering water quality issues.

Samples containing geosmin or 2-MIB were rated as acceptable up to 10 ng/L, above this concentration a significant decrease in acceptance was seen. These results are in agreement with the ADWG treatment goal recommendation. In contrast, interpreting these results in the context of the guideline suggests that 25 ng/L geosmin could be appropriate as samples are not rated as unacceptable. It is clear that this subjective guideline is not suitable for application to geosmin and 2-MIB as doing so would result in poor customer acceptance.

Asking volunteers whether they were likely to complain about the water and whether that would be in a social or formal context was included to investigate an anecdotal high level of dissatisfaction regarding the T&O of water (observed through personal conversation and social and mainstream media) and a proportionally low level of customer calls for T&O complaints. For chlorine, geosmin or 2-MIB, volunteers indicated an inclination to complain socially with a greater frequency than formally. This reinforces the notion that customer complaints are not necessarily a robust indicator of customer satisfaction and, in turn, water quality. Without seeking these complaints from customers the water utility may miss an important source of monitoring drinking water quality. Water utilities may overestimate customer satisfaction if they rely on customer complaints alone and should make themselves available to receive customer feedback in modern ways, perhaps via social media for example. It is interesting to note that a small number of volunteers indicated a tendency to complain for control samples, such as Sample 2A; this result may be a factor of social influences and context effects discussed by Lim (2011) and Dupont et al. (2010).

CONCLUSIONS

This body of work has investigated general trends in customer acceptance of three common sources of taste and odour issues in Australia. It is necessary to understand the social perception of T&O in order to justify water treatment costs in an increasingly economically regulated industry. Here, a modified Flavour Ratings Assessment method allows for subjective assessment of water taste and odour. Overall, volunteer responses show chlorine is acceptable at the concentrations seen in a metropolitan distribution system despite a significant decrease in acceptance from 0 to 1 mg/L and above. Chlorine residual must be detectable throughout the distribution network, therefore this decrease in acceptance is important to note but should not drive water utilities to compromise disinfection residual for improved aesthetics alone. A significant decrease in customer acceptance is observed when geosmin or 2-MIB concentration is greater than 10 ng/L. This result supports the ADWG treatment recommendation that geosmin and 2-MIB should not exceed a concentration of 10 ng/L which should be considered for adoption by water utilities. However, the ADWG general taste and odour guideline would indicate that a concentration of 25 ng/L geosmin or >30 ng/L 2-MIB would be compliant despite a significant decrease in acceptance. Finally, volunteers indicated a greater tendency to complain socially than formally, indicating that the absence of customer complaints may not reflect a static level of customer satisfaction and that utilities may be overestimating customer satisfaction if relying on customer complaints alone.

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REFERENCES

APHA, AWWA & WEF 1998 *Standard Methods for the Examination of Water and Wastewater*, 20th edn. American Public Health Association, Washington, DC.

Burlingame, G. A., Dann, R. M. & Brock, G. L. 1986 A case study of geosmin in Philadelphia's water. *J. Am. Water Works Assoc.* **78** (3), 56–61.

Dietrich, A. M., Hoehn, R. C., Burlingame, G. A. & Gittelman, T. 2004 *Practical Taste-and-Odor Methods for Routine Operations: DECISION TREE*. Awwa Research Foundation, Denver, CO.

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

Dupont, D., Adamowicz, W. L. & Krupnick, A. 2010 Differences in water consumption choices in Canada: the role of socio-demographics, experiences, and perceptions of health risks. *J. Water Health* **8** (4), 671–686.

Fox, J. 2005 The R Commander: a basis-statistics graphical user interface to R. *J. Stat. Software* **14** (9), 1–42.

Gerber, N. N. 1969 A volatile metabolite of actinomycetes, 2-methylisoborneol. *J. Antibiot.* **22** (10), 508–509.

Gerber, N. N. 1979 Volatile substances from actinomycetes: their role in the odor pollution of water. *CRC Crit. Rev. Microbiol.* **7** (3), 191–214.

Gerber, N. N. & Lechevalier, H. A. 1965 Geosmin, an earthly-smelling substance isolated from actinomycetes. *Appl. Microbiol.* **13** (6), 935–938.

Graham, D. & Hayes, K. P. 1998 Application of solid phase microextraction for the analysis of off-flavours in water. Proceedings of the WaterTECH Conference, 26–29 April, Brisbane, Australia.

Health Canada 2012 *Guidelines for Canadian Drinking Water Quality*. Federal-Provincial-Territorial Committee on Drinking Water, Ottawa, Canada.

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

Kennedy, M., Steele, M., Chapman, M. & Mallia, H. 2013 Fast-track augmentation of an existing DAFF system with powdered activated carbon for organics removal. *Ozwater'13*. Australian Water Association, Perth, Western Australia.

Knoblauch, J. 2013 Rethinking PAC handling. *Water Works May*.

Lim, J. 2011 Hedonic scaling: A review of methods and theory. *Food Qual. Prefer.* **22** (8), 733–747.

McDonald, S., Joll, C., Lethorn, A., Loi, C. & Heitz, A. 2013 Drinking water: the problem of chlorinous odours. *J. Water Supply Res. Technol.-AQUA* **62** (2), 86–96.

Medsker, L. L., Jenkins, D., Thomas, J. F. & Koch, C. 1969 Odorous compounds in natural waters. 2-exo-Hydroxy-2-methylbornane, the major odorous compound produced by several actinomycetes. *Environ. Sci. Technol.* **3** (5), 476–477.

Nakajima, M., Ogura, T., Kusama, Y., Iwabuchi, N., Imawaka, T., Araki, A., Sasaki, T., Hirose, E. & Sunairi, M. 1996 Inhibitory effects of odor substances, geosmin and 2-methylisoborneol, on early development of sea urchins. *Water Res.* **30** (10), 2508–2511.

NHMRC & NRMMC 2011 *Australian Drinking Water Guidelines Paper 6 National Water Quality Management Strategy*. National Health and Medical Research Council and National Resource Management Ministerial Council. Canberra, Commonwealth of Australia.

Oestman, E., Schweitzer, L., Tomboulian, P., Corado, A. & Suffet, I. H. 2004 Effects of chlorine and chloramines on earthy and musty odors in drinking water. *Water Sci. Technol.* **49** (9), 153–159.

Polak, E. H. & Provasi, J. 1992 Odor sensitivity to geosmin enantiomers. *Chem. Senses* **17** (1), 23–26.

R Core Team 2013 *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.

Srinivasan, R. & Sorial, G. A. 2011 Treatment of taste and odor causing compounds 2-methyl isoborneol and geosmin in drinking water: A critical review. *J. Environ. Sci.* **23** (1), 1–13.

The Council of the European Union 1998 Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

Watson, S. B. 2003 Cyanobacterial and eukaryotic algal odour compounds: signals or by-products? A review of their biological activity. *Phycologia* **42** (4), 332–350.

Whelton, A. J. & Dietrich, A. M. 2004 Relationship between intensity, concentration, and temperature for drinking water odorants. *Water Res.* **38** (6), 1604–1614.

WHO 2008 *Guidelines for Drinking-Water Quality*. WHO Press, Geneva, Switzerland, 668.

Young, W. F., Horth, H., Crane, R., Ogden, T. & Arnott, M. 1996 Taste and odour threshold concentrations of potential potable water contaminants. *Water Res.* **30** (2), 331–340.

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