TRIHALOMETHANE REMOVAL THROUGH EVERYDAY AERATION

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ABSTRACT

Trihalomethanes (THMs) are Disinfection By-Products (DBPs) that are formed through a chemical reaction between chlorine and organic matter during the disinfection process. MidCoast Council (Council) operates the Tea Gardens water supply scheme which has historically good compliance with Australian Drinking Water Guideline (ADWG) limits relating to THMs. The drought and bushfires of 2019 affected the aquifer water source, resulting in a significant increase in THM concentration and consistent non-conformance against the ADWG. Council initiated a project in 2021 to address this issue.

To reduce THM concentration, utilities can either reduce organic matter in the source water (pre-treatment) or remove THMs after formation (post-treatment). Council undertook a detailed assessment of options, considering engineering constraints, operational performance and lifecycle cost. The preferred pre-treatment option required a large capital investment (>$1.5M) and considerable ongoing operational expense. Post-treatment options required further investigation.

Council decided to undertake an investigation into THM removal after formation via aeration. This paper presents the findings, lessons learned, and steps Council took to solve the THM non-conformance, including the journey from benchtop trials to a full network scale aeration system. The project resulted in Council successfully meeting THM targets in line with the ADWG for a total capital cost of less than $40,000.

1.0 INTRODUCTION

The Tea Gardens Water supply scheme services the townships of Hawks Nest and Tea Gardens with water extracted from the Tea Gardens aquifer. The scheme was constructed in the 1960s and augmented in the 1980s. In 2013, a new 8 ML/day water treatment plant (WTP) was constructed that utilises membrane microfiltration technology to treat the water for distribution via the existing storage reservoirs.

Disinfection by-products (DBPs) are compounds that form when natural organic or inorganic constituents in a source water react with disinfectants during the drinking water treatment process. Specifically, Trihalomethanes (THMs) are disinfection by-products that form when natural organic matter (NOM) reacts with chlorine. THMs are suspected carcinogens and may increase the risk of health problems in the liver, kidney, and central nervous system. The level of THMs in the Tea Gardens water supply scheme has been historically high, in the range of 200-300 ug/L, however, results in 2021 climbed to an average of 350 ug/L, with all results consistently exceeding the Australian Drinking Water Guideline (ADWG) limit of 250 ug/L. Figure 1 presents the historical THM results for reticulation sample sites in Tea Gardens and Hawks Nest townships.

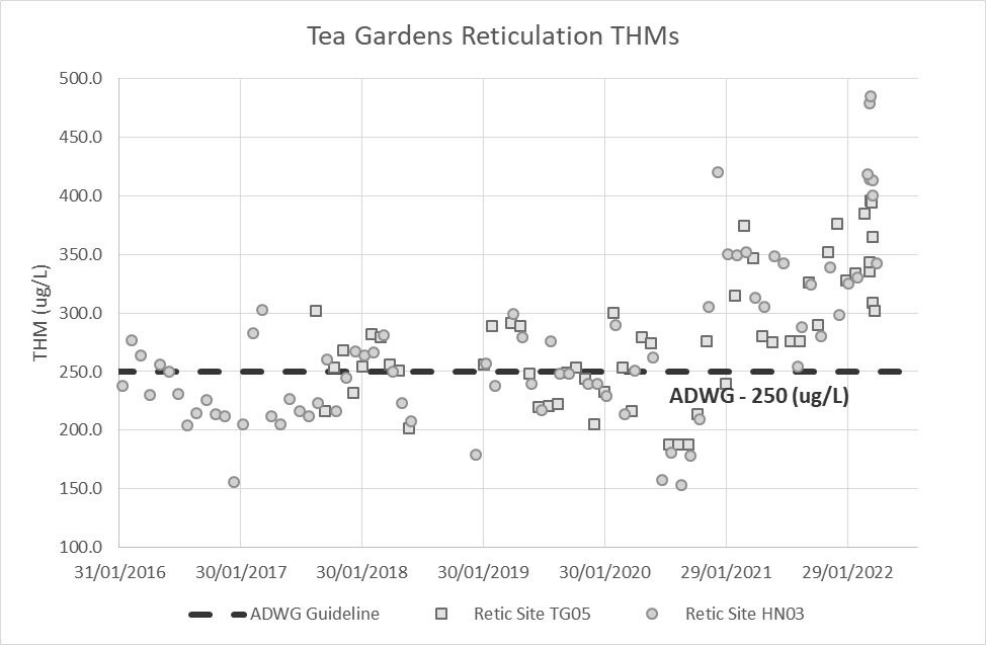

Figure 1: ***Tea Gardens and Hawks Nest Reticulation THM results 2016-2022***

2.0 DISCUSSION

2.1 Network Analysis

A review of the Tea Gardens water supply scheme from source to sink was undertaken to determine the root cause behind the elevation in THMs. A clear correlation between elevated rainfall in the catchment and an increase in THM concentration could be seen. It should be noted that elevated catchment rainfall did not increase raw or treated water Dissolved Organic Carbon (DOC) concentration. It is thought that the composition of organic compounds that make up DOC may have changed, exhibiting a higher THM forming potential, despite overarching DOC levels remaining stable.

2.2 Options Review

Several approaches exist for managing THMs for a drinking water treatment supply. A summary of the typical industry approaches is provided below:

Organic Carbon Reduction

THM formation can be controlled by reducing the amount of organic matter in the water prior to disinfection. This can be achieved through enhanced coagulation, activated carbon adsorption, ion exchange, nanofiltration, reverse osmosis, and precipitative softening. DOC reduction in the Tea Gardens WTP process is carried out through Aluminium Chlorohydrate (ACH) dosing and filtration. The ACH dose is limited due to its detrimental impact on the downstream membrane filtration unit; therefore, enhanced coagulation cannot be utilised. In order to achieve higher DOC/TOC removal efficiency, additional process treatment is required.

Alternative Disinfectant Selection

Reducing the amount of chlorine contact time or replacing chlorine with an alternate disinfectant can reduce or eliminate THM formation. Contact time reduction can be achieved by adding chlorine as far along the treatment process as possible, and by adding ammonia to form combined chlorine, or chloramines, that will form DBPs at a slower rate.

THM Removal via Aeration

As THMs are readily volatile, they can be removed after formation via aeration. This management method for THMs is typically called post treatment removal. Post treatment

removal can be a cost-effective solution for systems, because THM issues commonly occur at the far ends of the distribution system, meaning a much smaller amount of water would require treatment.

Council undertook an options analysis on the range of options, reviewing the treatment methods described above against technical and financial criteria. Most options scored highly from a technical aspect, but involved large capital and operating costs when implemented. THM removal after formation had many technical aspects that were unknown, but presented a competitively low capital and operating cost. Council decided to undertake trials to determine the effectiveness of THM removal via aeration.

2.3 Benchtop Trial

In November 2021, a benchtop aeration test was conducted. Four different air-to-water volumetric ratios were used to evaluate THM removal. The results are shown in Figure 2

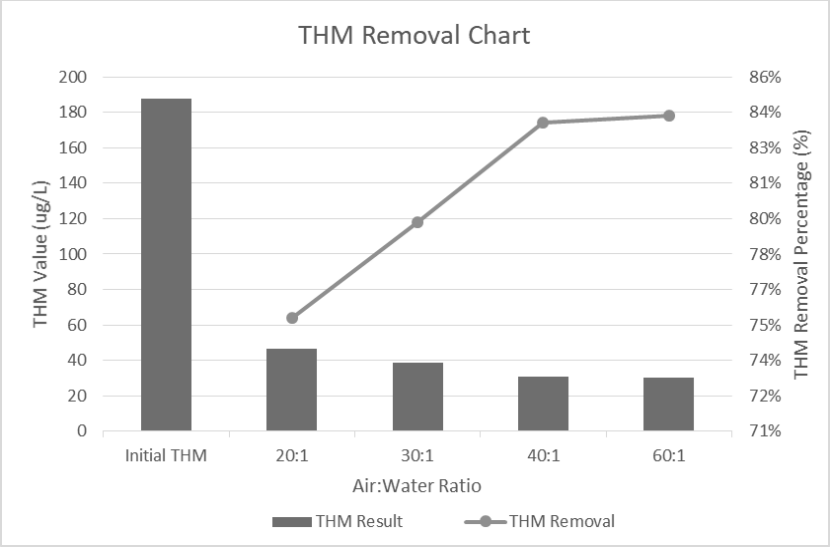

Figure 2: ***THM Removal Trend***

THM removal was demonstrated in the range of 70–84% at 20 °C. In this study, increasing the volumetric air-to-water ratio did not result in significantly higher THM removal. A free chlorine result of 3.3 mg/L was measured before aeration. Free chlorine loss was relatively stable, with a reduction of ~0.5 mg/L for all aeration setpoints.

2.4 Aeration System Design

Spray aeration was selected as the preferred aeration technique for this project. Spray aeration allowed for ease of integration into existing reservoirs without requiring physical entry to install or maintain equipment. This minimised risk to water quality and cut down on capital costs.

A spray nozzle supplier was engaged during the design of the aeration system to provide details on droplet diameter, or Souter Mean Diameter (SMD), for a range of pressures across several nozzle designs. It was determined that 3 to 4 nozzles per reservoir operating at 2 bar pressure would provide optimum SMD and spray coverage with minimal spray crossover.

The following table summarises the key design assumptions and figures used to achieve the desired THM removal for the onsite Clear Water Tanks (CWT) and offsite reservoirs.

Table 1: ***Recirculation System Design***

Parameter	Unit	Value	Comment

Nozzle Height CWT	m	1	Height above water - reservoir dependant.
Nozzle Height Reservoir	m	2	.
SMD	mm	~0.59	Souter Mean Diameter of droplet @ 2 bar
Sprayer Angle	Degrees	170	Full cone spray
Clear Water Tank			
Air:Water Ratio	A:W	3595	(Brooke & Collins, 2011)
Percentage THM Removal	%	~70%	Figure 4:13, Brooke, 2009
Design THM Removal	ug/L	80	
Required recycle rate	kL/d	950	
Reservoir			
Air:Water Ratio	A:W	7191	(Brooke & Collins, 2011)
Percentage THM Removal	%	~78%	Figure 4:13, Brooke, 2009
Design THM Removal	ug/L	150	
Required recycle rate	kL/d	879	

2.4 Network Trials

The first aeration trial involved aeration of one of two CWTs to baseline THM removal and validate the spray aeration process. The level of THM removal fluctuated between 53 to 93 ug/L, averaging 78 ug/L. Performance variability was caused by fluctuations in water age, resulting in lower THM formation time. Water age is dependent on plant production and transfer times, typically ranging from <6 to 48 hours. DOC levels remained constant over the trial period and variation in free chlorine levels between the two reservoirs ranged from 0.1-0.7 mg/L, averaging 0.25 mg/L. No noticeable drop in reticulation chlorine was identified.

Following the successful demonstration of THM removal in Trial 1, a network scale aeration trial was initiated in November 2022 to determine the THM removal effectiveness of aeration at both the onsite CWTs and offsite reservoirs. The trial included one week of baseline monitoring with no aeration, one week of monitoring with reservoir aeration operation and one week of monitoring with both CWTs and reservoir aeration. The diagram below illustrates the Tea Gardens WTP treatment train and reticulation network, including sample locations and associated analysis.

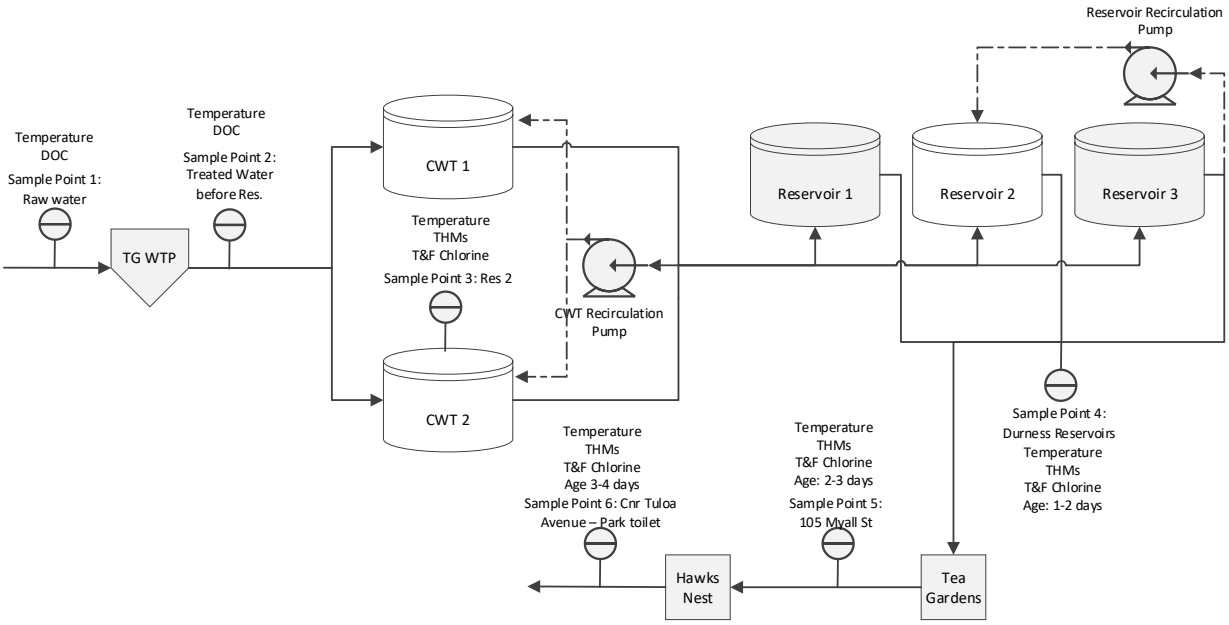

Figure 3: ***Tea Gardens Water Scheme Network Block Diagram***

Monitoring began on 15 November 2022, with spray aeration initiated at the Durness reservoirs on 21 November and the onsite CWTs on 30 November 2022. Spray aeration

was operated continuously during the respective trial periods. Figure 4 presents the THM results that are grouped and averaged by trial period (before and after aeration) against the estimated water age at the sample locations. As THM sampling did not occur every day, a linear trend was inserted between points to interpolate values on days that were not sampled.

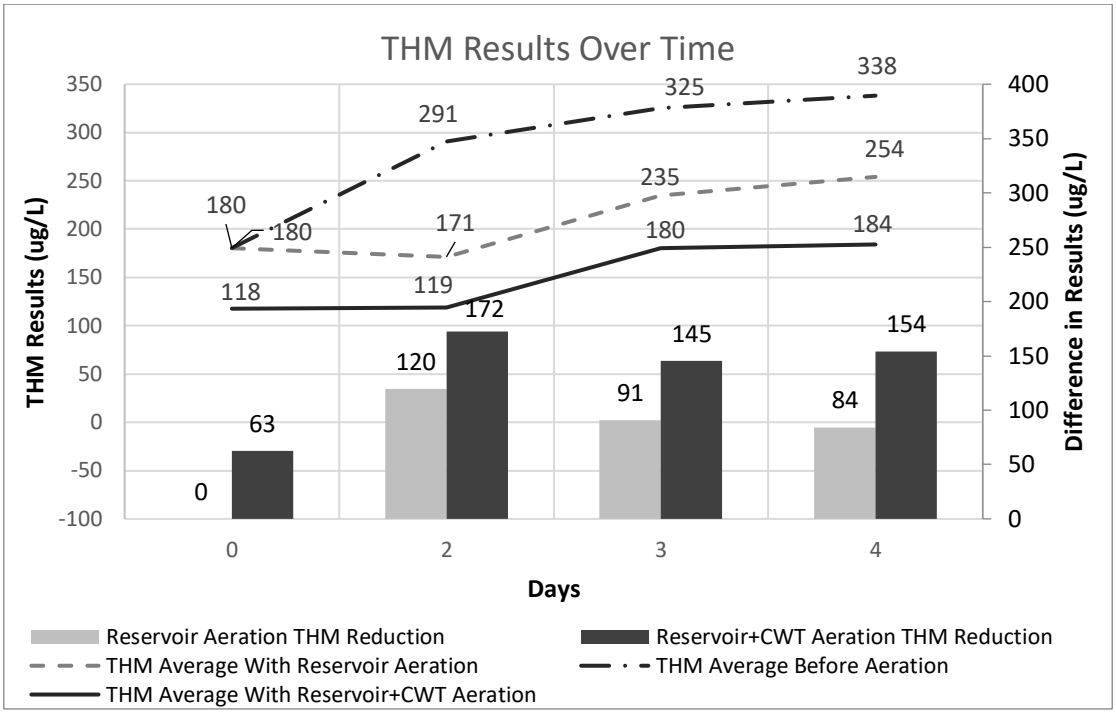

Figure 4: ***THM Network Performance***

A definitive drop in THM concentration can be observed in Figure 4 as a result of aeration. An average THM reduction of 120 and 63 ug/L was observed at the reservoir and CWT sites, with a combined THM reduction of 172 ug/L. This reduction was mirrored in downstream reticulation sites showing symmetry in the line trends, despite step changes reducing THM concentration at different stages in the process.

A review of free chlorine found little change in the reticulation chlorine results and chlorine dose setpoint at the plant before, during and after the aeration trial. It was observed however, that a slight drop in reservoir 2 free chlorine (0-0.2 mg/L) could be seen as a result of aeration.

The design target THM reductions of 150 and 80 ug/L for the reservoir and CWT systems were not achieved on average. It was identified in Trial 1 that the level of THM removal is strongly influenced by the initial THM concentration, requiring 1-2 days of formation time to allow for effective removal. While the reservoir site maintains a consistent water age, the reservoirs are hydraulically linked, filling and emptying from the bottom, with inlet and outlet lines connected. As the reservoir fills, there are periods of time where fresh, unaerated water can short circuit, allowing for THM formation to occur in the reticulation network, rather than the reservoirs. Despite the design targets not being achieved, THM results in the reticulation were maintained below the ADWG limits.

3.0 CONCLUSION

3.1 Outcomes of the Project

The total cost of this project, including equipment, project management and testing, approached $40,000. This was significantly below initial cost estimates for alternative

options. Since the implementation of the CWT and Reservoir aeration systems, 100% compliance has been achieved against the ADWG limits. Figure 5 presents the ongoing network performance.

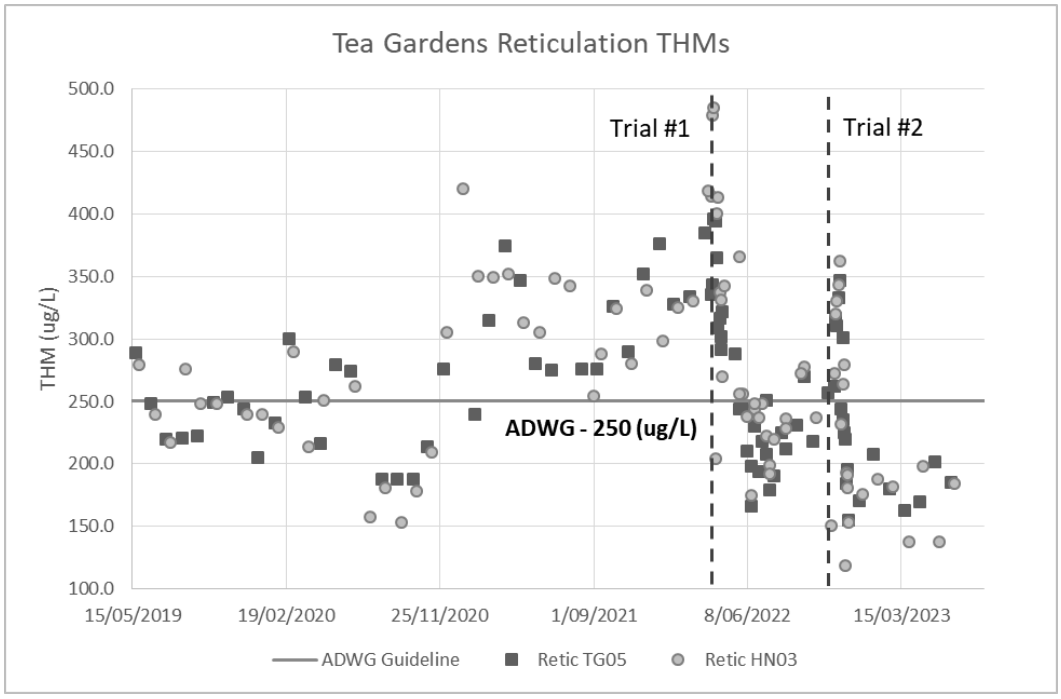

Figure 5: ***Reticulation THM Performance During and After the Aeration Trials***

The project highlighted the importance of trial before you buy when it comes utilising to novel solutions to solve complex issues. Each subsequent trial was an iterative process that built on the previous successes, while overcoming challenges and unknowns.

While the trial systems demonstrate good performance, the design of a permanent system is underway. The permanent system will incorporate the lessons learnt throughout the trial process to improve the overall efficiency of the system.

4.0 ACKNOWLEDGEMENTS

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5.0 REFERENCES

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