

NITRIFICATION IN CHLORAMINATED DRINKING WATER SUPPLIES



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ABSTRACT

Nitrification is a known drinking water quality issue in chloraminated systems where ammonia-oxidising bacteria (AOB) feed on free ammonia in drinking water, significantly increasing in number producing nitrite which is then used as food by nitrite-oxidising bacteria (NOB) which converts the nitrite to nitrate. Nitrification is a process which can occur rather rapidly and lead to a complete loss of monochloramine residual. There are also a number of different factors which influence the nitrification process making it a complex issue to understand, control and prevent.

Although nitrification is not an issue with a direct public health impact, it can however, increase water quality risks that may lead to public health concerns. Therefore prevention and early identification of nitrification is critical. This paper will examine examples of nitrification, identification of occurrences of nitrification, and also examples of the implementation of preventative and reactive control measures to manage nitrification in drinking water distribution systems across South Australia and Victoria.

1.0 INTRODUCTION

When I began working in the field of Drinking Water Quality Management, I was warned about nitrification, the havoc it could cause in terms of loss of chloramine and chlorine residuals. I was also warned that I had to be continually on my guard because it could appear and get out of control quickly. But when I asked questions about how to identify it, no one could give me a definitive answer but just that it involved rapid changes in trends of total chlorine, free ammonia, nitrites and nitrates, and that I would know it when I saw it. Ever since then I have been interested to find out more and understand better the causes of nitrification and how to prevent it occurring in chloraminated drinking water supply systems.

Nitrification is one of the major concerns and risks associated with chloramination of drinking water supplies. However the issue of nitrification is generally not well understood by many in the industry, both the causes of it, the management of it, or even why nitrification is of concern from a drinking water quality and public health perspective. This paper seeks to explain simply what nitrification is, its causes, its risks to drinking water quality and public health, and how it can be managed or prevented using examples from my work with water utilities across South Australia and Victoria.

2.0 DISCUSSION

2.1 Description of Nitrification

Nitrification is the proliferation of nitrifying bacteria, microorganisms that oxidize free ammonia to nitrite and nitrate (Regan *et. al.*, 2002). Free ammonia is added to the chloraminated distribution systems as excess free ammonia from the formation of chloramines and also that which is released from chloramine decay. Ammonia oxidising bacteria (AOB) are able to feed on the free ammonia in the water producing nitrite.

Although it is suggested that a chemical reaction between chloramines and nitrite may lead to the formation of more free ammonia and nitrate it is acknowledged that a community of nitrite oxidising bacteria (NOB) along with AOB will favour the biological oxidation of nitrite to nitrate by NOB (Regan *et. al.*, 2002). The proliferation of each of these microorganisms leads to often rapid depletion of chloramine residuals and the development of a microbial community in the distribution system and deterioration of drinking water quality. This is often observed as an increase in heterotrophic plate counts and coliform detections (Regan *et. al.*, 2002).

Although nitrification does not have direct impacts on public health, it is still an important process to control and ensure does not take control across distribution systems. This is primarily because nitrification leads to a rapid loss of chloramine residuals which are an important barrier in the management and protection of water quality in distribution systems. The loss of chloramine residual leaves the distribution system susceptible to microbiological contamination with potential public health implications.

2.2 Causes of Nitrification

There are a number of different factors which have been identified as contributing to the proliferation of AOB and NOB in chloraminated drinking water supplies. These factors include high free ammonia, water temperature $>15^{\circ}\text{C}$, low chlorine residual (<2 mg/L), low pH, and high water age.

Vikesland *et al.* (2001) highlights that while higher free ammonia will favour nitrification by providing ammonia for the AOB, higher free ammonia will also promote the formation of more stable chloramines. This highlights the need to get the chlorine to ammonia dosing ratio at an appropriate level at the treatment plant so that there is only a small amount of free ammonia remaining in the water following the formation of chloramines.

Nitrification is known to be more likely to occur in distribution systems where the chloramine residual is <2 mg/L (US EPA, 2002). This is likely because higher chloramine residuals enable better control of microorganisms in the water. But nitrite produced by AOB may also accelerate the decomposition of monochloramine leading to further degradation of chloramine residuals (WHO, 2004). Thus as AOB begin to proliferate, a more rapid decay of chloramine residual is to be expected.

Since chloramine residual typically decays over time as it is consumed gradually as a disinfectant, lower residuals are typically experienced where the water age is significant leading to higher risks of nitrification occurring. High water age also typically occurs in areas where there is minimal movement of water such as in tanks and dead end mains. In addition slow movement of water and sediment build-up may also encourage the growth of microbiological communities.

While lower pH may contribute to the viability of nitrifying bacteria, lower pH will also decrease the stability of chloramines and increase the rate of chloramine decay leading to lower chloramine residuals. Higher water temperatures are also known to increase the growth rate of nitrifying bacteria thus increasing the likelihood of nitrification occurring (US EPA, 2002).

2.3 Identification of Nitrification

The first challenge in management of nitrification is being able to identify when it has occurred or is likely to occur. Nitrification is able to be identified through careful monitoring of trends of various water quality parameters. The parameters which should be monitored when seeking to identify instances of nitrification are free ammonia, nitrite, nitrate and total chlorine.

AOB will feed on free ammonia leading to a loss of free ammonia producing nitrite and an increasing nitrite trend. NOB feed on increasing levels of nitrite leading to an increasing nitrate trend. As AOB and NOB increase chlorine residuals are depleted very quickly. The loss of chlorine residuals is then often accompanied by increasing standard plate counts and detections of coliforms and *E. coli*. The changes are often rapid, with complete loss of chlorine residuals sometimes occurring with one to two weeks.

Figure 1 below indicates just how quickly nitrification can take hold in a particular distribution system tank. The step change in both the free ammonia and nitrite data sets between mid-January and mid-February is highlighted by the fact that there is a month between results. The total chlorine and monochloramine data sets have weekly resolution which shows that although there was a gradual downward trend in both data sets there was a significant step change in the week from 22nd of January to 29th of January with total chlorine change from >0.4 mg/L to <0.1 mg/L indicating that nitrifying bacteria overwhelmed the tank in this week. Almost immediately after this loss of chlorine residual, coliform detections began in this tank. Although there was some drop in the chlorine residual prior to this and also some small increase in the nitrite trend, these changes on their own would not necessarily cause alarm. This highlights the need to have routine monitoring at an appropriate frequency for parameters including nitrite, nitrate, free ammonia and relevant chlorine species, but also to have a ‘turnaround time’ for sample results which is sufficiently short to enable swift action to control nitrification.

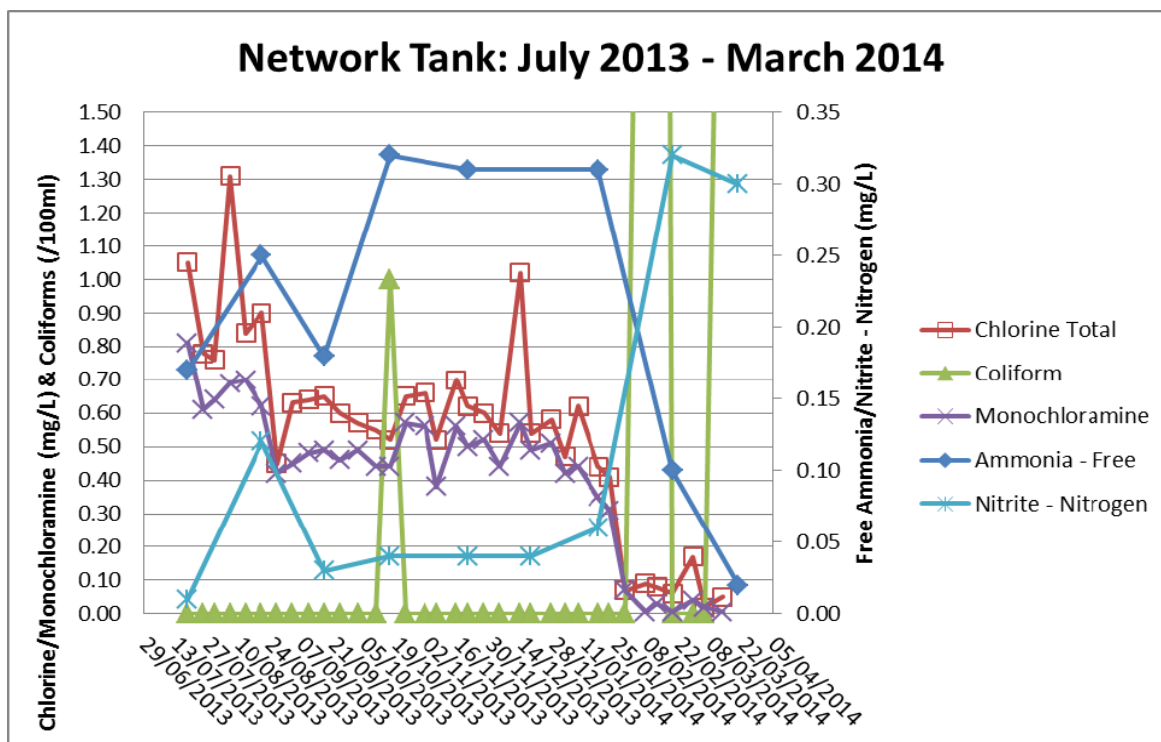


Figure 1: Example of water quality trends indicating occurrence of nitrification

2.4 Management and Prevention of Nitrification

There are a number of measures which can be used to prevent and control nitrification in chloraminated drinking water supplies. Firstly it is important to ensure that free ammonia levels downstream of dosing points are low as this minimises food available for the AOB. This is linked to dosing of chlorine at appropriate ratios to facilitate the formation of stable chloramines. Having a small amount of free ammonia in the water is indicative that the chlorine is at an appropriate point on the breakpoint curve. As demonstrated previously AOB and NOB can quickly proliferate and consume chlorine residuals. Therefore it is necessary to carefully monitor the results of routine monitoring for free ammonia, nitrite and nitrate. Examining trends in these parameters over longer periods of time will give the clearest signs of when nitrification is occurring at particular locations.

Experience has shown that nitrification is more likely to occur in portions of the system where turnover is lower and water age is therefore higher. This is likely linked to lower chloramine residuals, as maintaining higher chloramine residuals is known to be an effective means of controlling nitrifying bacteria (US EPA, 2002). Thus altering operation of distribution systems to reduce water age, increase turnover and increase distribution system chloramine residual levels is an important factor in managing the risk of nitrification occurring. This includes optimisation of dosing at treatment facilities, altering system storage capacity and valves arrangements to ensure that water age is minimised and chloramine residual decay is minimised. Minimising levels of Natural Organic Matter (NOM) in treated water has also been shown to decrease rates of chloramine decay (US EPA, 2002). Therefore maximising removal of NOM during treatment processes will also enhance penetration of higher chloramine residuals into the downstream distribution networks.

Booster chlorination may also be used to increase chlorine residuals in long distribution systems. Depending upon the water chemistry at the point of booster chlorination, this may accomplish different outcomes. If there is no free ammonia present in the water, then a free chlorine residual will be formed in the water. However, depending on how the downstream distribution network is configured, uncontrolled blending of water with a free chlorine residual with chloraminated water may lead to a reduction or loss of chlorine residual. If free ammonia is present from the breakdown of chloramines through the distribution system, then chloramines may be reformed provided an appropriate amount of chlorine is added such that breakpoint chlorination does not occur. Concentrations of free ammonia large distances downstream of treatment facilities are typically lower and therefore addition of chlorine will typically only enable the reformation of chloramine residuals at lower concentrations than at the treatment facilities. The concentration of free ammonia large distances downstream of treatment facilities in large distribution networks may also be variable depending upon various factors such as water chemistry, microbial activity and seasonal temperature variations, making the addition of the appropriate amount of chlorine to achieve optimal reformation of chloramines rather than breakpoint chlorination more difficult.

Periodic breakpoint chlorination to temporarily restore a free chlorine residual to distribution networks is another common method for controlling nitrifying bacteria (US EPA, 2002). This is because free chlorine is much more effective at inactivating AOB than chloramines. Once an episode of nitrification is underway, breakpoint chlorination is the most effective means of bringing numbers of nitrifying bacteria back under control (Kirmeyer *et al.* 1995).

2.5 Specific Examples of Nitrification Management

Having worked in various roles in water quality with various water utilities across South Australia and Victoria, I have faced a number of challenges in relation to management of nitrification in chloraminated drinking water systems. This has led to me instigating various actions to facilitate improved management and prevention of nitrification across various chloraminated drinking water supplies.

As already stressed, monitoring of water quality parameters such as free ammonia, nitrite, nitrate and chlorine species is crucial in the identification of nitrification and any indications that nitrification may be developing. As a result, in various distribution systems in which I have had responsibilities relating to water quality management I have worked to increase the frequency of free ammonia, nitrate and nitrite monitoring to a frequency of at least fortnightly in high risk areas of those networks. This increased expenditure was justified on the grounds that early intervention in management of nitrification to prevent it spreading throughout the network is much cheaper than having to coordinate a system wide free chlorination event to remove nitrification. Having results from routine sampling available in a sufficient 'turnaround time' from date of sampling is also important in keeping abreast of changes in water quality that may be of significance in relation to management of nitrification. When there are concerns that nitrification may be occurring, waiting 10 days for results is too long. The laboratories I have worked with have generally been able to achieve 'turn around times' of 5 days or less without too much additional cost.

As previously illustrated proliferation of AOB and NOB leading to a loss of chloramine residual may occur quite rapidly under the right conditions, therefore careful monitoring of water quality in high risk areas quite important. Nitrification is most likely to be evident first in areas of low flow such as in tanks and in dead end mains. Therefore distribution system tanks are generally the primary locations of concern regarding risk of nitrification occurring and should be monitored regularly. Often nitrification can begin in these locations and then spread quickly downstream and possibly more slowly upstream also, highlighting the need to be able to act quickly to control the nitrification before it spreads. Removal of occurrences of nitrification generally involves breakpoint chlorination of tanks to kill of AOB and NOB. Then over the following days as water turns over in the distribution system a monochloramine residual generally returns. When nitrification spreads throughout a distribution network a more systematic program of break point chlorination and flushing of mains is required to pull a free chlorine residual through the entire network to remove the nitrifying bacteria. This method has successfully been implemented by water authorities in Victoria.

When considering nitrification prevention strategies the primary factors leading to the proliferation of AOB and NOB needs to be considered first. My experience in South Australia was that nitrification primarily occurred during the winter period, indicating that water age was a key factor influencing the occurrence of nitrification. However in Victoria it seems that nitrification occurs more commonly in the summer period indicating that higher temperatures are a significant factor influencing the occurrence of nitrification events.

While working to manage nitrification in South Australia, one of the primary methods of preventing nitrification was through reducing water age by lowering distribution system tank operating levels during the low demand winter period.

However identifying when these changes should be made and negotiating with operators to implement the changes was often challenging. So I developed a system which involved the automatic generation of a weekly report which gave a rolling 30 day average daily flow from the treatment plant. After analysing several years of daily flow from the water treatment plant I was able to identify appropriate trigger points for changing between summer and winter tank settings. These values were documented in the water quality management plan for that water supply system and used successfully for a number of years without significant nitrification events occurring.

3.0 CONCLUSION

Controlling nitrification or the proliferation of AOB and NOB in chloraminated drinking water supplies is important as this leads to loss of chloramine residuals which form an important barrier in the management of drinking water quality and public health. There are many factors which can impact the risk of nitrification occurring meaning that a multifaceted approach to management is required from treatment plants through to the end of distribution systems. This includes maximising NOM removal through treatment processes, managing pH levels along with chlorine and ammonia dose rates to achieve the formation of stable monochloramine which will persist well in the distribution system, and managing distribution systems to minimise water age and promote higher chloramine residuals throughout the network.

But in order to be able to identify nitrification when it occurs or is at risk of occurring, there needs to be in place a robust routine water quality monitoring program which includes regular monitoring of free ammonia, nitrite, nitrate and chlorine species. This is important to provide baseline data to enable identification of concerning trends which are indicative of nitrification. This will enable swift action to bring nitrification under control before it spreads through the distribution network.

4.0 ACKNOWLEDGEMENTS

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