# NOVEL APPROACHES TO TRIHALOMETHANE MANAGEMENT

***Paper Presented by :***

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## ABSTRACT

Western Australia has numerous sources that are high in natural organic matter (NOM). During disinfection, the reaction between NOM and chlorine can cause problems in achieving effective disinfection, whilst minimising undesired disinfection by-products such as trihalomethanes (THMs). Bench-scale laboratory experiments have enabled THM formation to be predicted through the development of empirical models for individual sources. Through the use of the empirical models, operators were able to optimise the chlorine dose rates. However, some distribution systems require further minimisation of THM concentrations. This was achieved through the installation of a recirculation and aeration device providing a novel and cost effective solution to volatilise THMs. Aeration through spray nozzles dissipates the volatile THMs, leading to a 40 to 70% reduction in concentration. This novel concept will provide water utilities with a new option in maintaining THMs well below the Australian Drinking Water Guideline (ADWG) health value whilst longer term treatment options are considered.

## KEY WORDS

Trihalomethanes (THMs), Aeration, Natural Organic Matter (NOM), Drinking Water, THM Formation Potential (THMFP)

## 1.0 INTRODUCTION

The Water Corporation is the main supplier of drinking water in Western Australia, servicing a population of over 2 million people spread over 2 million square kilometers. It operates 244 water distribution schemes in urban and rural communities, making use of local surface or groundwater sources.

The southern part of Western Australia comprises of sparsely located towns with individual sources. Many of these surface water sources are high in natural organic matter (NOM). The interaction of NOM with chlorine during disinfection can create a difficult challenge for operators as they must achieve effective disinfection whilst minimising disinfection by-products such as Trihalomethanes (THMs). A low chlorine dose rate may result in insufficient residuals at the end of the distribution system, resulting in bacterial regrowth such as total coliforms. Conversely, a high chlorine dose rate can lead to the formation of THMs which exceed the health guideline value of 250 μg/L, as listed in the Australian Drinking Water Guidelines (ADWG).

Chlorine dose rate and reaction time are the most important factors that influence the formation of THMs, with temperature and pH secondary factors. THM Formation Potential (THMFP) can be developed by performing bench scale tests that vary the chlorine dose rate and reaction time. Understanding the formation of THMs under various conditions will assist operators in controlling THM concentrations in the distribution systems.

In some distribution systems effective disinfection cannot be achieved whilst maintaining THMs below the health guideline. Aeration has been employed by the Water Corporation for several years to reduce the THM concentrations within the system, by installing a tank inlet splash plate and a roof ventilator on tanks (Henderson and Koska, 2003).

This study investigated THM mitigation at two localities in southern Western Australia i.e. Denmark and Boddington. Initially THMFP tests were conducted and a new aeration technique trialled as an option for reducing THM concentrations.

## 2.0 DISCUSSION

### 2.1 Denmark Distribution System

Denmark town water supply is drawn from Quickup Dam located 6.5 km north east of the town. Quickup Dam water is treated by sedimentation, clarification and filtration prior to chlorination. Re-chlorination occurs at Horsley Road Reservoir before being stored in Horsley Road Summit Tank, where it is gravity fed into the distribution system.

In March 2002, chlorination was increased to overcome a detection of total coliforms in the reticulation. As a consequence, the THM concentrations exceeded the health guideline value of 250 µg/L on several occasions. While not an immediate health concern, this trend concerned both the Water Corporation and the Department of Health. This prompted an investigation into the reason for the exception, and to determine short term gap measures that would manage the THM issue, whilst awaiting enhanced treatment for NOM removal.

### 2.2 Denmark THM Formation Potential Tests

In order to understand and control the THMFP of the treated water, bench scale tests were conducted to observe the effects of chlorine dose rate and reaction time. The water used in the bench scale tests was sampled post treatment but prior to chlorination.

The treated waters were measured into 1 L brown glass bottles and dosed with known amounts of sodium hypochlorite (NaOCl), ranging from 0 – 10 mg/L. The samples were then allowed to react for seven days (168 hours) at a temperature of 20°C. Sub-samples were then analysed for THMs, dissolved organic carbon (DOC) and Ultraviolet absorbance ($UV_{(254)}$). DOC and $UV_{(254)}$ are a surrogate measurement for NOM. Free chlorine residuals were measured on day seven. The resulting THMs formed during this time frame are listed in Table 1 and shown in Figure 1.

From Table 1, chlorine dose rates between 4 – 10 mg/L prompted the formation of THMs above the health guideline value. At a chlorine dose rate of 10 mg/L the maximum THMs formed was 644 µg/L after seven days, with 9.48 mg/L of chlorine used. The high propensity for this water to generate THMs is well supported by the $UV_{(254)}$ and DOC values (*cf.* Table 1), indicating a high NOM concentration present in Denmark Treated waters.

**Table 1:** ***Total THMs Formed, Free Chlorine Residual and Calculated Chlorine Used at Day 7, $UV_{(254)}$, and DOC Measured at Various Chlorine Doses for Denmark Treated Waters.***

| $Cl_2$ dose (mg/L) | Free $Cl_2$ Residual Measured at Day 7 (mg/L) | Free $Cl_2$ Used Measured at Day 7 (mg/L) | Total THM (µg/L) | $UV_{(254)}$ | DOC (mg/L) |
|---|---|---|---|---|---|
| 0 | 0 | 0.00 | 0 | 0.128 | 6.8 |
| 2 | 0 | 2.00 | 91 | 0.119 | 6.6 |
| 4 | 0 | 4.00 | 252 | 0.105 | 6.6 |
| 6 | 0.45 | 5.55 | 362 | 0.094 | 6.6 |
| 8 | 0.03 | 7.97 | 517 | 0.088 | 6.6 |
| 10 | 0.52 | 9.48 | 644 | 0.079 | 6.6 |

Figure 1 shows that there is a strong linear relationship between THM formation and chlorine used, achieving a correlation coefficient of 0.993. This relationship had previously been observed by Boccelli *et al*., 2003 and references therein. The following THM Formation Potential (THMFP) model was proposed for Denmark Treated Waters based on chlorine used:

***[THMFP in µg/L] = (66) x [chlorine used in mg/L]***

The above equation concluded that if the chlorine used was greater than 3.8 mg/L, the THMs concentration would exceed the health guideline value.

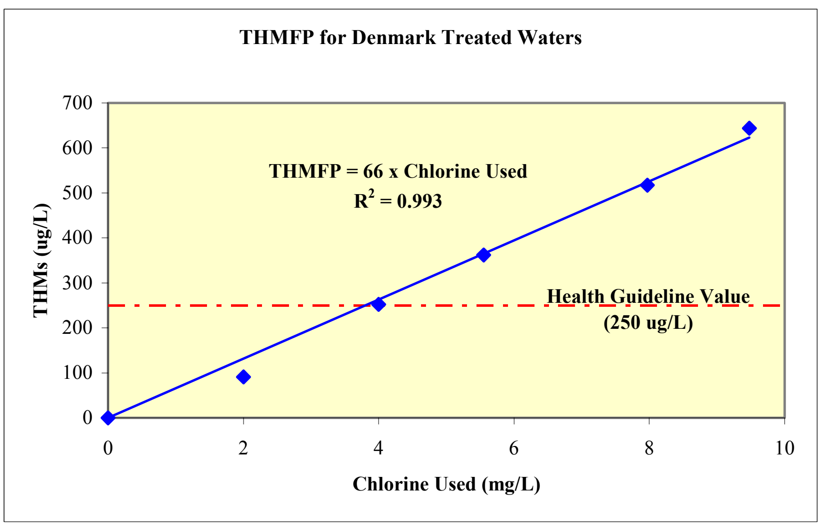


**Figure 1:** ***THMs Formed Versus Chlorine Used after a Seven Day Reaction Period for Denmark Treated Waters.***

Validation of the model occurred through profile sampling throughout the Denmark distribution system measuring the chlorine used and THMs. For example, on the inlet to Horsley Road Reservoir the THM concentration was 247 µg/L (laboratory result) with a chlorine used of 3.7 mg/L. This compares to the derived model calculated value of 244 µg/L, verifying the applicability of the model. Therefore, operators were able to use this model to predict the THMs formed in the distribution system when adjusting chlorine dose rates.

### 2.3 Denmark Reservoir Aeration Trials

At the time of the investigation, the chlorine dose rate was 7 mg/L at the outlet of WTP. At this dose rate, THMs could form as high as 462 µg/L, as calculated using the derived model. Therefore, it was pertinent to reduce concentrations to below the health guideline value. Henderson and Koska (2003) have shown that bench scale aeration tests i.e. cascading water from one 500 mL beaker to another between 5 to 10 times, resulted in THM concentrations being reduced by 35%. Following on from this work, the Water Corporation installed splash plates at a number of small tanks to aerate chlorinated water as it entered the tank. It was found splash plates successfully reduced THMs where the tank was less than 0.5 ML in volume. Effectiveness declined with increasing volume and there were doubts that this could be used at Horsley Road Reservoir, a reservoir with a volume of 4.5 ML. Additionally, the splash plate can only be utilised when inflow occurred. It was noted that inflow to Horsley Road Reservoir only occurred for 2 to 4 hours per day. However, if a recirculation system could be installed in the reservoir, the effective time for aeration could be increased by an order of magnitude. As a result, it was decided to trial continuous aeration (recirculating the reservoir contents through an aerator) at the Horsley Road Reservoir. The system consisted of a submersible pump located on the reservoir floor, flexible discharge hose and a section of slotted uPVC pipe (aerator) as shown in Figure 2.

**Figure 2:** ***Aeration at Denmark Horsley Road Reservoir***

Installation of the continuous aeration system in Horsley Road Reservoir, resulted in a reduction in the average THM concentrations value from 218 µg/L to 73 µg/L.

### 2.4 Boddington System Investigation

Boddington is supplied from Harris River Dam which is located on the Harris River approximately 192 km south of Perth. The water at Boddington complies with the aesthetic guidelines, however it contains a high concentration of NOM. Chlorination for disinfection occurs at the dam outlet and is re-chlorinated on the inlet to the 4.5 ML Boddington storage tank. Disinfected water then gravitates into the Boddington distribution system.

Boddington Town water supply has on occasion exceeded the health guideline for THMs

as shown in Figure 3.
This corresponded with $UV_{(254)}$ readings for Harris River Dam being greater than 0.07 during November to January, indicating high concentrations of NOM. THMFP tests were conducted to create the following model:

$$[THMFP \text{ in } \mu g/L] = (75) \times [\text{chlorine used in } mg/L]$$

The success of continuous aeration at Denmark to dissipate THM concentrations, prompted a similar approach to be trialled at Boddington Tank.

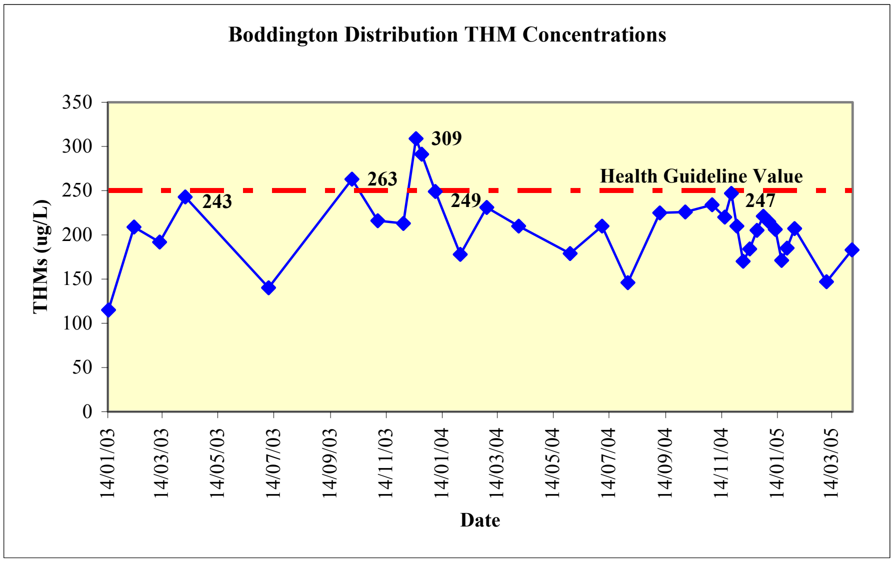


**Figure 3:** *Historical THMs Concentration in Boddington Distribution System*

## 2.5 Boddington Tank Aeration Trials

The trial recirculation and aeration system at Boddington Tank utilised an independent inlet and was comprised of 2 DN150 uPVC Class 18 aerator headers mounted to the inside of the tank wall, each with 3 off aerator spray nozzles at 1800 mm centres spraying slightly below horizontal.

The aerator headers were located in the vicinity of the tank inlet to maximise recirculation of the tank contents, particularly during periods of low water demand. The amount of water aerated per day was approximately 1.2 ML.

Figure 4 shows the THM concentrations pre and post installation of the recirculation and aeration system at Boddington. The effectiveness of the system is illustrated as the THM concentration at the outlet has continuously decreased since installation. Following system implementation, THMs decreased from 195 µg/L (31/08/04) to 85 µg/L (21/06/05). This reached a plateau of 76 µg/L for 2 weeks before a further reduction to 40 µg/L (12/07/05). The most recent THM sample (02/05/06) taken in Boddington's distribution system returned a result of 87 µg/L, well below the health guideline value.

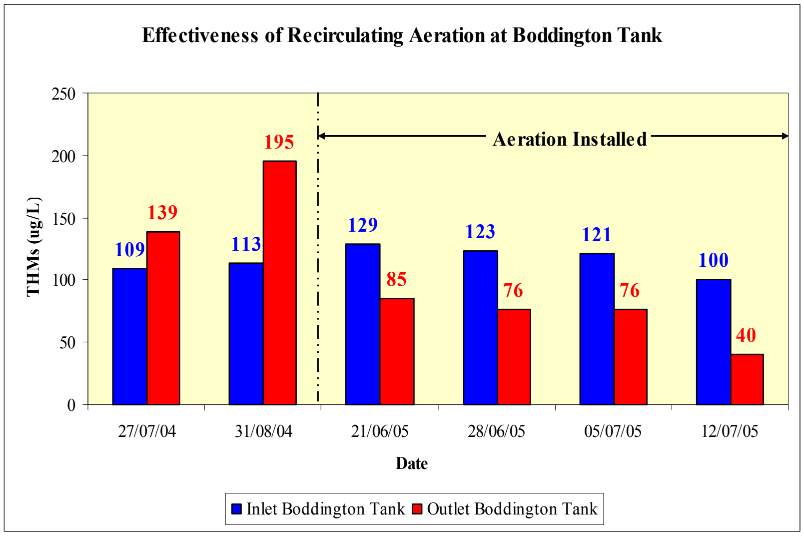


**Figure 4:** ***THM Concentrations at the Inlet and Outlet of Boddington Tank Pre and Post Aeration***

## 3.0 CONCLUSION

Potable source waters with high NOM concentrations have caused difficulties for operators to manage effective disinfection whilst maintaining THM concentrations below the health guideline value. Empirical models, based on bench-scale laboratory experiments have been developed which predict the formation of THM for a particular water based on chlorine used. These enable operators to optimise the chlorine dose rates.

Some distribution systems, struggle to maintain THMs below the health guideline value. At Denmark and Boddington, recirculation and aeration systems were installed to continuously aerate the waters to volatilise the THMs. This device was highly effective in reducing THM concentrations which have already formed in the distribution system.

## 4.0 ACKNOWLEDGEMENTS

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## 5.0 REFERENCES

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