WATER QUALITY IMPROVEMENT THROUGH TRACER STUDIES

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KEYWORDS

Tracer, Fluoride, Water quality

ABSTRACT

A project was run to track the reintroduction of fluoride to the Parkes Shire Council water distribution system. Consultation across the organisation identified a number of investigation areas including disinfection contact time, water age, areas at risk in the event of a contamination incident and system turnover.

University of Sydney third year chemical engineering students and Atom Consulting undertook intensive sampling the week the fluoride was first reintroduced. The sampling program had been designed in advance according to preliminary turnover calculations using the framework for the decisions involved in the monitoring study design (ANZECC & ARMCANZ, 2000). The study was designed to address the research questions emerging from Council consultation. To support the sampling process, SOPs and a sample site map were developed. All testing was carried out onsite with the support of Council water operators. Fluoride results were recorded and analysed according to the USEPA Disinfection Profiling and Benchmarking Guidance Manual (1999).

From the results of the sampling, the fluoride accumulation from backwash water was calculated and recommendations made on dosing adjustments dependant on raw water fluoride and number of backwashes per day. The travel time between reservoirs was calculated and understanding of distribution reservoir water age improved. The TWST detention time and specific baffle factor were determined and have been used to verify the disinfection critical control point. The data was used to identify distribution areas that require improvements and will be used by Council to verify their hydraulic model of the town distribution network.

INTRODUCTION

Parkes Shire Council brought a new water treatment plant online in March 2018. During the changeover from the old water treatment plant and the new one there was a period when no fluoride was dosed into the drinking water system. Atom Consulting identified that this was a unique opportunity to gather information about how water is distributed. In August 2018 a project the reintroduction of fluoride to the Parkes Shire Council water distribution system was tracked and the results analysed. Consultation across the organisation identified a number of areas that could be investigated by this study including:

- What is the residence time for the Treated Water Storage Tank (TWST)? What is the baffle factor?
- What is the travel time from the TWST to the Barton Street Reservoirs and the High Level Reservoir (HLR)?
- What is the water age in the distribution reservoirs?
- How does the water propagate through the distribution system? Does the fluoride trace align with current system understanding?
- Where are the most appropriate sampling points for operational and verification monitoring?
- Does one of the Barton Street reservoirs fill preferentially to the other)?
- What impact does backwashing with fluoridated water have on the required fluoride dose rate?

METHODOLOGY

The new fluoridation plant at Parkes Webb St WTP was turned on for the first time on Monday 27 August 2018 at 2:41 PM. Following this, samples were taken throughout the entire Parkes-Peak Hill water system to determine fluoride concentration distributions, as a proxy for water velocity. Sampling and analysis were carried out by Parkes Shire Council staff, Atom Consulting and students from the University of Sydney as part of their week-in-industry project from 27 August to 31 August 2018. Fluoride concentration was tested using a Hach HQ430d analyser and free chlorine using the Hach DR-6000 spectrophotometer at the Parkes WTP. Once the detailed study was complete, PSC staff continued opportunistic sampling for the following 3 weeks.
Sampling sites included all the reservoirs in the system, the NSW Health verification sample sites in Parkes, Cookamidgera and Peak Hill as well as

additional sites that were identified as points of interest by PSC staff including the airport and specific sporting fields.

The study was designed to address the research questions emerging from Council consultation. To support the sampling process, SOPs and a sample site map were developed. All testing was carried out onsite with the support of Council water operators.

RESULTS

Fluoride results were recorded and analysed according to the USEPA Disinfection Profiling and Benchmarking Guidance Manual (1999).

Baffle factor

The fluoride concentration of water entering and leaving the treated water storage tank (TWST) was collected manually every 5 minutes and on SCADA (Figure 1).

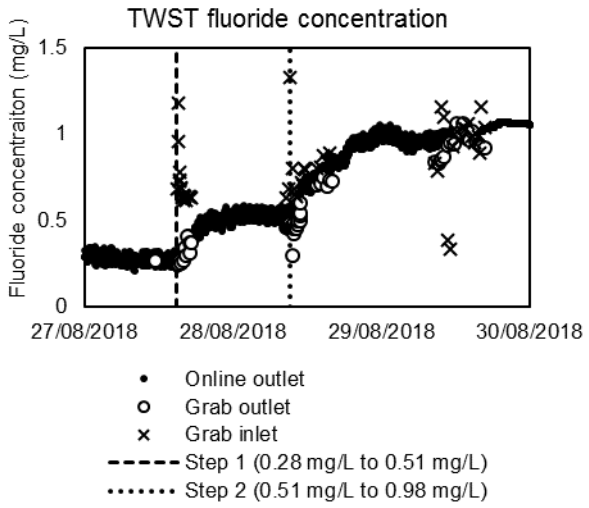

Figure 1: TWST outlet fluoride concentration results from step 1 and step 2

The baffle factor for the Treated Water Storage Tank (TWST) has been calculated by determining the actual residence time in the TWST (T_{10}).

Table 1: Baffle factor calculation nomenclature

Symbol	Meaning
C	Fluoride tracer concentration minus raw concentration in TWST outlet water (mg/L)
$C_{baseline}$	Fluoride concentration in raw water (mg/L)
$C_{measured}$	Fluoride concentration at steady state (mg/L)
Co	Fluoride dose concentration (mg/L)
C/Co	Dimensionless ratio: percentage of fluoride concentration compared to dose concentration
T_{10}	Residence time (min)
TDT	Theoretical detention time (min)
V	Volume of tank (L)
Q	Volumetric flow rate (L/s)

Residence time (T_{10}) is evaluated as the time 10% of the tracer that has been dosed (C_0) is detected in the TWST outlet (C).

$$T_{10} \text{ is the time when } \frac{C}{C_0} = 10\%,$$

To reduce variation in results from the online analyser data, a moving average of the data (C) was used with 5 minutes behind and 5 minutes ahead.

The dosing was carried out in two steps. The first step at 14:54 on 27 August 2018 took the TWST to a concentration of 0.51 mg/L and the second on 28 August at 09:14 from 0.51 mg/L to 0.98 mg/L. These concentrations were an average of the fluoride outlet online analyser data from the steady state period.

The baseline concentration is usually taken as the natural fluoride concentration in the water, however for this study the baseline of the second step was taken as the steady state fluoride concentration in the TWST, the results of this step were used to validate the first step results.

Plotting $\frac{C}{C_0}$ for the two steps produced Figure 2 and Figure 3. T_{10} value can be read from these graphs, results from this section are summarised in Table 2.

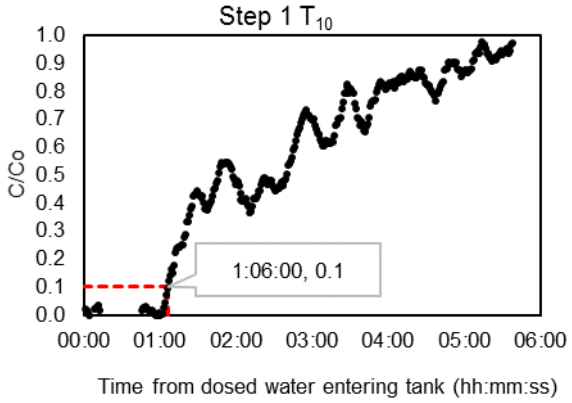

Figure 2: Fluoride ratio at TWST outlet showing T10 - step 1 (14:54 27 August 2018)

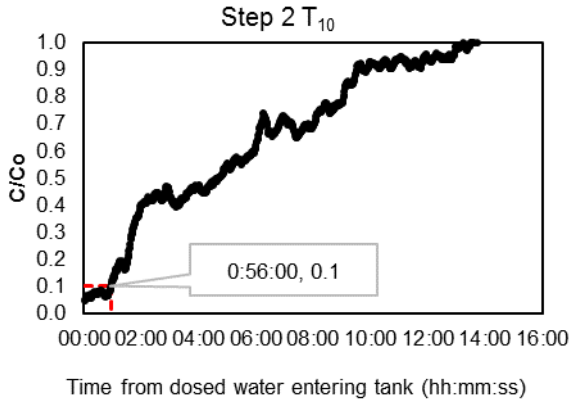

Figure 3: T10 fluoride ratio at TWST outlet showing T10 - step 2 (09:14 28 August 2018)

Table 2: Residence time calculations

	Step 1 27 August 2018	**Step 2 28 August 2019**
Dose time	14:54 ± 2.5 min	9:14 ± 2.5 min
$C_{baseline}$	0.28	0.51
$C_{measured}$	0.51	0.98
C_o ($C_{measured}$ - $C_{baseline}$)	0.27	0.45
T_{10}	**1 hr 6 min**	**56 min**

The theoretical detention time (TDT) is used to calculate the baffle factor. It represents the tank detention time in plug flow conditions. It is calculated by dividing tank volume by volumetric flow rate (USEPA 1999). A TDT value has been calculated for step 1 and step 2. Due to the variation in volume of water in the TWST (V) and TWST outlet flowrate (Q), ($\overline{\text{TDT}}$) was calculated as an average of the volume and outlet of the tank at each minute using the formula below.

$$\overline{\text{TDT}} = \frac{1}{n}\sum_{1}^{n}\frac{V_n}{Q_n} \quad (1)$$

Volume was calculated using the SCADA level reading at the beginning of each step and the inlet and outlet flows were added and subtracted to calculate the volume at each minute.
Results and variables of the calculation are summarised in Table 3.

Table 3: Theoretical detention time calculations

	Step 1 27 August 2018	**Step 2 28 August 2019**
Dose time	14:54 ± 2.5 min	9:14 ± 2.5 min
T_{10}	1 hr 6 min	56 min
T_{10} period	14:54 – 16:00	9:14 – 10:10
Average *V**	1,598 kL	1,625 kL
Average Q_n*	171 L/s	179 L/s
Average *TDT*	**2 hrs 5 min**	**2 hrs 9 min**

The baffle factor (k) can be approximated by dividing T_{10} by the average tank detention time (TDT) (USEPA, 1999).

$$k = \frac{T_{10}}{\text{TDT}} \quad (2)$$

The baffle factor was calculated for each step and averaged to calculate the TWST specific baffle factor, results in Table 4.

Table 4: Baffle factor calculations

	Step 1 27 August 2018	**Step 2 28 August 2019**
Dose time	14:54 ± 2.5 min	9:14 ± 2.5 min
T_{10}	1 hour 6 minutes	56 minutes
$\overline{TDT}$	2 hours 5 minutes	2 hours 9 minutes
Baffle factor (*k*)	**0.53**	**0.44**
TWST baffle factor (*k*)	**0.49**	

The following limitations of the fluoride tracer study are noted:

- New dosing system was not at steady state, there were spikes and drops in dosing
- Unable to take grab samples at night
- TWST Inlet online fluoride analyser data was inaccurate and could not be used for analysis, grab samples were only taken every 5 minutes, contact time is to the nearest 2.5 minutes
- Fluctuating raw water fluoride from changing source water may affect results.

Backwash fluoride accumulation

The DAFF (Dissolved Air Flotation Filtration) filters are regularly backwashed using treated water approximately once every 24 hours. The fluoride dose is set by the operators based on the raw water concentrations and there is a possibility that additional fluoride as a result of the backwashing process will exceed the target concentration. The aim of this analysis was to assess how much fluoride accumulates through the backwashing process.

When backwashing was run, the combined filter concentration increased from 0.22 mg/L (8:50 AM) to an average fluoride concentration of 0.45 mg/L (10:55 AM) which indicates that backwashing does have an impact on the combined filter concentration. This change may be partially due to changing raw water fluoride concentration.

A mass balance was carried out on the DAFF backwashing process and the results were used to develop a model to recommend fluoride dose rate at different production rates, numbers of backwashes

and raw water fluoride concentrations. See Table 5 for results of the mass balance and recommended changes to dosing.

Travel time
The flow velocity from the TWST to the Barton St reservoirs and the High Level Reservoir (HLR) can be approximated using the fluoride tracer results. The preliminary turn over calculations indicated that flow from TWST to HLR rising main would take approximately 24 minutes and TWST to Barton St would take 47 minutes.

Preferential reservoir filling
Barton Blue Reservoir (10 ML) and Barton Concrete Reservoir (45 ML) are fed from the same line from the treated water storage tank (TWST). Before the project was initiated the PSC operations staff had concerns that the tanks were not being fed evenly. Sampling results from the Barton St reservoirs are plotted in Figure 4.

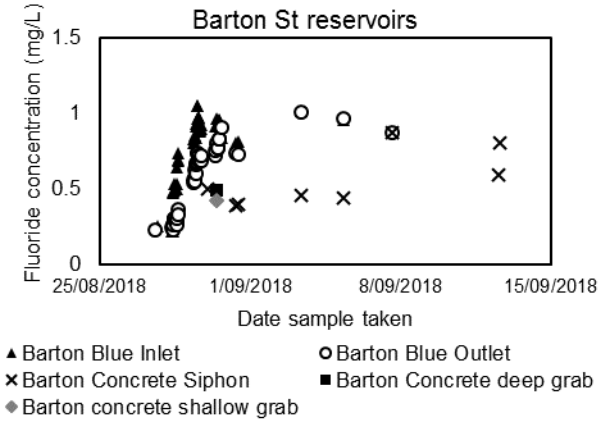

Figure 4: Fluoridation of Barton St reservoirs

The concrete reservoir had a fluoride concentration of 0.40 mg/L on 31 August 2018, while the blue reservoir inlet and outlet were above 0.73 mg/L, indicating that Barton Blue Reservoir is being filled preferentially.

There were some issues collecting appropriate data for this analysis. The Barton Concrete reservoir had not previously had a tap on the inlet or outlet. Three different methods were used to collect samples from this reservoir. The first was a grap sample from the surface of the reservoir. There was concern that this sample did not represent the average fluoride concentration in the reservoir. A deeper grab sample was taken until a siphon was installed in the reservoir.

Water age
Albert St Reservoir and High St Reservoir both have common inlets and outlets and are at risk of high water age.

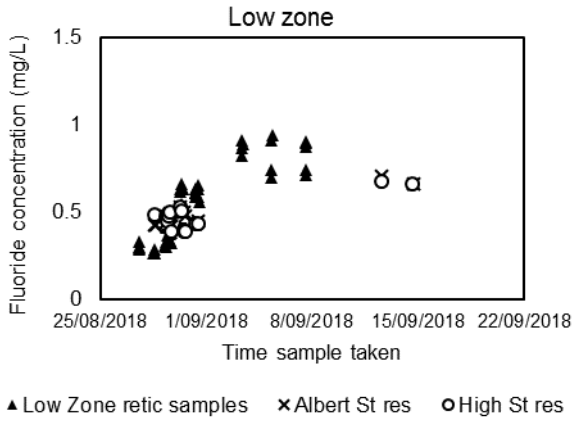

Figure 5: Fluoridation in Albert St Res, High St Res and the Low Zone

As Figure 5 demonstrates, the reservoirs and the low zones were comparable in fluoride concentration at the beginning of the sampling week, however by 31 August 2018 the results deviated. At the end of the sampling week the High St Reservoir was still at 0.44 mg/L of fluoride and Albert St Reservoir was at 0.45 mg/L. The water in the low zone, downstream of the reservoirs had increased to 0.63 mg/L by 31 August. This is possibly due to higher water demand on 31 August which could have reduced the amount of fresh water entering the reservoirs. As the reticulation results are different to the reservoir results it is possible that there are water age issues in the Albert St and High St Reservoirs.

CONCLUSION
Parkes Shire Council gained a deeper understanding of the risks in the Parkes-Peak Hill distribution system.

The TWST detention time and specific baffle factor were determined and have been used to verify the disinfection critical control point. The raw data was used to identify distribution areas that require improvements and will be used by Council to verify their hydraulic model of the town distribution network.

The project took advantage of a system shift, verifying the validity of the system critical control points and identifying a number of areas for future improvement works. Parkes Shire Council, Atom Consulting and the engineering students have worked together to improve Parkes distribution system understanding through this fluoride tracer study.

ACKNOWLEDGMENT

Many thanks to the Parkes Shire Council staff for being enthusiastic and cooperative throughout the whole project. Thank you to the four penultimate year engineering students who gave up their university break to undertake intensive sampling and analysis. Without either of these parties the project could not have been carried out.

REFERENCES

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Unites States Environmental Protection Agency (US EPA) 1999, Disinfection Profiling and Benchmarking Guidance Manual, Unites States Environmental Protection Agency (US EPA), USA.

Table 5: Recommended fluoride dose at different production, backwashing and raw water concentration

Raw water F concentration (mg/L)	**1 backwash/day**				**2 backwash/day**				**3 backwash/day**			
	Production rate (L/s)											
	90	**120**	**150**	**180**	**90**	**120**	**150**	**180**	**90**	**120**	**150**	**180**
0.2	0.786	0.789	0.792	0.793	0.772	0.779	0.783	0.786	0.760	0.770	0.777	0.781
0.25	0.736	0.739	0.742	0.743	0.722	0.729	0.733	0.736	0.710	0.720	0.727	0.731
0.3	0.686	0.689	0.692	0.693	0.672	0.679	0.683	0.686	0.660	0.670	0.677	0.681
0.35	0.636	0.639	0.642	0.643	0.622	0.629	0.633	0.636	0.610	0.620	0.627	0.631
0.4	0.586	0.589	0.592	0.593	0.572	0.579	0.583	0.586	0.560	0.570	0.577	0.581
0.45	0.536	0.539	0.542	0.543	0.522	0.529	0.533	0.536	0.510	0.520	0.527	0.531
0.5	0.486	0.489	0.492	0.493	0.472	0.479	0.483	0.486	0.460	0.470	0.477	0.481
0.55	0.436	0.439	0.442	0.443	0.422	0.429	0.433	0.436	0.410	0.420	0.427	0.431
0.6	0.386	0.389	0.392	0.393	0.372	0.379	0.383	0.386	0.360	0.370	0.377	0.381