

# IMPACT OF WATER QUALITY AND TREATMENT ON DISINFECTION BY-PRODUCT FORMATION



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# IMPACT OF WATER QUALITY AND TREATMENT ON DISINFECTION BY-PRODUCT FORMATION

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## ABSTRACT

Source water quality and water treatment plant operation and/or process can have a significant impact on treated water quality, particularly disinfection by-product (DBP) formation. Key factors affecting DBP formation were examined in three different scenarios commonly encountered by water authorities. These scenarios include: assessment of different source waters for blending; water quality change from drought to flood condition and evaluation of different water treatment processes. In all three scenarios natural organic matter or dissolved organic carbon concentration (DOC) and bromide had the greatest impact on DBP formation. When combining different water sources, the optimum blend composition was found to depend on both water quality and the disinfection strategy used. For chlorination, blending with greater amounts of ground water was found to be favoured due to its lower concentration of DOC which reduced DBP formation. In contrast, with chloramination, blending more surface water was favoured due to the presence of iodide in the ground water which was found to form medicinal taste and odours when chloraminated. Under drought conditions DBP formation was dependant mainly on bromide concentration while under flood conditions, DBP formation could be directly related to DOC concentration. Water treatment processes with multiple strategies for DOC removal reduced DBPs to the greatest extent.

## 1.0 INTRODUCTION

Disinfection of drinking water is essential for the elimination of pathogenic organisms. However, disinfection needs to be optimised to minimise the formation undesirable compounds (by-products) while still protecting public health. In chlorinated systems, trihalomethanes (THM<sub>4</sub>) and haloacetic acids (HAA<sub>9</sub>) are the most commonly formed disinfection by-products (DBPs) accounting for approximately 30-40 % of total DBP formation. For chloraminated systems, the impact of nitrosamines such as NDMA is emerging as an important DBP to the water industry. The formation of DBPs is related to a number of factors such as source water quality (dissolved organic carbon (DOC) concentration/character, bromide and iodide concentration), water treatment process (DOC removal) and distribution system conditions (pH, temperature, residence time and disinfectant dose). The aim of this paper was to explore the impact of water quality on DBP formation in three different scenarios that can be encountered by water authorities as described below.

1. Impact of blending difference source waters
2. Impact of source water quality change from dry to wet conditions
3. Assessment of enhanced DOC removal strategies such as ion-exchange and adsorption.

## 2.0 METHOD

For the blending tests, source waters were combined followed by jar testing to determine the optimum coagulant dose using aluminium sulphate (Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>.18.H<sub>2</sub>O). For DBP tests, treated water for each blend was produced using the optimum coagulant dose determined in the jar test. Disinfection by-product formation was determined using the simulated distribution system (SDS) procedure.

The chlorine dose is such to obtain a chlorine residual of approximately 0.5 mg/L at the desired contact time at the test temperature. The contact time and temperature used was specific to the distribution system being studied. The chlorine dose was determined by completing a chlorine demand test. For the chloramine decay tests a dose of 4.3 mg/L of monochloramine was used which was relevant for the distribution system being studied. Prior to testing all waters were stored at 4 °C. The impact of water quality change on DBP formation was completed by collation of water quality monitoring data obtained by the SA Water Corporation. Assessment of different WTP processes on DBP formation was determined by completing SDS tests as outlined above on product waters from four different treatment streams as described in Table 1. All water quality analysis was completed at the Australian Water Quality Centre.

**Table 1:** *Treatment strategies*

| Process                | Description   | Capacity (day-1) |
|------------------------|---|------------------|
| Coagulation            | Coagulation with aluminium sulphate (alum)  | 14.4 kL          |
| IX + MF                | Ion-exchange (IX) followed by microfiltration (MF)  | 1.5 ML           |
| IX + Coag              | IX treatment followed by coagulation with alum and polydiallyldimethylammonium chloride (polyDADMAC)        | 1.5 ML           |
| IX + Coag + Adsorption | Treated water from IX + Coagulation stream is passed through a pilot granular activated carbon (GAC) filter | 7.2 kL           |

### 3.0 RESULTS/DISCUSSION

#### 3.1 Impact of blending on different water sources on DBP formation

Water utilities often utilise water from different sources as it offers advantages of flexibility in supply. Blending water sources can be required for various reasons.

**Normal operating scenario:** Multiple water sources are required to either meet demand, water quality targets or prevent overuse of an existing resource such as ground water.

**Drought scenario:** An alternate water source, not normally used, is required to meet demand as existing water supply is either severely depleted or water quality is unsuitable for supply e.g. high salinity.

**Flood scenario:** Previously utilised water source becomes available after significant rainfall or existing supply is unsuitable due to high turbidity or DOC concentration.

Under a normal operation scenario, multiple sources can be blended to maximise the water quality benefits from each source and the water treatment process is designed to cope with this operating strategy. The greatest threat to water quality will occur under the drought and flood scenario and will be dependent on the similarity of the water quality of the alternate supply and the existing source water and the water treatment process. Blending can have an adverse affect when a new supply and perhaps the only alternative, has water quality challenges that are different from those of existing water sources resulting in the need to either upgrade or change the existing water treatment process. The impact of blending different waters on water treatment and particularly DBP formation was examined in the case study presented below.

The case study presented examined the blending of a ground water source (GW) and two surface waters (SWA) and (SWB) at different amounts as described in Table 1. After blending, samples were coagulated with alum to simulate the water treatment process followed by disinfection with either chlorine or chloramine.

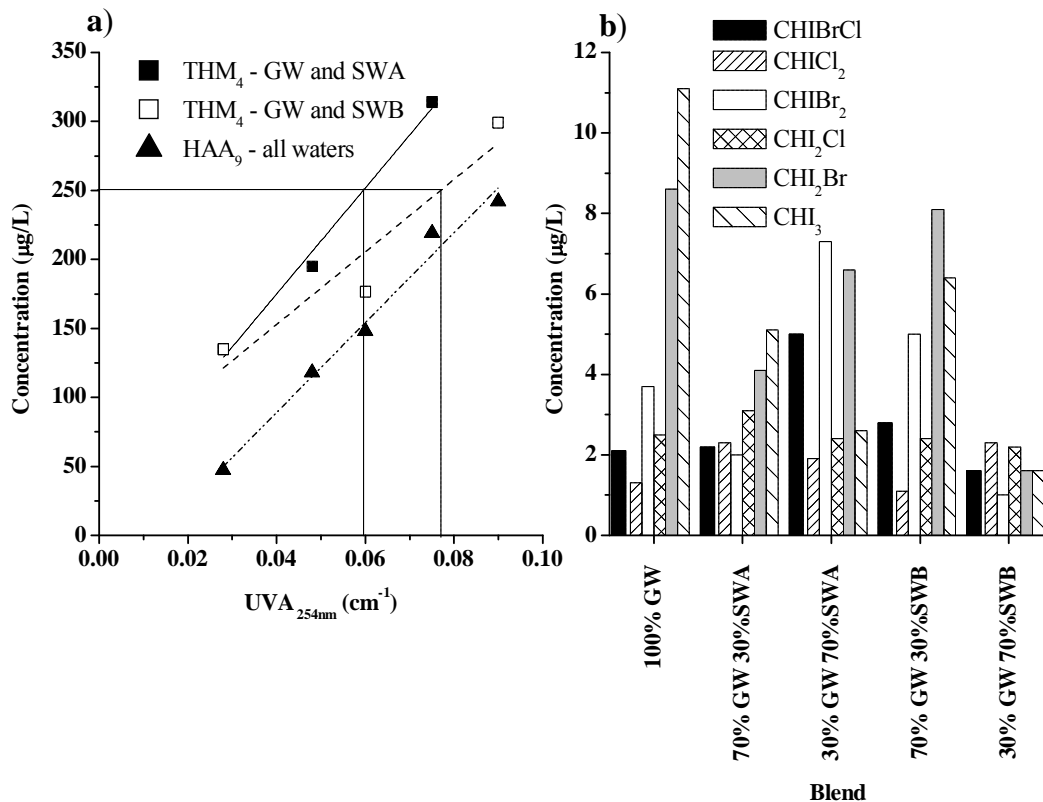
Treated water quality achieved with the optimum alum dose for each blend is shown in Table 2. The optimum alum dose was that required to achieve a treated water quality of  $\leq 0.2$  NTU and  $\leq 5$  HU for turbidity and colour respectively. The formation of THM<sub>4</sub>, and HAA<sub>9</sub> increased with treated water UV absorbance at 254 nm (UVA<sub>254nm</sub>) which increased as the amount of surface water blended increased. The UVA<sub>254nm</sub> at which THM<sub>4</sub> exceeded the Australian Drinking Water Guidelines (ADWG) of 250  $\mu\text{g/L}$  was 0.060 and 0.077  $\text{cm}^{-1}$  for blending with SWA and SWB respectively (Figure 1a). Based on the relationship between treated water UVA<sub>254nm</sub> and percent surface water blended, the amount of SWA and SWB blended should not exceed 52 and 46 % respectively to avoid exceeding the ADWG for THM<sub>4</sub>. Although treated water UVA<sub>254nm</sub> was lower for SWA blends, the higher bromide concentration (0.2-0.3  $\text{mg/L}$ ) resulted in higher THM<sub>4</sub> formation compared with SWB. The formation of HAA<sub>9</sub> formation was lower than THM<sub>4</sub>, however formation also increased with UVA<sub>254nm</sub>. Haloacetic acid formation is less sensitive to bromide concentration with the impact of bromide affecting the speciation of the haloacetic acids formed rather than the total concentration hence there is a very good relationship between HAA<sub>9</sub> formation and UVA<sub>254nm</sub> for all waters.

The formation of THM<sub>4</sub> and HAA<sub>9</sub> can be mitigated by the use of chloramines; however, the formation of other DBPs could be favoured. Hansson et al., (1987) found an objectionable medicinal taste in the water following chloramination using source water that contained 50  $\mu\text{g/L}$  and 0.7  $\text{mg/L}$  of iodide and bromide respectively. Khiari et al., (2002) determined that for iodinated trihalomethanes (I-THMs), the medicinal characteristics appeared to increase with the number of iodine atoms in the compound with odour threshold concentrations for CHBrI<sub>2</sub> and iodoform (CHI<sub>3</sub>) found to be 0.13 and 0.032  $\mu\text{g/L}$  respectively. Hansson et al., (1987) also determined the taste threshold for CHI<sub>3</sub> to be approximately 5  $\mu\text{g/L}$ . Based on the concentration of CHBrI<sub>2</sub> and CHI<sub>3</sub> in the blended samples it is likely that medicinal or plastic taste/odour was a result of the formation of these compounds (Figure 1b) which was confirmed by taste panel assessment (data not shown). The concentration of CHBrI<sub>2</sub> and CHI<sub>3</sub> decreased with an increase in surface water blend ratio due to a reduction of iodide concentration. The formation of I-THMs can be mitigated by reversing the order of addition of ammonia and chlorine from NH<sub>3</sub>+Cl<sub>2</sub> to Cl<sub>2</sub>+NH<sub>3</sub> or by switching to chlorination. Hansson et al., (1987) showed that reversing the order of addition resulted in the formation of  $<1$   $\mu\text{g/L}$  of CHI<sub>3</sub>.

**Table 2:** *Source and treated water quality*

| Percent Composition (%) |     |     | DOC (mg/L) | UVA <sub>254nm</sub> (cm <sup>-1</sup> ) | Colour (HU) | Bromide (mg/L) | Iodide (mg/L) | Turbidity (NTU) | Alum <sup>#</sup> dose (mg/L) |
|-------------------------|-----|-----|------------|--|-------------|----------------|---------------|-----------------|-------------------------------|
| GW                      | SWA | SWB |            |  |             |                |               |                 |                               |
| Source water            |     |     |            |  |             |                |               |                 |                               |
| 100                     |     |     | 1.2        | 0.045                                    | 8           | 1.0            | 0.05          | 2.3             | -                             |
|                         | 100 |     | 7.4        | 0.142                                    | 9           | 1.2            | 0.01          | 0.60            | -                             |
|                         |     | 100 | 10.9       | 0.207                                    | 16          | 0.7            | <0.01         | 2.0             | -                             |
| Treated water           |     |     |            |  |             |                |               |                 |                               |
| 100                     |     |     | 0.8        | 0.028                                    | 4           | 1.0            | 0.050         | 0.22            | 30                            |
| 70                      | 30  |     | 2.0        | 0.048                                    | 3           | 1.1            | 0.038         | 0.12            | 50                            |
| 30                      | 70  |     | 3.7        | 0.075                                    | 4           | 1.1            | 0.022         | 0.13            | 60                            |
| 70                      |     | 30  | 2.5        | 0.060                                    | 4           | 0.9            | 0.035         | 0.13            | 60                            |
| 30                      |     | 70  | 4.5        | 0.090                                    | 5           | 0.8            | 0.015         | 0.20            | 90                            |

<sup>#</sup>mg/L as Al<sub>2</sub>(SO<sub>4</sub>)<sub>3</sub>.18.H<sub>2</sub>O



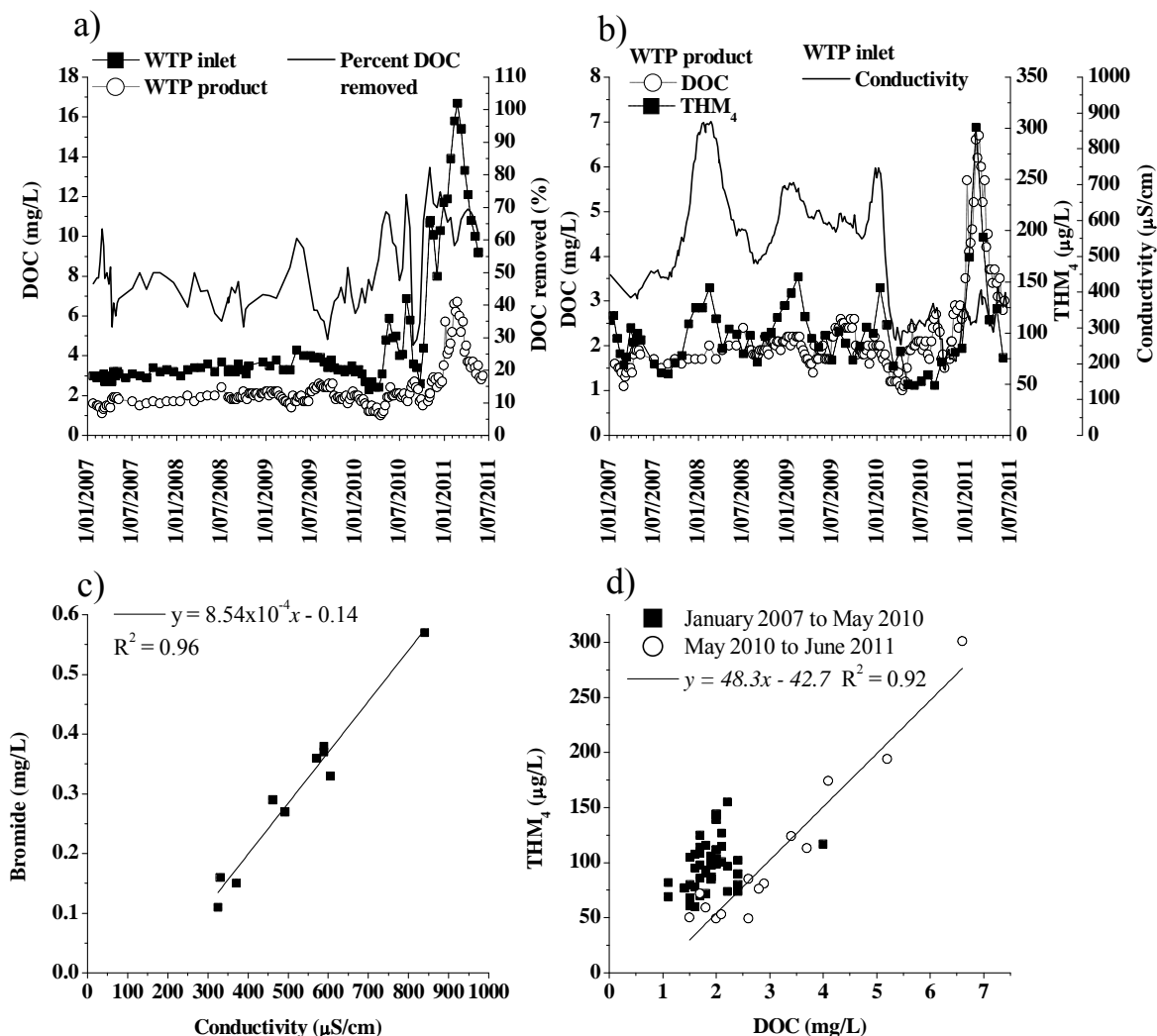
**Figure 1:** *DBP formation after 6 days at 22 °C a) THM<sub>4</sub> and HAA<sub>9</sub> for each blend as a function of UA<sub>254nm</sub>; b) I-THM formation for each blend after chloramination*

### 3.2 Impact of source water quality change on DBP formation

Surface source water quality is determined by catchment characteristics such as land use, soil composition, vegetation type/density and rainfall parameters such as quantity, frequency and intensity. Ground water intrusion can also impact on water quality, particularly in times of drought.

Analysis of WTP inlet and product water quality can provide valuable information for the relationships between WTP performance, water quality and DBP formation. Data collected from a South Australian WTP treating River Murray water is shown in Figures 2 a-d. Data was analysed for the period of time including the end of an extremely dry period in the Murray-Darling Basin (January 2007 to May 2010) followed by increased inflow resulting from water release from upstream storages and floods in the catchment. During dry conditions WTP inlet DOC concentration averaged  $3.2 \pm 0.4$  mg/L and percent DOC removal averaged  $45 \pm 7$  % ( $1.9 \pm 0.4$  mg/L DOC), (Figure 2a). Flooding in the catchment resulted in an increase in DOC concentration as organic matter was flushed from the catchment resulted in DOC concentrations above 10 mg/L between November 2010 and May 2011. Treated water DOC concentration increased on average by 58 % ( $3.0 \pm 1.4$  mg/L) although WTP performance for DOC removal improved with average percent DOC removal being  $63 \pm 13$  %. Improved DOC removal was a result of increased chemical dosing at the WTP and organic material that was easier to remove. In contrast to DOC, bromide concentration decreased from between 0.27-0.57 mg/L (January 2007 – April 2010) to between 0.11-0.15 mg/L (May 2010-May 2011) as the river was inundated with fresh water. Not surprisingly, bromide concentration was found to be directly related to conductivity (Figure 2c), meaning that at this site conductivity is a good surrogate for bromide concentration.

A change in conductivity of 120  $\mu\text{S}/\text{cm}$  is equal to approximately 0.1 mg/L change in bromide concentration which can impact on THM<sub>4</sub> formation. During the dry period, THM<sub>4</sub> formation was largely impacted by bromide concentration as spikes in THM<sub>4</sub> formation occurred during periods of high conductivity (Figure 2b). In contrast during the current wet period, THM<sub>4</sub> formation can directly related to treated water DOC (Figure 2d). Trending of this data allows treated water quality targets to be set with treated water quality target of  $\leq 6$  mg/L for DOC required to achieve the ADWG of 250  $\mu\text{g}/\text{L}$  for THM<sub>4</sub>. This data highlights how different water quality parameters can impact on THM<sub>4</sub> formation over time.

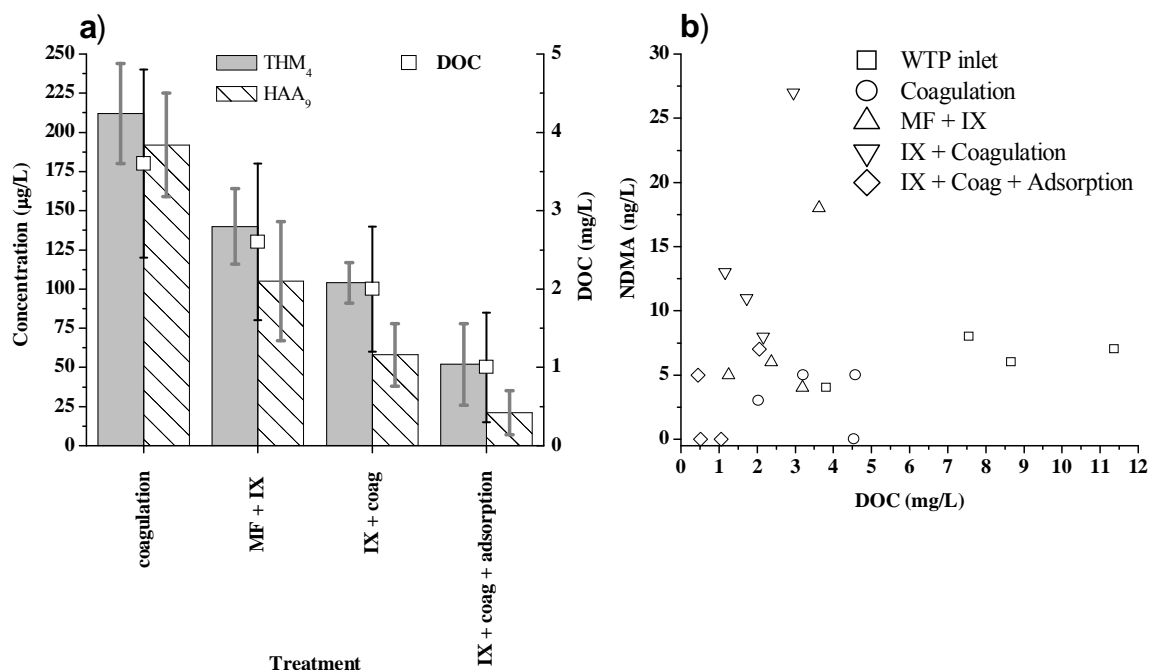


**Figure 2:** a) DOC concentration and removal; b) WTP product water DOC and THM formation and WTP inlet water conductivity; c) relationship between inlet bromide concentration and conductivity d) relationship between THM formation and DOC concentration

### 3.3 Impact of source water treatment process on DBP formation

In some instances particularly with poor source water quality, the only option to reduce DBP formation is to remove a greater portion of DBP precursors during treatment. The formation of THM<sub>4</sub> and HAA9 decreased with a reduction of treated water DOC (Figure 3a) with combined DOC removal processes (IX + coagulation and IX + coagulation + adsorption) giving the best results. Removal of DOC has the added benefit of reducing required chlorine dose which further reduces DBP formation.

In chloraminated waters, NDMA formation was independent of DOC concentration (Figure 3b) with similar concentrations formed in untreated water to those in treated waters. The higher concentration of NDMA formed in IX + coagulated treated water is thought to be related to the use of polyDADMAC coagulant aid, a known precursor of NDMA.



**Figure 3:** *DBP formation as a function of treatment process and DOC concentration after 7 days at 30 °C. a) THM<sub>4</sub> and HAA<sub>9</sub>, b) NDMA*

#### 4.0 CONCLUSIONS

Tests showed that independent of scenario, DOC, UV<sub>254nm</sub>, and bromide are critical parameters in regards to THM<sub>4</sub> and HAA<sub>9</sub> formation while iodide is important if chloramination is the disinfection strategy. DBP formation could be related to either treated water DOC concentration or UV<sub>254nm</sub>, which can be used to determine raw water blend composition and treated water quality targets to meet DBP goals. NDMA formation was found to be insensitive to DOC concentration.

#### 5.0 ACKNOWLEDGEMENTS

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