Managing chloramination – success story for Sydney water

D.C. Vitanage, P. Cresta, C. Doolan and P. Duker

Sydney Water (E-mail: *dammika.vitanage@sydneywater.com.au*)

Abstract Sydney Water's Woronora Delivery System periodically trialed chloramination over the last three years, with initial trials resulting in nitrification and bacteriological counts. A more planned and structured approach was used in June 2000 to reintroduce chloramination. The aim of the study was to assess the feasibility of chloramination as the preferred method of disinfection for the Woronora system, considering the impact on issues such as trihalomethane (THM) formation, nitrification, compliance performance and residual chlorine management. The implementation of chloramination and the optimisation of system hydraulics have resulted in significant improvements in water quality performance in terms of chlorine residuals, heterotrophic plate counts (HPC_{20}), total and faecal coliforms and disinfection by-products. Higher chlorine residuals were seen throughout the system, taste and odour complaints were reduced to negligible levels, THM levels declined by two-thirds and nitrification was not evident at any stage throughout the trial. A critical control matrix was developed as a vital management tool to address the issues that could impact on chloramination/nitrification in the system. Managing the nitrification balance in terms of the available ammonia and maintaining the chlorine to ammonia ratio close to 4:1 (as Cl_2:NH_3) within the total system and the maintenance of a higher residual chlorine level (>1.00 mg/L) were found to be the most critical factors in managing a chloraminated system.

Keywords Chloramination; chlorine to ammonia ratios; disinfection by-products (DBP); heterotrophic plate counts; nitrification; system optimisation

Water Science and Technology: Water Supply **Vol 2 No 5–6 pp 411–417** © IWA Publishing 2002

Introduction

The key drivers for the introduction of chloramination by Sydney Water (SWC) were:

- to reduce the level of disinfection by-products (principally trihalomethanes);
- to provide a longer lasting chlorine residual in the distribution system;
- to reduce the likelihood of customer taste and odour complaints concerning chlorine;
- greater resistance to UV degradation in open canals (in early years).

Managing chloramination has been a difficult process for many water authorities and drinking water systems using chloramine disinfection can experience sudden losses of disinfection residual accompanied by bacterial regrowth and subsequent deteriorating water quality. This has mainly been attributed to the onset of nitrification.

Sydney Water's Woronora Delivery System serves a population of 100,000 (approximately 2.5% of the total). The system comprises of 20 service reservoirs and 513 kms of mains (refer to Figure 1). Historically it has operated under a chlorinated disinfection regime, which has provided a reasonable level of disinfection ability within the major parts of the system. For this system chlorination is expensive, labour intensive, it requires secondary chlorination at reservoirs, requires high initial chlorine dose rates due to rapid initial chlorine decay, it results in unequally dispersed chlorine residual levels, has the potential for forming elevated trihalomethanes (THM) and the heterotrophic plate counts at 7 days 20°C (HPC_{20}) were variable.

Initial commissioning to introduce chloramination into the Woronora Delivery System was attempted on several occasions over the last three years. These all proved to be unsuccessful with noted increases in nitrification, HPC_{20}, as well as positive total coliform counts. This was attributed to excess ammonia being available to nitrifying bacteria. In this regard, the chlorine to ammonia ratios (Cl_2:NH_3) at the water filtration plant (WFP) ranged

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/411/407872/411.pdf
by guest

from anywhere between 2:1 and 25:1. A number of issues contributed to this including: differences in chlorine measurements (colorimetric method versus amperiometric titration method); WFP sampling point issues; dosing issues for both chlorine and ammonia; the dosing sequence of chlorine and ammonia after the clear water tank (CWT), WFP PLC (programmable logic controller) issues, WFP equipment issues and ammonia raw material strength.

Method

A plan was developed to detail the requirements and agree on the process for the implementation of the chloramination trial. The principle of locking up the free ammonia throughout the total system was the key strategy adopted. The chlorine to ammonia ratio was thus maintained as close as possible to 4:1. The initial set point for operation was planned to commence from 1.4 mg/L and further trials were implemented with approximate increments of 0.2 mg/L, up to a set point of 1.9 mg/L. There was a critical focus on the WFP to ensure that at the commencement of the system the $Cl_2:NH_3$ ratio was kept as close as possible to 4:1. In addition, all the previous improvements identified within the WFP were completed prior to the commencement of the trial and then fine tuning was undertaken based on the distribution system response. Within the distribution system, tablet dosing was reviewed and continued with the primary objective to maintain the $Cl_2:NH_3$ ratio. All the service reservoirs were operated at maximum cycling levels where possible and at the minimum operational levels. The existing hydraulic and chlorine models were also used to

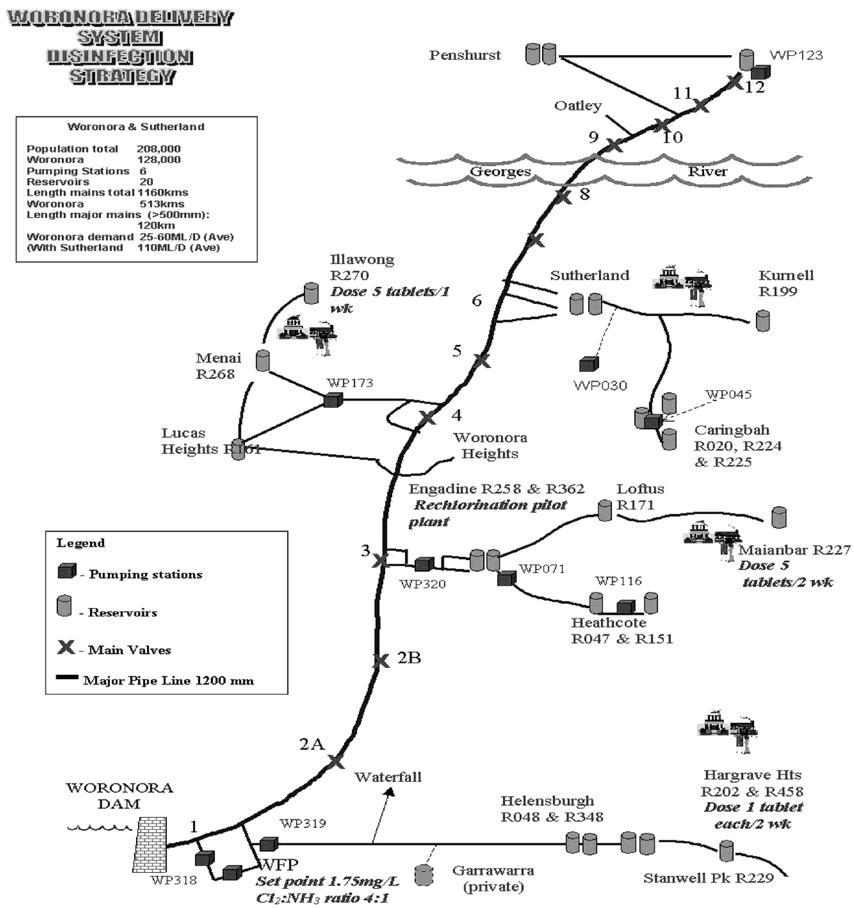

Figure 1 The Woronora delivery system

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/411/407872/411.pdf
by guest

plan this process. The plan included before and after water quality monitoring assessments, while the HPC_{20} was the key microbiological indicator used. Nitrites, nitrates and ammoniacal nitrogen were measured to verify nitrification. Data from existing compliance and additional monitoring was used with weekly analysis of the critical characteristics on how the system was responding and when it attained more stability, the monitoring frequency was changed to fortnightly and then to monthly. A critical control matrix was used to ensure that all the trigger points, contingencies and standard operational protocols were documented during the trial to ensure quality assurance and preventive strategies.

Results and discussion

Total chlorine

At the different stages of the trial the total residual chlorine level performance in relation to the percentage of samples collected is indicated in Figure 2. These are at three different set points 1.4 mg/L to 1.6 mg/L to 1.75 mg/L. Another trial was also conducted using a 1.90 mg/L set point. No significant improvements in performance were recorded in the system when using a 1.4 mg/L or 1.6 mg/L set point at the WFP. However, a 1.75 mg/L set point resulted in no sites having a total chlorine residual of <0.6 mg/L which meets the SWC internal target to provide a total chlorine residual of ≥0.6 mg/L (95% monochloramines) at the customers tap. The number of samples with a chlorine residual of >1.00 mg/L improved from 34% to 73%. When the 1.90 mg/L trial was undertaken there was no difference in performance from the 1.75 mg/L trial. It is important to note that the tablet dosing (secondary chlorination) programme was continually reviewed and adjusted as the set point increases were made. The dosing programmes objective shifted when it was determined that the management of the nitrogen balance and the Cl_2:NH_3 ratio was more critical than the maintenance of the total chlorine residual at the reservoir, which was ultimately a reflection of the set point increases at the WFP.

Figure 3 demonstrates how the tablet dosing was effectively used to maintain the Cl_2:NH_3 ratio by ensuring that dosing takes into account chlorine decay through the reservoir. If the total system hydraulics are managed the ammonia level is consistent. A baseline for chlorine and ammonia levels at strategic points in the system was determined and was found to be stable under the same operating conditions. These were incorporated into a quality control matrix and were used as the control mechanism for optimising the ratio. Figure 4 illustrates that under a chloraminated regime, the total chlorine residual range throughout the system is much tighter, with most sites having a residual of around

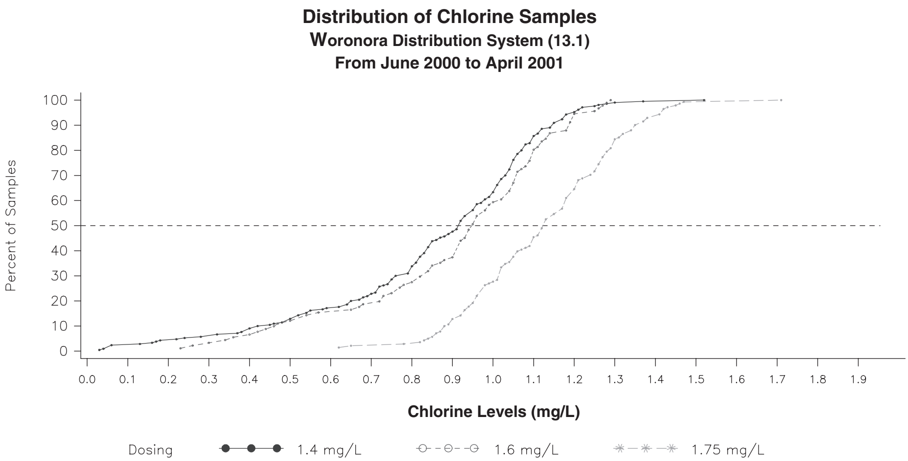

Figure 2 Residual chlorine performance within the distribution system

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/411/407872/411.pdf
by guest

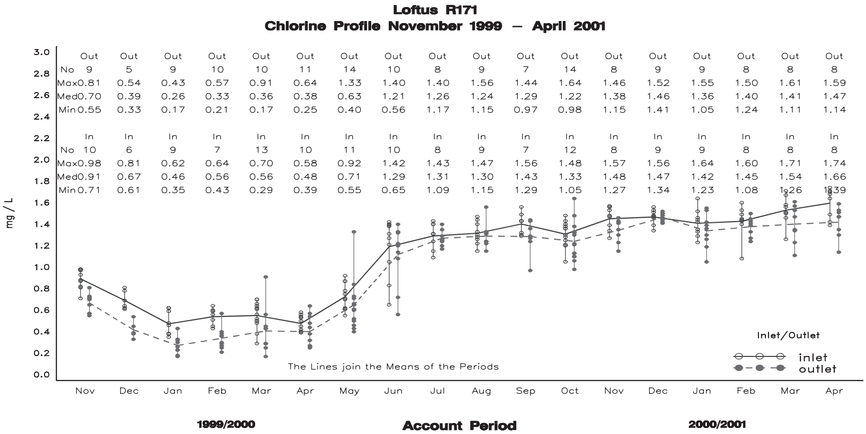

Figure 3 Total chlorine tablet dosing profile for Loftus reservoir

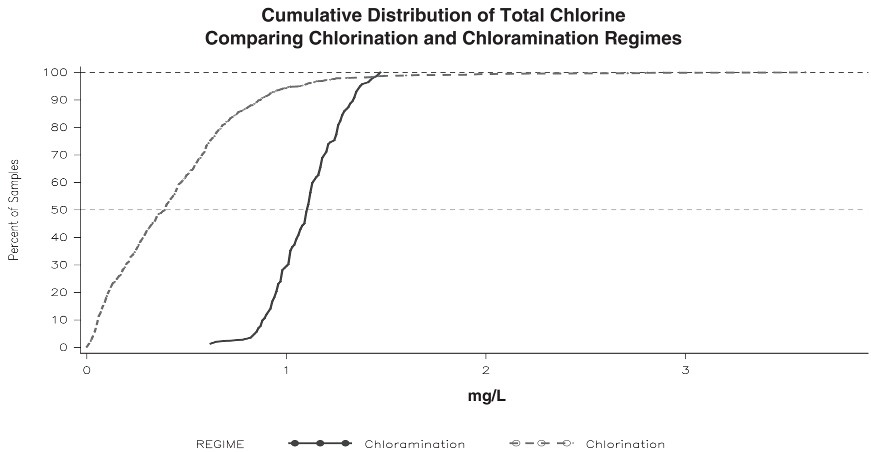

Figure 4 Total chlorine residual chlorination versus chloramination comparison

1.00 mg/L while under a chlorinated regime, the residuals range anywhere from 0–>3 mg/L.

Microbiological performance – HPC_{20}

The presence of HPC_{20} counts in increasingly elevated numbers can provide an early indication of significant nitrifying activity. HPC_{20} are much more responsive to residual concentration than coliform counts and give a good indication of general overall water quality. Previous Woronora nitrification experience has shown that at a nitrite level of >0.025 mg/L the HPC_{20} counts average around 2,200 cfu/mL. The best HPC_{20} performance was evidenced at a set point of 1.75 mg/L, when 74% of sites within the distribution system had counts <100 cfu/mL, 25% with counts between 100–1,000 cfu/mL and only 1% > with counts 1,000 cfu/mL.

In Figure 4 above, the performance of HPC_{20} is demonstrated at the same sampling sites throughout the system against the various set points. At a set point of 1.4 mg/L, 61% of sites had counts of <100 cfu/mL and 15% were >1,000 cfu/mL. At 1.6 mg/L there was a slight decrease in performance with only 42% of sites with counts of <100 cfu/mL, 52% had counts between 100–1,000 cfu/mL and 7% of sites had counts of >1,000 cfu/mL. It is believed that the shift in counts was a result of the shearing off of biofilms as the set point was increased to 1.6 mg/L. The system appeared to settle down and the positive impact of

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/411/407872/411.pdf
by guest

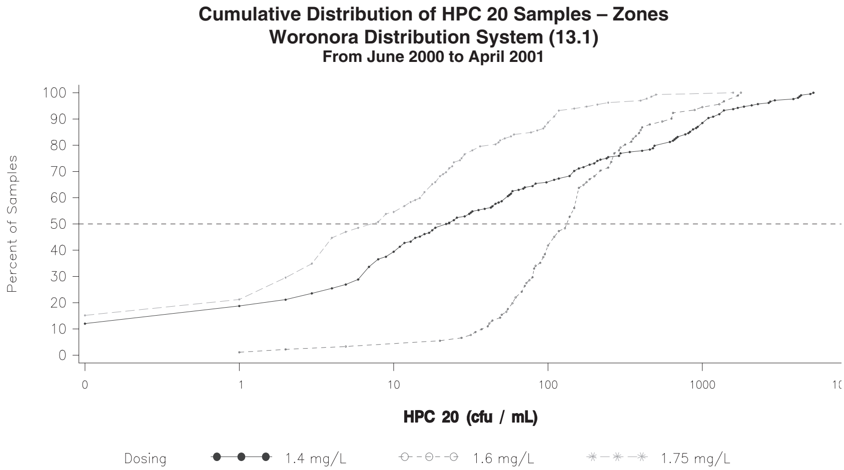

Figure 5 HPC_{20} performance within the distribution system at the different trial set points

increasing the set point further to 1.75 mg/L is clearly indicated by 86% of samples having counts <100 cfu/mL and only 1% >1,000 cfu/mL. This indicates that 1.75 mg/L is the optimum set point level for achieving greater HPC_{20} performance in both the reservoirs and reticulation.

Ammonia and nitrogen species (nitrite NO_2 and nitrate NO_3)

For nitrification to establish, a number of factors must be present including "available" ammonia which is utilised by the bacterial population. The more ammonia available, the greater the number and activity of nitrifying bacteria that can become established. Trends in ammonia are useful in conjunction with other nitrogen species to confirm the transformation to oxidised nitrogen. Nitrite is the most sensitive and reliable indicator of nitrification. A rise in nitrite concentration (termed as nitrite nitrogen NO_2-N) from <0.001 mg/L to 0.025 mg/L is a good indicator that nitrification is occurring. The measurement of nitrate is useful (termed as NO_3-N) in conjunction with other nitrogen species to confirm the trends in oxidation, but is an unreliable indicator if used alone. However, nitrate should also be tested for, since, without this parameter an absence of nitrite could mistakenly be interpreted as an absence of nitrification (Flood *et al*., 1998).

No nitrification was observed at any stage in the system. This was also confirmed by the R&D desktop study on nitrification (Jegatheesan and Cresta, 2001). Overall the ammoniacal nitrogen as N ranged from 0.01–0.42 mg/L. Nitrate levels ranged from 0.070–0.12 mg/L, with 99% of samples having <0.11 mg/L. The nitrate baseline levels at the WFP ranged from 0.04–0.09 mg/L. Nitrite levels ranged from <0.001–0.014 mg/L, with 98% of samples having ≤0.005 mg/L, well below the 0.025 mg/L level which indicates major nitrification. At the WFP the levels were <0.001 mg/L.

Chlorine to ammonia ratio as Cl_2:NH_3

Maintenance of the Cl_2:NH_3 ratio was initially unsatisfactory ranging anywhere from 1.25:1 to 26.4:1 within the system, due mainly to the inconsistent draw-down patterns placed on the WFP. These were significantly changed and are now tightly managed and maintained. The long detention times in parts of the distribution system also caused these ratios to often deviate from the desired level and thus required boosting by chlorine tablet dosing at the reservoirs. The tablet dosing programme was optimised to manage the Cl_2:NH_3 ratios throughout the system.

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/411/407872/411.pdf
by guest

The ammoniacal nitrogen levels and the Cl_2:NH_3 ratio were found to be critical factors in managing nitrification. The theoretical ratio for stoichiometric formation of monochloramine is 4.17:1 as Cl_2:NH_3. Ratios higher than 4:1 lead to breakpoint reactions which result in loss of chlorine residual and nitrogen, and the potential formation of dichloramine which causes taste and odour problems, while ratios lower than this will leave free ammonia in the system. Free ammonia could cause the onset of nitrification by supporting the growth of ammonia oxidising bacteria (AOB).

As maintenance of the Cl_2:NH_3 ratio is difficult in large distribution systems, to compensate for the initial demand in chlorine as well as the demand within the system, higher residual chlorine level need to be maintained. This is in order to inactivate the biofilm activity to minimise the risks of nitrification and also to ensure that the free ammonia is "locked up" as monochloramine wherever possible.

Trihalomethanes (THMs) and other disinfection by-products (DBPs)

Under a chloraminated regime the THM levels decreased by as much as two-thirds when compared against a chlorinated regime (from 70–175 µg/L for a chlorinated regime to between 38–56 µg/L for a chloraminated regime). Other DBP levels were well below the 1996 Drinking Water Guidelines. The HAA5 (haloacetic acids) DBP level maximum was measured to be 30 µg/L (the proposed US-EPA limit is 60 µg/L), while the remaining nine readings were between 14–23 µg/L.

Customer complaints

Taste and odour complaints can be associated with free chlorine or can also occur under a chloramination regime if the Cl_2:NH_3 ratio is out. If the ratio is not optimised the formation of dichloramines or trichloramines/nitrogen trichloride can occur causing taste and odour related complaints from consumers. In the Woronora Delivery System, the complaints declined by 75% under a chloraminated regime.

Chlorination versus chloramination improvements

Table 1 is intended to give an overview in relation to key characteristic levels under a chlorinated regime compared to a chloraminated regime. The minimum and maximum ranges have been recorded for each characteristic. To give an appreciation of how the results were

Table 1 Water quality improvements chlorination regime versus chloramination regime

Parameter	Chlorination 01/03/99–06/06/00			Chloramination 28/11/00–28/03/01		
	Min/ max range	% samples	Nominated level	Min/max range	% samples	Nominated level
Ammoniacal nitrogen (as N mg/L)	<0.01–0.01	97.1	<0.01	0.01–0.42	80	>0.26
Nitrite (as N mg/L)	0.001–0.008	97.1	<0.002	0.001–0.014	45.5	≤0.002
Nitrate (as N mg/L)	0.03–0.13	88.6	≤ 0.1	0.070–0.12	100	≤ 0.1
THM (µg/L)	70–175	70.4	≤ 102	38–56	76.2	≤ 50
HAA5 (µg/L)	NDA	–	–	14–30	–	–
Total coliforms (cfu/100 mL)	0–710 (10 failures)	–	–	0–13 (5 failures)	–	–
HPC_{20} (<100 cfu/mL)	0–100	71.7	≤ 100	<100	78.5	≤100
HPC_{20} (100–1,000 cfu/mL)	100–1,000	21.8	100–1,000	100–1,000	20.8	100–1,000
HPC_{20} (>1,000 cfu/mL)	>1,000	6.5	max 32,000	>1,000	0.7	max 1,600
Total chlorine (mg/L)	<0.02–3.6	73.1	≤0.6	0.62–1.47	100	> 0.6
Taste & odour complaints (per 1,000)	0.85	–	–	0.17	–	–

[1] Chlorination commenced on 19/02/99. Data was used from 01/03/99 to allow turnover in the system.
[2] NDA No data available

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/411/407872/411.pdf
by guest

distributed within the range, the table quotes a percentage of samples that were over or below a nominated level. For example, 70.4% of samples collected for trihalomethane analysis in a chlorinated system were greater than or equal to 102 μg/L but in a chloraminated system 76.2% were less than or equal to 50 μg/L.

Conclusion

Chloramination is more effective as a disinfection regime in managing water quality in the Woronora distribution system, particularly where there are long travel times. The potential for nitrification was reduced and no sign of nitrification was evident. With the maintenance of higher and consistent residual chlorine levels >1.00 mg/L within the system, the microbiological performance improved and any form of nitrifying bacteria were possibly inactivated. Chloramination was very effective in the reduction of disinfection by-products and the taste/odour customer complaints were reduced by 75% when compared against a chlorinated regime.

Maintaining the Cl_2:NH_3 ratio as close as possible to 4:1 within the entire system was critical to the success of the chloramination trial. The other critical aspect was the maintenance of the high chlorine residual with an initial set point of 1.75 mg/L which in turn resulted in the management of the initial chlorine demand and inactivation of the biological influence within the distribution system. Rechlorination using tablet dosing is possible with careful consideration to ensure that breakpoint does not occur and by only using an appropriate amount to "lock up" the chlorine and ammonia to prevent any free ammonia being used for nitrification. Management of the hydraulics within the total system was also essential in reducing the chlorine decay so that there would be minimum impact to the depletion of the Cl_2:NH_3 ratio. Keeping this ratio close to 4:1 in a system with long travel times (max >10 days) was difficult. However, the higher level of chlorine (>1.00 mg/L) at all service reservoirs was helpful in minimising this impact on the biological activity. It was possible to model chloramine decay using a first order decay model within the bulk delivery system.

A "Critical Control Points and Limits Disinfection Management Chloramination Regime QA Matrix" was a successful management tool in addressing the issues that could impact on chloramination/nitrification from the catchment to the customers tap. Ensuring that the total system was managed with a critical control matrix in line with the proposed Australian Drinking Water Guidelines Management Framework was a key strength of the trial. The willingness of all parties to work as a team, the openness of communication and coordination across the various business boundaries contributed to the success of the study.

The recommendation of the study (Vitanage *et al.*, 2001) for further improvements included automation and improvement of rechlorination processes within the distribution system and to continue further hydraulic optimisation of the total system. At the WFP, the R & D work presently in progress is to trial prechlorination and enhanced coagulation. Other operational improvements on mixing and loop times are presently in progress to improve the dosing process. The target of such work would be to specifically reduce chlorine demand, disinfection by-product formation and available nutrients for biofilm growth. If these targets are achieved then the quality control matrix can be adjusted accordingly to ensure that optimum Cl_2:NH_3 ratios can be maintain within the entire system.

References

Flood, J. *et al.* (1998). *Nitrification in the Woronora Delivery System Summer of 1997/98*. Report No.98/166.

Jegatheesan, V. and Cresta, P. (2001). *Management of chloramine decay and documentation of controls for preventing nitrification within SWC chloraminated systems*. AWT Environment, Science and Technology.

Vitanage, D. *et al.* (2001). *Disinfection Strategy for Woronora Delivery System, considering the characteristics of the system*. Sydney Water, Sydney, Australia.

Downloaded from http://iwaponline.com/ws/article-pdf/2/5-6/411/407872/411.pdf
by guest