MONITORING AND MANAGEMENT OF NITRIFICATION IN DRINKING WATER NETWORKS AND STORAGES

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ABSTRACT

A common theme across many Victorian water businesses in recent years has been the management of disinfection residuals and water quality in drinking water distribution networks. This is particularly notable in areas where chloramination is used as the primary disinfection method. Chloramination is necessary in drinking water networks with:

- low flow demand,
- long detention times, and/or
- high risk of disinfection by-product formation due to source water quality.

Nitrification is a fairly widespread issue for utilities using monochloramine disinfection for the drinking water network. It causes rapid depletion of the monochloramine residual in the network and enables regrowth of bacteria. Hence impairing disinfection and risking contamination of the drinking water supply.

This paper will present an investigation that Veolia has undertaken in monitoring of nitrification in drinking water networks and storages in the Bendigo area. Monitoring techniques have included:

- Investigation of site specific triggers for nitrification events.
- Identification of the most useful water quality parameters for early detection of network problems.

KEYWORDS
Nitrification, chloramination, network management, water quality.

1.0 INTRODUCTION

Since December 2010, various network assets and storages managed by the Veolia Bendigo team have experienced seasonal issues with maintaining disinfection residuals. The Bendigo and Castlemaine Water Treatment Plants (WTPs), both utilise chloramination as the final disinfection step of the treatment process. Nitrification is a common issue for utilities using monochloramine disinfection for the drinking water network. It causes rapid depletion of the chlorine residual in the network, allowing reestablishment of bacteria. Hence impairing disinfection and risking contamination of the drinking water supply.

Years of drought, followed by high rainfall and flooding events in 2010-2011 have resulted in significant changes to raw water quality characteristics for the Bendigo region. Recent raw water quality conditions have posed significant challenges to water treatment. Increased dissolved organic carbon in the water results in biofilm growth in networks. This enables the proliferation of nitrifying bacteria, which ultimately cause depletion of monochloramine levels. Given compromised disinfection levels, any form of contamination ingress into networks can lead to the presence of both coliforms and *E. coli*, significant risk indicators for public health.

Nitrifying bacteria are slow growing organisms and grow best in systems that experience long detention times, generally greater than 3 days. Warmer temperatures above 18°C facilitate the growth of the nitrifying bacteria, as does the presence of biofilms. Previous studies have shown nitrifying bacteria can resist the disinfecting properties of chloramine, at levels up to 2.0mg/L, even benefiting via utilisation of ammonia generated upon breakdown of monochloramine.

Even with treatment processes optimised, the removal of all nitrification precursors, such as the presence of free ammonia, is difficult in chloramination systems. It is important to detect the presence of nitrifying bacteria early to respond and address the effects on disinfection. Ultimately, nitrification can be identified via elevated levels of nitrite in the drinking water. Seasonal nitrite concentrations of up to 500µg/L have been detected in network storages around Bendigo, indicating the presence and increased activity of nitrifying bacteria at certain times of the year.

In this investigation the Veolia Bendigo team tracked the seasonal water quality trends for three drinking water storages and their associated networks. These included Edwards Road tank, and Specimen Hill reservoir in the Bendigo network, as well as Elphinstone tanks in the Castlemaine area. A substantial body of data was collected and analysed, enabling the development of correlations between the presence of nitrifying bacteria and the water quality parameters that can be used as a means of early detection. The aim being prevention of nitrification, and hence maintain chloramine levels, in order to provide quality disinfected drinking water.

Figure 1: ***Edwards Road Tank, a 15ML storage on the Bendigo drinking water distribution network***

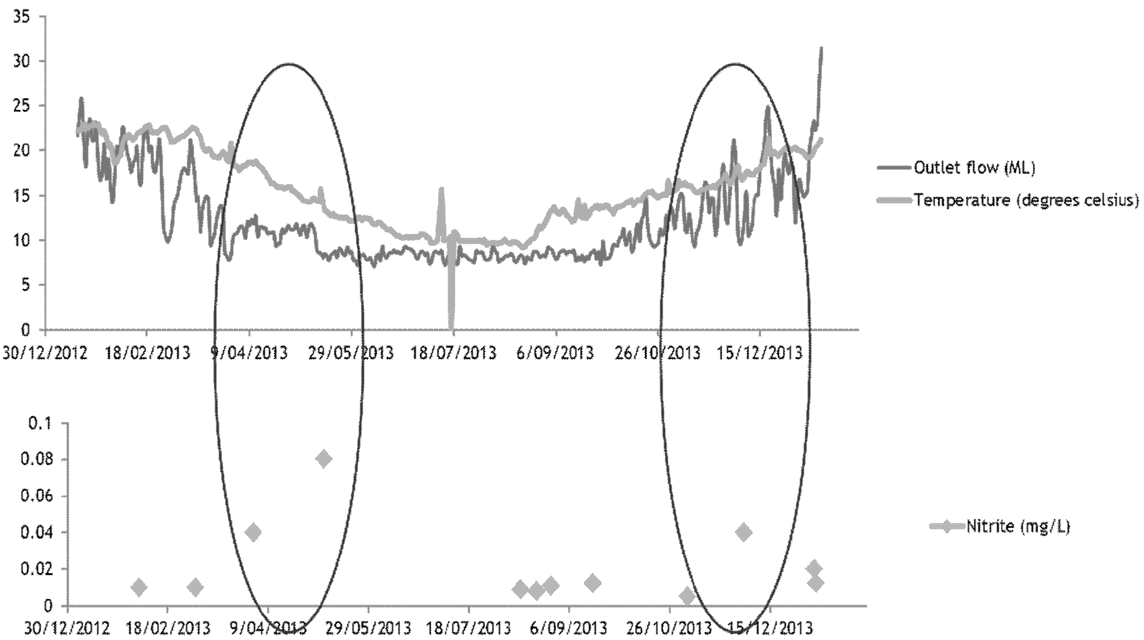
2.0 METHODS

For water quality monitoring, samples were taken from the inlet to and outlet from Elphinstone, Edwards Rd. and Specimen Hill storages. The samples were then analysed to obtain the temperature and pH, monochloramine, free ammonia and total chlorine residuals as well is the level of nitrite and nitrate present.

Comparisons and correlations were developed for seasonal trends for flow, tank residence time, chlorine and temperature, incorporating a detailed review of seasonal variation during nitrification events.

3.0 DISCUSSION

Data analysis and seasonal trends indicated Specimen Hill is most susceptible to nitrification during the months coming into and out of summer. Elphinstone and Edwards Rd. tanks, on the other hand, tend to show nitrifying activity during summer, particularly when water demand suddenly decreases after rain events.



<u>Figure 2:</u> ***Seasonal relationship between water temperature outlet flow and nitrite concentration in outlet at Specimen Hill reservoir.***

The formation of monochloramine between free ammonia and chlorine is highly dependent on pH. A substantial amount of monitoring and optimisation has been done to maintain pH above 7.8 at Specimen Hill reservoir. This has resulted in better formation of monochloramine residuals, despite warm water temperatures and the presence of nitrifying bacteria (See Table 1).

The breakdown of monochloramine occurs via two pathways, one facilitated by nitrifying bacteria and the other as a result of autocatalytic breakdown. The second mechanism is both temperature, pH and time dependent. Analysis of long term water quality data has shown Elphinstone tank, by comparison, is less likely to maintain pH levels above 7.8 and as a result has more autocatalytic decay of monochloramine compared to Specimen Hill. This is an important result and suggests that similar pH management and optimisation could be of benefit to management of Elphinstone tanks.

Table 1: ***pH management at Specimen Hill reservoir resulting in better***

monochloramine levels.

Date	**13/08/13**	**20/08/13**	**17/09/13**	**07/01/14**	**13/01/14**	**20/01/14**	**28/01/14**
Temperature ^{0}C	10.0	9.5	16.4	22.0	20.2	21.7	23.5
PH	7.7	7.6	7.7	7.8	7.8	8.0	7.8
Nitrite mg/L NO_2^- N	0.005	0.003	0.012	0.012	0.012	0.012	0.007
Nitrate mg/L NO_3^- N	0.9	0.8	0.9	1.0	1.3	1.4	1.4
Monochloramine mg/L	1.4	1.7	2.0	2.1	1.8	2.2	2.2

Trending of total inlet and outlet chlorine (see Figure 3) shows evidence of short-circuiting in both Specimen Hill and Edwards Rd tanks. This results in poor mixing and hence dead zones which in turn compromises disinfection residuals.

As shown in Figure 3 total chlorine trends fluctuate throughout the year for a number of reasons, not always related to nitrification. In monitoring nitrification, total chlorine is useful on a macro scale, whereby seasonal trends in chlorine residuals over a period of days or weeks can be considered indicative of possible nitrification activity. Hence it is important to maintain regular testing of nitrite concentrations during high risk periods to catch nitrification before chlorine residuals are compromised.

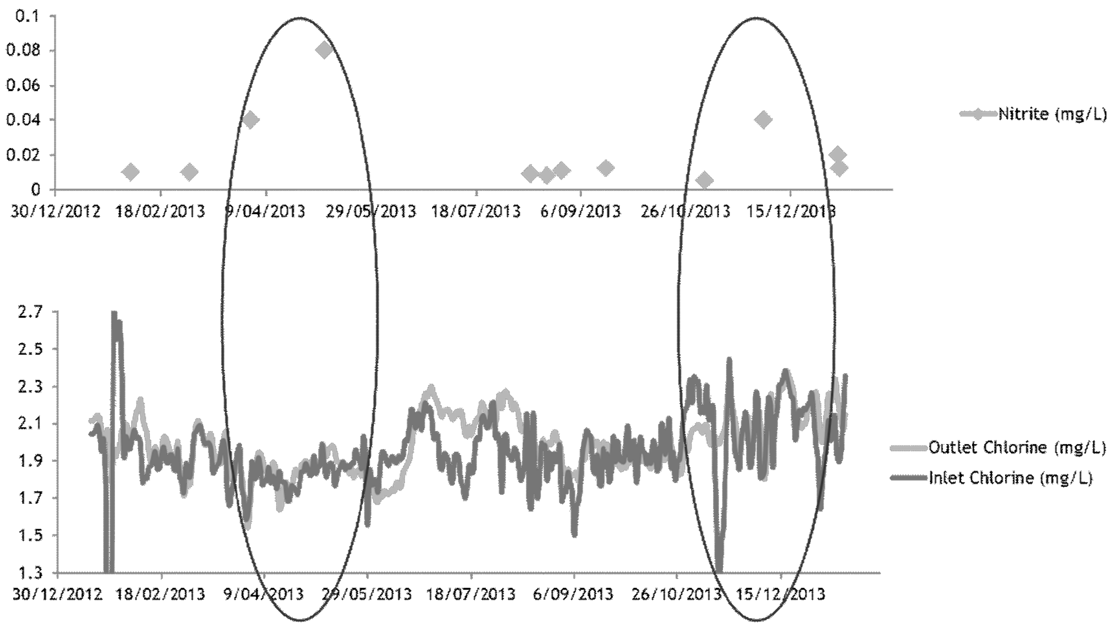


Figure 3: ***Relationship between inlet/outlet chlorine residuals and nitrite concentration in outlet at Specimen Hill reservoir.***

Table 2 summarises the result of the nitrification versus total chlorine analysis for the three storages investigated. Specimen Hill reservoir is susceptible to nitrification when total chlorine concentrations drop below 1.9mg/L, with a decrease of 0.2mg/L or more between the inlet and outlet.

Analysis of Elphinstone tanks suggest that total chlorine residuals which drop by 0.3 mg/L or more between the inlet and outlet indicate minor nitrification potential. The Edwards Rd. tank nitrification threshold seems to be 1.6mg/L at the outlet with associated decreases of 0.3mg/L across the tank.

Table 2: ***pH management at Specimen Hill reservoir resulting in better monochloramine residuals.***

Storage	Indicators of nitrification
Specimen Hill reservoir	Total chlorine concentration at outlet <1.9mg/L with > 0.2mg/L change between inlet and outlet concentrations.
Elphinstone Tanks	Sudden drop in total chlorine concentration >0.3mg/L
Edwards Road Tank	Outlet total chlorine concentration <1.6mg/L with associated decreases of >0.3mg/L between inlet and outlet.

The following table provides the correlations between key water quality parameters as indicators of risk of nitrification, on a scale ranked strong, moderate, and weak. Analysis of all of the data collected in this investigation found strong relationships between temperature, residence time and the presence of nitrite in storages. There is also a strong relationship between chlorine trends and nitrite. However the competing degradation mechanisms of nitrification and autocatalytic decay change according to the time of the year and which storage is being monitored. This reduces the efficacy of total chlorine as the sole indicator of nitrification activity, indicating regular nitrite monitoring in combination with total chlorine is a more effective strategy.

Table 3: ***Strength of correlations between key water quality parameters during nitrification events.***

	Residence Time	Nitrite	Nitrate	Ammonia	Monochloramine	Total Chlorine	pH
Temperature	Strong	Strong	Weak	Weak	Strong	Strong	Weak
Residence Time		Strong	Moderate/Weak	Weak	Moderate	Moderate	Weak
Nitrite			Moderate/Weak	Weak	Strong	Strong	Weak
Nitrate				Weak	Weak	Weak	Weak
Ammonia					Weak	Weak	Weak
Monochloramine						Strong	Moderate
Total Chlorine							Weak

4.0 CONCLUSION

During peak seasons for nitrification, it is recommend to do weekly analysis of nitrite concentrations at the outlet of network storages.
This would be beneficial in prevention of nitrifying bacteria generating exponentially under ideal growth conditions and compromising disinfection residuals.

The formation and stability of monochloramine is heavily dependent on pH and temperature. A substantial amount of monitoring and process optimisation has been done on maintaining treated water pH above 7.8 at Specimen Hill, in order to enhance the reaction and formation of monochloramine between free chlorine and ammonia. This has been met with some success in maintaining disinfection residuals, and may have further benefits if adopted for other network storages.

Whilst great effort has been made to adjust the volume of the tanks depending on temperature and usage, it is evident that when detention times increase during the warmer weather, particularly after rain events, nitrite concentrations spike and disinfection residuals become compromised. In order to prevent residence time being an issue, closer monitoring and management of storage levels in line with water demand and weather forecasts becomes crucial in reducing nitrification events.

Many network storages have issues with short-circuiting, whereby a substantial amount of fresh water entering the tank exits without mixing with the majority of the water stored in the tank. An alternative technique to reducing detention times in tanks is to implement tank mixing. Better tank mixing ensures that the entire tank volume is turned over regularly and there is less likelihood of "dead zones" in the tank.

5.0 ACKNOWLEDGEMENTS

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