Science Talks to Industry, WaterRA Research Symposium
16-17 July 2014

WaterRA 1064 Develop Evidence-based Approaches to Monitor and Manage Chlorine and Chloramine Disinfection Residual

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Outline

• Project Background / Knowledge Gaps
• Key Project Activities and Deliverables
• Research Product – Disinfection Guidance Manual
• What’s Next?
Project Background

Around September 2012

- AWQC / SA Water
- University of South Australia
- WA Water Corporation
- Central Highland Water
- Melbourne Water
- Power Water Corporation
- SEQ Water
- Allwater (Degremont)
Appendix 1 - Key questions and issues to be addressed as part of the Project

1. What is the effect of treated water dissolved organic carbon (DOC) or specific UV absorbance (SUVA) on disinfectant demand and decay – e.g. how strong is the relationship and what is the nature of the relationship?
2. Is there a target level (best practice) of DOC or SUVA in treated water to minimise disinfectant demand and decay, particularly in plants where conventional coagulation/flocculation and sedimentation/filtration or dissolved air flotation and filtration (DAFF) are the only means of DOC removal?
3. What is the effect of treated water pH level on disinfectant decay in chloraminated systems?
4. What is the effect of pH increases throughout the distribution system on the efficacy of free chlorine disinfection?
5. What is the effect of treated water bromide concentrations on disinfectant decay?
6. What are the impacts of nitrification on managing residuals in chloraminated systems? What is the best approach to preventively manage, monitor and respond (corrective action – both for small scale and large scale events)?
7. Ammonia levels related to nitrification in chloraminated systems – what are best practice levels for ammonia entering the distribution system (from the plant) and ammonia liberated from chloramine decay in the distribution system?
8. What is the effect of distributed water nitrite concentrations on disinfectant demand/decay and its relationship to nitrification in chloraminated systems?
9. What is the impact of media filter backwash water mode of disinfection (if any) and its effect on disinfectant decay in chloraminated systems (ammonia from chloraminated backwash water and filter media nitrification).
10. What is the relationship between maintaining a clean distribution network and minimising disinfectant decay (e.g. sediments, corrosion products, manganese, biofilms)?
11. What is the relationship between microbiological performance and residual disinfection levels (e.g. Heterotrophic Plate Counts (HPC) and coliforms)?
12. How can water supply managers balance the disinfectant residuals with aesthetic impacts on customers (chlorinous tastes and odours (T&O))?
13. Discussion on the aesthetic and health guideline values in the Australian Drinking Water Guidelines (ADWG) (chloramine as chlorine equivalent).
14. Provide guidance for water supply managers to balance required disinfectant levels and disinfection by-product (DBP) formation levels.
15. What is the relationship between disinfectant demand, water age and disinfectant decay? This may involve providing a link to available software tools.
16. Best practice review of minimum effective levels of disinfection at the extremities of the distribution (chlorine and chloramine) for system protection and nitrification control.

Status: Final for Distribution (17/09/2012)
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17. Assessment of why maintaining a disinfectant secondary residual is important – for microbiological performance, inherent system protection (bursts, ingress, pressure drops, backflow, cross connections, etc), biofilm reduction, regrowth, suppressing nitrification, etc.
18. Assess the significance of disinfectant residuals within the distribution system where a multiple barrier approach is applied to water safety.
19. Provide guidance on an approach for water supply managers to balance the need to maintain a residual versus cost and effort versus aesthetic impacts on customers.
20. Provide guidance on balancing aesthetic effects of spatial and temporal disinfectant variations in the distribution – i.e. in larger systems need to dose higher in order to get decent concentrations in the outer parts of a distribution, meaning customers closer to the treatment plant experience much higher disinfectant levels.
21. Detail how booster (secondary) disinfection can enable more uniform disinfectant residuals (both chlorinated and chloraminated systems) and provide a cost: benefit assessment of role of booster (secondary) disinfection.
22. In chloraminated systems – examine the impact of the order of addition of chlorine and ammonia e.g. does the order of addition affect demand, decay, C/t values, and its practicality if viruses are of concern? What is best practice?
23. Distribution system design and the impacts on maintaining a spatially and temporally consistent residual- water age, network water storages (tanks/basins), storage design (inlet/outlet structures, stratiﬁcation, storage levels), presence of ‘dead ends’ in the network.
24. Review of national and international guidance (ADWG/WHO etc), regulation, standards (e.g. ISO and country equivalents or derivatives) and best practise (‘industry standards’) with respect to secondary disinfection and monitoring thereof.
25. Survey of national and international secondary disinfection practices and attitudes – targets, outcomes and problems; dollar costs associated with secondary disinfection and cost-benefit optimisation, including formal cost-benefit modelling.
26. Review of relevant field and laboratory methods, commercially available sensors, and associated quality assurance/quality control (QA/QC). This should draw on work previously undertaken by the CRC for Water Quality and Treatment and also draw on industry knowledge of water authorities, the Water Industry Operators Association (WIOA) and commercial suppliers.
27. Review of decay modelling literature with emphasis on determining the relative importance of estimating component parameters via formal sensitivity analyses. This should draw on work previously undertaken by the CRC for Water Quality and Treatment
28. Brief review of systems which operate without chemical disinfection and their relevance (if any) to Australia’s distribution networks.

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<tr>
<th>Milestone</th>
<th>Description</th>
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<tr>
<td>1</td>
<td>Agenda for industry 1 workshop developed</td>
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<td>2</td>
<td>delivery</td>
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<td>3</td>
<td>Collation outcomes 3 industry workshop</td>
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<td>4</td>
<td>Completion of draft literature review + fact sheet 1</td>
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<td>5</td>
<td>Completion of draft guidance manual + fact sheets 2,3</td>
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<td>6</td>
<td>Completion of final guidance manual + fact sheet 4</td>
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<td>Roadshow component delivery begins</td>
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<td>7</td>
<td>(partner funded)</td>
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**Dates:**
- **2013**: Jul, Aug, Sep, Oct, Nov, Dec, Jan, Feb, March, April, May, Jun, Jul
- **2014**: Jan, Feb, March, April, May, Jun, Jul

**Water Research Australia**
Basic Chemistry

Chlorine Gas
\[ \text{Cl}_2 + \text{H}_2\text{O} \leftrightarrow \text{HOCl} + \text{H}^+ + \text{Cl}^- \]

Sodium or Calcium Hypochlorites
\[ \text{NaOCl} \rightarrow \text{Na}^+ + \text{ClO}^- \]
\[ \text{Ca(OCI)}_2 \rightarrow \text{Ca}^{2+} + 2\text{ClO}^- \]

\[ \text{HOCl} \leftrightarrow \text{H}^+ + \text{ClO}^- \]

To ensure HOCl is the dominant species formed, pH must be maintained <7.5, and preferably closer to.
Decay Related to Water Quality such as pH, Inorganic Ions & Organic Carbon Concentration etc.
Initial Dosing Point

- $\text{Cl}_2$ dose $\approx 6 \text{ mg/L}$
- Time $= 0 \text{ hrs}$

Managing disinfectant residuals in networks is a core water utilities activity.
Monochloramine Formation

- Water pH (8-9)
- Cl\textsubscript{2}/NH\textsubscript{3} ratio

\[ 5:1 \quad \text{HOCl} + \text{NH}_3 \rightarrow \text{H}_2\text{O} + \text{NH}_2\text{Cl} \]

**High Cl\textsubscript{2}/NH\textsubscript{3} ratio**

\[ 7:1 \quad \text{HOCl} + \text{NH}_3 \rightarrow \text{H}_2\text{O} + \text{NH}_2\text{Cl}_2 \quad \text{Dichloramine} \]
\[ 9:1 \quad \text{HOCl} + \text{NH}_2\text{Cl}_2 \rightarrow \text{H}_2\text{O} + \text{NCl}_3 \quad \text{Trichloramine} \]

Increase potential for taste and odour complaints

**Low Cl\textsubscript{2}/NH\textsubscript{3} ratio**

leads to free NH\textsubscript{3} and increases potential for nitrification

\[ \text{NH}_2\text{Cl} + \text{NO}_2^- + \text{H}_2\text{O} \xrightarrow{\text{Br}^-} \text{NO}_3^- + \text{NH}_4^+ \]

Research is needed to understand Nitrification
Back in the CRCWQ&T time

CRCWQT - DrCT (Disinfection Residual Control Tool) Project - 2002
Back in the CRCWQ&T time

DrCT Project

Report 2: Development of a Surrogate Disinfectant Demand Sensor

Fiona Fitzgerald and Christopher Chew

Australian Water Quality Centre, Adelaide


Fiona Fitzgerald, *Joshua Bell*, Mike Horries, *Dr. Alexander Boddyan

*United Water International Pty. Ltd, Adelaide, University of South Australia, Adelaide, Australian Water Quality Centre, Adelaide
Literature from CRCWQ&T / WQRA / WaterRA
Examples of AWWA reports relevant to this project

Conference Proceedings, AWA-Ozwater, AWWA-WQTC, etc

Develop a **database** to capture all relevant info proceedings (15 yrs of AWA, IWA and AWWA) – sharing info with Partners

Apart from the existing reports, conf papers, also will include industry internal reports (case studies already conducted and new case studies, if identified)
A. Impact of treatment and water quality related to disinfectant demand (Treatment Related)
B. Optimum disinfection conditions for chlorine and chloramines (Best Disinfection Practice)
C. Key factors affecting decay characteristics, such as bromide and nitrification (Chemistry Aspects)
D. The importance of distribution system management
E. How to balance between customer complaints, regulatory guidelines (i.e. disinfection by-product formation levels and minimum disinfectant residual required), and operational considerations (e.g. cost).

Draw together existing information on chlorine and chloramine residual maintenance into a guidance manual for Australian utility operators and water quality managers.
Guidance Manual - Why maintain a disinfectant residual?

The purpose of the manual is to provide WQ managers information and guidance on how to maintain the presence and effectiveness of a disinfection residual barrier in drinking water distribution systems.

The manual is divided into 3 parts – Part 1 Maintenance and monitoring of chlorine residuals in distribution systems, and Part 2 Maintenance and monitoring of monochloramine in distribution systems. Part 3 contains the sourced industry case studies.

Sub-headings - Chlorination

• What residual concentration is necessary in chlorinated systems?
• Factors impacting chlorine residual maintenance
• Factors impacting efficacy of chlorine residual barrier
• What are appropriate monitoring strategies to ensure chlorine residuals are maintained?
• How to balance between regulatory guidelines, consumer expectations and operational considerations

Regulatory guidelines
Microbial quality of water
Maintenance of effective “barriers” against contamination
DBP concentrations

Consumer Expectations
Aesthetic taste and odour issues caused by chlorine in water

Operational Considerations
Cost of supplying residual
Logistics of supplying residual
Seven Case Studies


2: Improving disinfection of drinking water supplies in remote NT communities – Power Water Corporation - a program to improve the level of service to communities by upgrading disinfection barriers using suitable technology capable of meeting the challenges of the operating environment


4: Impact of pH on monochloramine decay in Lal Lal WTP product water – Central Highlands Water

5: GAWS Chloramination Improvement Project – WA Water Corporation- to address the risk to public health posed by the presence of potentially pathogenic species (Naegleria) in large parts of the distribution system.
Seven Case Studies

6: Example of a Nitrification Response Plan – WA Water Corporation

To provide a standardised process for the management of and response to a nitrification incident. This includes:

• Methods to identify and confirm the presence of nitrification
• Implementing operational response actions
• Developing and implementing a long term response plan

7: Installation of mixers in the Sparkes Hill reservoir, SEQ Water

To counteract the impacts of nitrification, it was decided that re-chloramination facility be installed on Sparkes Hill #2 reservoir. Due to thermal stratification, parallel installation of physical mixing apparatus to ensure dosed chlorine was evenly dispersed throughout the tank.
Factsheets

Develop Evidence-based Approaches to Monitor and Manage Chlorine & Chloramine Residuals

The project aim is to produce a Guidance Manual for Chlorine and Chloramine Disinfection and Residual Management. The manual will include up-to-date information and tools to assist water authorities in optimising disinfection processes in their networks.

Participating Partners: SA Water (AHQG), University of South Australia, Power and Water Corporation, WA Water Corporation, Central Highlands Water, Melbourne Water, SEQ Water, Allwater.

Background

Optimisation of chlorine and chloramine residuals in distribution networks remains an ongoing challenge for network operators, despite a large amount of research invested in this area. The desired outcome of disinfection management is to ensure sufficient disinfection residuals are maintained in distribution systems to achieve adequate control of microbiological pathogens, but as not to create aesthetic water quality issues, or cause violation of regulated guideline values for disinfectants and disinfection by-products (DBPs).

Despite efforts in recent years, with many disinfection management strategies developed and reported, disinfection residual management still remains a complex optimisation problem and is a challenging task for operators. The Australian Water Quality Centre (AHQG) team has awarded a WaterRA project titled “Develop evidence-based approaches to monitor and manage chlorine & chloramine residuals”. The aim of this project is to provide water quality managers with the best available information and tools to assist them in achieving practical and improved disinfection system outcomes. The project will utilise information from literature, including research completed by the CRCWQAT and recent investigations by water utilities. Outcomes will be summarised in the form of a Guidance Manual for Chlorine and Chloramine Disinfection and Residual Management. The manual will provide guidance to enable water authorities to adopt disinfection residual management strategies that best meet their customers’ requirements.

Outcomes and Benefits

Outcomes. The aim of this project is to provide water quality managers with the best available information and tools to assist them in achieving practical and improved disinfection system outcomes. The primary deliverable of this project is a guidance manual addressing both metropolitan and regional distribution systems. The second objective for this project is a workshop/roadshow component which will allow verbal communication of the project outcomes (contained in the manual) to participating water utilities to facilitate the transfer of knowledge obtained as part of the project.

Benefits. The Guidance Manual for Chlorine and Chloramine Disinfection and Residual Management developed as part of this project will allow water authorities to address one of the most important hazards in drinking water supply: the loss of disinfectant residual in the distribution network. By providing guidance on the best practice approach to chlorine and chloramine disinfection management in the context of recent research and industry investigations in this area, this manual will assist water authorities in addressing the recommendations of the framework outlined in the Australian Drinking Water Guidelines.

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Project Officer: Amanda Byrne – SA Water (AHQG)

Project Partners: Tracey Holm, Benoît Goin, Jeremy Lucas (SA Water), Barbara Ayres (Water Corporation), Ben Holm, Brian Nix, Chris Owen (IDC Water), Jeremy Strickland, Derek Spinks (Melbourne Water), Ruth Botha, Luke Cotton, Wayne Sharp (Power Water Corporation), Ian Hurlstone (Warren Water), John van Leeuwen (University of South Australia)

Project Start Date: July 2018

End Date: June 2019

Factors impacting chlorine residual maintenance

Produced for WaterRA project: Evidence-based approaches for the monitoring and maintenance of chlorine and chloramine residuals

Participating Partners: SA Water (AHQG), University of South Australia, Power and Water Corporation, WA Water Corporation, Central Highlands Water, Melbourne Water, SEQ Water, Allwater.

Why maintain a chlorine residual?

Maintenance of a disinfectant residual barrier in distribution systems is recommended by the Australian Drinking Water Guidelines (ADWG) to provide protection against microbial contamination of the distribution system. This contamination can occur through growth of pathogenic species in the network (e.g. Legionella pneumophila) or invasive events into distribution system pipes or storages (e.g. cross connection, intrusion through pipe leaks etc). There is no known minimum chlorine residual concentration necessary to control all known hazards, however; if a consistent barrier is maintained it will provide some protection against these events.

What may impact chlorine residual maintenance?

- Natural organic matter (NOM): Larger concentrations of NOM in treated water greatly increase the rate of chlorine decay in distribution systems and reduce chlorine residual maintenance.
- Water age: Chlorine decayed water no longer maintains residual systems of water systems, and poor hygiene and service have increased.
- Rain and snow events: Reduced chlorine residual concentrations are also findings in winter due to increased NOM.

Management strategies to improve chlorine residual maintenance

Treatment improvements to generate a higher NOM will reduce the chlorine demand water. Actions to reduce NOM may include coagulation processes, and/or addition of adsorption or biological treatment steps; it will depend on the character of NOM present.

Reduction in water age can be achieved by decreasing the amount of water stored in the network by operating storages and reducing the amount of water in the distribution network. This will also reduce water age, improve taste and odour, and separate microbiological and separate contactors to limit short stagnation. Changing the operation of water networks to increase water velocity and reduce water age in winter; systems that have already optimised installation of chlorine residual storage tanks needs to be considered.

Factors impacting monochloramine residual maintenance

Produced for WaterRA project: Evidence-based approaches for the monitoring and maintenance of chlorine and chloramine residuals

Participating Partners: SA Water (AHQG), University of South Australia, Power and Water Corporation, WA Water Corporation, Central Highlands Water, Melbourne Water, SEQ Water, Allwater.

Why maintain a monochloramine residual?

Maintenance of a disinfectant residual barrier in distribution systems is recommended by the Australian Drinking Water Guidelines (ADWG) to provide protection against microbial contamination of the distribution system. This contamination can occur through growth of pathogenic species in the network (e.g. Legionella pneumophila) or invasive events into distribution system pipes or storages (e.g. cross connection, intrusion through pipe leaks etc). There is no known minimum monochloramine residual concentration necessary to control all known hazards, however; if a consistent barrier is maintained it will provide some protection against these events.

What may impact monochloramine residual maintenance?

- Water age: Higher concentrations of NOM in treated water increase the rate of monochloramine residual decay, and favor monochloramine residual maintenance.
- Water condition: Higher chlorine residual and higher temperature water results in higher rates of monochloramine decay. Chloramine residual will decrease with increasing water age, operational conditions, lower storage of large amounts of water in distribution systems (flow reductions) and initial high chlorine residual in storage will result in high water levels.

Notification – an important pathway for monochloramine residual loss

Notification is the process where free ammonia present in chloraminated water is oxidised to nitrite, and subsequently inorganic by nitrifying bacteria. Notification will result in a rapid loss in monochloramine residual. Notification is favoured by high temperatures, and in conditions where a large amount of excess free ammonia is present; this occurs in systems operated with a low Cl₂/Mn ratio.

Strategies to improve monochloramine residual maintenance

Treatment process improvement to reduce NOM concentrations in treated water will reduce monochloramine decay. Increase of treated water pH (above 8) will enhance the stability of monochloramine.

Reduction in water age will reduce monochloramine residual loss. This can be achieved by improved mixing and higher turnover in distribution system storages, and by operating distribution systems at a higher velocity via preferential-flow pathways.

Clearing of pipes through flushing and jetties may temporarily reduce water age and remove biofilms and pipe sediment responsible for accelerated chlorine decay.

Maintaining a higher Cl₂/Mn ratio closer to 2:1 in distributed water will limit excess ammonia reducing the risk of rapid chlorine loss through notification.

Implementing booster chlorination and chloramination in the system will improve residual maintenance and assist in maintaining a better Cl₂/Mn ratio to reduce notification.

Notification of distribution systems will require immediate corrective action to restore monochloramine residual. In many cases, breakpoint chlorination (BC) is used. BC, the system is temporarily chlorinated to a “breakpoint” where excess ammonia is oxidised and a free chlorine residual is produced. In addition to removing excess ammonia responsible for notification, this chlorine is also more effective in inactivating nitrifying bacteria.

BC coupled with flushing of nitrified water will restore residuals in the short term, longer-term management strategies to improve water quality and distribution conditions are needed to prevent additional notification events in future.
What’s Next?

Roadshow / Workshop / Training Course

If you are interested, please contact me

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