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**National Occurrence of
N-Nitrosodimethylamine (NDMA)**

An Investigation of 38 Australian Drinking Water Supplies

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To date, limited exposure data have been published on *N*-
nitrosodimethylamine (NDMA) occurrence in Australian
drinking water. Here, we present a comprehensive analysis of

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data from the largest survey of NDMA in Australian drinking water, with a total of 211 samples, from 38 drinking water treatment plants across five states and one territory. Samples were collected at the treatment plants after disinfection as well as in the distribution systems. Only nine water treatment plants reported NDMA above 5 ng/L. NDMA was detected in more than half of the samples collected (57 of 87) from these plants, but all detections were below the Australian Drinking Water Guideline (100 ng/L). In agreement with other studies, NDMA was more frequently detected in chloraminated waters than chlorinated waters. The dosing of certain coagulant aids, and addition of ammonia prior to chlorine during chloramination were key factors in the formation of NDMA. Overall the results show that the drivers for NDMA formation in Australia are similar to those found in other studies worldwide.

Introduction

The formation of *N*-nitrosodimethylamine (NDMA) in disinfected water supplies has attracted worldwide attention, given it has been classified as a potent carcinogen (1). Health guidelines for NDMA adopted by agencies around the world range from between 9 and 100 ng/L (2-6). NDMA has been detected in both chlorinated and chloraminated drinking waters, although higher concentrations have generally been associated with systems using chloramine as the disinfectant (7-9). While reported NDMA concentrations in drinking water supplies have tended to be lower than 10 ng/L (10), higher concentrations (>100 ng/L) have been observed with increasing residence time in the distribution system (11-13). Some studies have also reported the presence of NDMA in some raw waters (i.e. without disinfection) (12, 14). Factors that impact NDMA formation in drinking water include source water quality and the presence of precursors (15-17), choice of disinfectant (8, 12, 14), operational parameters such as pH or disinfectant dose (16), use of ion-exchange resins or certain nitrogen-containing coagulants (7, 18), and the residence time in distribution systems (11-13).

While some monitoring programs have been established by state water authorities or water utilities, there are limited published data on NDMA occurrences in Australian drinking water. This paper consolidates results of NDMA occurrence surveys collected across five states and one territory in Australia between 2007-2013, representing the most comprehensive analysis of NDMA concentrations in Australian drinking water supplies. Survey data were

analysed to determine the impact of water treatment processes on NDMA formation, and to identify key factors in the formation of NDMA in Australian drinking water treatment plants (DWTPs).

Methods

Sample Sites

A total of 211 samples were collected from 38 DWTPs around Australia (five states and one territory) between 2007 and 2013, with the majority (85%) collected between 2009 and 2011. The samples were collected as part of individual studies or monitoring programs undertaken by research organisations across Australia, and data were subsequently combined for this study. The DWTPs studied included ten from Victoria, three from New South Wales, two from South Australia, all studied by the Australian Water Quality Centre (AWQC), ten from Western Australia and three from the Northern Territory, studied by the Curtin Water Quality Research Centre (CWQRC), and ten from Queensland, studied by the Smart Water Research Centre (SWRC) at Griffith University, and the Advanced Water Management Centre (AWMC) at the University of Queensland. While some studies did test for other *N*-nitrosamines in addition to NDMA, there were significant variations in analytical method and limits of reporting. Therefore this paper discusses NDMA occurrence only as it was the only *N*-nitrosamine measured in all studies.

In terms of disinfection, 18 of the 38 DWTPs tested used chlorine and 14 DWTPs used chloramine. Six plants used mixed disinfection treatment trains; four plants used pre-ozonation followed by chlorination or chloramination (DWTPs 29, 31, 37 and 38) and two plants used UV disinfection in addition to chlorine or chloramine disinfection for additional microbial protection (DWTPs 14 and 24). Figure 1 shows the general classification of these DWTPs according to pre-treatment process before disinfection. Disinfection (chlorination or chloramination) was the sole treatment process for eight DWTPs (21%), while four plants (11%) utilised filtration (e.g., granulated activated carbon or membrane filtration) or sedimentation without coagulation before disinfection. One disinfection-only plant (DWTP 15) that utilised chloramine is unusual because the raw water reservoir includes pre-treated groundwater, surface water and desalinated water, and both chloramination and chlorination are used in the large distribution system to maintain residual. All other DWTPs (26, 68%) utilised coagulation for treatment, with 15 plants following a relatively conventional treatment process (coagulation, flocculation, sedimentation, filtration and disinfection, with pH adjustment and pre-chlorination as required). Four plants (DWTPs 2, 3, 23, and 30) utilised coagulation and direct filtration

(e.g. membranes or dissolved air flotation and filtration) instead of clarification by sedimentation. Seven DWTPs had atypical aspects to their pre-treatment, including incorporation of desalinated water (DWTPs 5 and 36), use of ion exchange resins for NOM removal (DWTP 21), and ozonation throughout the treatment process (DWTPs 29, 31, 37 and 38). The target chlorine or chloramine residuals leaving each DWTP were generally between 1 and 3 mg/L, although three chloramination plants (DWTP 14, 15 and 26) servicing large distribution systems had treatment plant target residuals of between 3 and 4.5 mg/L.

Figure 1. General classification of DWTPs surveyed in this study according to treatment type (percentages reported as percent of total number of drinking water treatment plants (DWTPs)).

In addition to sampling, operational data were collected for each plant, including description of the treatment regime, the use and dose of primary coagulants and coagulant aids, disinfection dose(s), pH, target disinfectant residual leaving the plant, and system detention time at the sampling point. In the case of chloramination, details of the order and time between chlorine and ammonia addition were also obtained. Where possible, operational parameters were obtained for the exact dates when samples were collected, although for some DWTPs or systems little or no data were available and collection of operational data were challenging for systems where the water authorities providing distribution system water samples were not responsible for initial

water treatment. Physicochemical characteristics such as pH, total dissolved solids (TDS), temperature, dissolved organic carbon (DOC) and disinfectant residuals were also recorded for raw and treated water samples, where possible.

Sampling and NDMA Analysis

Table 1. Details of sampling and analytical methods for NDMA for each laboratory

<i>Laboratory</i>	<i>AWQC</i>	<i>CWQRC</i>	<i>QHFSS</i>
Preservation Agent	Sodium thiosulphate pentahydrate 120 mg/L	Ascorbic acid 20 mg/L	Sodium thiosulphate 80-100 mg/L
Sample volume	500 mL	1000 mL	1000 mL
Blanks	Tap water treated with UV light	Ultrapure water and quenching agent	Ultrapure water
SPE cartridge resin	35-50 mesh activated charcoal	LiChrolut® EN and Carboxen™ 572	Coconut charcoal
Ionisation mode (GC-MS)	Positive CI with isobutane	Positive CI with ammonia	Positive CI with ammonia

Samples were collected in glass amber bottles or aluminium foil-covered polyethylene bottles containing a quenching agent, kept cool and in the dark in an ice box during transport to the laboratory, and then refrigerated in the dark at 4°C until extraction. All laboratories used laboratory blank samples to quantify contamination introduced through the analytical process. In addition, CWQRC also included trip and field blanks in each sampling event to determine if there was any contamination through the sampling process, storage and transport. Trip blanks remained unopened until analysis, and field blanks were opened at each sampling location. Samples were then analysed for NDMA at one of three laboratories, AWQC, CWQRC or Queensland Health Forensic and Scientific Services (QHFSS). Analysis was carried out using solid-phase extraction (SPE) followed by gas chromatography-mass spectrometry (GC-MS), with minor variations between laboratories. Details of small variations between the sampling protocol and analytical method used by each laboratory are listed in

Table 1. The concentration of NDMA was quantified against a deuterated internal standard (isotope dilution procedure) and the limits of reporting (LOR) ranged between 1 ng/L and 5 ng/L.

All three laboratories undertook two rounds of inter-laboratory comparison testing as part of the NDMA survey undertaken by the AWQC and funded by Water Quality Research Australia (WQRA, now known as Water Research Australia Ltd). During each round, duplicate samples containing between 10 and 130 ng/L NDMA were sent to each independent laboratory for analysis. Results obtained from CWQRC and QHFSS compared well with those of the AWQC. With the exception of one sample, all results were within 13% relative standard deviation (RSD) (19).

Data Analysis

All data, excluding blanks and replicates, were pooled into a common dataset. The normality of the dataset was tested by calculation of the Kolmogorov-Smirnov Statistic and the Shapiro-Wilk Statistic (SPSS Statistics v20) and the data were found to have a poor fit to the normal distribution curve. Therefore median was chosen for data analysis rather than average because it is less affected by outliers and because it is more suited for data that does not follow a normal distribution. As the LOR for NDMA analyses varied for each of the testing laboratories, the highest LOR was chosen as the limit for all samples. Therefore if a result was < 5 ng/L then it was allocated a value of < 5 ng/L (i.e. zero for calculations), and this will influence percentage detection calculations and other statistics.

Calculation of median concentrations incorporated all data points including samples reported to be below LOR, and these were assumed to be equal to the LOR for the purposes of that calculation. While this conservative approach will overestimate the actual median concentration of chemicals reported below LOR in more than 50% of samples, it was deemed appropriate given our primary goal of assessing the safety of treated drinking water. As most samples ($>80\%$) did not contain NDMA above the LOR, average and median concentrations were also calculated solely based on samples in which NDMA ≥ 5 ng/L.

Results & Discussion

Overview of Occurrence Data

A total of 211 post-disinfection samples were collected and analysed in this study. Of these, 95 samples were collected at, or within 2km of, the treatment

plant and 116 were collected in the distribution system. The Australian Drinking Water Guidelines recommend maintaining a chlorine or chloramine residual greater than 0.5 mg/L for control of *Naegleria fowleri* (1) and therefore we expected disinfectant residual throughout the distribution system. Disinfectant residual data collected in 27 of the 38 DWTP confirmed this, although the residual was not always > 0.5 mg/L.

Figure 2. Distribution of NDMA concentrations in all water samples. There was a higher frequency of detection and higher concentrations in chloraminated samples than in chlorinated samples.

Figure 2 shows that the majority (80%, n = 169) of all samples contained NDMA concentrations below 5 ng/L, while 12% (n = 25) contained NDMA concentrations between 5 and 10 ng/L. As the majority of all disinfected samples measured NDMA below 5 ng/L, the median concentration of all disinfected samples was also < 5 ng/L. Of the 211 disinfected samples, 126 were from chloraminated systems while the remaining 85 were from chlorinated systems. Figure 2 shows that only 5% of samples (n = 4) from chlorinated systems contained NDMA above 5 ng/L. On the other hand, 30% (n = 38) of samples from chloraminated systems were measured with NDMA levels of 5 ng/L or higher. Chloraminated samples also recorded a much higher maximum NDMA concentration (74 ng/L) than the chlorinated samples (14 ng/L).

Further data analysis demonstrated that all NDMA detects ≥ 5 ng/L were from nine specific DWTPs, where 48% of all samples (n = 88) contained NDMA > 5 ng/L (Table 2). There was a wide variation in observed NDMA

levels, with two DWTPs (4 and 14) exhibiting significantly higher levels of NDMA (up to 46 ng/L and 74 ng/L, respectively) than the other plants. The high NDMA concentrations measured in DWTP 4 and 14 have previously been studied, and were attributed to factors that include poor source water quality, the method of chloramination and DWTP management practices (20). Despite these results, all detections were below the Australian Drinking Water Guideline of 100 ng/L for NDMA.

As shown in Table 2, where NDMA was present at ≥ 5 ng/L, the median concentration for distribution system samples was generally higher than for treatment plant samples, with the exception of DWTP 4. In addition, a higher percentage of distribution system samples contained NDMA compared to the treatment plant samples (30% versus 8%). This is consistent with results of other surveys suggesting that NDMA can continue to form and increase with time in the distribution system (11-13).

Table 2. Summary of the percentage detections, median and maximum NDMA concentrations observed for each of the nine DWTPs that detected NDMA in one or more samples. TP = treatment plant; DS = distribution system. Results are determined using the maximum LOR for these nine DWTPs (3 ng/L).

<i>Plant No. and Disinfection type</i>	<i>% detect ≥ 3 ng/L (total no. samples)</i>	<i>Median (maximum) (ng/L)</i>	<i>Median of TP samples (ng/L)</i>	<i>Median of DS samples (ng/L)</i>
2 Chloramine	67% (9)	3 (12)	n.a.	3
3 Chloramine	67% (6)	4 (5)	4	4
4 Chloramine	100% (6)	53 (74)	74	39
5 Chloramine	75% (4)	7 (21)	<3	15
9 Chlorine	44% (9)	< 3 (9)	n.a.	< 3
10 Chlorine	33% (9)	< 3 (14)	n.a.	< 3
13 Chloramine	100% (9)	7 (10)	4	8
14 Chloramine	100% (9)	19 (46)	15	23
15 Chloramine	50% (26)	< 3 (10)	<3	4

n.a. = not available; no TP samples were analysed at these plants.

Influence of Operational Parameters on NDMA Formation in Chloraminated Systems

While there was insufficient data to investigate NDMA formation in chlorinated DWTPs due to the limited number of detections, the dataset was

further evaluated to assess the factors influencing NDMA formation in the 16 chloraminated systems.

Table 3. NDMA occurrence and corresponding factors (Y = Yes, N = No) in chloramination plants. Plants in which NDMA was detected are bolded. n.d. = not detected, n.a. = data not available

<i>Plant No.</i>	<i>Median NDMA ng/L</i>	<i>Polymer used as coagulant aids</i>	<i>Addition of ammonia first</i>	<i>Raw Water DOC >10 mg/L</i>
2	3	Y	N	n.a.
3	4	Y	Y	N
4	53	N	Y	Y
5	7	Y	Y	Y
6	n.d.	N	n.a.	n.a.
7	n.d.	N	n.a.	n.a.
8	n.d.	N	n.a.	n.a.
12	n.d.	Y	N	N
13	7	Y	N	Y
14	19	Y	Y	Y
15	3	N	Y	N
25	n.d.	N	N	n.a.
26	n.d.	N	N	n.a.
27	n.d.	N	N	n.a.
36	n.d.	Y	N	n.a.
38	n.d.	N	N	n.a.

Relationships between operational parameters and NDMA concentrations in chloraminated waters were initially assessed by calculation of Spearmans’s correlation coefficients (SPSS Statistics v20). However, it was found that correlations were heavily skewed by the significantly higher NDMA concentrations reported in DWTP 4. Furthermore, the dataset was quite limited as only seven of the 16 chloraminating DWTPs had detections of NDMA in their waters. Instead, the dataset was qualitatively evaluated with focus on impact of chloramination practice (order of reagent addition and contact time), use of nitrogen-containing coagulants and coagulant aids, as well as raw water

chemistry on NDMA formation. Table 3 presents a summary of the key factors and NDMA concentrations in the 16 DWTPs using chloramination. The influence of these factors on formation of NDMA are discussed in detail below.

Chloramination Practice

The order of chlorine and ammonia addition during chloramination has previously been reported to have a significant effect on NDMA formation (18, 21-23). Contact with free chlorine prior to ammonia addition can reduce NDMA formation, because chlorinated NDMA precursors tend to be less reactive (22-24). In contrast, the addition of chlorine after ammonia has been shown to enhance NDMA formation from dimethylamine, a model NDMA precursor, by up to an order of magnitude (22). This increase was attributed to the localised formation of dichloramine at the point of chlorine addition, due to high localised Cl:N ratio. NDMA formation from dichloramine is higher than from monochloramine.

The disinfection practice at eight of the 16 chloraminating DWTPs in this study was to chlorinate prior to adding ammonia, while five DWTPs added ammonia prior to chlorine. There was no chloramination information available for the remaining three plants (21 samples). Typically, the time between addition of ammonia and chlorine ranged from seconds to a few minutes but DWTPs that added chlorine first employed a longer contact time (2.5-30 hours). Table 4 compares NDMA concentrations for DWTPs that use the two different reagent addition scenarios. Only two of the eight DWTPs that practise chlorine addition first, had NDMA detected post-disinfection, while all five plants that practised ammonia addition first had NDMA detected in one or more of their samples. Higher NDMA concentrations were also found in waters that were treated with ammonia first compared to those that were treated with chlorine first. The two DWTPs with the highest average NDMA concentrations (DWTP 4 and 14) both added ammonia before chlorine.

Table 4. Distribution of NDMA concentrations in chloraminated samples based on order of addition of chlorine and ammonia.

<i>Order of addition</i>	<i>% detect ≥ 5 ng/L (total no. of samples)</i>	<i>Median (ng/L)</i>	<i>Maximum (ng/L)</i>
Chlorine first	19% (54)	< 5	12
Ammonia first	55% (51)	6	74

Coagulation and Coagulation Aids

Most of the DWTPs in this study (25 out of 38) used coagulation as part of their water treatment process. Alum was the most commonly used coagulant, but other coagulants such as ferric chloride and Magnasol 489, a mixture of polyaluminium chlorohydrate and polydiallyldimethyl ammonium chloride (polyDADMAC), were also used. The primary coagulant dose varied greatly, ranging from 5 mg/L to 240 mg/L. There was no correlation observed between the primary coagulant dose and NDMA concentration in the treated water. In some instances where no coagulant was used, NDMA was still observed in the final product water suggesting the presence of precursors in the raw water.

Fifteen of the DWTPs also employed various coagulant aids, which varied in dose, ranging from 0.005 mg/L to 4.7 mg/L. Even though higher coagulant doses can potentially remove more NDMA precursors, the use of certain coagulant aids can potentially add NDMA precursors to the water. For example, polyDADMAC, a nitrogen-based polymeric coagulant has received attention for its reported propensity to form NDMA during chloramination (18, 25). PolyDADMAC was used in some water treatment plants in South Australia and Queensland, including some of the DWTPs presented here.

While there was no clear evidence to suggest that the generic use of coagulant aids resulted in higher level of NDMA in the disinfected water, when coagulant aids were utilised, NDMA was only observed when polyDADMAC and/or Magnafloc LT22 was used in chloraminating DWTPs. NDMA was not detected in DWTPs that used other coagulant aids (e.g. Flopam AN 910 PWG, Magnafloc LT20, Magnafloc LT21, Magnafloc LT25, Nalco 44560, Nalco 3482, Magnafloc LT425, SNF AN 905). Among the six DWTPs utilizing PolyDADMAC, NDMA was detected in two of the three chloraminating plants between 7-46 ng/L, but was not detected in any of the three plants using chlorine disinfection. PolyDADMAC consists of quaternary amines with dimethylamine-functional groups and it has been proposed that NDMA formation can occur from both the dimethylamine-moieties (25, 26) or the quaternary amines themselves (27), which act as NDMA precursors. In this study higher NDMA concentrations were observed in plants using polyDADMAC, when

chloramination was the disinfection process and not chlorination. This suggests that polyDADMAC may have an influence in forming NDMA in DWTPs, but only when chloramine disinfection is used.

Only four DWTPs utilised Magnafloc LT22 as the exclusive coagulant aid, all of which practiced chloramination, and all of which detected NDMA at least once. Magnafloc LT22 is a polyacrylamide-based polymer and there have been no studies to-date relating NDMA formation to its use. However, certain polyacrylamides used in water treatment have been reported to form NDMA also through the dimethylamine-moieties in the polymer structure (25, 26). While the exact composition of Magnafloc LT22 was unknown, it is possible that its structure contains dimethylamine-moieties which can explain the NDMA formation observed in these plants.

In order to assess the contribution of these nitrogen-based polymers towards NDMA formation during water treatment, NDMA formation potentials (FP) were determined from different commercially available coagulant aids used in Australia. Coagulant aids (10 mg/L) were dosed with a high concentration of monochloramine and analysed for NDMA after seven days of contact time, based on the procedure by Mitch *et al.* (28). Of the five coagulant aids tested, only polyDADMAC and Magnafloc LT22 formed > 10 ng/L NDMA (Table 5). PolyDADMAC showed an extremely high NDMA FP of 15,000 ng/L, several orders of magnitude higher than any of the other coagulant aids. While Magnafloc LT22 had a high NDMA FP (160 ng/L), formation was much lower than that from polyDADMAC. While both polymers may have the potential to form NDMA during chloramination, the extent of their impact will depend on specific water treatment conditions. Doses of chloramine and coagulant aids used in the DWTPs are much lower than the conditions of the FP procedure. Therefore the contribution of Magnafloc LT22 to NDMA formation may not be significant; on the other hand, the use of polyDADMAC could still have significant potential for NDMA formation under DWTP conditions due to its high FP.

A previous study of NDMA formation from polyDADMAC compared the role of the bulk polymer with degraded components or impurities of the polymer solution, by performing NDMA FP experiments on polyDADMAC before and after dialysis (29). The dialysis retentate was found to have a much higher NDMA FP than the dialysis permeate, suggesting that most of the observed NDMA formation was due to interaction of monochloramine with the retained polymer, rather than with small degraded molecules or impurities. In another study, it was reported that polyDADMAC remains as a contaminant in treated water when it is used as a sole coagulant, but not when it is used in conjunction with alum (30). In the DWTPs surveyed here, polyDADMAC was typically used with alum, however, these findings suggest that even higher concentrations of NDMA can be expected if polyDADMAC is used as the primary coagulant.

Table 5. NDMA formation potentials of various coagulant aids. Coagulant aids (10 mg/L, buffered to pH 7) were dosed with 2mM monochloramine (140 mg/L Cl₂) and analysed for NDMA after seven days contact time, based on the procedure by Mitch et al. (28). Samples (50 mL) were analysed by liquid-liquid extraction followed by GC-MS with ammonia PCI.

<i>Sample</i>	<i>NDMA FP (ng/L)</i>
Blank (Ultrapure water)	< 2
Flopam AN 910 PWG	6
Magnafloc LT25	6
Magnafloc 800 HP	6
Magnafloc LT22	160
PolyDADMAC	15,000

Raw Water Chemistry

Raw water parameters, including pH, TDS, temperature, DOC and turbidity, were evaluated for relationships with NDMA concentrations, by calculation of Spearmans’s correlation coefficients (R). There were no correlations observed between NDMA concentrations and any raw water parameters, except for DOC. As shown in Table 3, it appears that higher NDMA concentrations (> 5 ng/L) were found in plants with higher raw water DOC (> 10 mg/L). Raw water DOC showed a significant positive correlation with average NDMA concentrations (R = 0.9, p <0.01, data not shown) However, the relationship was heavily skewed by the significantly higher NDMA concentrations reported in DWTP 4, and there was no significant correlation observed when data from DWTP 4 was removed.

Furthermore, six of the eight DWTPs practised some form of conventional treatment and/or filtration before disinfection, and therefore some DOC removal is expected before disinfection. Raw water DOC therefore cannot be directly related to NDMA formation in these cases. Another limitation is that the concentrations of NDMA and its precursors are typically orders of magnitude lower than DOC (ng/L compared with mg/L), and may not be directly comparable.

DWTP 4, which did not use any form of coagulation, exhibited the highest NDMA concentrations. A previous study (20) has also identified that DWTP 4 had poor source water quality, and the treatment process (microfiltration) was not effective in removing DOC. However, laboratory tests using DWTP 4 source water demonstrated that, even with alum coagulation, NDMA precursors were not effectively removed compared with total DOC (20). This is consistent with previous findings that NDMA precursors are usually low molecular weight hydrophilic compounds (31), and are therefore unlikely to be effectively removed through conventional treatment processes.

There are clearly limitations in assessing NDMA formation according to bulk parameters such as DOC and organic nitrogen. Rather, the nature of natural organic matter in the source water is more important for determining NDMA and can vary for each water source. Measurements of NDMA precursors (i.e. NDMA-FP) may be a more useful indication of the potential of a source water to produce NDMA under certain water treatment conditions.

Conclusions

The concentration of NDMA in Australian drinking water was variable, but all detections were below the Australian Drinking Water Guideline of 100 ng/L. As expected, chloraminating plants were found to have higher concentrations, and more frequent detections of NDMA than chlorinating plants. The order of reagent addition during chloramination had a significant impact on NDMA formation, where the addition of ammonia before chlorine typically led to higher NDMA concentrations, as compared to addition of chlorine first. Under certain conditions, some nitrogen-containing coagulant aids may provide precursors for NDMA formation upon chloramination. Employing free chlorine contact time before ammonia addition can help to control NDMA formation in chloraminating systems. These findings are the first demonstration of the influence of operational factors on NDMA formation in Australian DWTPs at the full-scale, and overall they are consistent with previously reported findings from both laboratory studies and other drinking water systems worldwide.

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Figure 1. General classification of DWTPs surveyed in this study according to treatment type (percentages reported as percent of total number of DWTPs).
141x102mm (300 x 300 DPI)

Figure 2. Distribution of NDMA concentrations in all water samples. There was a higher frequency of detection and higher concentrations in chloraminated samples than in chlorinated samples.
98x59mm (300 x 300 DPI)

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An Investigation of 38 Australian Drinking Water Supplies**

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