CHLORINE RESIDUAL VS CT, USING OPERATIONAL DATA TO DETERMINE REAL WORLD TREMDS

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ABSTRACT

The Australian Drinking Water Guidelines 2011 (ADWG 2011) contains a Framework for the Management of Water Quality. The Framework outlines a structured risk-based approach to the management of drinking water. This framework is made up of 12 elements ranging from communication to training to process control. Element 3 requires Critical Control Points (CCP) to be identified using a risk assessment. CCPs are defined as an activity, procedure, or process at which control can be applied and which is essential to prevent a hazard or reduce it to an acceptable level.

A common CCP used in the water industry is chlorine residual which is in place to ensure appropriate disinfection when chlorination is used. Typically, low disinfection CCP limits are set by calculating the minimum chlorine residual needed to achieve a chlorine contact time (Ct) of 15 mg/L.min as recommended in the ADWG 2011. This is done by reverse engineering the Ct calculation to solve for residual. Variables commonly use in the equation are baffling factor and detention time. Less commonly pH and temperature can also be used. Given that these variables can be constantly changing simply using chlorine residual may not be an accurate measurement of primary disinfection.

This study compares chlorine residual against Ct using operational data from multiple Water Treatment Plants from New South Wales (NSW) and Victoria (Vic). It is intended that any findings will help water utilities better understand the relationship between chlorine residual and Ct.

1.0 INTRODUCTION

The disinfection of drinking water using chlorine is a common treatment process with two critical variables, time and concentration. Ct is used to describe this relationship between these two variables. It is expressed as mg/L.min and is determined using the below equation.

$$Ct = \text{concentration (mg/L)} \times \text{time (minutes)}$$

Other variables can also be taken into consideration when calculating Ct. Temperature will affect the reactivity of the disinfection agents, the lower the temperature the slower the chemical reactions. The pH of the water will affect the effectiveness of the free chlorine residual. Free chlorine is the sum of hypochlorous acid and hypochlorite ion. The pH of the water will determine the ratio of these two compounds. The higher the pH the more hypochlorite ion will be present and less hypochlorous acid. Given that hypochlorite ion is 70 to 100 times less effective at disinfecting microbes than hypochlorous acid, pH will play a critical role in the effectiveness of the disinfection rate.

Typical water storages do not have perfect mixing or plug flow conditions. This will nearly always lead to a degree of short circuiting, which will reduce the Ct available for disinfection. When calculating retention time within a water storage, a baffling factor should be determined ither by tracer study or calculation of theorised baffling using the below equation, in this manner short circuiting can be accounted for.

$$\text{Baffling factor} = \frac{Time\ for\ 10\%\ of\ the\ inlow\ to\ be\ discharged\ from\ the\ outlet}{Theoretical\ detention\ time}$$

Using the above equation, it can be shown that the lower the time for 10% of the water to be discharged the lower the baffling factor. A perfect plug flow storage would have a baffling factor of 1.0, whilst an extremely poorly baffled tank would have a factor of 0.1. The USEPA Manual for Disinfection Profiling and Benchmarking Guidance Manual (1999) gives predetermined baffling factors for different examples of tanks.

Table 1: ***Table of USEPA baffling factor values and descriptions***

Baffling Factor	Description
0.1	None, agitated basin, very low length to width ratio, high inlet, and outlet flow velocities. Can be approximately achieved in flask mic tank
0.3	Single or multiple inlets and outlets, no intra-basin baffles
0.5	Baffled inlet or outlet with some intra-basin baffles
0.7	Perforated inlet baffle, serpentine or perforated intra-basin baffles, outlet weir or perforated launders
1.0	Very high length to width ratio (pipeline flow) (greater than 40:1) perforated inlet, outlet and intra basin baffles

2.0 DISCUSSION

The disinfection process is a critical process in the delivery of safe drinking water. For this reason, strict CCPs are usually set in place, routinely tested, and heavily regulated. Overwhelmingly chlorine residual is used for monitoring the effectiveness of chlorine disinfection. High/ low and CCP alarms are typically set using a chlorine residual on the discharge of a clear or treated water storage. High alarms or high CCPs are typically set at 5 mg/L which is the health limit in the ADWG (2011). Low CCPs are more complicated. They are typically set by calculating a minimum chlorine residual needed to achieve a Ct of 15 mg/L.min. Given that to calculate Ct accurately other variables need to be taken into consideration, simply relying on chlorine residual may not be an accurate indicator of overall disinfection performance.

Given the importance of disinfection and the time and effort put in place to ensure correct operation of such systems. Any CCPs put in place should closely reflect real public health risks. According to ADWG (2011) a breach of a CCP by definition pose an unacceptable health risk. Therefore, CCP limits should be scrutinized and be clearly justifiable, as to why a public health risk is present if breached.

2.1 Method

The data used in this paper was sourced from 13 individual Water Treatment Plants from six different Water Authorities across NSW and Victoria. The data was collected from 2020 to 2023 and there is approximately one month's worth of data from each plant. The data collected was real time data which was extracted using the Water Authorities Supervisory Control and Data Acquisition system (SCADA). This data had an updating range from 9 minutes as a minimum to every second as a maximum. For ease of use, all data presented in this paper will be taken from 15 minute intervals. The data used to calculate instantaneous Ct was chlorine residual (mg/L), flow rate (L/s), contact tank volume (%) and pH (units). Contact tank capacity and baffling factor were also known constants for each treatment plant. Where baffling factor was unknown by the Water Authority a baffling factor of 0.3 was used.

The data was primarily used to determine the strength of the correlation between Ct and chlorine residual. Correlations between Ct and flow rate, pH and contact tank volume were also calculated using the same data. To determine the strength of correlation, the Pearson correlation coefficient was used. Using this coefficient, a numerical value is assigned to the strength of the correlation. For example, +1 would be a positive linear correlation, 0 would represent no correlation and -1 would be a negative linear correlation. The below table details the relationship between numerical value and correlation strength.

Correlation Coefficient	Strength	Direction
>0.5	Strong	Positive
Between 0.3 and 0.5	Moderate	Positive
Between 0.0 and 0.3	Weak	Positive
0.0	None	None
Between 0.0 and –0.3	Weak	Negative
Between –0.3 and –0.5	Moderate	Negative
< –0.5	Strong	Negative

2.2 Results

Pearson Correlation Coefficients between Ct and the four variables were calculated.

<u>**Table 2:**</u> ***Pearson Correlation Coefficients results for Ct variables***

Treatment Plant	Chlorine Residual	Flow Rate	pH	Tank Volume
1	-0.2	-0.8	-0.3	0.8
2	0.7	-0.5	-0.5	0.4
3	0.2	-0.7	-0.3	0.2
4	0.7	-0.3	-0.4	0.3
5	0.6	-0.7	-0.3	0.0
6	0.6	-0.3	-0.7	0.5
7	0.7	-0.7		0.3
8	0.6	-0.7	-0.4	0.2
9	0.4	-0.4	-0.3	0.8
10	0.4	-0.9	-0.4	0.2
11	0.4	-0.8	-0.2	0.3
12	0.4	-0.8	-0.3	0.3
13	0.6	-0.4	-0.2	0.6
Average	**0.5**	**-0.6**	**-0.4**	**0.4**

Chlorine residual varied between -0.2 - 0.7 and had an average correlation coefficient of 0.5, which is a moderate, positive correlation. Flow rate varied between -0.3 - -0.9 and had an average correlation coefficient of -0.6, resulting in a strong, negative correlation. pH varied between -0.2 - -0.7 and had an average of -0.4 resulting in moderate, negative correlation. Tank volume varied between 0.0 - -0.8 and had an average of 0.4 resulting in a moderate, negative correlation.

2.3 Treatment Plant 1

This treatment plant had a significantly lower than expected chlorine residual correlation score of -0.2. This is unexpected given that an increase in chlorine residual should result in an increase in Ct. it also has a high negative correlation between Ct and flow rate. On further investigation into treatment plant processes, these lower-than-expected correlations were determined to be a result of residual trimming of the Chlorine Dose rate at the entry to the Water storage.

Figure 1: ***Treatment Plant 1 Ct vs Residual***

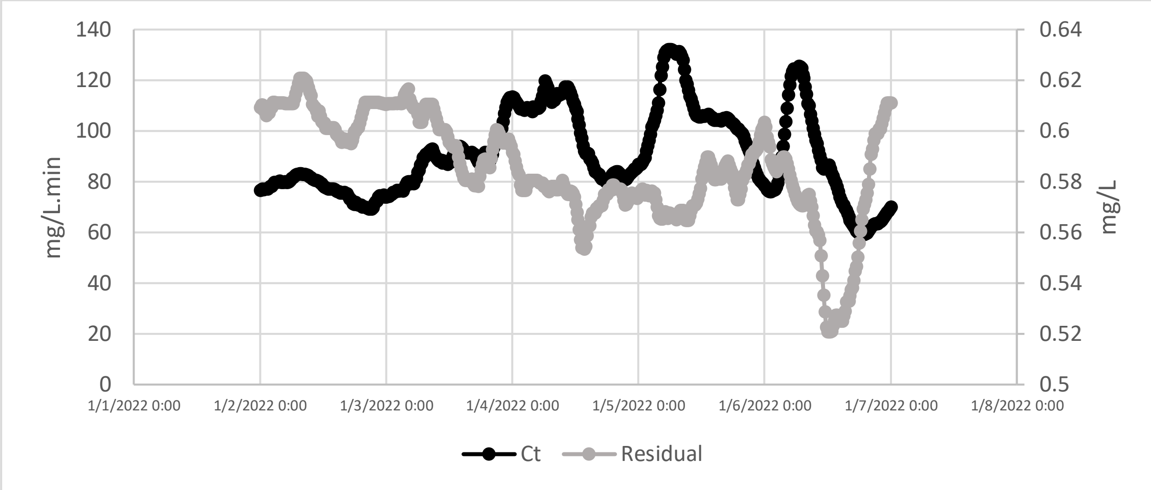
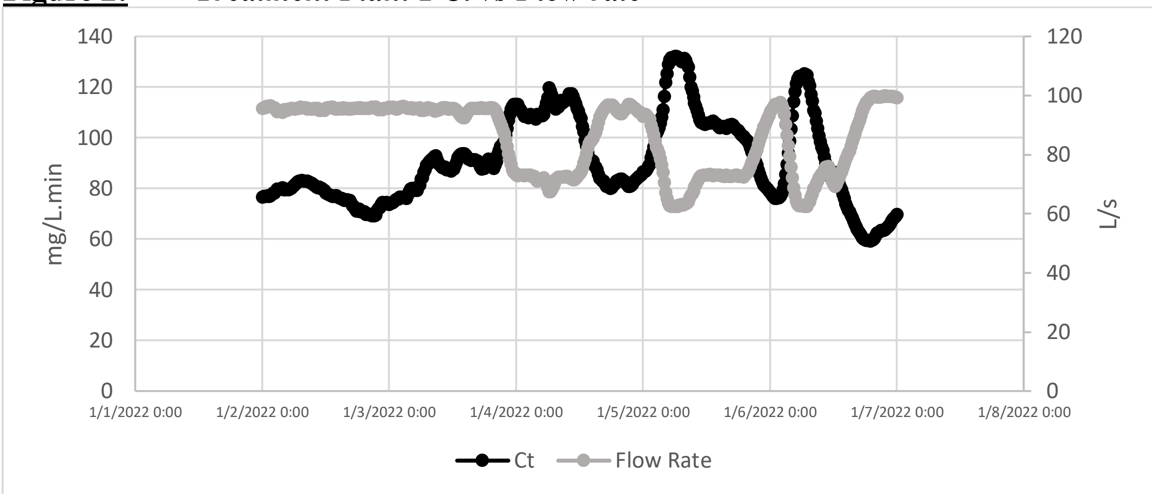


Figure 2: ***Treatment Plant 1 Ct vs Flow rate***

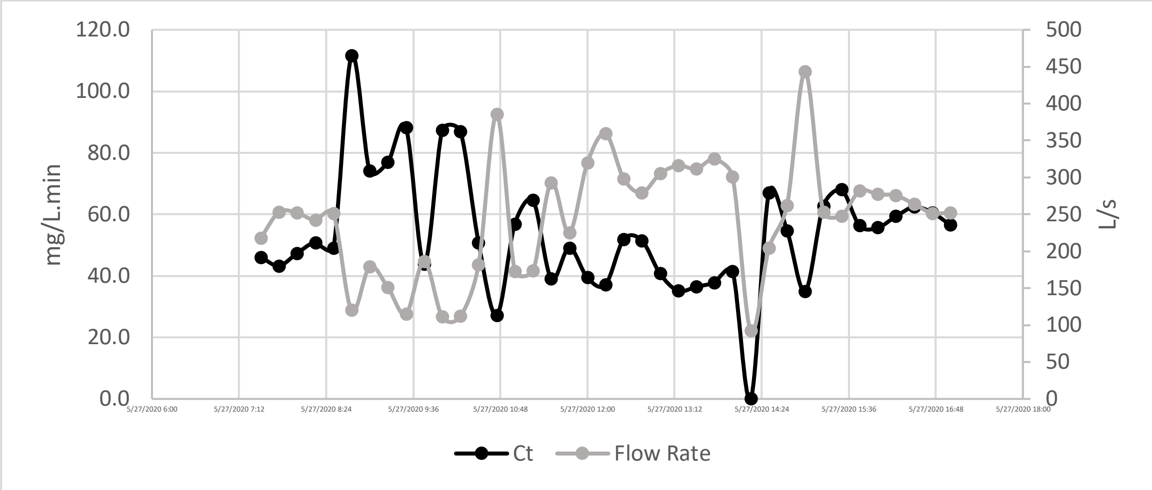


As demonstrated in figure 2, as flow rate increases there is an opposing decrease in Ct, similarly in figure 1 a residual decrease corresponds to a Ct increase. As mentioned, the chlorine dose rate in this storage is residually trimmed at the entry point, when flow rates are constant the concentration entering the tank can be seen to be very stable. However, changes in flow rates will affect detention time within the storage and thus affect Ct and chlorine residuals are different rates. A 20% decrease in flow rate on the 4/1/2022 resulted in a 5% decrease in chlorine residual, this trend can be seen to repeat throughout the data, providing an explanation for the negative correlation of Ct and residual.

2.4 Treatment Plant 3

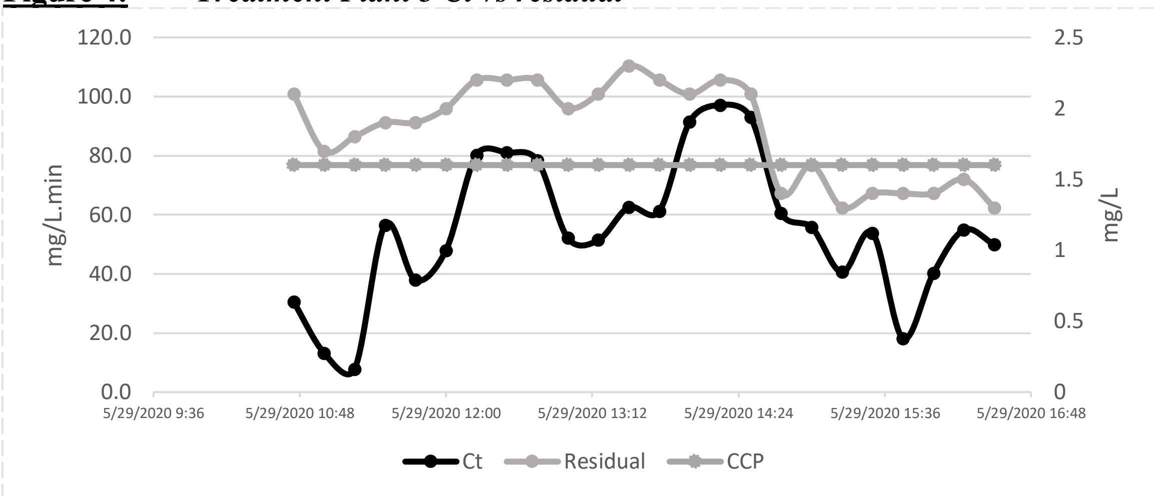
This Treatment Plant has a significantly lower than average correlation between chlorine residual and Ct (0.2). It also haa a higher than average correlation between flow rate and Ct. Examination of the data (Figure 3) indicates Treatment Plant 3 has a highly variable flowrate, fluctuating by a factor of 3, over the course of a single run.

Figure 3: ***Treatment Plant 3 Ct vs Flow rate***



Treatment plant 3 stood out as having instances when chlorine residual was above the treatment plant low residual CCP of 1.6 mg/L, but calculated Ct value were below 15 mg/L.min (Figure 4). Later in the same time period, the residual fell below the plants 3's CCP of 1.6mg/L however calculated Ct remained above 15mg/L.min (Figure 4).

<u>Figure 4:</u> ***Treatment Plant 3 Ct vs residual***



The Correlated Data suggests variations in Ct and Residual are strongly influenced by fluctuating flow rates and may in fact be the key parameter when determining Ct at Treatment Plant 3.

2.5 Treatment Plant 5

This plant has what would be considered a typical correlation of coefficients for the four variables within the collected data set. One aspect that stands out from this data is the low calculated Ct. This low Ct calculation is reenforced by the captured data which demonstrates that Ct is below 15mg/L.min for 99.8% of the entire period. The same data also shows that over the same period the chlorine residual remained consistently well above the low CCP of 0.5mg/l.

<u>Figure 5:</u> ***Treatment Plant 5 Ct vs residual***

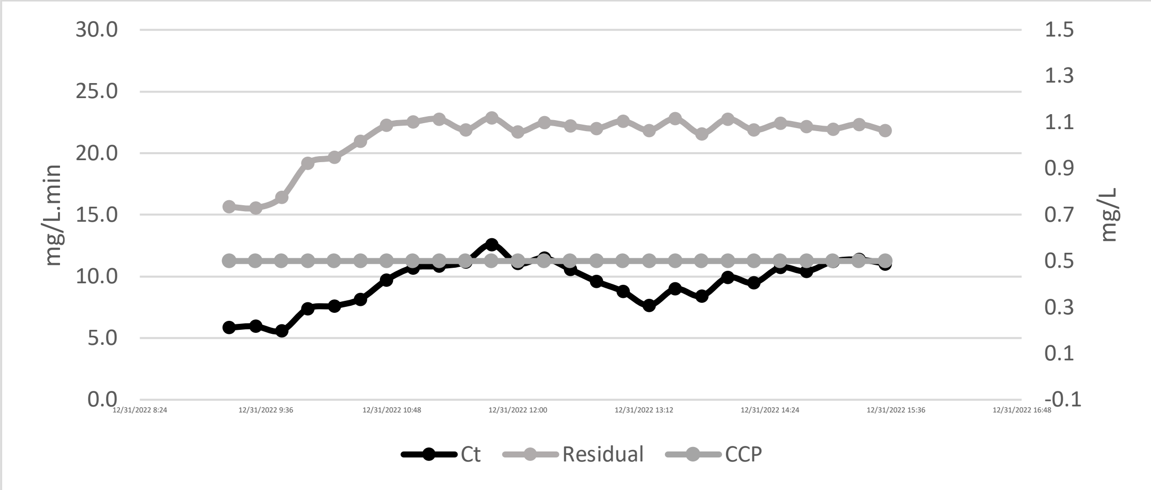


Figure 5 shows a typical six hour run of Treatment Plant 5.

3.0 CONCLUSION

The Pearson Correlation Coefficient between Ct and chlorine residual in the 13 Water Treatment Plant sampled was on average 0.5. This result places the correlation as moderate in nature. The results also suggest that flow rates are a key Determining Variable to calculated Ct.

Two of Treatment Plant sampled showed significant short comings in achieving consistent Ct results above 15 mg/L.min. Given the small number of sites sampled in the paper, it is hard to extrapolate these results, though there is some inference in the data to suggest a. significant number of Treatment Plant are producing water below the ADWG (2011) target of 15 mg/L.min. As a side note both Water Authorities were contacted by the Author of this paper and neither Water Authority was aware of such short comings in achieving appropriate Ct values.

It is commonplace for chlorine residual to be used when determining chlorine disinfection CCP set points This is primarily due to the ease of measurement and widely available online instrumentation. However, when calculating Ct there are more variables than just chlorine residual. Given this information Water authorities must decide whether to treat flow rate and tank volume as a variable or as constants. If residual alone is to be used, they must be considered constants. This in turn will lead to the question “what values should we be using?”. Calculating Ct using both average values or worst case values has limitations and drawbacks.

When average values are used, there could be significant periods of times when Ct values could fall below 15 mg/L.min, with chlorine residual staying above CCP limits. This was shown to be the case with Treatment Plant 3. In this instance it was assumed the contact tank volume would remain at 100% while the treatment plant was in operation. In reality the water level varied significantly which in turn significantly altered the Ct.

If worst-case values are to be used it could be assumed that the flow rates are always at the maximum value possible while tank volumes are low. This approach would safe guard Water Authorities from falling below 15 mg/L.min but could also allow for situations where a CCP is breached but Ct values never fell below 15 mg/L.min. It is worth noting, the worst-case values stance appears to be the most widely adopted within the water industry even though ADWG (2011) states that any breach of a CCP must pose an unacceptable health risk. Through the findings of this paper, it is possible to infer that the worst-case values stance is at best out of step with the intent of the ADWG (2011) as it is possible that no unacceptable health risk is posed.

This paper proposes there is in fact an alternative method to the use of chlorine residual as the low CCP limit in a chlorine disinfection process. This new method would use the continuous monitoring of process variables combined with automated control equipment to produce a real time Ct value. This instantaneous value would then be used to set the low CCP limit in a chlorine disinfection process. This method would negate the limitations of using chlorine residual, which have been shown in this paper. These limitations involve either the under reporting of breaches of a Ct below 15 mg/L.min or the over reporting of breaches when in fact the water has been satisfactory disinfected to ADWG (2011) standards.

Chlorine residual will remain a critical water quality parameter independent of Ct for the purpose of wider network demands and protection. For this reason, chlorine residual alarms both high and low would remain in place and play a critical role in the delivery of safe and aesthetically pleasing water.

The modern treatment plant operator now has access to and control over more instantaneous data and prosses variables than at any point before present, access to this new technology is only set to increase as the country's aging water treatment plants are continually upgraded and brought into the modern era of continuous data monitoring.

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5.0 REFERENCES

A Lanchbery Guide to the measurement and use of Ct. *Water Industry Operators Association Australia; Water Research Australia*

P Mosse, M Braden, T Hourigan Practical Guide to the Operation and Optimization of Chlorine and Chloramine Disinfection . *Water Industry Operators Association Australia*

National Health and Medical Research Council. *Australian Drinking Water Guidelines 2011 Version 3.5*

USEPA Disinfection Profiling and Benchmarking Manual 1999. *United States Environmental Protection Agency*