FACTORS THAT IMPACT ON MONOCHLORAMINE DECAY AND NITRIFICATION

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ABSTRACT

The River Murray is the major drinking water source for regional South Australia. Treated water produced in these regional areas is transferred in above ground pipes to consumers often located in excess of 100 km from the water treatment plant. To satisfy disinfection requirements, chloramination is practiced as it offers greater stability over chlorine for the long residence times and high temperatures that are encountered. A major challenge for operating a chloraminated distribution system is the prevention of nitrification that can result in the rapid degradation of monochloramine residual. For the first decade of the 21st century drought conditions predominated and generally nitrification events in chloraminated distribution systems were isolated. However drought breaking rains in the Murray Darling Basin in 2010-2012 resulted in two major flood events that caused extreme changes in water quality, and nitrification events subsequently became more widespread. Distribution system water quality monitoring showed that an increase in product water DOC concentration was a key factor in the loss of monochloramine residuals. Also in 3 of 4 WTPs investigated, monochloramine decay tests identified the presence of microbiological monochloramine decay accelerating the overall monochloramine decay rate, increasing the likelihood of nitrification. Overall, combining water quality monitoring and monochloramine decay tests helped identify key factors impacting on nitrification.

1.0 INTRODUCTION

The majority of consumers in regional South Australia depend on treated chloraminated water from the River Murray for their drinking water supply. To reach customers, water is transferred up to several hundred kilometres mostly in above ground pipes. A major challenge in managing disinfection in a chloraminated distribution system is to prevent nitrification. Nitrification is a biological process where ammonia (NH_3) is converted to nitrite (NO_2^-) by ammonia oxidising bacteria (AOB) and ammonia oxidising archaea (AOA). Nitrite is then converted to nitrate (NO_3^-) by nitrite oxidising bacteria. Nitrification events coincide with rapid degradation of chloramines (Wolfe et al., 1988; Cunliffe, 1991) but the mechanism by which this occurs has not yet been established. Remedial action required to recover sections of the distribution system affected by nitrification involve chlorination and mains flushing supported by additional water quality monitoring.

A study of South Australian distribution systems, (Cunliffe, 1991) showed nitrifying bacteria were detected in 64% of samples collected from five chloraminated water supplies in South Australia. Nitrifying bacteria were present more often in samples with a lower monochloramine residual being found in 83% of samples with a monochloramine residual $\leq$ 1.0 mg/L but also in 20.7% of samples that contained more than 5.0 mg/L of monochloramine. In a recent study, Hoefel et al. (2011) found AOB and AOA in the Woolpunda distribution system in South Australia. The wide distribution of nitrifying bacteria within a chloraminated distribution system means that controlling nitrification is about ensuring that there is sufficient monochloramine residual present to control their growth.
If conditions persist that favour the growth of AOB and AOA then nitrification will occur.

Factors affecting monochloramine residual and nitrification are described in Figure 1.

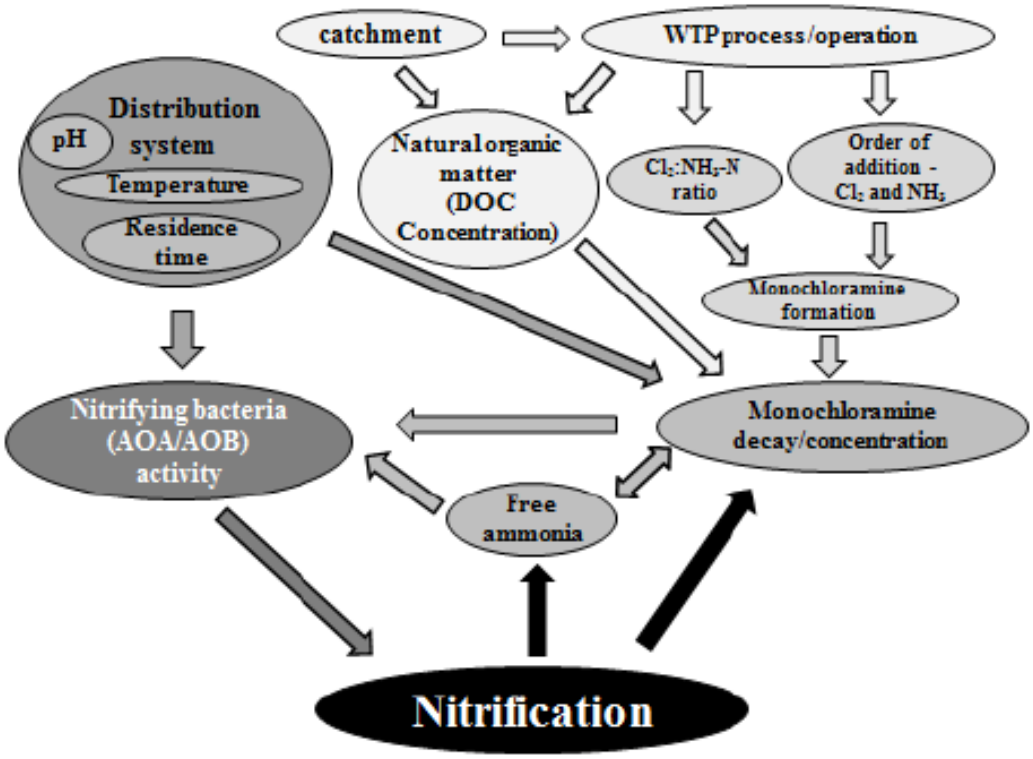

Figure 1: ***Factors that impact on monochloramine decay and nitrification***

Drought breaking rains in the Murray-Darling Basin in 2010-2011 resulted in a significant water quality change in the River Murray in South Australia. In this paper, the applied procedures and water quality monitoring implemented during this period will be outlined, as well as an assessment of the value of each test to provide useful information to better manage chloraminated distribution systems and prevent nitrification events.

2.0 DISCUSSION

2.1 Methodology

Distribution system data was collected by Australian Water Quality Centre (AWQC), SA Water Corporation as part of their routine water quality monitoring program. Analysis was completed using National Association of Testing Authorities (NATA) accredited methods as is detailed in Table 1. Water quality analysis does not provide information about the stability of monochloramine or monochloramine decay rate. Tests to assess monochloramine decay were completed in chloraminated samples obtained immediately after disinfection (WTP product) with monochloramine decay monitored in the laboratory at room temperature (22 ± 2 ^{o}C). WTP product water obtained prior to disinfection was chloraminated in the laboratory as described in Table 2. Chloramination under uniform disinfection conditions allows direct comparison of monochloramine decay to be made. Monochloramine decay was further investigated by calculation of the microbial decay factor (F_m) from monochloramine decay in samples before and after 0.2 µm membrane filtration as described by Sathasivan et al. (2005). Filtration through a 0.2 µm filter removes the effect of microbiological agents, including nitrifying bacteria, and the effect of abiotic particles on monochloramine decay.

The use of the microbial decay factor has been found to provide accurate early warning for the onset of nitrification (Fisher et al., 2009; Sathasivan et al., 2010)

Table 1: *Water quality analysis*

Class	Analysis	Relevance
Natural organic matter (NOM)	• Dissolved Organic Carbon	• Impact on chloramine decay rate
Disinfectants	• Monochloramine • Dichloramine • Total chlorine	• Disinfection
Nutrients	• Nitrite • Nitrate • Free ammonia	• Nitrification status
Physical	• pH • Temperature	• Impact on chloramine decay rate

Table 2: *Chloramination conditions*

NH_2Cl target (mg/L)	Cl_2 dose (mg/L)	NH_3-N dose (mg/L)	Order of Dosing	Cl_2:NH_3-N Ratio	Temperature (^oC)	pH
4.0	4.0	0.88	Ammonia + Chlorine	4.5:1	30 ± 2	8.4 ± 0.1

2.2 Results

Toward the end of 2010, routine distribution system water quality monitoring showed that monochloramine residuals were declining; particularly at the extremities of networks such as at Raukkan Tank (Figure 2a) located on a side branch main, 50 km from Tailem Bend WTP. Monitoring of WTP product water showed an increase in DOC concentration (Figure 2b) which corresponded with the decline in monochloramine residual (Figure 2a). Decline in monochloramine residual ultimately resulted in sustained period of nitrification as indicated by decrease in free ammonia and increase in oxidised nitrogen (nitrite and nitrate) as shown in Figure 2c.

In response to the change in monochloramine residual profiles in distribution systems, monochloramine decay was assessed in WTP product water from four WTPs treating River Murray water. The greater stability of monochloramine in Morgan WTP product water can be clearly seen with the average 3-day monochloramine demand being 1.5 mg/L lower than the other WTP product waters (Figure 3). The greater stability of monochloramine in Morgan WTP product water was surprising as all WTPs have similar treatment processes (coagulation/flocculation/sedimentation/media filtration) and utilise the same source (River Murray). The monochloramine decay profiles in Summit and Swan Reach WTP product waters was similar to that shown for Tailem Bend WTP Product water (January 2011 – Figure 4) while in Morgan WTP product water microbiological monochloramine decay was absent (data not shown). Further investigation described by Cook et al. (2014) found that rapid monochloramine decay in Tailem Bend, Summit and Swan Reach WTP product waters was determined to be microbiological in nature and possibly related to backwashing of media filters with chloraminated water. Media filters at Morgan WTP are backwashed with filtered water taken prior to disinfection.

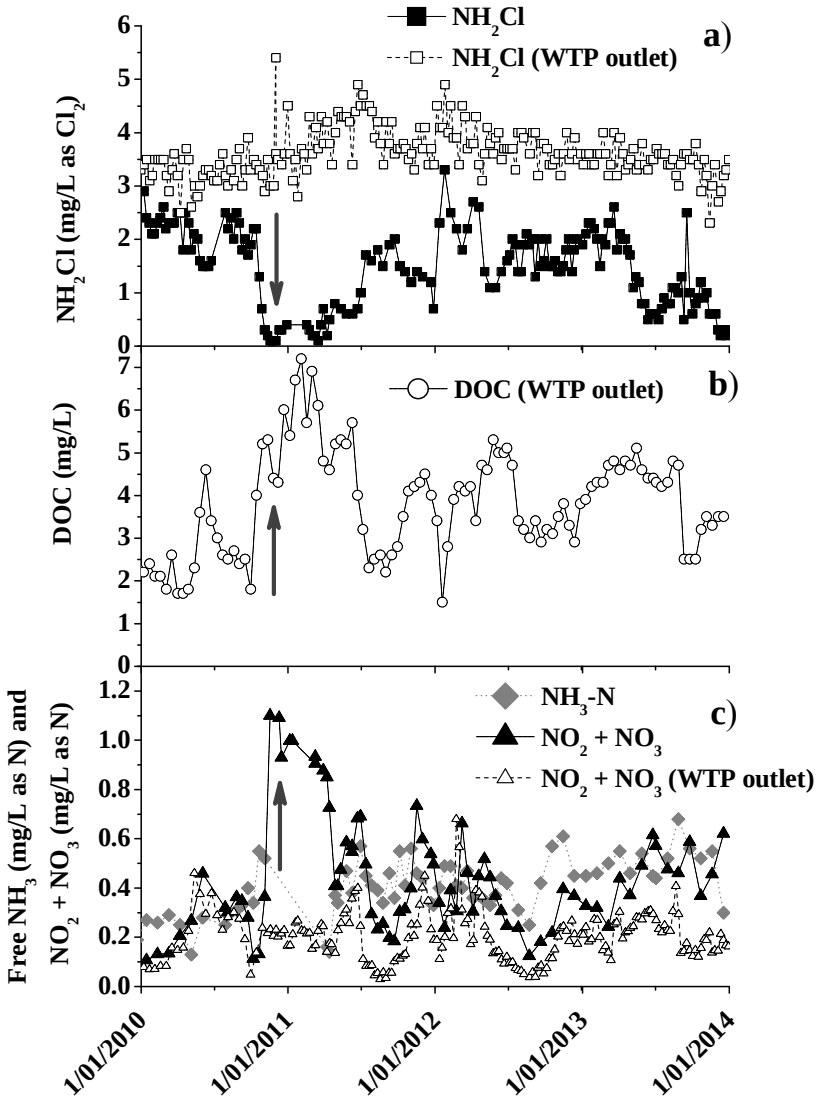

Figure 2: ***Water quality at Raukkan Tank (full data points) and Tailem Bend WTP product water (open data points) a) monochloramine residual b) DOC concentration; and c) free ammonia and total oxidised nitrogen***

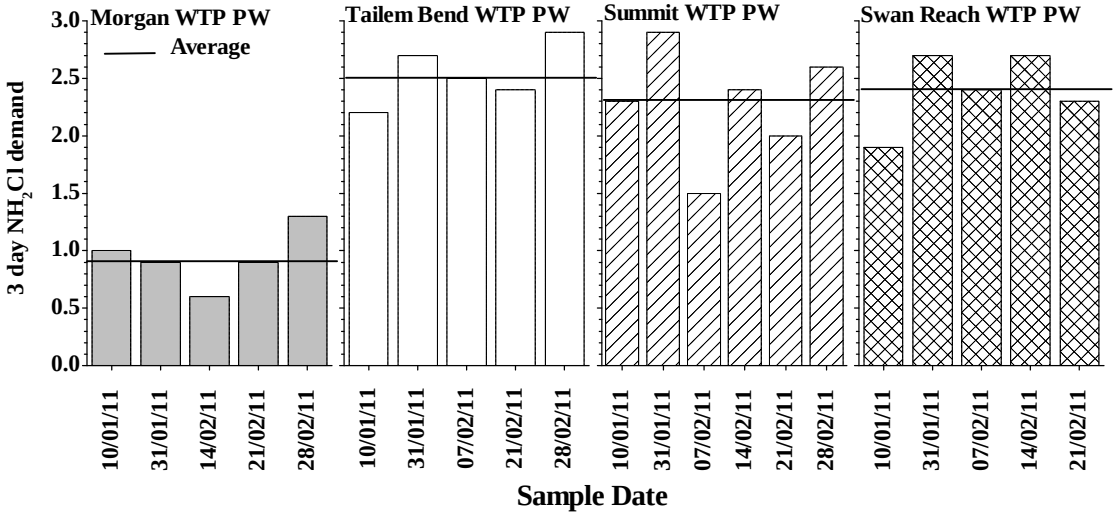

Figure 3: ***3 day monochloramine demand in WTP product water at 22 ± 2 °C (January – February 2011)***

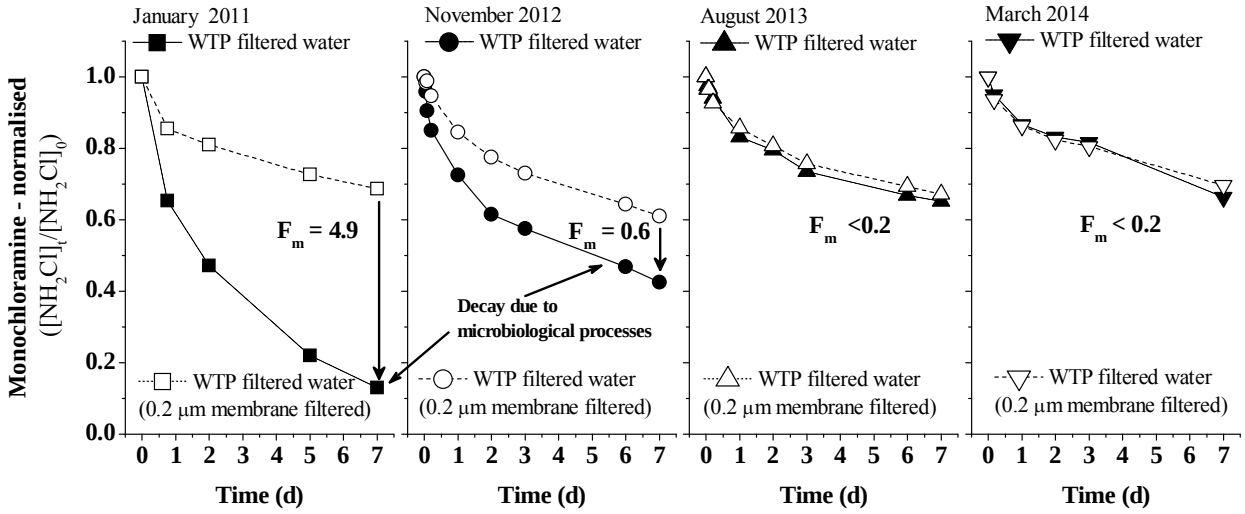

Figure 4: ***Monochloramine decay in Tailem Bend WTP filtered water, with and without filtration through a 0.2 μm filter, January 2011 – March 2014***

Additional monochloramine decay tests completed in Tailem Bend WTP product water showed the microbiological monochloramine decay component was present in November 2012 (F_m = 0.6) but was absent in August 2013 and March 2014 (Figure 4). This result suggests that factors impacting on microbiological monochloramine decay changed. Further research is underway to understand the factors (water quality and/or WTP operation) causing rapid monochloramine decay. Chlorine addition prior to ammonia was found to mitigate impact of microbiological monochloramine decay with effectiveness of chlorine increasing with chlorine dose and contact time (C.t) (Cook et al., 2014). Testing to assess F_m analysis to provide an early warning for the onset of nitrification was completed for Raukkan Tank that had previous nitrified (Figure 2). At the time of sampling (August 2012), based on water quality analysis (Table 1) the tank was not nitrified, although the presence of microbiological monochloramine decay (F_m = 0.6) was identified (Figure 5) and 2 km downstream of the tank a location within the Raukkan distribution system (DS) was nitrified with a high F_m of 4.2 determined (Figure 5). Analysis of F_m is continuing to be evaluated in South Australian distribution systems for its application as an early warning tool for nitrification.

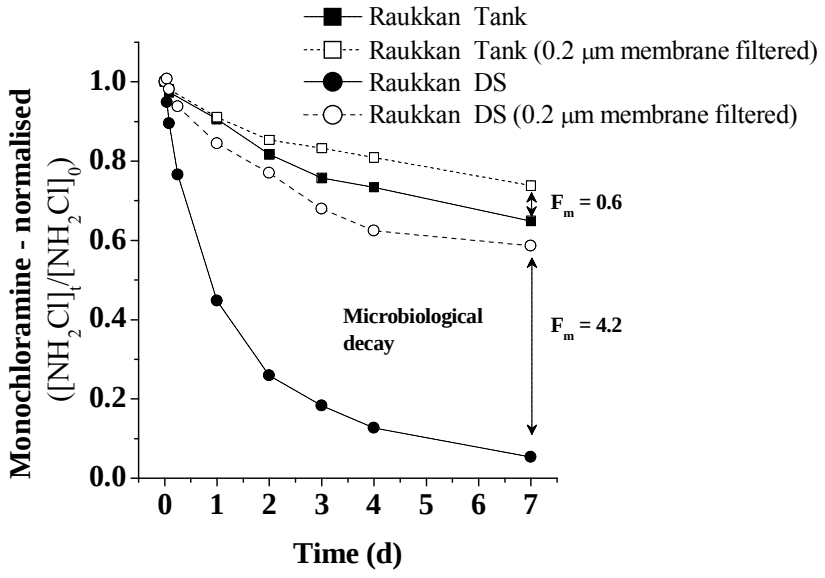

Figure 5: ***Monochloramine decay in Raukkan Tank and distribution system***

3.0 CONCLUSION

Distribution system water quality monitoring showed that product water DOC concentration was a key factor in the loss of monochloramine residuals. In 3 of 4 WTPs investigated, monochloramine decay tests identified the presence of microbiological monochloramine decay accelerating the overall monochloramine decay rate increasing the likelihood of nitrification. Overall, combining water quality monitoring and monochloramine decay tests can help identify key factors impacting on nitrification. Assessment of the test strategies used in this study are summarised in Table 3.

Table 3: ***Summary of test strategies used***

Test strategy	Advantages	Disadvantages
Water quality analysis	• Valuable for long term data trending • Assessment of nitrification status	• Microbiological monochloramine decay not determined • Does not predict nitrification
Monochloramine decay in WTP product waters	• No chemical dosing required in the laboratory • Monochloramine stability in water determined	• Microbiological monochloramine decay not determined • More difficult to compare each WTP
Microbiological decay factor F_m	• Monochloramine decay tests under uniform conditions to compare each WTP • Possibility to predict the onset of nitrification	• Samples need to be filtered and chloraminated in the laboratory which add to the cost of testing • Analysis requires monitoring over a 7 day period • Sampling frequency and locations still to be determined

4.0 ACKNOWLEDGEMENTS

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