Optimisation of conventional water treatment processes in Adelaide, South Australia

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Abstract Supplying drinking water in metropolitan Adelaide to meet contractual and Australian Drinking Water Guidelines is a challenge as source waters contain high concentrations of natural organic matter (NOM) that often exceed 10 mg/L dissolved organic carbon (DOC). The US EPA indicates that enhanced coagulation is the best available technology to control DOC in drinking water treatment plants. United Water has used enhanced coagulation at Metropolitan Adelaide WTPs since 1997 to improve water quality in the distribution system. NOM reduction has led to treated water with a lower chlorine demand allowing a greater residual penetration enabling improved bacteriological compliance. Disinfection by-product formation has also been controlled within the distribution system. Pathogen treatment barriers to remove *Cryptosporidium* and *Giardia* have been strengthened by adopting improved filter pre-treatment, enhanced coagulation and filter pre-chlorination to reduce particle breakthrough at all suitable WTPs.
Keywords Conventional; DBP; pathogens; quality; treatment; water

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Introduction

United Water International (UWI) is Australia's largest private water utility providing services for customers in Australia and New Zealand. At its base in Adelaide, South Australia, UWI operates and maintains six water and four wastewater treatment plants as well as water and sewer reticulation networks for 1.1 million customers under a 15-year outsourcing contract awarded in 1995. The asset owner, SA Water, is responsible for managing raw water sources (quality and supply) as well as upgrades and renewals of capital assets including water treatment plants. Improving water quality and operational performance is a priority shared by many Water Utilities. This paper reviews optimisation strategies adopted at UWI-operated conventional water treatment plants to meet contractual and Australian national water quality requirements as well as reducing the risk of pathogen breakthrough.

Adelaide's raw water

Adelaide's raw water is supplied from several sources (local catchment and River Murray) containing a high concentration of dissolved organic carbon (DOC), often >12 mg/L. DOC arises from decaying natural organic matter (NOM) and impacts on water quality making it important to control. NOM is the precursor for chlorinated disinfection by-products (DBPs). It exerts a chlorine demand and lowers chlorine residual, weakening the disinfection barrier. This is particularly important in the distribution network where the absence of chlorine residual can lead to bacteriological contamination. NOM is a nutrient source for heterotrophic bacteria. NOM can also impact on aesthetic water quality contributing to colour, taste and odour (Myponga raw water colour is > 50 HU). Peak DOC concentrations are normally found in raw water during the summer (December–March).

Treated water quality targets

UWI is required to comply with the Australian Drinking Guidelines (NHMRC/AWRC, 1996) as well as satisfy contractual targets. Requirements for THMs are less stringent than those recognised internationally (250 µg/L and 200 µg/L respectively). The UK Drinking Water Regulations MAC is 100 µg/L while the US EPA MAC is 80 µg/L. Australian standards are health based and the guidelines state, "*THM concentrations fluctuating occasionally (for a day or two annually) up to 1 mg/L are unlikely to pose a significant health risk*". They continue, "*action to reduce THMs is encouraged, but must not compromise disinfection, as non-disinfected water poses significantly greater risk than THMs*".

Water treatment plants

Surface water is treated using a common treatment train including alum coagulation and flocculation, rapid gravity filtration and chlorination. Sedimentation is employed at five plants while in in-filter dissolved air flotation (DAF) is used at Myponga plant (Table 1). At all plants apart from Myponga, settled water is chlorinated before rapid gravity filtration. Filtered water is chlorinated for final disinfection at all WTPs.

Optimisation initiatives

Enhanced coagulation trials (1995)

Before 1995, WTPs serving Metropolitan Adelaide were operated in a conventional mode using alum doses suitable for turbidity removal achieving little DOC control. As a result, bacteriological performance in the distribution networks was poor. High colony count concentrations were present and coliforms were occasionally detected. High treated-water chlorine demand restricted chlorine residual penetration into the network. Enhanced coagulation was identified as the simplest way of reducing chlorine demand by removing NOM (Kaeding, 1997). The US EPA (1998) indicates that enhanced coagulation is the best available technology for the removal of THM precursors (NOM) at water treatment plants. Enhanced coagulation optimises coagulation pH and can be achieved by using higher coagulant doses than required for turbidity removal or by acid dosing (Kavanaugh, 1978). Alum coagulation pH is a critical control parameter and best DOC removals were reported at a pH of 5–6. Aluminium solubility increases sharply at a pH < 5.7 and allowing a safety margin, UWI optimises coagulation for organics control at a pH of 6.0.

Barossa WTP was selected as a demonstration site and laboratory jar tests indicated that DOC removal rates could reach > 55% if an alum dose of 100 mg/L $(Al_2SO_4)_3.18H_2O$ was used. Results showed that by increasing the alum dose from conventional rates (40 mg/L) to 90 mg/L decay kinetics were significantly improved leading to a more persistent free-chlorine residual. Alum requirements and hence sludge production could be minimised if dosed with 60 mg/L alum and sulphuric acid to achieve a coagulation pH of 6.0. A full-scale trial was initiated in May 1996 using a conventional dose of 35 mg/L (phase 1) followed a month later by an increase in alum dose to 60 mg/L with acid to achieve a coagulation pH of 6.0 (phase 2). Phase 2 results were impressive: DOC removal increased from 18% to over 40%, plate counts were reduced by 87%, coliforms were not detected and chlorine residual

Table 1 Details of United Water operated WTPs in Adelaide

Plant	Date built	Design flow Ml/d	Treatment process train
Anstey Hill	1980	313	Horizontal sedimentation,
Barossa	1982	160	Dual media RGF (anthracite/sand)
Hope Valley	1977	273	
Little Para	1984	160	
Happy Valley	1989	720	Coagulation, flocculation, horizontal sedimentation, mono media RGF.
Myponga	1993	50	Dissolved air flotation, mono media RGF.

penetration in the distribution system increased allowing chlorine dose rates to be lowered. The improved bacteriological performance was noted 7–10 days after the optimised coagulation began.

Full-scale implementation of enhanced coagulation (1997-to present)

Enhanced coagulation was implemented at all UWI-operated WTPs in Metropolitan Adelaide in 1997 to improve chlorine residual penetration, minimise bacteriological contamination and control THM formation. The process is not without its drawbacks, notably increased cost of treatment (chemical and sludge handling) and so optimisation is essential. Coagulation pH is the critical control parameter for DOC removal (Figure 1). In Adelaide, coagulant dose is optimised first for plant operability. Myponga is operated in full-enhanced coagulation mode to achieve low filtered water turbidity. Secondly, for water quality in the networks, indicated by bacteriological and residual chlorine performance. Local WTP supervisors monitor UV absorbance at 254 nm (UV_{254}) several times each week together with on-line turbidity at key process stages and coagulant and polymer doses are adjusted as required.

Enhanced coagulation has reduced the requirement to undertake jar testing as coagulant dosing is controlled by pH feedback. Progress on enhanced coagulation optimisation is reviewed at monthly Water Quality Committee meetings attended by WTP and network managers. Dose rates for alum and chlorine are adjusted in light of raw, process and network water quality trends. Optimisation is targeted at ensuring adequate bacteriological and chemical quality in the networks whilst maintaining chemical usage as low as possible (Kaeding, 2001). The greatest challenge to water quality in Adelaide is normally found during the summer period when raw water DOC concentrations are high. Water temperatures in the networks can exceed 30°C increasing chlorine decay rates and the potential to form THMs.

Parasite risk minimisation initiatives (1999-Present)

The 1998 Sydney water crisis (Clancy, 2000) highlighted the risk of parasite breakthrough in Australia. *Cryptosporidium* oocysts are resistant to conventional disinfection and require removal if contamination of final water is to be avoided (Rose, 1988). Two initiatives were undertaken by UWI to minimise this risk. A filter optimisation research study using particle counters (Roder, 2000) demonstrated that improved removal of particles in the *Cryptosporidium* oocyst size range could be achieved using rapid gravity filtration if settled water was chlorinated with a dose of 1–2 mg/L (Figure 2). Particle counts decreased

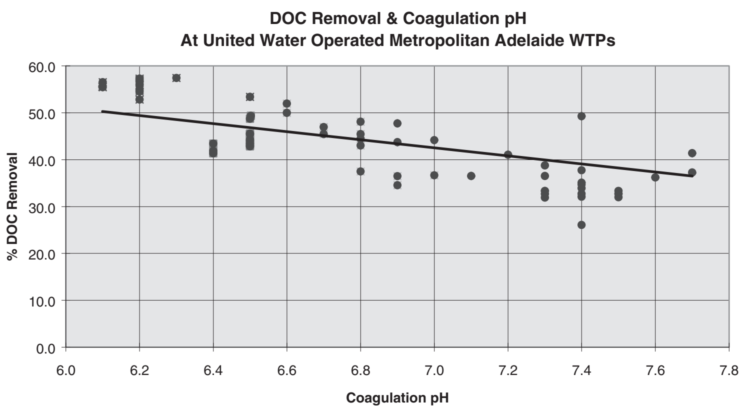

Figure 1 Coagulation pH and DOC removal

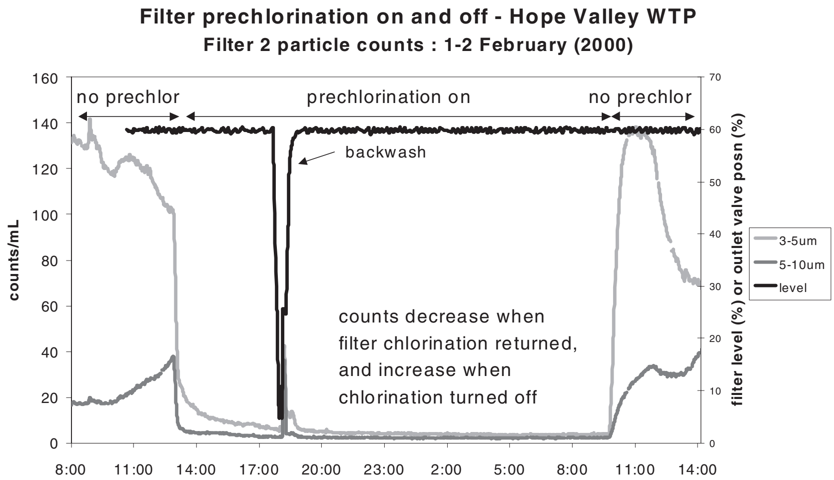

Figure 2 Filter pre-chlorination and filtered water particle count

rapidly when pre-chlorination was used and increased just as quickly when the pre-chlorination was terminated. It is interesting to note the effect is both rapid and reversible and was not dependent upon long-term dosing of chlorine. This process was standard practice at Hope Valley and Happy Valley for biological and manganese control. Other workers reported similar improvements if ozone was applied before filtration (Wilczak, 1992; Chipps, 1998).

An independent "Parasite Risk Assessment" was completed to audit the integrity of UWI operated WTPs (Brignal, 2000). The report concluded that "*the designs of the WTPs operated by UWI all present barriers to the passage of protozoan parasites Cryptosporidium and Giardia*". It was viewed that in their current state the majority of the plants are at "*moderate risk*", "*principally due to the practice of recycling untreated dirty filter wash water to the main process stream*". The report recommended that filter pre-chlorination be used at all appropriate WTPs; coagulation be optimised using pH for DOC removal, this is in-line with other workers (Edzwald, 2000); and, that turbidity be used as the key performance parameter for assessing process efficiency for the removal of particles. Best practice for the operation of filters to minimise pathogen breakthrough is to target filtered water turbidity consistently at or below the range 0.1–0.2 ntu (Nieminski, 1995). Several capital upgrades were recommended and modifications have been made to plants identified as being most at risk. Improvements have been made to the inlet hydraulics at Myponga WTP and backwash treatment has been installed. Also, one filter has been modified to demonstrate the benefits to be found by using combined air water filter backwashing. Backwash treatment has been installed at Hope Valley WTP as well. An acid dosing facility has been installed at Barossa to optimise enhanced coagulation and is currently being commissioned.

Current UWI drinking water research activities

Two key issues raised following the Parasite Minimisation projects are the focus of current UWI drinking water research. Filter pre-chlorination and enhanced coagulation optimisation to minimise THM formation.

THM formation at WTPs and distribution system

THM formation was tracked at key process and network locations at all metropolitan Adelaide WTPs over a full range of seasons (Figure 3). Pre-chlorination of Anstey Hill

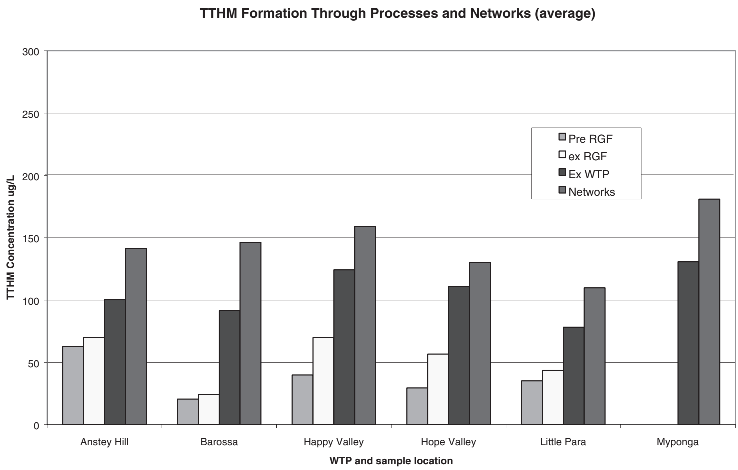

Figure 3 THM formation at key process and network locations

raw water made interpretation difficult. Mean results for all other plants using filter prechlorination show that THM concentrations form rapidly in the settled water duct where precursor concentrations are greatest (21–40 µg/L) under short contact times (5–15 minutes) before filtration. Filtered water THM concentrations range from 24–70 µg/L. THM concentration measured at the plant outlet after final chlorination ranged from 78–131 µg/L and 110–181 µg/L within the distribution system (Table 2).

Simulated distribution system

Simulated distribution system (SOS) studies are useful techniques that can demonstrate water quality following disinfection (Koch, 1991). A modified SDS procedure was used to indicate water quality using three coagulation treatments.

Methodology. Eight raw water samples were collected between November 2000 and October 2001 from Happy Valley, Hope Valley (later changed to Barossa for operational reasons) and Myponga WTPs. Each sample was split to allow two alum treatments as indicated using laboratory jar test techniques. Split 1 was dosed with alum approximately 20 mg/L lower than that used at the WTP (conventional treated samples). Split 2 was dosed with alum to achieve a coagulation pH of 6.2 (enhanced coagulation samples). In these trials, optimised coagulation was defined at pH 6.2 for treatment cost requirements. After standard flash mixing, flocculation and settlement treatments, settled water was filtered

Table 2 THM concentration profiles at process and network locations

Sample location	Anstey Hill WTP THM µg/L	Barossa WTP THM µg/L	Happy Valley WTP THM µg/L	Hope Valley WTP THM µg/L	Little Para WTP THM µg/L	Myponga WTP T HM µg/L
Pre RGF mean (range)	63 (4–148)	21 (15–25)	40 (9–57)	30 (1–52)	35 (23–55)	
Ex RGF mean (range)	70 (6–153)	24 (18–28)	70 (39–90)	57 (38–81)	44 (32–63)	
Ex WT mean (range)	100 (44–155)	92 (40–128)	124 (100–150)	111 (82–155)	78 (59–90)	131 (99–180)
Networks mean (range)	141 (67–200)	146 (78–245)	159 (80–207)	130 (62–180)	110 (73–152)	181 (133–236)

using a coarse filter paper (Whatman number 1) to simulate rapid gravity filtration. The two-jar test treated waters together with a treatment plant (coagulated/settled/filtered) water sample were pH corrected to 7.4 (to simulate full treatment) and then chlorinated. Doses were selected to achieve a final residual after three days contact within the range 0.5–1.5 mg/L. DOC, bromide, UV_{254}, turbidity and colour were measured before chlorination. Chlorine residual and THM (after quenching) were measured upon completion of contact time.

Results and discussion. Results show that highest DOC removal was achieved for enhanced coagulated treatments and that DOC concentration correlated with THM formed in the three day modified SDS test (Figure 4). THM yields for all waters were within the range 29–34 µg/mg (THM/DOC). Plant-treated three-day SDS water samples when bench chlorinated gave THM concentrations within the range found in network samples (Table 3). Variation is expected as THM formation is time dependent. Sampling from the distribution system provides a range of water ages leading to a range in THM formation. Glass bottle SDS tests do not include pipe wall effects. Other workers have shown that pipe wall effects can act as a reservoir for THM precursors increasing THM formation by 15% (Rossman, 2001).

Conclusions

When optimising the operation of a WTP, risk identification, quantification and minimisation are balanced against cost of treatment (operational and capital). In Adelaide, chlorination of final water is essential and must not be compromised. Filter pre-chlorination is highly beneficial in reducing filtered water particle counts and hence the risk of pathogen breakthrough. Both applications give rise to THMs. Enhanced coagulation removes precursors to enable Australian NHMRC guidelines and contractual requirements for THMs to be achieved. UWI optimises coagulation for the removal of NOM and good aluminium

Table 3 Comparison of SDS and network THM concentrations

Mean THM concentration SDS µg/L,		Mean THM concentration network µg/L	
Barossa	*Happy Valley*	*Hope Valley*	*Myponga*
SDS = 168, NW = 146	SDS = 155, NW = 159	SDS = 122, NW = 130	DS = 173, NW = 181

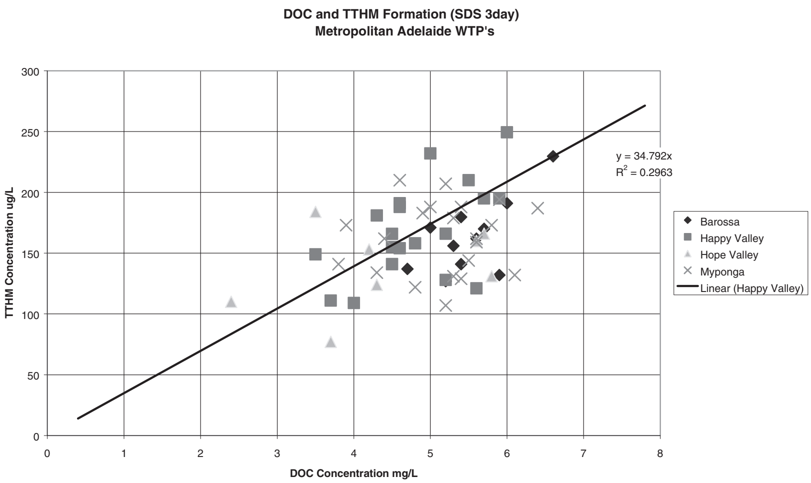

Figure 4 THM formation SDS 3 day versus DOC concentration

chemistry and not *Giardia* cyst or *Cryptosporidium* oocyst concentration. Enhanced coagulation is an effective filtration pre-treatment process that is beneficial when aiming to achieve consistently low filtered-water turbidity. There is considerable scope to optimise enhanced coagulation by acid dosing. Changes to plant chemical dosing are not sufficient to achieve all goals. Capital upgrades are required to treat backwash water and so improve treatment barriers. However, if trends in water quality standards continue to tighten, upgrades to the main treatment process train together with changes to disinfection/networks operation may be required to achieve compliance.

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